Global perspective on the use of low quality coals

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Abstract

This report examines the global situation with regard to the scale, location and major uses of low quality coals and addresses the individual countries where they currently play, or in the future, are likely to play, an important role in energy production.

Around half of the world's estimated recoverable coal reserves comprise low value coals, predominantly lignites, subbituminous coals, and high-ash bituminous coals. By rank (on a tonnage basis) anthracite and bituminous coals account for 51% of the world's reserves, subbituminous coal 32%, and lignite 18%. For decades, many coal-producing countries have witnessed a steady decline in the quality of the coal produced. Often, this reflects the increasing exhaustion of reserves of higher grade coals and a growing reliance on reserves of lower quality. For instance, this overall downward trend in coal quality has been occurring in the USA since the 1950s although similar trends can be observed in many other parts of the world. Despite the drawbacks associated with their use, many countries are turning increasingly to the use of indigenous reserves of lower quality coals. In some cases, these comprise the only significant energy resource available. Often, such coals are mined relatively inexpensively via opencast techniques. Their use provides a secure source of energy and helps reduce dependence on imported supplies. Industry observers are convinced that the long-term future of coal-derived energy supplies will include the greater use of low rank and low quality coals, a trend that is already discernible in many parts of the world.

Abbreviations

CCC	(IEA) Clean Coal Centre
CCS	carbon capture and storage
CFB	circulating fluidised bed
CFBC	circulating fluidised bed combustion
CTL	coal-to-liquids
CV	calorific value
DRB	demonstrated reserve base
EDR	economic demonstrated reserve
EOR	enhanced oil recovery
EPRI	Electric Power Research Institute, USA
ESP	electrostatic precipitator
EU	European Union
FBC	fluidised bed combustion
FEED	front end engineering and design
FGD	flue gas desulphurisation
Gt	gigatonne (1 billion tonnes)
IDGCC	integrated drying gasification combined cycle
IGCC	integrated gasification combined cycle
LHV	lower heating value
MoU	memorandum of understanding
MPa	megapascals
NETL	National Energy Technology Laboratory, USA
OECD	Organisation for Economic Cooperation and Development
PCC	pulverised coal combustion
PRB	Powder River Basin
R&M	renovation and modernisation
SC	supercritical
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SNG	synthetic natural gas
TRIG	transport integrated gasification technology
UCG	underground coal gasification
USC	ultra-supercritical
US DOE	Department of Energy, USA
US EPA	Environmental Protection Agency, USA
WCI	World Coal Institute
WEC	World Energy Council
ZEP	zero emissions platform

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Coal rank and coal classification systems

It can sometimes be difficult to define precisely a particular coal as there are a range of different definitions and categorisation systems applied in different parts of the world. For instance, American, Australian and European definitions are slightly different, and in fact overlap (Couch, 1988; Carpenter, 1988).

Generally, the term 'coal' refers to a whole range of combustible sedimentary rock materials spanning a continuous quality scale. For convenience, this continuous series is usually divided into four main categories:

- anthracite
- bituminous coal
- subbituminous coal
- lignite/brown coal

Classification of different types of coal into practical categories for use at an international level is often difficult for two reasons:

1 Divisions between coal categories vary between classification systems, both national and international, based on calorific value, volatile matter content, fixed carbon content, caking and coking properties, or some combination of two or more of these criteria.

2 Although the relative value of the coals within a particular category depends on the degree of dilution by moisture and ash and contamination by sulphur, chlorine, phosphorous and certain trace elements, these factors do not affect the divisions between categories. Coal quality can vary and it is not always possible to ensure that available descriptive and analytical information is truly representative of the body of coal to which it refers.

The International Coal Classification of the Economic Commission for Europe (UN/ECE) recognises two broad categories of coal:

- hard coal – coal of gross calorific value (CV) of >5700 kcal/kg (23.9 GJ/t) on an ash-free but moist basis and with a mean random reflectance of vitrinite of at least 0.6. Hard coal is calculated as the sum of coking coal and steam coal;
- brown coal – non-agglomerating coal with a gross CV of <5700 kcal/kg (23.9 GJ/t) containing >31% volatile matter on a dry mineral matter-free basis. Brown coal is calculated as the sum of subbituminous coal and lignite.

Subbituminous coal is defined as non-agglomerating coal with a gross CV between 4165 kcal/kg (17.4 GJ/t) and 5700 kcal/kg (23.9 GJ/t). Lignite is defined as non-agglomerating coal with a gross CV less than 4165 kcal/kg (17.4 GJ/t). Confusingly, national statistics for some countries treat subbituminous coals as steam coal and not brown coal, whereas in others, this may not be the case. For instance, under the US classification, lignites and subbituminous coals are classified as brown coal.

For many years, the IEA has adopted the UN/ECE definitions of hard and brown coal for presenting statistics relating to coal production, trade and consumption. This classification system is based on the inherent qualities of the coal in question and not on its final use. In this way the classification system attempts to be objective and simple to apply. However, data presented in the national publications of some countries may differ from that presented by IEA sources as the former may have adopted a different coal classification and reporting system that better suits the particular national needs. Each country with a coal industry has tended to develop its own criteria in order to classify its domestic coals, often for a particular application. These classification parameters were often chosen for historical reasons (Carpenter, 1988). Consequently, there may sometimes be quite sizable differences in the scale of reported coal deposits, rates of consumption and so on, cited in different sources of data. Often, the particular classification system used is not cited.

Coal reserves and resources

Annually, large amounts of fossil fuels are consumed. If these are to be available on demand at all times, proven reserves of adequate size are needed. For this reason, mining companies secure their annual output in advance for some decades by exploring and developing coal and lignite deposits. These developed quantities, economically-minable using current technology at current prices, are termed reserves. Conversely, resources include known (but not currently economically-minable deposits) along with assumed deposits that have not yet been proven by exploration. Each year, resources move into reserves as further information on deposits is obtained or new extraction programmes are developed (Thielmann and others, 2007). This conversion of resources into reserves replaces some of the reserves extracted via ongoing mining operations. The sum of reserves plus resources is termed total resources.

1 Introduction

Current estimates for the world's proved recoverable coal reserves suggest a total of between 1019 and 1025 Gt (OECD/IEA, 2008, 2009; Thielemann and others, 2007). On a regional basis, OECD reserve totals are 254 Gt for North America, 73 Gt for Europe, and 79.5 Gt for the Pacific region (thus, OECD total of 407 Gt). Transition economies amount to 230 Gt – Russia accounts for 116.5 Gt, and China, 192 Gt. Total reserves for Asia are 116.8 Gt, with India accounting for nearly 96 Gt of this total. There are also smaller deposits in South and Central America (19.9 Gt) and the Middle East and Africa (53 Gt) (OECD/IEA, 2008).

Although coal deposits are distributed widely, ~80% of the world's recoverable reserves are located in just five regions, namely the USA (28%), Russia (19%), China (14%), other non-OECD Europe and Eurasian regions (10%), and Australia/New Zealand (9%). In recent years, typically, these five regions have produced ~ 5 Gt/y of coal between them, representing ~70% of total global production. In 2008, global hard coal production amounted to more than 5.6 Gt and (based on IEA definitions) lignite/brown coal production was 951 Mt (OECD/IEA, 2009; WCI, 2009).

Total proven global reserves of lignite stand somewhere between 149.8 Gt and 283.2 Gt, depending on the source (BP, 2008; Chakraborty and others, 2009; OECD/IEA, 2008). However, recent estimates suggest that there could be more than 6000 Gt of lignite in the countries with the largest deposits; these include Russia, the USA, Australia, Germany, Greece, the Czech Republic, and Serbia. Depending on the prevailing prices for competing fuels, several per cent to as much as 50% of these resources might be economically feasible to recover (Michel, 2008).

By rank (on a tonnage basis) anthracite and bituminous coal account for 51% of the world's estimated recoverable coal reserves, subbituminous coal accounts for 32%, and lignite for18% (BP, 2008; EIA, 2009). Regionally, lignite makes up ~14% of American coal reserves, 15% of Asian, 18% of European, and 48% of Australian. Reserves of subbituminous coal are located predominantly in the USA and the Russian Federation which, together, represent 74% of the world's total, followed by China (13%), Ukraine (6%) and Brazil (3%).

Several estimates for lignite and subbituminous coal reserves and production are given in Table 1. The most recent data (2009) from the World Energy Council is shown in Figure 1 (Chakraborty and others, 2009).

1.1 What constitutes a 'low grade' or 'low quality' coal?

The degree of alteration that occurs as coal matures from peat to anthracite is referred to as the rank of the coal. Low rank coals include lignite and subbituminous coals. As they contain less carbon, these have lower energy content than coals of higher rank. However, when issues associated with low grade coals are considered, rank becomes less important. There is no single universally accepted definition of low grade or low value coal. A coal that has only limited use because of undesirable characteristics such as high mineral matter content, can be so termed. All low rank coals (subbituminous coals and lignites) are generally categorised into low grade coals because of high moisture content and low heating value; these coals usually require the application of specific technologies for their successful use in power generation and other industrial processes. Anthracites and semi-anthracites are also sometimes classified as low grade coals as a result of ignition and burnout problems. However, for bituminous coal, it can sometimes be difficult to classify which coals are low or high grade although it can generally be stated that bituminous coals with one or more of the following troublesome properties related to their use can be classified as 'low grade' coals:

- low heating value, implying low efficiency;

Table 1 Estimates of lignite and subbituminous coal reserves and production, Mt							
Country	Proven subbit coal + lignite reserves *	Proven reserves of subbit coal †	Proven reserves of lignite †	Lignite production ‡	Brown coal production §	Production by type¶	
						Subbit coal	Lignite/ brown coal
Australia	39,400	2100	37,400		72.4	35.1	67.7
New Zealand	538	205	333			2.6	0.3
Albania		0	794				
Bulgaria	1991	63	1928	26.1	28.7		28.4
Czech Rep	2828	2617	211	47.5	52.7	5.2	49.7
Germany	6556	0	6556	175.3	173.5		180.4
Greece	3900	0	3900	65.6	65.7		66.3
Hungary	3103	170	2933	9.8	9.8		9.8
Poland	1490	0	1490	59.4	59.6		57.5
Romania	410	0	1364	35.1	34.7		35.8
Serbia	13,879	379	13,500	36.4	37.4		37.1
Spain	330	300	30			3.1	6.2
Turkey	1814	0	1814	79.6	73.1	0.8	72.1
USA	129,358	100,086	30,374		68.7	475.1	71.3
Canada	3107	871	2236		34.9	25.1	10.5
Mexico		300	51				
Russia	107,922	97,472	10,450		76.0		71.1
Kazakhstan	3130	0	3130				4.3
Ukraine	18,522	16,577	1945				0.2
Uzbekistan		0	2000				
China	52,300	33,700	18,600				
India	4600	0	4258		32.2		34.0
Pakistan	2069	167	1814				
Indonesia	2607	1809	798		38.0	30.2	4.3
Thailand	1354	0	1354		17.6		18.2
S Korea		135					
Argentina		424					
Brazil	7059	7068				3.4	2.3
Chile		1150					
Colombia		381					
Total N America	132,816						
Total S & Central America	8042						
Total Europe & Eurasia	170,204						
Total Middle East & Africa	174						
Total Asia Pacific	103,444						
EU	21,143			441.3			
OECD	193,083						
FSU	132,386						
World Totals	**414,680**	**266,837**	**149,755**		**951.4**		

* BP Statistical Review 2009 – citing data from WEC, 2009; † Chakraborty and others, 2009 – citing WEC, 2009 and BP, 2008 data; ‡ Euracoal, nd; § OECD/IEA, 2008, 2009; ¶ IEA, 2010 – Energy stats online – for individual countries (2007 data)

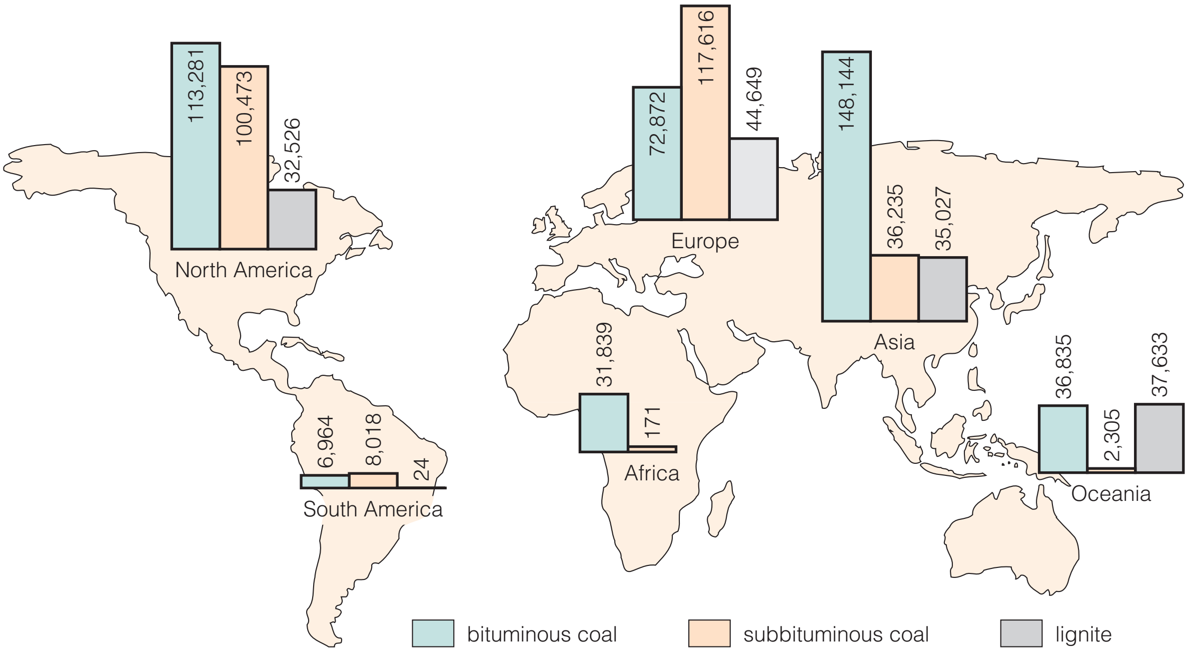

Figure 1 Proven recoverable coal reserves, Mt (Chakraborty and others, 2009)

- high moisture content, which also translates into low efficiency;
- low volatile matter content, related to flame stability;
- high ash content, related to ash problems and efficiency;
- high sulphur content, implying high SO_2 emissions and high control costs;
- low ash fusibility, having potential for slagging;
- high alkali/alkaline content, having potential for fouling and/or slagging;
- low Hardgrove Grindability Index, implying high milling power consumption.

In summary, a coal is categorised as low grade if it has one or more troublesome properties related to use, particularly in power plants. To avoid upgrading, the vast majority of low grade coal usage is dedicated to local power stations located close to the mine, and designed specifically to operate on the characteristics of the particular low grade coal (Katambula and Gupta, 2009).

1.2 Declining coal quality and the growing importance of low grade/value coals

For decades, many coal-producing countries have witnessed a steady decline in the quality of the coal produced. Often, this reflects the increasing exhaustion of reserves of higher grade coals and a growing reliance on reserves of lower quality. This trend is particularly apparent in many of the long-industrialised nations, where significant coal production may have been taking place for several centuries. For instance, this overall downward trend in coal quality has been occurring in the USA since the 1950s. Part of this decline has resulted from the depletion of some higher energy resources, most notably in the Appalachian area, and the subsequent increased production of subbituminous coal that started in the 1970s. However, there has been a reduction in CV across all ranks of US coals.

In Europe, coal reserves of many countries are predominantly of lower quality. This is due partly to unfavourable geology, but also to the long history of coal extraction in many industrialised European nations. Thus, the majority of easily recovered hard coal reserves have already been exploited. As a result, many current EU Member States now find it necessary to opt either for expensive, complex underground extraction of high-quality coal at great depths, or for the exploitation (often via opencast techniques) of lower-quality reserves. Thus, as a result of depletion, declining coal quality and high

Figure 2 Part of the Niederaussem opencast lignite mine and power plant complex in Germany (photograph courtesy of RWE Power)

production costs, hard coal production is generally two to three times more expensive than imported hard coal. As a result, some EU countries no longer produce their own coal. However, lignite is a different case. The EU has greater reserves of lignite than of hard coal, and reserves are available and exploited in a larger number of countries. An example is shown in Figure 2.

Lignite production in Europe is usually based on opencast techniques, which keeps extraction costs low; European lignite production is, without subsidies, generally cost-competitive with imports of hard coal. It represents an important energy source for the EU, helping to reduce energy import dependency.

Many non-European countries are also experiencing an overall decline in quality. In Asia, India has seen a steady decline in domestic coal quality. This has been among the key factors responsible for reducing overall efficiency and creating difficulties in many coal-fired power plants. These were designed for coals of a particular quality, and the use of higher ash levels and less consistent properties has resulted in a range of operational problems. For example, in Uttar Pradesh, quality issues daily reduce the region's power generation capacity by 800–1000 MW. These problems are replicated elsewhere in the country. Although Indian coals have always had high ash contents, quality has declined as, in recent years, increased use of opencast mining (up from 20% in 1970 to the current level of ~85%) has increased levels of inert materials present in the coal produced. This has been reflected by a steady deterioration of gross CV. During the 1960s, coal CV was ~5900 kcal/kg. By the 1970s, this had fallen to 5250, falling further to 4200 in the 1980s, and 4000 in the 1990s. The current level is around 3500 kcal/kg (Hindu Business Line, 2009). Similarly, in South Africa, many existing mines are approaching the end of their economic life. There is a common consensus that the development of new reserves will be much more costly than the development of the old deposits. In addition, the quality of the coal from these new reserves is considered to be less than that of coal from existing fields (Kavalov and Peteves, 2007).

These problems are typical of those being experienced in many coal-producing countries around the world, where exhaustion of good quality and/or easily accessible reserves is forcing increasing reliance on lower quality coal deposits. However, despite their drawbacks, such coals may be the only indigenous resource readily available and many industry observers are convinced that the long-term future of coal-derived energy supplies will include the greater use of low rank and low value coals, a trend that can already be seen in many parts of the world. In many countries such as Germany, it is widely considered that domestic lignite will remain an indispensable domestic source of energy for many years (Daehnert, 2006).

Even where countries currently depend on imported hard coal, the situation may change as many of the major coal-exporting countries are experiencing a combination of logistical or production constraints and it is clear that the international market is beginning to accept coals with lower heating value. Increasingly, lower grade coals are being traded and marketed around the world (CoalTrans, 2008). As supplies of better grades dry up or become prohibitively expensive, there will be little option but to start using such existing resources more effectively. The use of lower grade coals is expected to continue increasing for the foreseeable future. The use of lignite is forecast to continue growing at an average rate of ~1%/y. It will remain of particular importance for power generation. By 2030, total global coal use is forecast to have reached 7 Gt/y. This is expected to comprise 5.2 Gt of steam coal, 624 Mt of coking coal, and 1.2 Gt of lignite/brown coal (WCI, nd).

1.3 Advantages and disadvantages of using low grade/quality coals

Advantages

Various reasons for using either low rank or low quality coals are cited. Many are self-evident and focus predominantly on access to an affordable, secure source of energy for power generation and other industrial and commercial uses. They include:

- security of supply. There is only limited international trade in most low rank/quality coals, hence most is sourced from indigenous deposits and used locally. Compared with oil and natural gas, the cost of production remains relatively unaffected by market and other outside forces. This helps keep the cost of electricity generation low and imparts a stabilising effect on its price;
- in many countries, such coals represent the only major indigenous resource – there may be few, if any, economically-viable alternatives. The utilisation of indigenous resources helps reduce the need for imported sources of energy. This miminises reliance on outside sources and clearly has a positive impact on national trade balance. For instance, annually, through the use of indigenous lignite, Greece avoids importing ~80 million barrels of oil and 12,000 Mm^3 of natural gas (Kaldellis and others, 2009);
- as a consequence of using large-scale surface mining techniques, extraction costs are often low. Some lignites and subbituminous coals represent the cheapest fossil fuel-based sources of energy;
- the maintenance of a national mining industry and attendant power generation sector may be an important local factor as they may provide many long-term jobs.

Disadvantages

However, there are some less positive aspects to consider:

- although lignite extraction costs are currently generally low, in some countries, these may increase in the future as the more easily accessible reserves become exhausted and deeper reserves are tapped. As a result, production may become more difficult and prices increase. Even where opencast mining is adopted, accessing deeper reserves entails the removal of greater volumes of overburden. The thickness of this can vary enormously and in many locations, is increasing. For example, some lignite reserves in Louisiana in the USA are covered by layers that vary between 7 and 50 metres in thickness;
- the general decline in CV being experienced effectively means that a greater volume of lower quality coal (and probably overburden) will need to be mined in order to supply the equivalent amount of energy provided by a smaller quantity of higher quality coal. More ash may be produced and there may be other environmental consequences associated with increased mining activity;
- the long distance transport of high ash/moisture coals reduces profitability and increases overall environmental impacts. For instance, in India, although coal is used is used in all states, it is produced in only nine. Thus, long distance transportation is common. Some 70% of thermal coals are transported more than 400 km to the end user. In 2002, in an effort to minimise the associated drawbacks, the transport of coal with ash levels >34% was banned. This has helped reduce coal transport costs and minimise transport bottlenecks. Because some power plants are now obliged to use only cleaned coals, they now produce less ash and CO_2. This will become increasingly important as the country's coal demand continues to increase in the future;
- where coals with high moisture and/or ash contents are used, there may be associated preparation costs. Moisture may need removing using a drying technique, and ash removed via some form of coal preparation process such as froth flotation. All such upgrading invariably increases process

complexity and impacts on overall production costs. Upgrading will reduce the final amount of coal produced, and upgrading plants (washery or drying units) will generally generate emissions, effluents and tailings for disposal. The amounts of the latter can be considerable. For example, South Africa generates ~65 Mt/y of discards from the washing of export coals. An estimated >1 Gt has so far been stockpiled. This could have doubled by 2020;
- where low rank coals are upgraded, there may be an increased tendency for spontaneous combustion to occur during storage and transport. The incidence of such fires is expected to rise with their increased application (Okoh and Dodoo, 2005). Low rank coals are more susceptible to spontaneous combustion than most bituminous coals. Unless suitable precautions are taken, in extreme situations, uncontrollable fires may start. As a result, stockpiles may require mechanical compaction and circulation. To obviate this problem, most lignite mined goes directly to the power plant with a minimum of intermediate storage/stocking. The amount of lignite held as a buffer in hoppers might amount to just a few hours of plant operation. In the case of a plant shut-down, hoppers may either need to be inerted (with nitrogen or CO_2) or emptied (Couch, 2004). This clearly adds a degree of complexity, and hence cost, when using such coals;
- where high ash coals remain unwashed, but used directly in power plants, considerable quantities of ash can be produced which require disposal in an environmentally-acceptable way or utilised to serve some useful purpose;
- the characteristics of different lignite reserves can show considerable variation (even within the same deposit) and this must be taken into consideration. Some (such as Australian) can have a very high moisture content. Others (such as those from Greece, Romania and Turkey) may contain >35% moisture, but also have >25% ash. Some may have a very low sulphur content, whereas others may be much higher (such as those from Bulgaria and Thailand) (Couch, 2004). Globally, lignites with heating values in the range from 5 to >16 MJ/kg are both mined and used. For instance, the energy content of Canadian lignite can be three times that of a Greek one. Examples of property variations from different sources are shown in Table 2.

Although the variation of some properties can be significant, in practice the upper extremes may not be exploited commercially.

1.4 Lignite/brown coal production and consumption

For countries with lignite reserves, a particular advantage of its use as a source of energy is that it usually offers a very high security of supply. No other fossil fuel energy carrier offers lignite's availability (likely to remain so for many decades) with such a degree of certainty. Crude oil, uranium and natural gas reserves amount to 40 to 70 times the current annual global consumption. For hard coal, this ratio is 150 times, and for lignite, it is well over 200 times (Thielemann and others, 2007).

Although global reserves of low-rank and hard coals are similar, the individual consumption trends are quite different. The world consumes much more hard coal than lignite/brown coal and the gap between the two continues to grow. Furthermore, the preference is naturally for coal that is easier (and cheaper) to recover. Without a corresponding increase in hard coal reserves, which are likely to become more difficult and expensive to exploit than previously, global reserves of higher quality coals will be exhausted much sooner than those of lower quality (Kavalov and Peteves, 2007).

Global lignite production peaked at 1189 Mt in 1990. Since then, production has varied between 913 and 956 Mt/y (OECD/IEA, 2009). Since 2006, there has been an overall upward trend in production although there was a slight dip to 951 Mt in 2008, reflecting the impact of the downturn in the global economy. However, the upward trend is expected to resume, and output is forecast to carry on increasing at a rate of 1%/y. In recent years, individual national growth rates have varied between zero and 2%/y.

Currently, twelve countries produce more than 20 Mt/y of lignite; in each, it makes an important

Table 2 Properties of lignites from different countries (CoalPower; WEC, 2004, 2007; Couch, 2004; Euracoal and individual national sources)

Country	Moisture content, % as-mined	Ash content, % db	Sulphur content, % db	CV, MJ/kg LHV
Australia	46–70	1–7.4	0.28–1.74	9.8–15.2
Bulgaria	23–56	20-48	0.9-7.0	6.7–15.0
Canada	32–41	8–25	0.3–1.1	10.6–17.0
Chile	10	14.4	0.9–1.0	
China	19.6–50	8.6–40	0.2–4.7	9.0–13.3
Colombia	17	25	0.7	16.8
Czech Republic	9.6–55.0	10–40	0.37–6.0	9.0–20.0
Germany	40–63	1–53	0.15–3.6	6.7–15.0
Greece	41–65	3.5–25	0.3–1.0	5.0–11.0
India	6–55	5–48	1.5–4.5	10.0–12.0
Indonesia	35–75	1–15	0.1–2.4	<17.4
Kosovo	35–50	12–21	<1.0	5.8–8.4
Laos			0.7–1.1	8.0–10.0
Malaysia	15–25	4–18	0.05–0.3	4.5–6.2
Myanmar	9.7	8.9	0.93	
New Zealand	38.0–45.0	5.0–30.0	0.3–4.6	13.0–19.0
Philippines	55–60	15	0.3–0.6	9.5
Poland	50–55	5–11	0.59	5.0–10.3
Romania	40–43	30–40	1.2	7.0–8.6
Russia	16.5–58	8.4–45	0.3–7.7	6.0–15.0
Serbia	43–55	18–25	0.5–0.9	6.8–7.5
Spain	8–50	14–70	1.2–>9.0	7.0–17.0
Slovenia	36	14	1.4	11.3
Slovakia	15.2–33.9	20.7–33.9	1.4–2.0	10.7–11.6
Thailand	12–49	10–55	10.5	5.0–10.0
Turkey	10–60	10–56	0.2–4.7	4.6–22.3
USA	30–44	4–20	0.2–1.4	5.0–17.4
Ukraine	30–40	29–46	Up to 3.3	12.4
Vietnam		20–40	2.5–6.2	10.4–18.4

Under some national categorisation systems, some examples may be considered as subbituminous coals

contribution to national energy supply. In 2008, the eight biggest lignite producers comprised Germany, Turkey, Russia, the USA, Australia, Greece, Poland and the Czech Republic. Apart from these major producers, there are also many countries where output is less, but nevertheless, important in the respective national energy mixes. Since 2000, lignite output has fallen in countries such as Hungary and Canada, whereas it has increased in Australia, Indonesia, Turkey, Serbia, Romania, India and Bulgaria (Figure 3). Unlike some hard coal production, lignite is often produced relatively

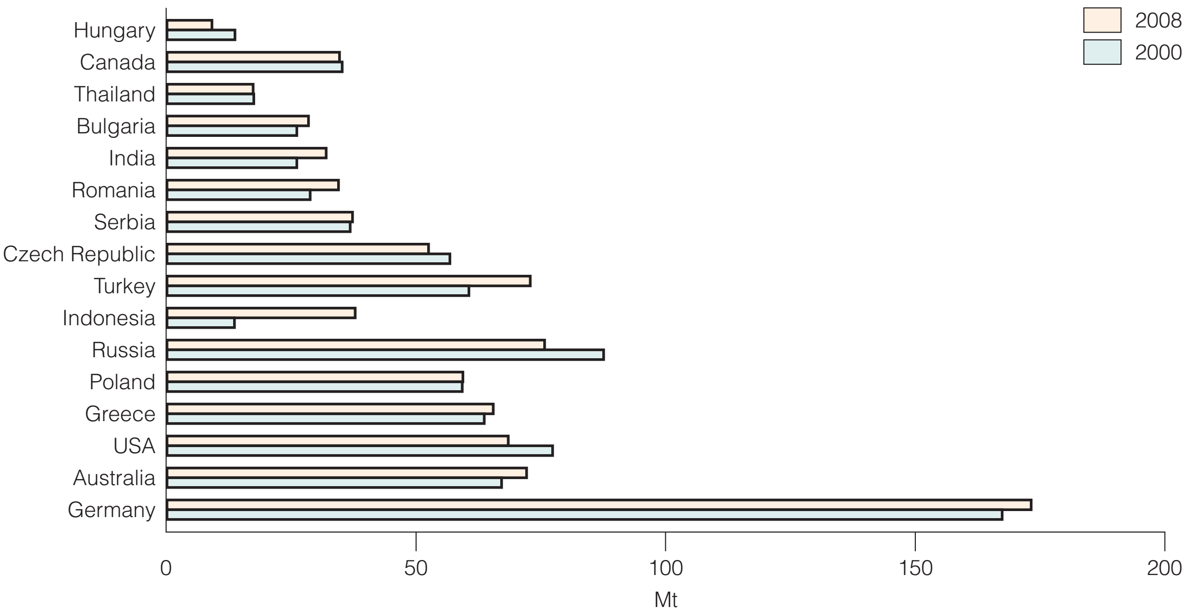

Figure 3 Lignite production in 2000 and 2008, Mt (OECD/IEA, 2009)

Figure 4 One of Neyveli Lignite Corporation's (NLC) PCC power plants in Tamil Nadu. The company operates 2 GW of lignite-fired generating capacity and is also the country's largest lignite producer (photograph courtesy of NLC)

inexpensively from large-scale opencast mines.

There is little international trade in lignite as its lower energy content makes long-distance transportation costly, even within the countries of production themselves. As a result, the vast majority is used in power stations or co-generation plants, either in minemouth locations or close at hand. The majority of such plants are based on conventional pulverised coal combustion (PCC) technology (an example is shown in Figure 4) although in some countries (such as Germany, India and Poland) a number of fluidised bed combustion plants also utilise lignite. A small number of integrated gasification combined cycle (IGCC) plants are also fuelled with lignite; these comprise the 400 MW Vresova power plant in the Czech Republic that uses Lurgi fixed bed gasification technology, and the 60 MW Sanghi IGCC plant in India (U-gas). In Australia, HRL has developed a fluidised bed-based IGCC fuelled on lignite and incorporating an integrated drying system. A 10 MW pilot plant has operated successfully at Morwell and commercial-scale development is planned.

Although power generation is lignite's most important market by far, it is also used in a variety of other major industrial sectors such as iron and steel manufacture, pulp and paper, cement, and chemicals production. Some is also utilised for residential, commercial and industrial heating (mainly in the form of briquettes and FBC fuel). The biggest non-power users comprise Germany (11.6 Mt/y – most of the OECD Europe annual total of ~13 Mt; OECD/IEA, 2009), Russia (12 Mt/y), the USA (5 Mt/y), and Bulgaria (3 Mt/y). Smaller amounts are used in many other countries.

A significant non-power market for lignite is the production of *Patent fuels*, or brown coal briquettes. The former is a composition fuel manufactured by shaping coal fines with a binding agent such as pitch. Brown Coal Briquettes (BKB) are composition fuels manufactured from brown coal. This is crushed, dried and moulded under high pressure into evenly-shaped briquettes without the addition of binders. Germany is the biggest European briquette producer, followed by Bulgaria. About 9% of the latter's coal production is used for making briquettes; in 2007, production exceeded 1 Mt, used mainly for commercial and residential heating. In recent years, lignite from the Maritsa East Mines has been the major supply for briquetting. These mines produce ~3 Mt/y of brown coal, used to produce most of the country's briquette output. The Brikel briquette plant has a production capacity of 1.3 Mt/y; around 250 kt/y are supplied to the Maritsa East power plant (Brikel, nd; Methanetomarkets, 2009) with much of the balance used for heating. A typical Bulgarian binderless fuel briquette contains ~11% moisture, up to 22% ash, and up to 3.8% sulphur.

Brown coal/lignite briquettes are also produced in the Czech Republic (247 kt in 2007), Hungary (10 kt) and Greece (97 kt) (UN data, 2009). In the Czech Republic, Sokolovská uhelná, a.s, is a major manufacturer of brown coal/lignite briquettes. This forms part of its portfolio of activities that include coal mining, heat production, power generation and chemical production. In Greece, lignite extracted at the Ptolemais-Amyndeon Lignite Centre is fed mainly to power plants although some is also supplied to a briquette factory.

1.5 Subbituminous coal production and consumption

Subbituminous coals generally have characteristics that fall some way between those of lignite and bituminous coals. However, some individual subbituminous coals may have properties that overlap with those of either category. They are used primarily as fuel for power and/or co-generation and heat plants. Total proven reserves of subbituminous coal amount to 266.8 Gt (BP, 2008; Chakraborty and others, 2009). The world's biggest individual reserves are located in the USA, the Russian Federation, China, Ukraine, and Brazil. The bulk of these reserves are located predominantly in the first two which, together, represent 74% of the total. This is followed by China (13%), Ukraine (6%) and Brazil (3%). At current rates of extraction, this represents around 145 years of global production.

The USA has the biggest individual proved reserves of subbituminous coals (>100 Gt), representing some 37% of the country's demonstrated coal reserve base (DRB). All such reserves are located west of the Mississippi, mostly in Montana and Wyoming, with the biggest individual reserves being in the Powder River Basin (PRB). The PRB is the largest source of coal mined in the USA and contains one of the largest deposits of coal in the world. In 2007, it produced 396 Mt of coal. The USA currently uses about a billion tonnes of coal a year; currently, around 40% comes from the PRB. The amount from this source has been increasing steadily over the last 20 years. Within the PRB, the single most productive mine (also in the USA) is the Black Thunder Mine – in 2007, this one mine produced 78 Mt, nearly 20% of Wyoming's total coal production. The mine produces low-sulphur subbituminous coal suitable for use as power station fuel without any preparation apart from crushing. Black Thunder coal has a heating value of 20.3 MJ/kg, an ash content of ~5%, and as-received moisture of 25–30%.

The next biggest subbituminous coal reserves are in Russia. Many basins contain coal in the European part of Russia (Moscow, Donetz and Pechora Basins), in western Siberia (Kuznetsk and Kansk-Achinsk Basins) and in eastern Siberia (Lena and Tunguska Basins). The Kuznetsk Basin holds most of the proved reserves and represents more than half of Russian production. The country has reserves comprising 49 Gt of bituminous coal, 10.5 Gt of lignite, and 97.5 Gt of subbituminous. Around three quarters of the latter are potentially extractable via opencast mining.

In China, coal deposits are located in most of the country's regions, although three-quarters of proven

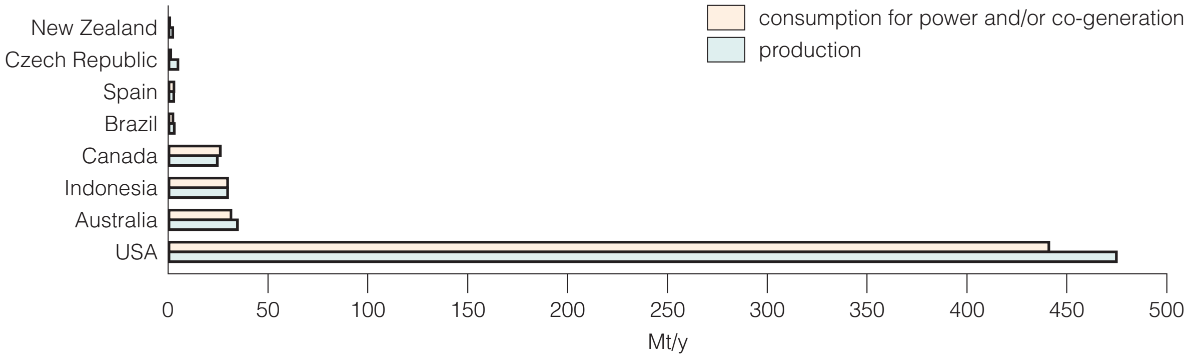

Figure 5 Subbituminous coal production and consumption, Mt/y (IEA, 2010 – Energy stats online for individual countries, 2007 data)

recoverable reserves are in the north and northwest, particularly in the provinces of Shanxi, Shaanxi and Inner Mongolia. China's total proved recoverable reserves amount to 114.5 Gt; this comprises 62.2 Gt of bituminous coal and anthracite, 33.7 Gt of subbituminous coal and 18.6 Gt of lignite (WEC, 2004). Elsewhere, there are sizable coal reserves in the Ukraine (16.6 Gt), Brazil (7.1 Gt), the Czech Republic, Australia, and Indonesia. There are also other smaller deposits in various other Asia-Pacific, European and South American countries.

The vast majority of subbituminous coal produced is used for power generation and/or co-generation purposes. As noted, the USA is the biggest producer and consumer (Figure 5). Subbituminous coal is used in all the major types of generating technology. Globally, PCC technology dominates as many countries have power plants firing subbituminous coals. There is also a growing number that have adopted CFBC technology (for instance, China and the Czech Republic) and an IGCC plant in Spain uses a blend of subbituminous coal and petcoke.

1.6 High ash bituminous coal production and consumption

As noted in Section 1.1, some bituminous coals can be difficult to categorise as low or high grade. However, generally, lower grades are associated with factors such as low heating value, high moisture content, low volatile matter content, high ash content, and so on. One of the most important national economies to rely heavily on low grade bituminous coal is that of India. In this case, the main problem is the very high ash content of most Indian coals. As a consequence of their drift origin, most coals contain high levels of inorganic impurities (up to 60%). This is often bound within the coal matrix, making it difficult to remove beyond a certain level. Ash separation processes are often hindered by the presence of high levels of near-gravity materials. Furthermore, depending on origin and location, coal properties can vary significantly.

Unsurprisingly, the high ash content of Indian coals frequently results in technical difficulties and higher costs at power plants, many of which were designed to use lower ash coals. Problems have worsened due to the depletion of better grades of coal, coupled with the increasing use of opencast mining (with problems of residual overburden). Furthermore, the ash in Indian coals is often high in silica and hence, abrasive. These factors, and the high levels, require consideration when designing and operating power plants and special measures may need adopting.

Bituminous coals typically supplied to Indian power plants may vary considerably (Mills, 2007):

- ash content of between 25% and 55%, although in general this is ~41% (often ~11% higher than most boilers were designed for). Impurities may include shale, stones and occasional pieces of iron;
- moisture content between 4% and 7%, although in rainy seasons, it can increase substantially;
- sulphur content of between 0.2% and 7%;
- volatile matter content between 1% and 36%, although it generally falls between 18% and 25%;

- gross CV of between 12.98 and 21.35 MJ/kg, although in general it is ~17.58 MJ/kg. On average, 0.0009 MJ/kg of coal is used to generate 1 kWh of electricity.

In some parts of the country, lignite is the major fuel source for thermal power generation. Lignite is not cleaned and different grades are produced solely by selectively mining different seams or parts of seams. It is not uncommon for lignite properties to vary quite widely, even within the same region or even seam. Compared to indigenous hard coals, moisture and sulphur levels are generally higher, although ash levels and calorific values tend to be lower. Indian lignites are considered further in Section 4.2.

In other countries (such as South Africa) some existing coal production capacity is reaching the end of its economic life and it seems likely that development costs for new reserves will be higher than those of older deposits. Coal quality is also likely to be lower. South Africa still has large, although not unlimited, amounts of coal. However, the Witbank and Highveld coalfields are approaching exhaustion (in 2005, an estimated 9 Gt of recoverable coal remained in each) and new deposits will therefore need to be tapped (Jeffrey, 2005). However, coal quality and/or mining conditions of some alternatives (such as the Waterberg, Free State and Springbok Flats coalfields) could be significant barriers.

In 2008, the country produced 236 Mt of bituminous coal. This was low in sulphur but high in ash (up to 45%). Currently, nearly a third of output is washed and exported. Annually, this generates ~65 Mt/y of discards. It is estimated that more than a billion tonnes has so far been stockpiled. This could have doubled by 2020. However, Eskom has successfully demonstrated the use of low grade coal with an ash content as high as 40%, for instance, at its Lethabo power station. Thus, potentially, up to 25% could be added to the country's reserves of economically-viable coal (South African Chamber of Mines, nd).

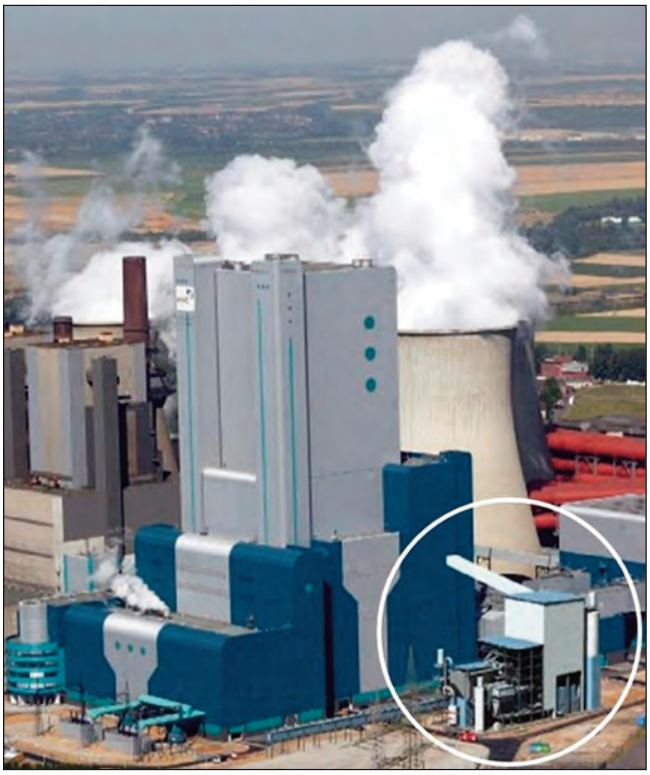

Figure 6 The WTA demonstration lignite drying plant on Niederaussem K in Germany (photograph courtesy of RWE Power)

1.7 Upgrading of low grade and low rank coals

The successful utilisation of low quality coals may be affected by various characteristics that can include low heating value, high moisture level, volatile matter level, ash content and behaviour, flame ignition and stability, plus a propensity for low temperature oxidation or spontaneous combustion. Therefore, a key step to increasing the use of such coals is to upgrade them into a form that is economically more valuable. Upgrading processes can be classified into three broad categories: drying, cleaning and briquetting.

Drying is of particular importance for the efficient utilisation of high moisture subbituminous coals and lignites and there are both evaporative and non-evaporative drying processes. Most advanced is the WTA process developed by RWE in Germany and deployed at the Niederaussem K Power plant (Figure 6).

Commercial application is also being developed as part of the Hazelwood 2030 project in Australia. Amongst the other techniques being developed is the *DryFining* process, being pursued in the USA by Great River Energy. Here, a full-scale commercial demonstration plant (115 t/h) is now in operation on a 546 MW unit of the Coal Creek Station in North Dakota. In Australia, lignite densification via evaporative drying combined with mechanical attrition is now being pursued by at least three Australian companies.

Non-evaporative dewatering processes remove water from the coal in liquid form, thus saving the latent heat of vaporisation and helping minimise overall greenhouse gas emissions generated by the process. Examples include the *Hydrothermal* process, which uses either steam or water at high temperature and pressure to expel capillary water from the raw coal, and the *Mechanical Thermal Expression* (MTE) process, which involves compressing and heating coarse crushed coal, to effectively squeeze out water.

Coal cleaning is practised widely in most coal-producing OECD nations and coal-exporting countries. Most cleaning plants process bituminous coal; there is currently little incentive to clean low-rank subbitumious coals and lignites.

Briquetting and pelletising are well established techniques for converting either coal fines or low rank coals into higher-quality solid fuels. Briquetting can form part of an integrated coal drying or dewatering process, as described above. The major drawbacks to the use of briquettes include the cost of binder materials (where employed) used to impart strength to the finished briquette, limited markets, and adequate technical standards.

Techniques for coal upgrading have been examined fully by Dong (2011).

1.8 Introduction to case studies

In the following chapters, the use of low value coals is examined for selected countries. Those chosen have access to reserves of low rank and/or low grade coals (subbituminous coals, brown coal/lignite, or high-ash bituminous coals) that are either already being exploited or being actively considered for exploitation in the future. For each country, the scale of known reserves and their ease of exploitation is examined. Possible future uses or developments are noted.

Where already being used, the types of application are examined. In most countries, by far the largest use is for power and/or co-generation purposes. However, there are also other industrial applications where, on a more localised basis, low quality coals may be of particular importance. These are reviewed below.

2 North America

This chapter covers the USA, Canada and Mexico.

2.1 USA

The USA has the world's biggest global proven recoverable coal reserves (238 Gt, around a third of the world total). It has the biggest proven reserves of subbituminous coal (100 Gt) and the second largest lignite reserves (30 Gt). As of January 2008, the US demonstrated reserve base (DRB) was estimated to contain 447 Gt of coal, the largest in the world. This comprises resources that have been identified to specified levels of accuracy and may support economic mining using current technologies. The US EIA estimates that around 238 Gt may be recoverable.

Of the four main coal ranks, bituminous coal accounts for over half (54%) of the DRB. Reserves are concentrated primarily east of the Mississippi River, with the biggest deposits in Illinois, Kentucky, and West Virginia. All subbituminous coal (37% of the DRB) is west of the Mississippi River, mostly in Montana and Wyoming. Lignite accounts for ~9% of the DRB, and is found mainly in Montana, Texas, and North Dakota (EIA, 2010a; Bessereau and Sanière, 2007). Figure 7 shows the location of major US coal reserves.

For many years, there has been a gradual overall decline in the quality of coals mined in the USA. The average calorific value of US coals has decreased from 29.2 MJ/kg in 1950 to 23.6 MJ/kg in 2007 as production has moved progressively from anthracite and bituminous coals to subbituminous western

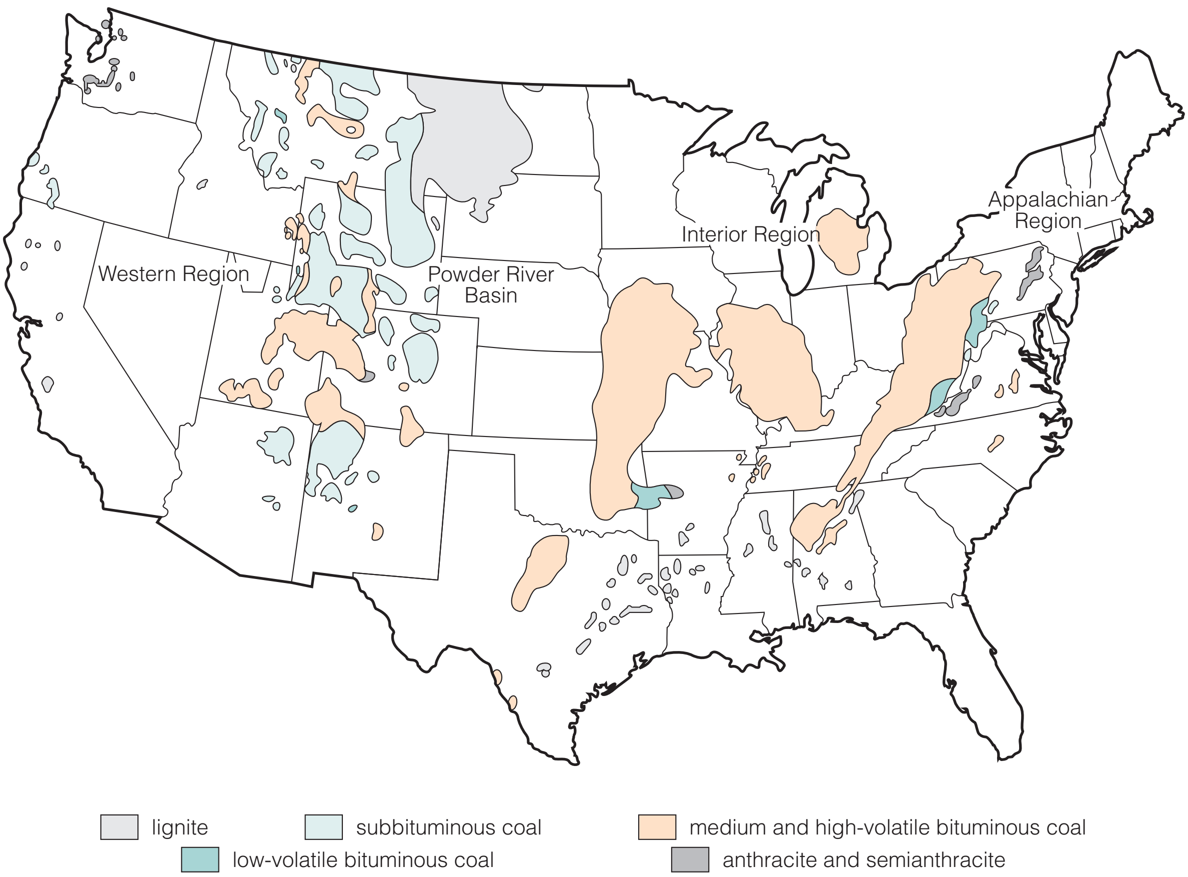

Figure 7 US coal types by region

coals. By 2030, the average CV may have fallen to slightly above 20 MJ/kg (Höök and Aleklett, 2009). Part of this decline in CV has resulted from the depletion of some higher energy resources, most notably in the Appalachian region, and the subsequent increased production of subbituminous coal that started in the 1970s. However, there has been a reduction in CV across all ranks of coal.

Overall, almost 93% of coal produced in the USA is consumed by the power generation sector. Coal-fired power plants generate around half of the country's electricity.

2.1.1 Subbituminous coals

Subbituminous coals are mined only in the western US, most prominently in the **Powder River Basin** (PRB). This is the biggest individual source of subbituminous coal in the USA and one of the largest coal deposits in the world. The PRB is a region in southeast Montana and northeast Wyoming, about 190 km east to west and 320 km north to south. In 2007, the PRB produced 396 Mt of coal, more than twice the production of second-place West Virginia, and more than the entire Appalachian region. It supplies about 40% of the one Gt of coal used annually in the USA. Over the last 20 years, the amount of coal produced in the PRB has been increasing steadily (Figure 8).

Between 1990 and 2008, deep mined coal output decreased from 385 Mt to 324 Mt. Conversely, opencast mining increased from 548 Mt to 738 Mt (Figure 9).

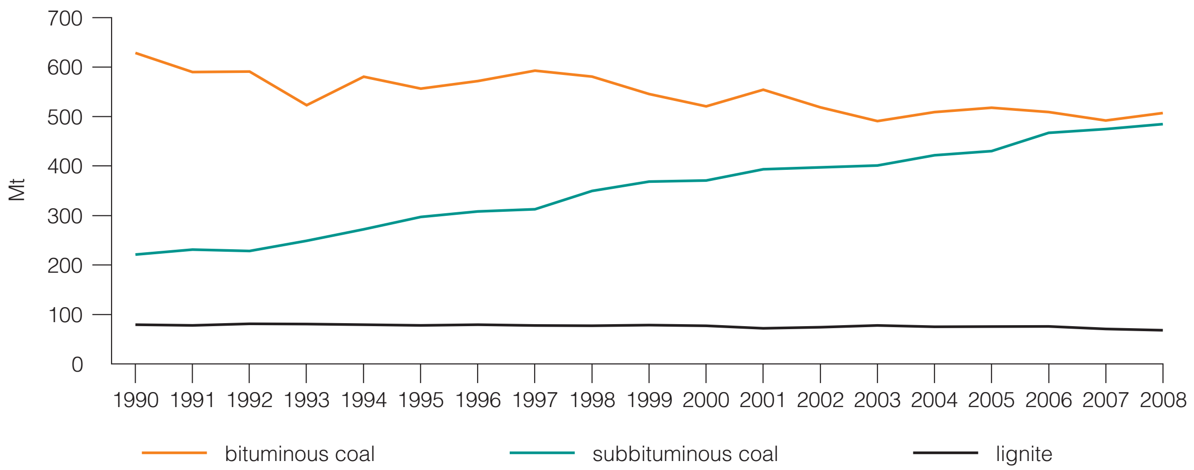

Figure 8 US coal production 1990-2008 by coal type (EIA, 2010a,b)

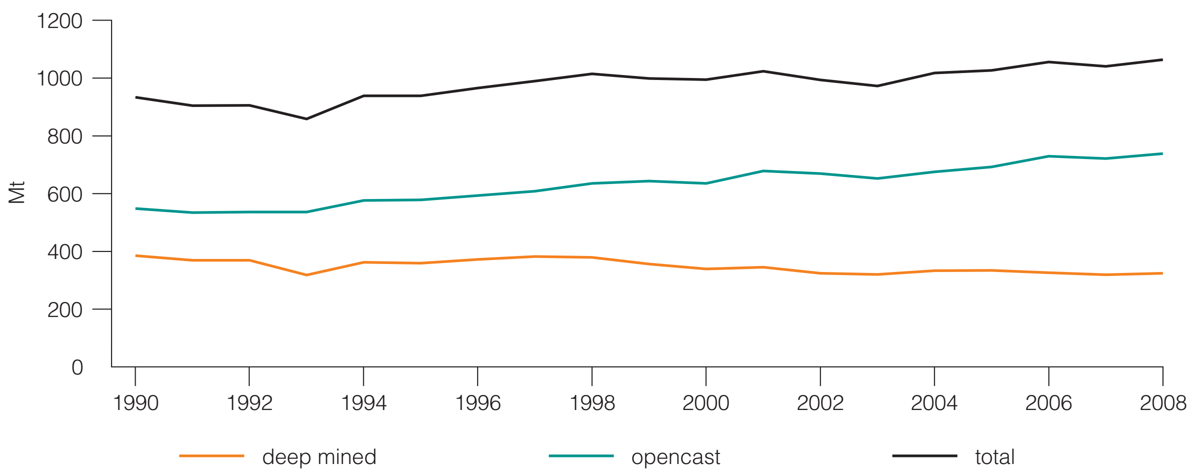

Figure 9 US coal production 1990-2008 by type of mining (EIA, 2010a,b)

2.1.2 Lignites

Texas is a major coal-producing state, with reserves totaling some 21 Gt, of which 9 Gt are considered economically recoverable. Lignite is the most abundant coal type in the state, found generally from northeast Texas in a swathe southwestward to near the Rio Grande River. Mining operations in the state are located along this area of deposits (TMRA, nd).

Coal is in competition with natural gas which is the leading fuel source for electricity generation in Texas (Combs, nd). Annually, the state consumes ~93-94 Mt of coal, >95% for power generation, with the balance used for various industrial purposes. Approximately 27% of the state's electricity is generated from lignite. According to the Bureau of Economic Geology of Texas, the demonstrated reserve base of surface mineable lignite is sufficient to fuel power generation for at least 100 years (AEG, 2009).

The state has 13 active lignite mines, and 11 coal-fired power plants (19 units with a total capacity of 11 GW) that use coal as a main or back-up fuel. Nine of the plants burn only subbituminous coal, five burn both subbituminous coal and lignite, and the remaining four burn only lignite. Lignite is also produced in other states that include North Dakota, Louisiana and Mississippi. North American Coal ranks as the nation's largest individual lignite producer and amongst the top ten coal producers in the US. It operates six mines in North Dakota, Texas and Mississippi, producing around 32 Mt/y. A major US lignite consumer is the Great Plains synfuels plant near Beulah in North Dakota. Since 1984, this has been using Lurgi gasifiers to produce SNG and other products. Since 2000, CO_2 has been captured and piped to Canada for enhanced oil recovery applications (Figure 10).

Figure 10 A major lignite consumer is the Great Plains synfuels plant near Beulah in North Dakota. Since 1984, this has been using Lurgi gasifiers to produce SNG and other products. Since 2000, CO_2 has been captured and piped to Canada for enhanced oil recovery applications (photo courtesy of Basin Electric Power Cooperative)

Most lignite produced in the USA is used in power generation or co-generation plants close to the source. The characteristics of power generation grade lignite and subbituminous coals are noted in Table 3.

Table 3 US power generation coal quality (EIA, 2010b)

Coal type	Average sulphur content, wt%	Average ash content, wt%
Lignite	0.86	13.8
Subbituminous	0.34	5.8
Bituminous	1.68	10.6

There are currently a number of new coal-fired power generation projects proposed in the USA. These include 4.3 GW of subbituminous coal-fired capacity and 2.7 GW of lignite-fired. There is also 3.5 GW of new bituminous coal-fired capacity proposed (Shuster, 2010).

Although the major use for both subbituminous coals and lignites is for power generation, a number of alternative uses are currently being pursued. For instance, an ongoing project is developing technology for the liquefaction of low rank US coals (the Silverado Green Fuel Demonstration Project). The technology treats low rank coals in order to dehydrate them and release waxes and resins. The end product is an oily liquid, demonstrated as suitable as a power plant fuel. Alternatively, it is claimed to have the potential as a feedstock for further processing (via gasification and liquefaction) to produce transport fuels and fertilisers (Silverado, 2010). Silverado Green Fuel Inc and the Mississippi Development Authority are currently building a US$26 million demonstration plant in the Red Hills EcoPlex in Mississippi. It will utilise local supplies of low rank coals.

2.1.3 US Clean Coal and CCS projects using low value coals

There is a growing number of carbon capture and storage projects under development or proposed in the USA. Many intend to use bituminous coal, although there are a significant number that are using, or plan to use, either lignite or subbituminous coals. Examples of major projects are listed in Table 4. In a further development, the potential for storing captured CO_2 in unmineable lignite seams has been examined recently in the USA. A field test sponsored by the US DOE and carried out in North Dakota demonstrated that opportunities to permanently store CO_2 in this manner may be more widespread than previously thought. The study also investigated the feasibility of combining CO_2 storage with enhanced methane production.

There are also a number of proposed coal-to-liquids projects based on the use of lignite or subbituminous coal. Examples are shown in Table 5. All are currently believed to be at the feasibility stage.

2.2 Canada

At the end of 2008, Canada had a total of 6578 Mt of proven coal reserves. Anthracite and bituminous coal amounted to 3471 Mt, and subbituminous coal and lignite was 3107 Mt (871 Mt of subbituminous coal and 2236 Mt of lignite) (BP, 2009). Most coal is located in the Western Provinces, although there are also reserves in Ontario, Nova Scotia, New Brunswick and Northern Canada. More than 90% of the country's resources are in the Western Canada Sedimentary Basin which extends from the Canadian Shield to the Rocky Mountains through Manitoba, Saskatchewan, Alberta and northeastern British Columbia. Resources comprise subbituminous deposits (in Alberta), lignite (mostly in Saskatchewan), bituminous coal, and semi-anthracite. Almost all Canadian coal is produced via opencast techniques. Mining of subbituminous coal is limited to Alberta.

Around 25–26 Mt of subbituminous coal plus 10.5 Mt of lignite is produced each year in Canada, mainly for power generation. The country has ~20 coal-fired stations and coal-fired power generation is particularly important in several provinces. It accounts for ~50% of the electricity generated in Nova Scotia, 70% in Alberta, and 46% in Saskatchewan (NRCAN, nd). Five of Alberta's nine mines produce subbituminous coal and three in Saskatchewan produce lignite; all is used for thermal applications.

Lignite is found in southern Saskatchewan, southeastern Alberta and southwestern Manitoba although currently, only the Saskatchewan deposits are being mined; at present, only the Ravenscrag Formation contains lignite deposits of economic interest. This is an extension of lignite-bearing beds distributed through North and South Dakota, Montana and Wyoming in the USA. The surface-mineable deposits are located in three coal basins, namely Estevan, Willow Bunch/Wood Mountain, and Shaunavon. Measured economic lignite resources of current interest exceed 1.3 Gt (via opencast, at depths of 35 metres). There are also significant additional indicated, inferred and speculative reserves. Saskatchewan is currently the third largest coal producer in Canada, accounting for ~14–17% of total production. All Saskatchewan mines are opencast operations. Around 90% of all lignite produced is consumed within the province, almost all by minemouth power plants. The remainder is exported to

Table 4 Examples of US clean coal and CCS projects and proposals using lignite or subbituminous coal

Project	Fuel	Comments
Post-combustion CO_2 capture		
Dakota Gasification, North Dakota	Lignite	CO_2 capture using Rectisol 5 kt/d CO_2 capture for EOR in Weybourn field Started operations in 2000
PCOR, Williston Project, Montana/Dakota	Lignite	CO_2 capture using scrubber 1 Mt/y capture for EOR
Basin Electric, Powerspan, Antelope Valley, North Dakota	Lignite	120 MW slipstream project Ammonia based ECO2 scrubber 1 Mt/y CO_2 capture for EOR Doosan Babcock and HTC Purenergy undertaking FEED
NRG/Powerspan, WA Parish, Texas	Subbituminous coal	CO_2 capture using Fluor Econamine scrubber Used for EOR or stored geologically Pilot start-up in 2014
Tenaska, Sweetwater, Texas	Lignite	Amine scrubber CO_2 captured to be used for EOR
We Energies/Alstom, Pleasant Prairie, Wisconsin	Subbituminous coal	Alstom chilled ammonia process 5 MWth pilot plant on slipsream started up in 2008
Oxyfuel combustion		
FutureGen II, Meredonisia, Illinois	Range of coal proposed	Refit of mothballed oil-fired 200 MW Meredonisia power plant >1 Mt/y CO_2 capture. Piped to Mattoon for storage Construction starting in 2011
B&W, Air Liquide, Barberton pilot plant	Lignite, subbituminous and bituminous coals	Large scale (30 MWth) pilot PCC burner testing facility Started up in 2008
IGCC + CCS projects		
Excelsior Energy, Mesaba, Minnesota	Subbituminous and bituminous coals	600 MW project using E-Gas technology CO_2 capture via Selexol or amine scrubber Up to 3 Mt/y captured for EOR
Mississippi Power/Southern Co, Kemper County, Mississippi	Lignite	582 MW project 65% CO_2 capture proposed. To be used for EOR
Summit Power – NowGen, Odessa, Texas	Subbituminous PRB coals	400 MW project 90% CO_2 capture proposed. 3 Mt/y for EOR
Texas Energy/Luminant, Texas	Lignite and PRB coals	Several candidate technologies being evaluated
Wallula Resource Recovery, Washington	Subbituminous PRB coals	915 MW project proposed, using MHI technology Reportedly in permitting stage

Ontario and Manitoba, mainly for power generation. Saskatchewan's (and Canada's) largest individual lignite-fired power plant is SaskPower's 813 MW Boundary Dam plant.

The dominant form of technology used for Canadian coal-fired power plants is conventional PCC.

Table 5 Examples of US coal-to-liquids projects based on lignite or subbituminous coal (Couch, 2008; Cicero, 2008)

Lead project developer	Partners	Location	Feedstock	Capacity, bbl/d
Alaska IDEA	Alaska NRTL CPC	Beluga Cook Inlet, Alaska	Subbituminous coal	80,000
Peabody/Rentech	na	Montana	Lignite/ subbituminous coal	10,000–30,000
Baard Energy	CEC	Wellsville, Ohio	Subbituminous coal/biomass	35,000–50,000
Synfuels Inc	GE, Haldar-Topsoe, NACC, ExxonMobil	Ascension Parish, Louisiana	Lignite	na
Headwaters (American Lignite Energy)	NACC, GRE, Falkirk Mining	North Dakota	Lignite	32,000–40,000
Silverado Green Fuel Inc	Mississippi Development Authority	Red Hills EcoPlex, Mississippi	Lignite and possibly subbituminous coals	na

The country's most efficient subbituminous coal-fired power plant is the Genesee 3 station, southwest of Edmonton, Alberta. This 450 MW supercritical PCC unit is fired on Albertan subbituminous coal supplied from an adjacent opencast mine. Opened in 2005, Genesee was the first sliding pressure coal-fired SC boiler (supplied by Babcock-Hitachi) to be commissioned in North America. The plant's design efficiency is 41.4% (LHV). Because of the type of coal used, it was based on a reference SC boiler design of a Japanese plant firing a range of imported coals (Henderson, 2007). Table 6 lists Canadian power plants currently firing either lignite and/or subbituminous coals.

Table 6 Canadian power plants firing lignite and/or subbituminous coals (CoalPower)

Plant	Capacity, MW	Fuel
Atikokan	215	Lignite
Battle river, Forestburg	730	Subbituminous
Boundary Dam, Estevan	875	4 Mt/y lignite
Brandon	105	Imported PRB subbituminous
Dodds-Roundhill (proposed IGCC)	150	Subbituminous
Genesee, Warburg	1270	4 Mt/y subbituminous
Keephills, Wabamun	766	3 Mt/y subbituminous
Keephills 3, Wabamun	450	Subbituminous
Nantocoke	3920	6 Mt/y subbituminous/bituminous blends
Poplar River, Coronach	592	4 Mt/y lignite
Shand, Estevan	300	2 Mt/y lignite
Sundance, Wabamun	2112	9 Mt/y subbituminous
Thunder Bay, Wabamun	326	1 Mt/y lignite + PRB subbituminous

Within the country, there is a growing number of clean coal and carbon capture projects based on the use of indigenous lignite or subbituminous coal, either proposed or being developed. Examples are given in Table 7.

Table 7 Examples of Canadian clean coal and CCS projects and proposals using lignite or subbituminous coal (IEA Clean Coal Centre internal sources; Stobbs, 2009)

Project	Description	Carbon capture
EPCOR (Capital Power Enbridge) IGCC, Genesee, Edmonton	270 MWe Subbituminous coal fuelled Siemens gasifier FEED completed but project currently on hold	1.25 Mt/y CO_2 capture for EOR
EPCOR (Capital Power Enbridge), Genesee power plant, Edmonton	Subbituminous coal-fired plant SC PCC Post-combustion capture amine pilot proposed	1 Mt/y CO_2 capture
TransAlta/Alstom Project Pioneer, Keep Hills 3	Chilled ammonia CO_2 capture system	1 Mt/y CO_2 capture and use for EOR
Sherritt International gasification plant, Totfield	Subbituminous coal fuelled Will produce hydrogen and other products	1 Mt/y CO_2 capture and use for EOR
ATCO Power minemouth project	Proposed fully-integrated carbon capture, transportation and storage project Subbituminous coal fuelled	1 Mt/y CO_2 capture
Bow City Power, Calgary	Proposed 1 GW subbituminous coal-fired power plant plus post-combustion amine scrubber	Up to 90% CO_2 capture Use for EOR
SaskPower, Poplar Station, Coronach	Lignite-fired PCC power plant CO_2 capture pilot proposed in 2009	CO_2 to be piped to Montana for storage
SaskPower, Boundary Dam power plant	Lignite-fired PCC power plant Amine scrubber project being developed SNC Lavalin supplying system Fluor Econamine FG Plus technology	CO_2 use for EOR
Alter NRG CTL project, Fox Creek, Alberta	Proposed coal-to-liquids plant Capacity of 40,000 bbl/d	CO_2 use for EOR

2.3 Mexico

Mexico's reserves of lignite and subbituminous coals are relatively small (51 Mt and 300 Mt respectively, at the end of 2007) and compared to petroleum and natural gas, coal plays a relatively small role in the country's energy production and consumption (only 6% of total energy consumption).

Mexico has seven significant coal basins spread across the country. Around two thirds of known reserves are located in the northeastern province of Coahuila, near the border with the USA, although there are also reserves in Sonora and Oaxaca. In 2008, the country produced around 10 Mt of subbituminous coal (>80% of total national coal output) plus 1.9 Mt of coking coal. Coal quality is generally poor (high ash and/or moisture content). Depending on the source, ash levels can vary between 18% and 63%, and moisture content between 24% and 60%. Coking coal produced is used for steel production with the remaining production being used for power generation. Coal-fired capacity produces only ~9% of the country's electricity.

3 Europe

Europe has substantial reserves of coal and lignite and historically much of its industrial development has been based on their exploitation. However, coal reserves of many countries are currently, predominantly of lower grades. This is due partly to unfavourable geology, but also to the long history of coal extraction in many industrialised European nations. Thus, many easily recovered hard coal reserves have already been fully exploited. As a result, some EU Member States have been forced to import coal or opt either for expensive, underground extraction of higher quality coal at greater depths, or to exploit more easily accessible lower-quality reserves.

WEC and IEA data suggest that EU reserves of hard coal amount to 8.4 Gt (resources of 24.4 Gt) with lignite at 20.9 Gt (resources of 31.0 Gt). Lignite reserves are present in a swathe from Germany through Central Europe and the Balkans, to Greece (European Parliament, 2008). The biggest individual European producers of lignite and/or subbituminous coals are Germany, Turkey, Greece, Poland, the Czech Republic, Serbia, Romania, Bulgaria, and Hungary. Lignite is also produced in smaller amounts in Slovenia, Slovakia, Albania, Macedonia, and Bosnia and Herzegovina. The biggest individual reserves are in Germany (6556 Mt of lignite) (BP, 2009).

Europe is the third largest global coal consumer, after China and the USA. In 2008, EU-27 coal supply amounted to 820 Mt. This comprised 153 Mt of indigenous hard coal production, 230 Mt of imported hard coal, plus 441 Mt of indigenous lignite. If the lignite output from other major non-EU countries (Turkey – 73 Mt, and Serbia – 37 Mt) is added to this latter total, the European lignite total amounts to ~550 Mt. Overall, around two thirds of EU coal consumption is derived from indigenous production. Low CV coals are an important domestic source of energy for OECD Europe, accounting for around half of total coal consumption on a tonnage basis, and a quarter on a CV basis.

As noted, lignite is produced in significant quantities in many European countries. These are examined below.

3.1 Bulgaria

Bulgaria has limited reserves of fossil fuels, its indigenous energy resources consisting mainly of low rank lignite and brown coal. These play a significant role in the country's energy security, being used mostly for power generation. Some bituminous coal and anthracite is also imported for steel making and power generation. In 2008, the country imported 4.91Mt of hard coal (4.49 Mt of steam coal) (OECD/IEA, 2008) mostly from Russia and other parts of the former USSR.

Most of Bulgaria's lignite reserves are in the central and western parts of the country. In 2009, reserves were estimated to amount to 1928 Mt (Pudil, 2009). Since 2002, 25–26 Mt is produced annually, exclusively by opencast mining. The bulk of production comes from the three Maritsa Iztok mines belonging to Mini Maritsa Iztok EAD, and is supplied to three minemouth power plants (total of 2.24 GW capacity). Annually, around 22 Mt goes to the power plants, with a further 3 Mt being used for the production of 1 Mt of briquettes, destined mainly for household use.

Mini Maritsa Iztok is the largest mining company in the country and other producers have much lower outputs. For instance, brown coal (~3 Mt/y) from the Bobov Dol mines in southwestern Bulgaria, and the Stanyantsi, Beli Breg, and Chukurovo mines, is supplied mainly to the 630 MW Bobov Dol power plant. The Pernik mines, west of Sofia, supply the Republica power plant (although reserves are nearing depletion). Overall, national coal output comprises 88.7% lignite, 10.9% brown coal and 0.4% hard coal (Euracoal, 2008).

Coal is important to Bulgaria's economy, as coal-fired power plants produce a significant proportion of the country's electricity. Bulgaria has a total installed generating capacity of 11.4 GW. This includes 1475 MW of hard coal fired plants, and 3370 MW fired on lignite and/or brown coal. Indigenous lignite and hard coal play a major role in the country's power sector. Annually, lignite and hard coal generate around 42–44% of the national total (45.8 TWh in 2007). Nuclear power supplies much of the balance (35%), with smaller contributions from oil (0.9%), natural gas (5%), and other systems such as hydro (10%).

Bulgarian coal-fired power plants are all conventional PCC subcritical facilities. In many cases, average unit capacity is small, with most of the larger units of only around ~210-220 MW. Some are fired on indigenous lignite/brown coal, while others fire imported bituminous coal or anthracite. Recent years have seen a number of projects undertaken, aimed at reducing the environmental impact of coal-fired plants. At some plants, a series of upgrades have been applied. For instance, the upgrade and modernisation of the lignite-fired Maritza East III power plant was completed in 2009.

There has only been one major coal-fired power plant built in recent years, the 670 MW AES Maritsa East (New) I lignite-fired plant. This was constructed on a turnkey basis by Alstom. It operates at subcritical steam conditions and is equipped with Alstom advanced pulverised lignite firing boilers. Emission levels are reportedly fully compliant with the latest EU standards. Commercial operations began during 2009.

3.2 Czech Republic

Coal (both brown and black) is the Czech Republic's only significant indigenous energy resource and it remains the core fuel within the country's energy sector. In 2008, total proven coal reserves were an estimated 4501 Mt. Reserves of subbituminous coal and lignite amounted to 2828 Mt (BP, 2009). Some 45% of the country's primary energy consumption is provided by hard coal and lignite. Lignite makes up a major component of the country's reserve base and is expected to remain an important energy source in the Czech Republic for some years. Czech lignites can have have ash contents between 10% and 40%, moisture contents between 25% and 41%, and sulphur contents between 0.37% and 1.8%.

Annual coal production has remained at between 49 and 53 Mt/y for some years. Hard coal is extracted in North Moravia, near the cities of Ostrava and Karviná. Around 13 Mt is produced each year, around half of which is used in the metallurgical and chemical industries. Most of the Republic's electricity is generated by coal-fired stations located close to coal mines. These produce nearly two thirds of the country's output. Much of the balance is provided by the Republic's two nuclear plants at Temelín and Dukovany.

Lignite is produced mainly in the Northern Bohemian Brown Coal Basin and used predominantly for power generation. The biggest producer (~24 Mt/y – nearly 50% of total national production) is Severoceské doly, a.s. (now part of the ČEZ Group). The ČEZ Group is the country's largest coal consumer and the biggest electricity generator, supplying over 70% of the nation's electricity.

The second largest lignite producer is MUS, which produces ~15 Mt/y from two opencast mines (CSA and Vršany) in Bohemia. Reserves at the former will last to 2017-20, the latter to 2058. There are also a further 750 Mt of high-quality lignite not currently being exploited. Lignite is also mined in the Doly Nástup Tušimice brown coal mining area (14 Mt/y), the Bílina brown coal mining area (9 Mt/y), the basin around Sokolov (10 Mt/y), and near Hodonin and Breclav. Total national lignite production in 2008 amounted to 52.7 Mt; hard coal production was 7.5 Mt (OECD/IEA, 2009).

In terms of power generation, the Republic is currently more than self-sufficient and is able to export as much as 25% of its overall production. In a typical year, around 60% of the country's total

Table 8 Major Czech power plants fired on lignite and/or subbituminous coals (CoalPower)

Plant	No units	Capacity, MWe + MWth	Annual consumption, Mt/y
Hodonin	2	105 + 262	0.5
Komorany I and II	10	239 + 449	10.79
Chvaletice	4	800 + 100	3.3
Ledvice II	2	220 + 80	1.3
Ledvice III	1	110 + 308	0.5
Melnik I	6	352 + 500	n/a
Melnik II	2	220 + 530	1.05
Melnik III	1	500 + 1195	1.4
Opatovice	7	360 + 480	1.9
Pocerady	5	1000 + 100	5.8
Porici	3	165 + 214	0.5
Prunerov I	4	440 + 92	2.1
Prunerov II	5	1050 + 100	5.0
T700 Litvinov	5	109	n/a
Tisova	4	184 + 324	0.9
Tisova II	1	112	0.6
Tusimice II	4	800 + 100	4.4
Vresova I	4	220 + 350	1.5
Vresova II	2	400 + 85	1.4

electricity output (88.4 TWh in 2007) is provided by coal-fired stations, with a further 30% being generated by nuclear power plants. Overall generating capacity is 17.6 GW, of which, around 10.6 GW is coal fired. Many plants are conventional PCC plants using subcritical steam conditions, although in recent years, a number have been repowered using CFBC technology. PCC plants fired on brown coal (the least expensive option) produce most of the electricity generated by thermal stations (47 TWh in 2007), with hard coal-fired units producing only 7.7 TWh. Major Czech power plants fired on lignite and/or subbituminous coals are shown in Table 8.

As noted, a number of these are based on CFB technology, this having been used to replace outdated PCC plant. In many situations, it has been less expensive to repower using CFB technology than to equip old plants with modern FGD and other emissions control systems. Advantageously, repowering with CFB technology has often resulted in increased generating capacity from a particular site. Major CFB projects fired on lignite/brown coal are in place at a number of power and co-generation plants that include ČEZ Tisová (86 and 100 MWe), ČEZ Porici (2 x 55 MWe), ČEZ Hodonin (60 MWe and 45 MWe), Ledvice 3 (110 MWe), and Zlin (25 MWe and 30 MWe) (Mills, 2007a).

There are also two projects based on the use of supercritical PCC technology. At the Ledvice site, a new brown coal fired 660 MW SC unit is replacing two decommissioned subcritical units. Start-up is scheduled for 2012. Coal for the new plant will come from Doly Bilina mine (Mills, 2007). A second brown coal fired 660 MW SC PCC project, similar to the Ledvice plant, is planned for development at the Pocerady site in the period 2010-15. In April 2006, a business plan for the plant's development was submitted by ČEZ.

The country also hosts the Vresova IGCC plant, located at the former gas works belonging to Sokolovska uhelná (SUAS). Here, two 200 MWe gas turbines are fired on syngas produced by 26 old fixed bed gasifiers. These consume ~2000 t/d of local lignite and can produce ~200,000 m^3/h (~4,700,000 m^3/d) of raw gas.

There are currently two proposals for carbon capture and storage projects to be located at ČEZ's Ledvice and Hodonin power plants. The Ledvice site is being considered as the location for *The North Bohemia Clean Coal Demonstration Project*. This will be fitted to the new 660 MW SC PCC unit under construction; an amine scrubber will capture CO_2 from plant flue gases. This will then be piped for storage in deep sedimentary aquifers in the Central Bohemian Permocarboniferous Basin. Start-up in 2015 has been suggested. The second project is the *Hodonin CO_2 Separation Project*, to be located at the Hodonin CFB-based co-generation plant. Fuel is a combination of local lignite and biomass. An amine scrubber has been proposed, with CO_2 storage in depleted oil/gas reservoirs or deep sedimentary aquifers. A potential start-up date of 2015 has been suggested (Budinsky, 2008). There appears to be potential for EOR application in the Hodonin area (AF Power, 2008).

3.3 Germany

Even though, over the past decade, their shares have declined, hard coal and lignite remain Germany's main fuels for power generation. In 2007, the country's reserves of hard coal were estimated to be 118 Gt and its lignite reserves, 40.8 Gt. The country meets a significant proportion of its energy needs from these. In 2008, 19.1 Mt of hard coal and 175.3 Mt of lignite was produced from deep and opencast mines. The hard coal industry is in the process of being restructured and there are currently seven operational deep mines in three areas (the Ruhr, Saar and Ibbenbüren coalfields). The Ruhr is the most productive, producing ~75% of the country's total output.

As a result of its availability and cost, lignite is of critical importance to the country's energy supply. It is used mainly for power generation (~165 Mt/y, around 92% of total lignite production). Overall, lignite accounts for around a quarter of Germany's electricity generation. The accessible geological lignite deposits (between the Rhineland and the tri-country region of Germany, Poland, and the Czech Republic) are considered sufficient for maintaining current levels of lignite power generation for more than two centuries. Lignite is viewed as providing long-term energy security at stable and controllable cost.

Lignite production is centred in four mining regions, all of which rely exclusively on opencast techniques. These comprise the Rhineland (54.7%), Lusatia (33.4%), Central Germany (10.7%), and Helmstedt (1.2 %). Rhineland has the largest production capacity (~97 Mt/y) and the biggest opencast mines; these supply ~12 GW of lignite-fired power plants. Output from the Lusatia field is around 59 Mt/y, this being fed mainly to 7 GW of power generating plants in the area. The Central German field produces ~19 Mt/y and feeds >3 GW of generating capacity. Recent years have seen demand for lignite reaching the limits of production and this has prompted a number of major players to consider capacity extensions (Hartung and Milojcic, 2007).

Total German installed generating capacity is currently ~143.3 GW. This includes 27.7 GW from hard coal fired plants, and 20.4 GW from lignite-fired plants. In 2007, total power supply amounted to 633.8 TWh; of this, hard coal fired capacity generated 142.3 TWh and lignite-fired plant, 156 TWh. In some eastern parts of the country, as much as 85% of electricity is generated from lignite.

Thus, the vast majority of lignite output (~93%) is used for power generation and district heating. Two of the country's biggest generators (RWE AG and Vattenfall Europe AG) rely heavily on the use of indigenous lignite. RWE produces the greatest proportion of its power (41%) from lignite and operates three large opencast mines (Hambach, Garzweiler and Inden) that supply the Niederaussem site. The remaining lignite production (7%, around 13 Mt/y) is used by other power companies, some municipal utilities, chemical, cement, and sugar factories, as pulverised FBC fuel, for lignite coke production, and for manufacturing briquettes for domestic heating.

The world's three largest lignite-fired generating plants are located in the state of Saxony, two at Lippendorf and one at Boxberg. Lignite is used to generate 85% of electricity in Saxony. Despite

Table 9 Recent German projects and proposals for advanced lignite-fired power plants

Client	Location	Capacity, MWe	Technology	Schedule
Vattenfall	Boxberg	907	USC PCC	Start-up 2000
	Boxberg	675	USC PCC	Start-up 2011
Vattenfall Europe generation/Hitachi Power Europe	Moorburg	2 x 820	USC PCC	Start-up 2010
RWE Power	Neurath BoA	2 x 1100	USC PCC	Start-up 2009-10
RWE Power	Niederaussem K	1027	USC PCC	Commercial start-up in 2003
Vattenfall	Walsum	750	USC PCC	Start-up 2011

some decline in output since 1990, lignite remains by far the most important fuel for stationary applications in eastern Germany. Some of the world's most advanced lignite-fired PCC power plants are located in the country and a number of others are proposed or under development (Table 9).

In recent years, clean coal technologies have been applied increasingly to Germany's lignite-fired power plants. All have been equipped with FGD systems and most have been modernised and upgraded in various ways in order to increase efficiency. For instance, in the Lusatian lignite mining area, 4 GW of old capacity was updated at the Janschwalde and Boxberg sites. Stepwise increases in efficiency have been achieved during the past few decades. For example, at Niederaussem in 1963, a 150 MW plant began operation (efficiency of 31% LHV). During the 1960s and 70s, capacity was increased by 300 and 600 MW respectively (efficiencies of 34% and 35%). And in 2002, the present 1 GW BoA 1 unit came on line (efficiency of 43%) (Daehnert, 2006).

Plant efficiency has been increased in a number of ways. At the Niederaussem BoA unit, one of the most important has been the adoption of the WTA lignite drying process, developed by RWE.

Table 10 Examples of properties of different German lignites (Michel, 2008)

Region	Ash, %	Moisture, %	Sulphur, %	CV, MJ/kg
Lusatia	4.0–12.6	52–60	0.3–1.1	7.48–9.0
Middle Germany	6.5–8.5	48–55	1.2–2.1	9.0–11.5
Rhineland	1.5–8.0	50–60	0.15–0.5	7.8–10.5

Although lignite properties vary (Table 10) the raw lignite feed here has a moisture content in excess of 50%. Therefore, in current conventional boiler technology, a significant part of the combustion energy is expended in evaporating the moisture, reducing the efficiency of the steam cycle and rendering it less efficient than boilers using drier fuel sources. By pre-drying using atmospheric, fine grain, fluidised bed technology, the latent heat of evaporation can be recovered and used to continue the evaporation process in lieu of combustion energy, thus boosting the overall efficiency of the power cycle. Features of the WTA process include (Katambula and Gupta, 2009):

- lignite drying in a fluidised bed with superheated steam;
- supply of the drying energy via a heat exchanger installed in the drier;
- use of drying vapours by means of a heat pump process for drier heating;
- use of the vapour condensate for coal or condensate pre-heating in the power plant;
- feed grain size of raw coal input of less than 2 mm.

Recently, several important projects aimed at reducing CO_2 emissions from coal-fired power plants have come on line. Two different approaches are currently being trialled. The first is the use of oxyfuel technology, this being applied by Vattenfall to a 30 MWth pilot plant at its 1600 MW Schwarze Pumpe power plant site. This forms part of Vattenfall's programme to develop and commercialise oxyfuel technology and is viewed as a crucial stage in scaling up the technology for a 250–350 MW demonstration. The main objectives of the Schwarze Pumpe project include validation of engineering techniques, improved understanding of oxyfuel combustion dynamics, and a demonstration of the capture technology. The initial test programme will run for three years although the plant has a planned lifetime of at least a decade. The programme will focus predominantly on the optimisation of oxyfuel technology within the plant's major components. During the course of the programme, a range of lignites and hard coals will be combusted in mixtures of oxygen and recirculated CO_2.

The second CCS project is taking place at the lignite-fired Niederaussem site, where post-combustion carbon capture is being examined using an amine scrubber. The project partners comprise RWE Power, BASF, and Linde Group. The pilot plant started operations during 2009 and currently captures ~7 t/d of CO_2. The programme is concentrating on testing new technological developments and novel BASF solvents (Henderson and Mills, 2009).

3.4 Greece

Lignite is the country's most abundant indigenous energy resource and is of major importance to the Greek economy. It accounts for around a third of primary energy consumption and is used to generate >50% of the country's electricity. Estimates vary, although the total proven reserves scattered throughout the entire Greek region appear to lie somewhere between 3.9 and 5 Gt (BP, 2009; Kaldellis and others, 2009). Some 3.2 Gt of this total is considered to be commercially exploitable; the government-owned Public Power Corporation (PPC) has exclusive rights to 63% of this. The main exploitable reserves and selected characteristics of Greek lignite deposits are shown in Table 11.

Table 11 Greek lignites (Kavouridis, 2008)

Region	Exploitable reserves, Mt	Ash content, % db	Heating value, MJ/kg
Ptolemais-Amynteon	1595	29.2	5650
Florina	325	39.6	8180
Megalopolis	237	32.6	4350
Elassona	169	34.8	8300
Drama	900	39.0	4370

Greece is currently the second largest lignite producer in the EU, and the sixth largest global producer. Lignite is produced mainly by PPC (OECD/IEA, 2008, 2009). In 2008, total national output was 73.1 Mt (OECD/IEA, 2009), some 97% of which was produced by PPC. The company operates five major opencast sites in the Western Macedonia region, Northern Greece and the Peloponnese region (Megalopolis). Four of these mines constitute the Western Macedonia Centre, with an annual production of 55–57 Mt/y. The complex in the Peloponnese region (the Megalopolis Centre) produces ~14 Mt/y. Apart from PPC's mines, a small lignite mine (output 1.8 Mt/y) is also operated by a private company in the Florina basin. Opencast mining techniques were first introduced into the Greek lignite sector in 1958 and are now used widely.

Since 1995, there has been a gradual upward trend in production (Figure 11). During the period between 1970 and 2005, lignite production increased at an average annual rate of ~7%/y (Kavouridis, 2008). At the present rate of consumption, it is expected that commercially-exploitable

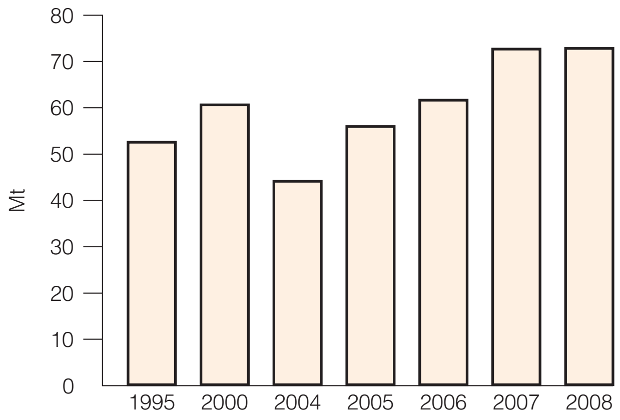

Figure 11 Greek lignite production (1995-2008) (OECD/IEA, 2009)

reserves will last for between 25 and 50 years. Since the early 1970s, lignite has been used to meet a growing proportion of the country's electricity needs, predominantly for base load applications.

A large proportion (~97%) of the country's lignite output is consumed by the power generation sector. Much is fed from lignite mines directly to power plants via conveyer systems. Ash content can range between 15% and 40%, moisture content between 9% and 66%, and sulphur content between 0.3% and 6.4% (Kavouridis, 2008). To counteract these variations, different grades are sometimes blended in order to meet specified power plant requirements. Around 0.8 Mt/y of hard coal is also imported from South Africa, Russia, Venezuela and Colombia.

The country has an installed generating capacity of 12.7 GW, of which some 5.3 GW is lignite fired. With one exception, all lignite-fired power plants are owned by PPC and fuelled on lignite from its own mines. PPC's fleet generates ~90% of the country's electricity. In 2008, total power generation (interconnected and Greek islands) amounted to 60.8 TWh. Lignite's share was 53.1%, with the balance coming mainly from oil (15.8%), gas (17.4%) and other systems (13.7%). Most of PPC's stations are conventional subcritical PCC-based plants. However, in 2003, the company's 330 MW lignite-fired plant at Achlada, Florina, came on line; this uses supercritical steam conditions.

3.5 Hungary

Hungary's energy production structure is similar to that of many of the newer EU Member States, being based largely on the use of indigenous fossil fuels (lignite, brown coal, oil and natural gas). However, domestic oil and gas production has peaked and is expected to decline gradually. At present, the country imports around 80% of its oil and gas requirements, exclusively from Russia.

The country has estimated resources of 1.6 Gt of hard coal plus of 9 Gt of lignite. Proven coal reserves amount to 3.3 Gt – this comprises 2.93 Gt of lignite, 170 Mt of subbituminous coal, plus a similar amount of bituminous coal. Thus, lignite accounts for >85% of the country's solid fuel reserves (OECD/IEA, 2009). Lignite and brown coal reserves are concentrated mainly in the regions of Transdanubia and in the northern and northeastern areas. Since 2005, the main production sites have been the Mátrai Erömü ZRT (MÁTRA) two opencast mines at Visonta and Bükkábrány, and a single deep mine that supplies the Vertes group of power plants. MÁTRA's lignite field has proven reserves of ~800 Mt, and produces ~8 Mt/y. Overall, in recent years, national lignite production has decreased although output is currently being maintained at around 10 Mt/y. Some 95% of this is used in power stations. At present rates of extraction, economically viable lignite reserves are expected to last for more than a century. It is anticipated that indigenous lignite will continue to supply a significant proportion of the country's energy needs for many years.

Hungary has a total installed generating capacity of 8.85 GW. Coal-fired stations comprise 133 MW of hard coal-fired capacity, plus 1.5 GW of lignite-fired. National electricity generation in 2007 amounted to some 40 TWh. In 2007, hard coal-fired stations provided only 0.2 TWh, and lignite-fired plants 7.1 TWh. The biggest lignite-based power generator is MÁTRA, with a market share of 15%. MÁTRA's (86 MWe + 2304 MWth) major co-generation plant is located at Visonta. This consumes around 8 Mt/y of local lignite.

Lignite characteristics can differ significantly between locations. Depending on the source, ash levels can vary between 20% and 50%, and moisture between 19% and 45%. Sulphur levels can be high, varying between 0.8% and 4.9%. The Vertes Group’s 240 MW Oroszlany power plant consumes 1.7 Mt/y of lignite with an ash content of 42%, moisture content of 14%, and sulphur content of 3.4%. MÁTRA’s Visonta plant uses lignite with an ash content of 43%, moisture content of 46%, and sulphur content of 2%.

In February 2010, it was announced that a consortium comprising major Hungarian energy producers, utility companies, and the Geophysical Institute of Hungary intended to deploy a CCS demonstration project at the lignite-fired MÁTRA power plant. Two new 200 MW blocks are also planned within the next five years. The plant is the largest single CO_2 point source in Hungary, emitting approximately 6 Mt/y. According to work carried out as part of the FP6 GeoCapacity programme, the country’s estimated CO_2 storage capacity could exceed 3000 Mt, with many potential storage sites located in the vicinity of the MÁTRA plant (Azbej, 2010).

3.6 Kosovo

Kosovo, one of the poorest countries in Europe, declared independence from Serbia in 2008. Lignite is of great importance to its economy, particularly for power generation as nearly all (~97%) of its electricity is produced from this source.

Kosovo’s proven lignite reserves are distributed across the Kosovo, Dukagjin and Drenica Basins, although mining has so far only taken place in the Kosovo Basin, where two opencast mines are in operation (Bardh and Mirash). These are operated by the public-owned mining and power company Korporata Energjetike e Kosovës (KEK). Geologically, these mines are exploiting one of the most favourable lignite deposits in Europe (Mining Journal, 2005). Extraction costs are generally low. There are also several other smaller basins that include Malishevë and Babush i Muhaxherëve. It is estimated that lignite reserves available in the fields currently being exploited will be sufficient for the next decade. For the period beyond this, new mines will need to be developed in order to meet the demand of existing and planned power plants (Kosovo White Paper, nd).

Currently, the country suffers from persistent power shortages. However, recent years have seen a number of proposals for new power generating capacity. The latest proposal involves North American Coal Corporation and is for a 1 GW lignite-fired plant. The proposed €700 million plant will be located near the Sibovc opencast mine; this already feeds two existing power stations and will also supply the new one (Bytyci, 2009). In total, the Kosovan power sector currently consumes around 7–8 Mt/y of local lignite, and other sectors a further 0.5 Mt/y. Lignite quality tends to vary, depending on the source. Moisture content varies between 35% and 50%, ash content between 12% and 21% (average 14–17%), with sulphur content between 0.35% and 1%. Some 29% of the total proven reserves have a CV of >8.4 MJ/kg; 43% falls between 7.7 and 8.4 MJ/kg, and 25% is between 5.8 and 7.7 MJ/kg (Kosovo White Paper, nd).

In 2005, the *Kosovo Energy Strategy* was developed and approved by the Government. It has since confirmed that electricity demand is rising and that the country needs more domestically-produced energy. More generating capacity is required to provide an effective and affordable supply based on local resources. Existing generating capacity should be renovated, lignite mining should be increased, and new lignite-fired generating capacity should be built were amongst it’s recommendations (Haxhiu, 2008). In 2009, the government gave the go-ahead for the development of a new 2 GW lignite-fired power plant (Kosova C or Kosova B) one of the biggest investments since the country’s independence. It will reportedly adopt modern technology (probably supercritical PCC) and will meet current European environmental standards. It will be built near the existing Kosovo B plant, and will, initially, produce 1 GW. Once operational, Kosova A, built during the 1960s, will be closed (by 2015). Concurrently, Kosova B will be renovated and modernised.

3.7 Poland

Poland has proven hard coal reserves of 6012 Mt plus 1490 Mt of lignite (BP, 2009). Hard coal resources are predominantly in Upper Silesia and in the Lublin basin. Combined, hard coal and lignite supply some 68% of Polish primary energy needs. Both are strategic fuels for power generation. Although production of hard coal has declined in recent years (from 103 Mt in 2000 to 84 Mt in 2008) Polish lignite mines are expected to maintain a production capacity of 65–70 Mt/y for some years, and lignite is expected to continue playing an important role for power generation until at least 2035.

Polish lignite is mined exclusively by opencast methods. Typically, annual production in recent years has been around 60 Mt, some 99.7% of which is fed directly to minemouth power plants. Major mining operations are located in the central region (in the Belchatów and Konin-Adamów basins) and south-western part of the country. The Belchatów mine produces ~30 Mt/y of lignite (~55% of total national production) and is expected to remain in operation until 2038. Lignite from here is fed exclusively to PGE Elektrownia Bełchatów's 4.4 GW minemouth Belchatów power plant. This complex generates ~20% of the country's electricity. Lignite from the site is the cheapest power generation fuel in Poland. In August 2009, PGE KWB Belchatów S.A. began lignite mining operations at the Szczerców field, one of the three fields making up the Belchatów lignite deposit (this has estimated reserves of 620 Mt). Once fully operational, the Szczerców mine is expected to have a capacity of 36.5 Mt/y.

The Konin-Adamów basin contains two major mines. The first is the Konin mine which comprises several opencast sites and has a production capacity of 12 Mt/y. Lignite is supplied to three minemouth power plants (the 1.2 GW Patnów I, the 464 MW Patnów II and the 583 MW Konin stations). The lignite reserves at operating mines in the basin are around 88 Mt. There are also satellite deposits not currently being exploited with estimated reserves of ~294 Mt. The second mine is the Adamów mine, which comprises three opencast sites with a combined production capacity of 5 Mt/y; it supplies ~9% of Poland's energy requirements. Current working reserves are 63 Mt, plus satellite deposits of 726 Mt. All output is fed to the 600 MW Adamów minemouth station. The Adamów mine is expected to remain in operation until 2023 and the Konin mine until 2040. The Turoszów lignite basin is in the southwest of Poland. This has reserves of >400 Mt. Annual production is ~11 Mt/y, supplied mainly to the 2 GW Turów power plant. The mine is expected to remain in operation until 2040. Typically, Polish lignites have an ash content of 5–11%, a moisture content of 50–55% and a sulphur content of ~0.6%.

A small amount of lignite is exported (~28 kt/y) (Polish Geological Institute, 2008). However, nearly all output is used by the power sector, with around a third of the country's electricity being generated by lignite-fired plants. The sector has a total installed capacity of 32.4 GW. Hard coal fired plants comprise 20.7 GW and lignite fired plants, 9.3 GW. Annual generation amounts to around 162 TWh; in 2008, 97.3 TWh came from hard coal plants, and 51.3 TWh from lignite stations.

More than 50% of Polish power stations are over 25 years old. However, the lignite-fired plants are among the newest in Poland (Table 12). Most power plants are conventional PCC units

Table 12 Major Polish lignite-fired power and co-generation plants

Plant	No units	Capacity, MWe	Type	Annual consumption, Mt/y
Adamów, Turek	5	600	Co-gen	4.03
Belchatów	12	444 (376 MWth)	Co-gen	35.1
Belchatów II	1	830	Power	0.44
Konin	8	1600 (64 MWth)	Co-gen	4.54
Turów	10	2025 (132 MWth	Co-gen	3.86
Patnów	6	1200	Power	8.54
Patnów II	1	464	Power	n/a

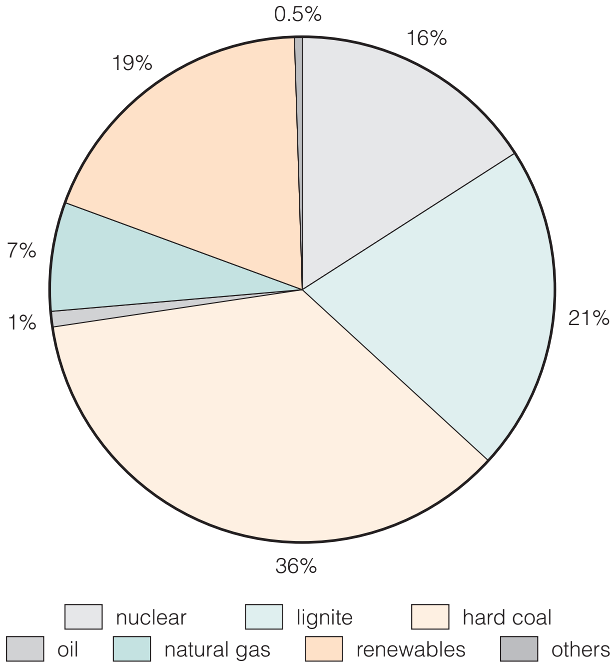

Figure 12 Breakdown of Polish power generating sector by fuel type in 2030 (Polish Ministry of Economy, 2010)

although there are several supercritical projects in hand and a number of old PCC plants have been repowered using CFB technology. The biggest is at the Turów site where six CFB units (total capacity of 1491 MWe) are now operating using lignite supplied by the KWB Turów mine. The Turów plant is the largest individual CFB-based facility in the world. The predicted make-up of the power sector in 2030 is shown in Figure 12.

A carbon capture and storage project is currently under development at the lignite-fired Belchatów site where a post-combustion carbon capture pilot plant is being built. This is using an Alstom/Dow amine scrubber to capture 100 kt/y CO_2 from flue gases of the existing Unit 12. It is scheduled to start up in 2011. Phase II of the project may focus on the installation of a larger project on the site's new lignite-fired 858 MW supercritical unit. This could capture up to 1.8 Mt/y of CO_2 and be operational by 2015.

3.8 Romania

The country has hard coal resources of 936.8 Mt and lignite resources of 3538 Mt. Proven reserves amount to 801 Mt of hard coal and 1364 Mt of lignite. There are also small deposits of subbituminous coal (Euracoal, 2009). Lignite deposits are located mainly in the Oltenia basin in the southern part of the country. More than 90% of total output comes from seven major opencast operations (Rovinari, Rosia, Pesteana, Pinoasa, Motru, Berbesti and Mehedinti), with most fed directly to nearby power and co-generation plants. Annually, from a total production of 35–36 Mt/y, some 22 Mt is used for power generation and 12.6 Mt for co-generation. Currently, the balance of the country's coal requirement is met from domestically-produced hard coal (2.5–3 Mt from the Jiu Valley) plus ~4 Mt/y imports. By 2020, lignite production is expected to have increased. Romanian lignites generally have ash contents that vary between 30% and 40%, moisture contents of around 40–43%, and sulphur content of around 1.2%.

Romania's National Lignite Company has several ongoing projects aimed at upgrading its facilities. It is modernising its mines at Rosiuta, Pesteana and Rosia, at a projected cost of €35 million. It also intends to invest a further €2 million in upgrading the power grid and electrical installations at its opencast mines.

As elsewhere, the vast majority of lignite produced is used by the power sector. The country has 15 GW of coal-fired generating capacity, some 13.3 GW of which is lignite-fired (*see* Table 13). Annual electricity generation amounts to 63–66 TWh, and typically, lignite fired stations produce ~35–40% of this. A breakdown of the power sector for 2008 is shown in Figure 13. Electricity demand is forecast to continue increasing from current levels, rising to 72.2 TWh in 2012 (coal – 29.7 TWh), and 100 TWh in 2020 (coal – 34.9 TWh). Much of the coal component will continue to be provided by indigenous lignite (ZEP, Romania, 2010).

There are ongoing programmes at several existing power plants, aimed at improving efficiency and

Table 13 Main Romanian lignite-fired power plants (CoalPower)

Plant	No units	Capacity, MWe + MWth	Lignite consumption, Mt/y
Borzesti	3	150 + 440	0.43
Brasov	2	100	0.89
Craiova	5	375	n/a
Craiova II	2	300 + 330	0.67
Drobeta-Turnu Severin	4	200 + 776	2.15
Giurgiu	3	150 + 357	0.55
Govora	2	100 + 150	0.95
Isalnita	8	985 + 540	0.44
Paroseni	4	300 + 95	0.41
Rovinari	4	1320	0.4
Turceni	5	1650	4.99

reducing environmental impact. The biggest is at the SC Complexul Energetic Turceni SA co-generation facility at Turceni, where two lignite-fired 330 MW PCC units are being rehabilitated and modernised. New boilers with steam conditions of 540°C/19.2 MPa are being installed, with environmental improvements being achieved through the installation of low NOx burners, wet limestone FGD, and new ESP units.

In December 2010, Romania's Institute for Studies and Power Engineering selected Alstom's Chilled Ammonia Process as the basis for the development of a carbon capture and storage demonstration project to be located at the Turceni power plant. This will be integrated into Unit 6 at the Turceni power plant which will, concurrently, be retrofitted to a capacity of 330 MW. The *Romanian CCS Demo Project* represents the first step towards realising the government's CCS action plan; it will be presented as a candidate project for European Union NER300 (New Entrant Reserve) funding for CCS projects.

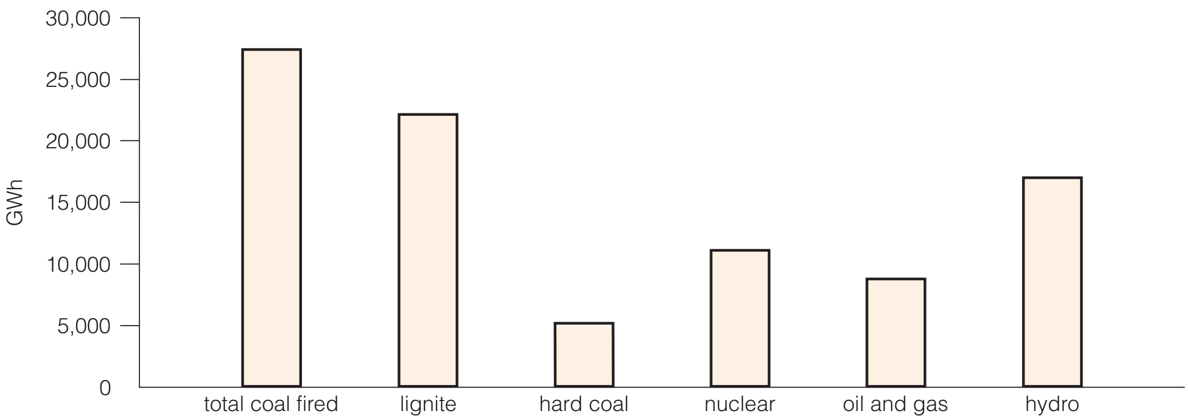

Figure 13 Breakdown of Romanian power output, 2008 (ZEP-Romania, 2010)

3.9 Serbia and Montenegro

At 13.5 Gt, Serbia possesses the largest lignite reserves in Europe. Lignite represents 98% of domestic coal production and makes a substantial contribution to the country's energy supply. The country also has smaller subbituminous coal reserves of around 571 Mt. A significant proportion of the country's lignite reserves are located in the Kosovo Basin. However, in 2008, Kosovo declared independence from Serbia, effectively removing these.

For a number of years, lignite has been extracted from seven opencast sites and in 2008, production amounted to 37 Mt. Most was used for power generation (~34 Mt/y). Major lignite reserves include those at Kolubara and Kostolac; the biggest deposit is located at Kolubara where four modern opencast mines are in operation (combined production of around 29 Mt/y). In the Kostolac field, three opencast mines (Klenovnik, Cirikovac and Drmno) operate with an annual production of around 7 Mt. In recent years, the Kolubara mines have produced ~75% of the country's total output, with much of the balance coming from Kostolac. The Kolubara site has mineable reserves of around 2.2 Gt and Kostolac, around 700 Mt. Some deep mining is also carried out under the control of the Public Enterprise for Underground Coal Mining Resavica (PE UCM Resavica). This operates eight sites with 11 pits, most of which produce lignite. Typically, lignites have an ash content between 18% and 25%, moisture content between 43% and 55%, and sulphur content between 0.5% and 0.9%. Average CV (LHV) is around 7.26 MJ/kg.

Table 14 Serbia's main lignite-fired power plants

Plant	No units	Capacity, MWe	Consumption, Mt/y
Kolubara	5	270	1.6
Kosovo A*	5	800	2.9
Kosovo B*	2	680	3.1
Kostolac A	2	310	1.7
Kostolac B	2	700	3.1
Morava	1	125	0.4
Nikola Tesla A	6	1650	11.0
Nikola Tesla B	2	1200	11.3

* now part of independent Kosovo (CoalPower)

Serbia has an installed power generating capacity of 8.4 GW, some 5.2 GW of which is lignite fired. Recently, total power supply has varied between 36.5 and 39 TWh. In 2007, the total generation of 36.52 TWh comprised 26.04 TWh from lignite (over 70% of total), 10.04 TWh from hydro, with very small contributions from gas and oil. The country's most important lignite-fired thermal power stations are shown in Table 14. The two Nikola Tesla stations are the largest individual conventional generating units in the Balkans. The Kolubara, Nikola Tesla, and (partly) Morava stations are supplied with lignite from the Kolubara basin. A total of approximately 27 Mt/y is fed to these facilities, with a further 2 Mt/y of crushed, dried lignite supplied to various industrial applications.

The government has plans for the construction of 3 GW of new generating capacity. This includes proposals for several new lignite-fired plants (Kolubara B – 2 x 350 MW, TENT B3 – 700 MW supercritical, and expansion of the existing Nikola Tesla B) (Serbian Ministry of Mining and Energy, 2009).

3.10 Slovakia

The Slovak Republic has relatively abundant energy resources although at present, the majority are not being exploited. The country's dependency on imported energy sources is more than 90%. Estimates suggest that exploitable lignite reserves are between 70 and 83 Mt, and resources at around 525 Mt (Pudil, 2009). There is also a single hard coal deposit in the eastern part of Slovakia, although this is not currently economically exploitable.

Lignite is extracted by three companies at five underground mines located in the central, southern and western parts of the country. The biggest producer is Hornonitrianske bane Prievidza (HBP). The company extracts lignite at the Handlova and Novaky deposits, located in the Horna Nitra region. These supply around 2 Mt/y to the ENO power plant. Since 2000, national production has varied between 2.42 and 3.65 Mt/y (2008) (OECD/IEA, 2009).

Installed generating capacity is 7.7 GW, of which, 1180 MW is coal/lignite fired. There are four coal-fired power plants currently in operation. Two are fired on imported hard coal whilst the Novaky A and B (total of 518 MWe) co-generation plants fire local lignite. In 2007, lignite-based power generation amounted to 1.9 TWh, representing 6.7% of the total generation of 28.2 TWh. Hard coal generation amounted to 4.0 TWh. In 2007, as a result of the closure of some nuclear capacity, the country became a net importer of electricity.

3.11 Slovenia

Although lignite production is modest compared to some other European producers, it still plays an important role in meeting national energy needs. In particular, indigenous lignite is used to generate more than a third of the country's electricity.

In 2007, the country had lignite resources amounting to 616 Mt, and reserves of 110 Mt. Slovenia has two major lignite deposits, one at Velenje in the north, and one in the central region near Trbovlje. However, the only operational site is the Velenje mine, located in the Šaleška valley. It is the deepest lignite mine in the world. It supplies the country's two lignite-fired power plants and is expected to continue operating until 2040. Typically, output is around 4–5 Mt/y. The country produces no hard coal.

Almost all lignite output is used for power generation. Total power plant capacity amounts to 2.8 GW of which, some 1.26 GW is lignite fired. The country has three coal-fired power plants. The Ljubljana plant is fired on ~1 Mt/y of imported (Indonesian) hard coal. The two others, the (725 MWe + 200 MWth) Termoelektrarna Šoštanj co-generation plant and the 125 MWe Trbovlje power plant, both fire indigenous lignite. These use around 4 Mt/y and 0.65 Mt/y respectively. Total national electricity generation is around 15 TWh/y. The two lignite-fired stations generate around 36% of this total. Typically, Slovenian lignite has an ash content of around 14%, a water content of 36%, and a sulphur content of 1.4%.

In July 2010, it was announced that the European Bank for Reconstruction & Development was to co-finance (via a loan of €200 million), with the European Investment Bank, a modernisation programme for the state-owned lignite-fired Šoštanj co-generation plant. This facility produces nearly a third of Slovenia's electricity output and is considered crucial to the country's energy security. The EBRD loan will support the construction of a new 600 MW capacity coal-fired unit (probably supercritical) that will replace five existing low efficiency, high carbon intensity units. CO_2 savings are expected to amount to 1.2 Mt/y, approximately 8% of Slovenia's total greenhouse gas emissions. Furthermore, the new unit is to be built CO_2 capture-ready.

3.12 Spain

Spanish hard coal reserves are estimated to be 1156 Mt, and lignite, 354 Mt (Euracoal, 2008). The country's main lignite fields are in Galicia, Ginzo de Limia, Arenas del Rey, and Padul.

In 2007, most Spanish coal was burnt in local power stations. The country produced 4.4 Mt of anthracite (OECD/IEA, 2009), 3.1 Mt of subbituminous coal, and 6.2 Mt of lignite (IEA, 2010). All lignite production was consumed in minemouth power plants (nearly 2 GW combined capacity). However, by the end of 2007, lignite production had virtually ceased, with just a residual production of 0.2 Mt/y coming from the Meirama mine (IEA, 2010). This followed the closure of Endesa's As Pontes mine, formerly the largest individual lignite producer in Spain. Closure resulted from exhaustion of economically-recoverable reserves. Only restoration and closing works are continuing up to 2012. Spanish lignites have ash contents ranging from 14% to 70%, moisture contents between 8% and 50%, and sulphur contents between 1.2% and 9%. The ash and moisture contents of hard coals can also be high, at up to 35% and 12% respectively.

The country’s largest subbituminous coal reserves (of ~200 Mt) are in Teruel. However, as a result of their high sulphur content (4–6%), only limited exploitation currently takes place, with output being fed to several FGD-equipped power plants. Some subbituminous Spanish coals are referred to as ‘black lignites’.

Around 90% of the country’s coal demand stems from the power sector, with the balance from various industrial processes, predominantly iron and steel and cement production. The Spanish power sector has a total installed generating capacity of 94.7 GW. This includes 16.7 GW of hydro, 7.7 GW of nuclear, 11.9 GW coal-fired, 7.2 GW using fuel/gas (including the Puertollano IGCC plant), 23.1 GW of CCGT, and 15.7 GW of wind power (IEA, 2010). Total annual generation in recent years has been around 305 TWh. Typically, around a quarter of this has been provided by coal (~74 TWh). Historically, some 8% came from low quality local coals although this level has now fallen significantly. During first part of 2009, only 2 TWh were supplied by such plants.

Until recently, several major stations were fired on local lignites. One of the biggest was Endesa’s 1400 MW As Pontes plant. Originally fired solely on local lignite, during the 1990s, it switched to the use of a 50:50 blend of lignite with imported subbituminous coal. In 2005, as a consequence of resource depletion, it was converted to run on imported coal alone. A new import terminal was built in nearby Ferrol, capable of handling around 5 Mt/y of Indonesian subbituminous coal for the plant. The conversion has reduced the plant’s CO_2 emissions by more than 1 Mt/y, along with lower emissions of SO_2, NOx and particulates. Ash production has also decreased by 1.7 Mt/y.

Unión Fenosa also converted its 550 MW lignite-fired Meirama power station to operate on Indonesian coal. This was the biggest individual boiler in the world to be converted from lignite to bituminous coal firing. It had previously operated using 2.8 Mt/y of lignite blended with 20% Indonesian coal. The conversion was prompted by the decreasing availability of local lignite and the introduction of tighter NOx and SO_2 emission regulations in 2008.

Apart from use in conventional power plants, low grade indigenous coals have also been used in two more advanced systems. The first was the Escatron pressurised fluidised bed combustion (PFBC) facility, one of only a handful of such units in the world. It was built as a repowering exercise by a consortium comprising ABB Carbon and Babcock & Wilcox Española, replacing an old coal-fired boiler. Initial operations started in 1990. Fuel was high sulphur (5–8%), high ash (25–36%) ‘black lignite’. However, reports in 2010 suggest that the plant has now been closed. The second plant remains in operation. This is the ELCOGAS 335 MW Puertollano IGCC plant (Figure 14). The plant’s basic fuel is local high ash (~40+%) subbituminous coal blended in equal proportion with high sulphur (5.5%) petcoke from the Puertollano REPSOL refinery. However, the system can tolerate variations as much as 25:75 coal:coke with little impact on gas quality. At full operational capacity, the plant burns 700 kt/y of mixed fuel.

Figure 14 The ELCOGAS 335 MW IGCC plant at Puertollano (photograph courtesy of ELCOGAS)

The Puertollano plant is currently hosting a 14 MWth carbon capture and hydrogen production pilot facility. This has the capacity to treat 2% of the site's syngas, capturing 100 t/d of CO_2 and producing 2 t/d of high purity hydrogen. The plant comprises a shift unit to convert CO into CO_2, a CO_2 separation unit based on amine absorption, and a hydrogen purification unit. It forms a sub-project of Spain's national CO_2 initiative, PSE-CO2.

3.13 Turkey

Coal accounts for almost half of Turkey's total primary energy production and is likely to remain the predominant energy source in the coming decades. The country has sizable proved reserves of subbituminous coal and lignite. Reserves are estimated at around 278 Mt of bituminous coal and anthracite, 761 Mt of subbituminous coal, and 3140 Mt of lignite (WEC, 2004; Euracoal, 2008). Lignite, therefore, is Turkey's most important energy resource. Deposits are found in most regions of the country. The most important known reserves are those in the basins of Afsin-Elbistan (the biggest, 40% of the total), Mugla, Soma, Tuncbilek, Seyitomer, Beypazari and Sivas.

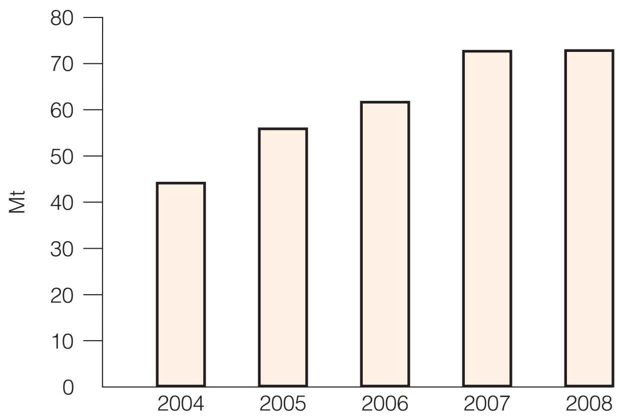

Figure 15 Turkish lignite production (OECD/IEA, 2009)

As, in recent years, the government has closed a number of unprofitable hard coal mines, so the amount of lignite produced has increased steadily (Balat, 2008) (Figure 15). State-owned and private companies produce, process, and distribute lignite, although the state-owned Turkish Coal Enterprises retains the majority market share.

Lignite is extracted mainly from opencast operations (~90%) with the balance coming from deep mines. Each has supply contracts with specific power stations. Thirty opencast and nine deep mines are operated by Turkish Coal Enterprises, producing some 40 Mt/y of lignite. The Electricity Generating Authority also produces lignite for three power plants. However, the private sector, which currently supplies only small amounts to the power sector, is presently experiencing growth. Some forecasts suggest that total Turkish output could rise to 185 Mt/y by 2020.

The quality of the lignite is generally poor. CV varies significantly between deposits, ranging from 6.6 to 14.7 MJ/kg (LHV), although almost 80% of the total reserves have a CV of less than 10.46 MJ/kg. Those with lower CV are usually supplied to power plants although even here properties can vary significantly. CV of power station grades can fall between 4.6 and 17.1 MJ/kg (LHV), ash content between 16% and 47%, moisture content between 17% and 53%, and sulphur content between 0.9% and 3.4% (CoalPower). Lignites with higher CVs are generally directed towards household (~6%) and industrial use (~12%) (Inaner, 2005). However, despite the low CV of many power station grades, due to the country‘s dependence on imported fuels, the Turkish Government has specified that any expansion of coal-fired power generation should be based on the use of indigenous lignite.

Most of the country's lignite output (~75%) is used for power generation. A few power plants rely on imported and indigenous hard coal, but most fire local lignite. Total installed coal-fired generating capacity is ~9 GW (2 GW hard coal-fired, 7 GW lignite-fired). In recent years, approximately 26% of Turkey's electricity has been generated by hard coal and lignite-fired stations (Euracoal, 2009). The balance is provided mainly by natural gas and hydropower. Lignite consumption at individual stations varies between 0.7 to >9 Mt/y (CoalPower). Recent estimates suggest that Turkey's power consumption will increase by 4–6% by the end of 2010, with demand increasing to 203 TWh. The return of economic growth could further boost demand to 357 TWh by 2018. Potentially, from 2014 or 2015, the country could face an electricity supply shortfall.

Most of the country’s power plants comprise conventional PCC power plants, although there is a 320 MW CFB plant operating at Can, in northwestern Turkey. This 2 x 160 MW plant fires high-sulphur lignite from local mines in two Alstom-supplied CFB boilers.

Although most of the country’s lignite production is currently used for power generation, there are ongoing technical and economic feasibility studies examining its gasification to produce pipeline-quality synthetic natural gas. Feasibility studies are being carried out by Turkish Coal Enterprises, and testing has confirmed that Turkish lignite is suitable for gasification. Afsin-Elbistan in central Turkey has been suggested as a possible location for the first gasification plant. Success would make Turkey more energy self-sufficient and help reduce its dependency on imported natural gas.

4 India

The country has proven coal reserves of 58.6 Gt, most of which are bituminous. There are also lignite reserves of 4.6 Gt, the bulk of which are in Tamil Nadu (87% of the total). India's total proven hard coal reserves rank it third behind the USA and China. Unfortunately, the majority of Indian hard coals have high ash content, low CV, variable properties, and are difficult to clean (Mills, 2007; Bessereau and Sanière, 2007). Despite this, as the country's major energy resource, coal remains vitally important to the growing Indian economy, being used extensively by both the power sector and major industries.

India's total installed generating capacity is around 147 GW. Utilities make up 124 GW of this total, with a further 22 GW in the form of captive power plants. Thermal stations (56 coal-based, 10 gas-based) account for 82.4 GW (Mills, 2007). For Indian thermal coals, a range of grades with different CVs and ash contents are produced. However, in practice, some power station coals (the biggest market) can fall outside these limits. Coals typically supplied to Indian power plants may have an ash content of between 25% and 55% (although in general, this is ~41%), a moisture content between 4% and 7%, a sulphur content of between 0.2% and 7%, and a gross CV between 12.9 and 21.4 MJ/kg (although usually towards the upper limit).

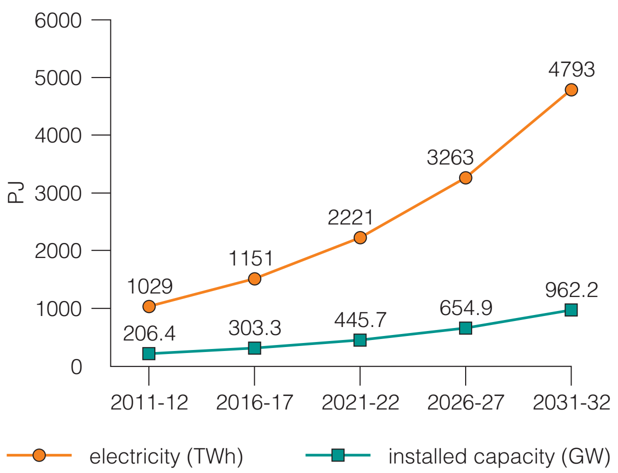

Figure 16 Projected Indian electricity requirements (assuming 8% growth) (Mills, 2007)

Recent years have seen a significant increase in electricity demand, an upward trend that is set to continue (Figure 16).

4.1 Hard coals

Hard coal deposits are spread over 27 coalfields, mainly in the eastern and southern central parts of the country, predominantly in Andhra Pradesh, Jharkhand, Orissa, Chattisgarh and West Bengal. There may be additional reserves of ~60 Gt in the northern region of Gujarat and large quantities of coal are known to exist at deeper levels of the Bengal basin, beneath the Deccan trap, and in younger formations of central India.

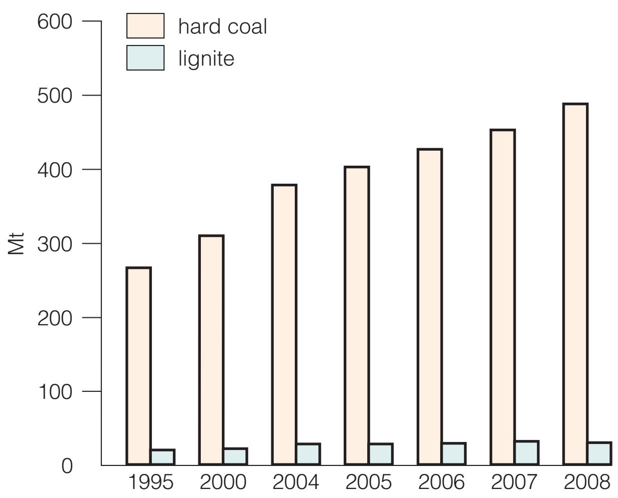

Figure 17 Indian hard coal and lignite production (OECD/IEA, 2008)

Production and consumption of Indian bituminous coal has increased steadily for some years. In 2000, some 311 Mt was produced although by 2008, this had risen to 489 Mt (Figure 17). The largest coal-producing company is Coal India Ltd (CIL), a public sector enterprise of the Indian government. CIL is the largest individual coal company in the world (and also the largest corporate employer in India) and annually produces ~85% of India's total coal output. Singareni Collieries is the second major producer, a joint undertaking of the Government of Andhra Pradesh and the Indian government. It is the main source of coal for India's southern region and produces ~10% of the country's coal. Mining activities are concentrated in four districts of Andhra Pradesh, and both underground and opencast techniques are employed.

A large proportion of Indian coal is used for power generation. Indian electricity demand has risen sharply in recent years, and during the last decade, production and consumption has increased by ~64%. The projected rate of increase up to 2020 is the highest in the world. Unsurprisingly, power generation is the biggest coal-consuming sector, with coal-fired stations generating ~70% of India's electricity (Kessels and others, 2008).

Much of the coal supplied to Indian power plants comes from reserves of reducing quality. In some cases, greater use of opencasting has further compromised quality. To help counter this, since 2002, long distance transport of coal containing more than 34% ash has been prohibited. The high ash content (up to 60%) of Indian bituminous coals results in technical difficulties and higher costs at power plants. However, in 2007, only 20% was still being washed. As a consequence of their drift origin, many contain high levels of inorganic impurities. This is often bound within the coal matrix, making it difficult to remove beyond a certain level. Ash is also often high in silica and hence, abrasive. This, and its high levels, requires consideration when designing power plants and special measures may need adopting. However, most Indian hard coals are generally low in sulphur and trace elements.

4.2 Lignite

India is estimated to have between 35 and 38 Gt of lignite that could be viable. Much of this is located in Tamil Nadu with the remainder in Rajasthan and Gujarat. There are also smaller deposits in Jammu and Kashmir and Kerala. All of these geological reserves have not been fully proven. Those considered as proven are located mainly in Tamil Nadu. Within the latter, some 4.2 Gt of lignite have been identified within the Neveli lignite fields in Cuddadore District, of which ~2.4 Gt have been proven. As noted, geological reserves have also been identified in a number of other locations and states. In most cases, lignite produced is used for minemouth power generation although a limited amount is also used for other industrial purposes

In response to the growing demand from lignite-fired power plants, production has been increasing steadily for some time (Metalworld, 2008). Total annual Indian lignite production is currently ~32 Mt/y, around 27 Mt of which is used for power generation. The country's largest lignite producer is the Neyveli Lignite Corporation (NLC), a Central Government Public Sector Undertaking. This is operated (and 94% owned) by the Indian government. NLC operates three large opencast mines in Neyveli with a capacity of ~28 Mt/y. The company is also the biggest operator of lignite-fuelled power generating capacity in India. Lignite produced is used in NLC's two thermal power plants that have a combined capacity of 2070 MW. The company is also developing a 2.1 Mt/y lignite mine-cum-power project (2 x 125 MW) at Barsingsar in Rajasthan, as well as several others. Other lignite producers include Gujarat Mineral Development Corporation Ltd (typically 6–7 Mt/y), and Gujarat Industries Power Company Ltd.

On an India-wide basis, nearly 80% of hard coal and lignite produced is used for power generation although in Tamil Nadu, it is nearly 90%. In Gujarat, apart from power generation, lignite is also supplied to a range of industrial users that include manufacturers of cement, textiles, chemicals and ceramics; these account for >40% of lignite consumption in the state.

Lignite properties can vary significantly, even within the same region. They are not cleaned prior to use although different grades may be produced via selective mining of different seams or parts of seams. Ash levels are generally lower than Indian bituminous coals.

5 Pakistan

In 2008, the country had proven coal reserves of 2069 Mt consisting almost entirely of subbituminous coal and lignite (BP, 2009). Most of this total was of lignite (1814 Mt in 2007). At the moment, Pakistan produces only small amounts of coal, and it plays a minor role in the country's energy mix. Coal is produced in a number of coalfields with most production falling into the lignite and subbituminous categories. Pakistani estimates suggest that active coalfields in Sindh, the main coal-producing region, have an estimated total reserve of 8.6 Gt. These include Lakhra (the largest coalfield; this produces around 50% of the country's total annual output), Sonda-Thatta, Jherruck, Oagar, Indus East, Meting-Jhimper and Badin. Other fields in the country are thought to contain further reserves in excess of 0.5 Gt (Couch, 2004; Bhutto, 2004).

Over the past decade, Pakistan's coal production has fluctuated between 3.1 and 4.9 Mt/y; in 2008, it was 3.4 Mt (OECD/IEA, 2009). All output comes from several hundred small underground mines. Some 80% of this is consumed by the brick industry, with only a small amount being used for power generation. The biggest individual user in this sector is the 100 MW Khanot power plant, that fires ~750 kt/y of subbituminous coal from the Lakhra coalfield.

The government plans a much greater role for indigenous coal in the future. Under their *Vision 2030* strategy plan, there are proposals for coal-fired power generation to be increased from its current low level of around 200 MW to a capacity of 19.9 GW by 2030. Coal's share in the overall energy mix is planned to increase from 5% to 19% by 2030, and 50% by 2050 (Sultan, 2008).

5.1 The Thar coalfield developments

For some years, the country has been in the throes of an energy crisis. There is currently an estimated generating capacity shortfall of ~4 GW and there are regular electrical outages and load shedding. Lahore is currently experiencing outages of up to 15 hours a day. However, during the 1990s, a substantial coalfield was discovered in the Thar Desert in Sindh, and it is hoped that supplies from here will ultimately help to overcome the country's electricity shortage.

Thar coal is a low-ash, low-sulphur lignite-subbitmunous coal, with a moisture content ranging from 42% and 49%. It has a higher CV than other indigenous coals. The total resource is thought to be between 175 and 200 Gt and it is suggested that there is the potential to supply some 20 GW of power generating capacity by 2019. Some estimates suggest that these deposits could sustain up to 100 GW of generating capacity for at least 300 years.

In 2008, the Pakistan government handed over the development of the Thar coal project to the Sindh government, mainly to expedite the building of a 1000 MW coal-fired power plant. The discovery of the Thar deposits sparked interest from both domestic and foreign developers. Chinese and other companies carried out surveys and feasibility studies of the proposed Thar mine and power project and offered investment. There has also been interest from Germany and Australia. In 2009, South Korea's Pan Energy Development Company signed an agreement with the government for a stake in a coal mine in Thar; an output of 10 Mt/y by 2015 was suggested. Korea Electric Power Corp was also involved in talks. However, it now appears that the first developments may involve a joint venture (Sindh Engro Coal Mining Company) between the Sindh government and Engro Power. The two have agreed on a 60:40 arrangement to exploit Thar coal for power generation. Under the agreement, the first project will be a detailed feasibility study for an opencast mine with an annual capacity of 3.5 to 6.5 Mt and a power project of between 600 and 1000 MW (Sheikh, 2009).

In late 2010, it was announced that an underground coal gasification-based pilot-scale power generation plant was being set up using Thar coal. The project was launched by the Planning Commission of Pakistan, Pakistan Atomic Energy Commission and National Engineering and Scientific Commission. A start-up date in 2011 has been suggested.

6 Australia and New Zealand

6.1 Australia

Coal is of immense importance to Australia, both as a major export and as a domestic source of energy. The country accounts for ~6 % of world hard coal production, with black coal resources located in most states. There are significant quantities of high quality black coal in New South Wales and Queensland (41% and 57% of economic demonstrated reserve (EDR) respectively) and there are also small, but important, resources in Western Australia, South Australia and Tasmania. Lignite is mined principally in Victoria and South Australia, where it is used mainly for electricity generation. There are also smaller lignite deposits in Western Australia and Tasmania. The country has proven total coal reserves of 76.2 Gt. These comprise 36.8 Gt of anthracite and bituminous coal, 2.1 Gt of subbituminous coal, and 37.4 Gt of lignite (BP, 2008). Thus, the country's lignite resources are substantial, with 24% of the world's EDR located in Australia.

In 2008, 325 Mt of hard coal were produced (around 75% from opencast operations), and 72.4 Mt of lignite (OECD/IEA, 2009). Australia accounts for around a third of the world trade in black coal and around 60% of the global metallurgical coal trade. More than three quarters of hard coal output is exported. Most lignite production is in Victoria, with a smaller amount (~3.8 Mt/y) coming from operations in South Australia. Total lignite output has fluctuated around 66–67 Mt for some years, although in 2008, it increased. At current rates of extraction, it is estimated that black coal reserves could last for more than a century, and lignite reserves more than 500 years.

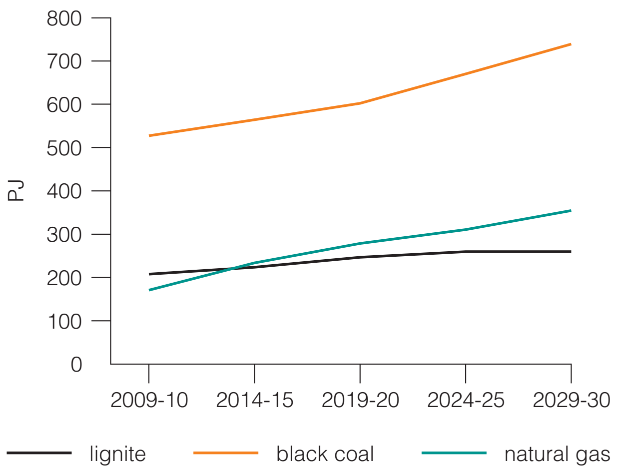

Figure 18 Projected Australian electricity generation by fuel (ABARE, 2008)

The Australian power generation sector comprises 21 GW of black coal-fired capacity, plus 6.6 GW fired on low rank coals. Around a third of Australian electricity is generated using the latter. Victoria has 6555 MW of lignite-fired generating capacity, and South Australia 770 MW. Overall, the amount of both hard coal and lignite used is forecast to increase (Figure 18). As elsewhere, the main use will remain as a power plant fuel, used close to source.

6.1.1 Victorian lignite/brown coals

In terms of nomenclature, in Australia, lignite is defined as a non-agglomerating coal with a gross CV of less than 17.435 MJ/kg, including brown coal which is generally less than 11 MJ/kg (ABARE, 2008).

Major lignite mining companies in Victoria include CLP Australia (17.7 Mt production in 2006), Hazelwood (18.7 Mt/y), and Loy Yang (29.8 Mt/y). In South Australia, the South Australian government operates the Leigh Creek mine, with an output of around 3.5–4 Mt/y. In Victoria, local lignite has provided most of the fuel for the electricity generation sector since the 1920s. The cost of recovery can be very low – for instance, in the Latrobe Valley, it can be as little as a few (A$) dollars per tonne. It is currently used to produce ~96% of the electricity used in the state and its low cost is a major advantage to industry in the region. However, generation inevitably produces a significant amount of CO_2 and in an effort to reduce this, a number of major clean coal and CCS-related R&D initiatives are ongoing or proposed. In the Latrobe Valley, there are a number of active projects that involve utilities, research providers and academia. These cover a broad range of topics that include carbon capture, improved combustion efficiency, gasification, and lignite dewatering.

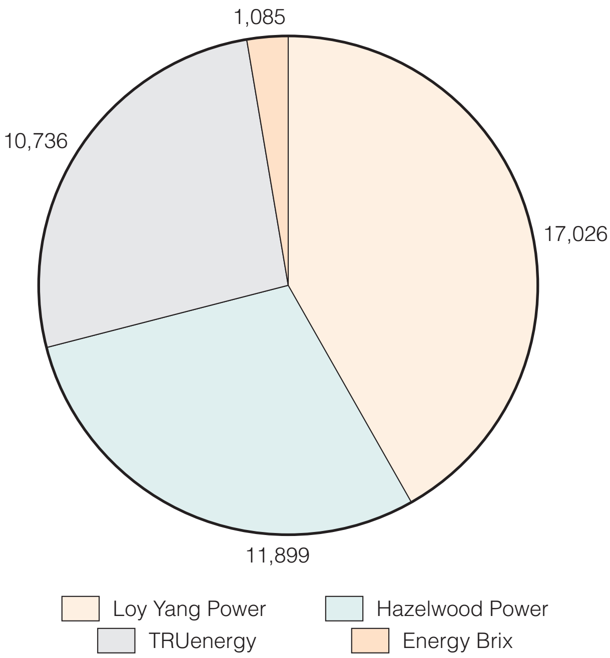

Figure 19 Output of major Victorian power generators, 2007 (ABARE, 2008)

The area hosts a number of major lignite-fired power generation facilities. The Latrobe Valley Energy Industry operates four major power stations located adjacent to local deposits. These comprise Loy Yang Power (2200 MW), Loy Yang B (International Power and Mitsui), International Power Hazelwood (1600 MW – Hazelwood Power), and TRUenergy Yallourn (CLP Group – 1480 MW). Together, these stations supply >85% of Victoria's electricity. Energy Brix Australia also generates electricity for Victoria as well as producing lignite briquettes. Electricity generation of these four is shown in Figure 19. Of these, the Loy Yang station is the largest, generating around a third of the state's electricity. With an annual output of around 30 Mt, its attendant opencast mine is the largest in the country. Lignite from here is also supplied to the Loy Yang B 1000 MW station (Victoria Department of Primary Industries, 2010).

6.1.2 Lignite-based CCT and CCS projects and proposals

Lignite drying/dewatering initiatives

As elsewhere, the high moisture content of Australian lignites reduces efficiency and increases costs for power plants. Dewatering the lignite feed can effectively reduce CO_2 emissions from all types of plant using the fuel, although a key requirement is to avoid significant additional energy consumption during drying. Dewatering will help maintain low-cost coal-based electricity generation in Australia by reducing capital costs for new plant and fuel requirements.

There are several types of drying and dewatering processes being developed or considered for potential application to Australian lignites. Several of these are at relatively advanced stages in their development. These include:

- Mechanical Thermal Expression (MTE) dewatering. Heat is supplied to the lignite while it is compressed so that evaporation is prevented. Up to 80% of the water can be removed. A 15 t/d demonstration plant operated at Loy Yang A power station during 2008.
- RWE (Rheinbraun) Fine Grain Steam Fluidised Bed Drying (SFBD). The technology has been used to treat Victorian lignites. The SFBD technology is the world's first raw lignite drying process to incorporate an integrated system for energy utilisation of the dryer vapours. It has successfully reduced moisture content from >60% to ~12%. As part of the *Hazelwood 2030 Project* (objective of reducing CO_2 emissions by 30–40% via coal drying, boiler and turbine upgrades, and post-combustion CO_2 capture) International Power/Mitsui plans a 70 t/h demonstration plant at its Hazelwood station. The technology is also being considered for several other projects.
- ECT Coldry process. Environmental Clean Technologies (ECT) has signed a deal to supply

Vietnamese company Thang Luong Investment and Joint Stock Company with treated Victorian lignite pellets. Eventually, up to 20 Mt/y could be supplied. The aim is that the technology will be fast tracked to commercialisation, starting with a plant to produce 2 Mt/y of treated lignite from late 2013. In subsequent stages, output will increase to 5, 10, then 20 Mt/y, subject to the State of Victoria delivering rail and port infrastructure upgrades. It is claimed that the Coldry process produces pellets that can be stored and transported safely and has a CV equal to that of black coal.
- Potentially, there are also a number of other drying systems. In recent years, several have been considered for deployment on Australian lignites. Candidate technologies have included the *Windhexe* drying system from Vortex Dehydration Systems of the USA; the GTL Energy drying system, and technology from Exergen (Campisi and Woskoboenko, 2009).

Gasification and IGCC

For some years, HRL Ltd has been developing a lignite-fuelled IGCC system that incorporates an integrated drying system (IDGCC). Currently, there are plans to develop the *Dual Gas Demonstration Project* with China National Electric Equipment Corporation (CNEEC). This 400 MWe project will be located at Morwell in the Latrobe Valley and will comprise two HRL air-blown fluidised bed gasifiers and a 400 MW combined cycle plant. Victorian lignites will form the main fuel, with natural gas used for system start-up and as a supplementary fuel. Construction is scheduled to begin in 2010 with plant operations from 2013. Several CCS options are being considered (Campisi and Woskoboenko, 2009).

In Western Australia there is a proposal by Perdman Industries and Samsung Corporation for a lignite gasification plant (the Collie Gasification Project). This will use subbituminous coal for the production of 2 Mt/y of urea. Construction is scheduled to begin in 2010 with start-up planned for 2013. Samsung is lead engineering contractor. Various possible CCS options are being considered. In the Latrobe Valley, Latrobe Fertilisers Holdings Ltd has proposed a 1.2 Mt/y urea fertiliser plant. This will produce ammonia via gasification of local lignites.

Oxyfuel combustion

Apart from the hard coal fired oxyfuel project at the Callide A power station in Queensland, there is also ongoing work focused on application of the technology to lignite-fired plants. Monash University is examining its use (coupled with underground CO_2 storage) as a means of developing near-zero emission lignite power plants using Australian lignites. The research involves International Power Hazelwood, Loy Yang B, Loy Yang Power, TRUenergy and HRL.

Coal-to-liquids

There are several lignite-based CTL projects at various stages in their respective development. These include:
- **Blackham Resources/Synfuels China Co project, Western Australia**
  Late in 2009, Australian energy company Blackham Resources signed an agreement with Synfuels China Co Ltd (a division of the Institute of Coal Chemistry of the Chinese Academy of Sciences) for the establishment of CTL Fischer-Tropsch diesel facility in the Esperance Region, based on Synfuels China technology. The process will involve lignite drying (using innovative Synfuels China drying technology) prior to its gasification and subsequent treatment. A series of technical and project-related evaluation activities are ongoing (Infomine, 2009).
- **Ignite Energy Resources Pty Ltd projects**
  Ignite Energy Resources (IER) is developing a supercritcal water reactor system to convert lignite into high-value oil and coal products. An MoU has been entered into to develop a commercial test plant for the technology at TRUenergy's Yallourn mine. IER is also operating a pilot scale project in Somersby, New South Wales, converting Gippsland Basin lignite to synthetic crude oil and high grade coal.

Several other lignite-based CTL projects have also been proposed in Australia although their precise status is currently unclear.

Underground coal gasification

In March 2010, Cougar Energy signed an MoU with Ignite Energy Resources to develop a joint venture underground lignite gasification project in Victoria's Gippsland region. The UCG technology being adopted is that of Ergo Exergy. The exploration lease granted covers ~400 km² within the Gippsland area.

Carbon capture and storage

Currently, there are a number of lignite-based initiatives under way or proposed, evaluating several different technologies at a number of sites (Table 15). Understandably, most are located in Victoria.

Table 15 Major lignite-based CCS projects

Location	Technology	Status
Loy Yang power station	Amine scrubber >85% capture target 1000 t/y CO_2 capture	CSIRO mobile pilot plant started up in 2008 fed by flue gas from Loy Yang Power's Unit 2. MEA used to set baseline; various amine blends benchmarked. Best solvent identified reduced energy penalty by 25% without compromising kinetics (Meuleman, 2010).
Yallourn power station	(Calera) mineral carbonation project	Will use captured CO_2 to produce cement and aggregate materials. Funding from Calera and Australian and Victorian governments. If pilot trials are successful, additional funding will come from the Australian government.
Hazelwood Power Station (Hazelwood 2030 Project)	CO2CRC H_3 capture project. Several technologies being examined (solvents, membranes and vacuum swing adsorption) Some overlap with *Latrobe Valley Post Combustion Project* (LCPCC) based at Hazelwood and Loy Yang	Will trial several CO_2 capture technologies. Will test and evaluate improved solvents, compare equipment performance, investigate impurities removal and optimise solvent capture processes. Amino acid-based post-combustion CO_2 capture research facility started up in July 2009. Will capture 25–50 t/d CO_2 from slipstream on Hazelwood's Unit 8. Some CO_2 will be used to neutralise ash water, producing calcium carbonate and effectively sequestering the CO_2. Funded by International Power with support from LETDF and the Victorian Government's Energy Technology Innovation Strategy Large Scale Demonstration Plant fund (ETIS LSDP).

6.2 New Zealand

New Zealand has significant coal resources, mainly in the Waikato and Taranaki regions of the North Island, and the West Coast, Otago and Southland regions of the South Island.

Total in situ coal resources are estimated at around 15 Gt of which, ~9 Gt is judged to be economically recoverable. The in-ground lignite resource is 11 Gt, of which, technically and economically recoverable deposits are estimated at 6.2–7 Gt; these are located mainly in ten major deposits in Otago and Southland. Total bituminous and subbituminous in-ground resources are ~3.5 Gt, although there is some uncertainty of how much of this is recoverable. Some 80% of the country's total economically recoverable coal reserves are considered to comprise South Island lignite. The balance consists of 15% subbituminous coal and 5% bituminous coal.

In 2008, bituminous + subbituminous coal production amounted to 4.7 Mt (2.48 Mt bituminous, 2.18 Mt subbituminous). A further 253 kt of lignite was also produced, mainly from the South Island (Crown Minerals, 2009). Coal is currently produced from a total of 25 operating mines, five deep and 20 opencast. Production is centred mainly in the Waikato (1.8 Mt), on the West Coast (2.6 Mt) and in Southland (0.4 Mt). Over 60% of national production comes from two large opencast operations at Rotowaro and Stockton, and a further 16% from the two largest underground mines, Huntly East and Spring Creek. The state-owned Solid Energy is New Zealand's largest coal producer, producing >80% of the country's coal. Some premium grade bituminous coal (low ash and sulphur contents) is exported. Although lignite makes up 80% of national coal resources, current production levels represent only ~5% of total production. NZ lignite is high quality with low sulphur and low ash contents.

Coal in New Zealand is currently used to generate electricity, and also in several industrial sectors. In 2007, 40% of coal output was used for power/co-generation purposes, 26% by industry, 6% by the commercial sector, and the balance by other transformation. Coal supplies ~10% of the country's electricity and accounts for ~9% of primary energy consumption. There is only one coal-fired power station, the 1000 MW Huntly Power Station on the North Island.

Solid Energy, in conjunction with Ergo Exergy of Canada, is proposing the construction of a US$22 million underground coal gasification pilot project (capacity of 30 kt/y coal) within the existing Huntly West coal mining licence area at Waikato on the North Island. The pilot will operate for a two-year period. A test/drilling programme is under development. Waikato coals vary in properties but are all classified as subbituminous. Seams in the north of the region generally have low to medium ash and low sulphur contents, whereas those in the south have medium to high ash and sulphur contents. L&M Energy also plans to examine the use of UCG in the Waikato coalfield and has applied for prospecting rights in the region (Coal Association of New Zealand, 2010).

6.2.1 South Island lignite

South Island lignites are currently being evaluated for their potential as feedstock for large-scale petrochemical processing (via gasification coupled with CCS, as opposed to being used for combustion purposes) into a range of energy products that could include diesel, jet fuel, methanol, and chemicals. It is estimated that if extracted at a rate of 20 Mt/y, lignite could provide energy and feedstock for most of New Zealand's transport fuel and petrochemical requirements for over 300 years (Crown Minerals, 2009). The country is currently heavily dependent on imported transport fuels. Thus, lignite has great potential for electricity generation, synthetic fuels, DME, methanol, ammonia/urea-based fertilisers and hydrogen production. Overall, it is considered that it will play a strategic role in New Zealand's energy future. Around 6.3 Gt of South Island lignite is considered to be technically recoverable.

It has been suggested that development of a single South Island lignite resource could potentially provide:

- 71 Mt of transport fuels – 15–20 years national supply;
- all of NZ's fertiliser requirements for 127 years, plus additional exports worth ~US$540 million per year;
- all domestic methanol requirements, plus an annual export income of US$1 billion;
- all of the South Island's electricity demand for 60 years;
- 1.2 Mt/y of hydrogen for ~60 years – enough to fuel 90% of the NZ vehicle fleet via hydrogen fuel cell technology.

L&M Central Otago Lignite, a company that holds exploration permits for the Hawkdun lignite deposit on South Island, has noted that a single new mine in Central Otago could supply all of the country's diesel requirements for many years. It has proposed that a new mine be built at Hawkdun but is also exploring options at several others sites (Kaitangata, Ashers-Waituna, near Invercargill). The company will seek mining permits for the site(s) selected.

One of the most recent proposals is that for a major lignite-to-urea facility for Southland. The coal producer Solid Energy, and fertiliser company Ravensdown are investigating the building of a (gasification-based) lignite-to-urea plant in eastern Southland. The plant would cost around US$1 billion and enable the country to become self-sufficient in urea, and could potentially open up export markets. New Zealand currently imports ~0.5 Mt/y of urea, mostly from the Middle East and China. Studies are being carried out to examine the economics and possible location of a 1.2 Mt/y plant producing urea for fertiliser production. This would require 2 Mt/y of lignite. Potentially, plant construction could begin by 2012, with start-up by late 2014. The project may be run in parallel with a proposed lignite-to-diesel plant. Options for CO_2 management at the latter are being considered (3News, 2009).

As part of a pre-feasibility study, Solid Energy is also undertaking geotechnical work at its former lignite mine (Mataura) with a view to setting up a lignite upgrading and briquetting plant. The proposed plant would be capable of producing up to100 kt/y of briquettes from Southland lignite for export and commercial use. The project is a joint venture with US-based GTL Energy Ltd, and is one of three lignite conversion projects proposed by Solid Energy in Southland.

Solid Energy is progressing all its Southland lignite projects in parallel as it considers that there are sufficient resources to accommodate its briquetting plant, coal-to-fertiliser project, lignite to transport fuel project, and many others besides (Coal Association of New Zealand, 2010).

7 China

China's extensive coal reserves are of critical importance to its growing economy – some 95% of the country's fossil energy resources are coal-based, with petroleum and natural gas making up the remainder. The country is the largest global producer and consumer of coal, a situation that is expected to continue for many years. China's coal resources rank third largest after the USA and Russia. There are coal deposits in many parts of the country although 75% of recoverable reserves are located in the north and northwest, particularly in Shanxi, Xinjiang, Shaanxi, Inner Mongolia and Guizhou Provinces (Bessereau and Sanière, 2007).

China has deposits of all types of coal, from lignite to anthracite, although estimates tend to vary and there remains a degree of uncertainty over the scale of the country's coal reserves. However, BP and WEC data suggest that there are proved reserves of anthracite + bituminous coal amounting to 62.2 Gt, and those of subbituminous coal (33.7 Gt) + lignite (18.6 Gt) of 52.3 Gt, giving a total of 114.5 Gt (BP, 2009; WEC, 2004). Some estimates suggest that lignite reserves may be slightly lower at 17.8 Gt (Energy Watch, 2007). However, other sources suggest that, potentially, up to 130 Gt of lignite (mostly in northeastern China) could be exploitable (Asia Pacific Partnership, 2008). A significant proportion of the country's lower rank subbituminous coals and lignite are located in more remote areas such as the Inner Mongolia Autonomous Region.

In 2008, China produced a total of 2.76 Gt of coal. Production continues to rise and forecasts suggest that by the end of 2010, annual output will have increased to around 3 Gt/y. However, coal production is expected to peak within the next decade, possibly around 2015. Forecasts suggest that by the end of 2010, a total of 120 Gt of hard coal and 19 Gt of lignite will have been extracted (Energy Watch, 2007).

7.1 Coal use

7.1.1 Power generation

Around half of China's coal output is used for power generation and coal-based plants produce nearly three quarters of the country's electricity. The vast majority of the coal used is bituminous and lignite's contribution is relatively small at ~5%. Even if lignite production was significantly increased, compared to hard coal use, its overall impact would be limited (Energy Watch, 2007). However, in some locations, it remains important (particularly for power generation) and in recent years, its level of use has been increasing. The Inner Mongolia Autonomous Region is currently the most important region for lignite consumption.

China's first lignite-fired generating units came on line in 1978 (Yuanbaoshan Unit 1) and lignite is currently used in all major types of power plant. By the end of 2010, it is expected that more than 15 GW of lignite-fired plant (of >200 MW capacity) will have been developed in China. The largest component comprises conventional subcritical PCC power plants. Most of these have unit sizes ranging from 100 to 600 MW, with annual lignite consumption of the biggest plants approaching 2 Mt/y (CoalPower). There are also lignite-fired SC and USC plants coming on line in growing numbers. In 2008, there were more than ten sets of 600 MW USC PCC under construction (Asia Pacific Partnership, 2008). In March 2010, the first lignite-fired USC unit, designed and manufactured in China, was successfully commissioned. This was the 600 MW unit of the Phase I development of the Liaoning Qinghe power plant, belonging to China Power International. During full-load test operation, unit performance was reportedly high. The success is likely to stimulate the development of similar projects in the region (Tordesillas, 2010). Lignite is also being used in large-scale CFB units;

by 2008, there were at least six 300 MW CFB units in operation, all located in the south west of China. The first 300 MW unit came on line in 2006 (Kai Yuan PP) (Asia Pacific Partnership, 2008).

7.1.2 Gasification and IGCC applications

In 2006, a demonstration fixed bed gasifier, incorporating BGL slagging technology, was commissioned in China, using a feedstock of high moisture lignite. UK-based Advantica and Yunnan Coal Chemical Group jointly developed a pilot project to demonstrate the technology in China. Successful operation has since resulted in plans to develop a lignite-fuelled gasification-based commercial plant for the production of 200 kt/y of methanol (Williams and others, 2007).

Late in 2009 it was announced that Beijing Guoneng Yinghui Clean Energy Engineering Co Ltd (Beijing Guoneng) had awarded US-based KBR a contract to provide licensing, engineering services and equipment for the implementation of KBR’s and Southern Company’s Transport Integrated Gasification technology (TRIG) for a power plant operated by Dongguan Tianming Electric Power Co Ltd in Guandong Province. This will be the first commercial application of the technology. The 120 MW plant is currently under construction and will, reportedly, be fuelled on Chinese low rank coals and lignite. The TRIG technology is being added to an existing gas turbine combined cycle plant so that it can use syngas, rather than fuel oil. Operations are expected to begin in 2011. The project’s second phase will be an 800 MW IGCC power plant (*Sun State IGCC Power Plant*).

7.1.3 Non-power uses

Apart from power generation use, lignite also forms an important energy source for a number of major industries. It is particularly important for a growing number of coal-to-chemicals processes and projects. For example, in Yunnan, the Yunnan Jiehua Group employs 14 lignite-fuelled fixed bed gasifiers to produce syngas that feeds a fertiliser plant, one of a number of such projects.

There are currently a significant number of upgrading and coal chemical projects and proposals based on the use of domestic lignites. Table 16 lists some examples of major projects in the pipeline.

During the past year, several major prospective lignite-based projects have been announced or are in the process of being developed. These include:

- **Yunnan Jiehua Clean Energy Development Co Ltd, Yunnan**
  In 2009, it was announced that a joint venture (the Yunnan Jiehua Clean Energy Development Co Ltd) had been formed between China Three Gorges Project Corporation and Yunnan Coal Chemical Industry Group to develop Chinese lignite resources for clean, sustainable energy production. Yunnan Jiehua Chem Group has extensive experience in the pressurised gasification of lignite and the use of syngas for liquids and chemicals production.
- **Evergreen China K-Fuel projec**t
  In early 2010, a joint venture (JV) was set up between US-based Evergreen Energy (via its subsidiary, Evergreen China) and Chinese industry investors, to develop a project in China based on the former’s K-Fuel technology. The NDRC has approved and endorsed the project and a letter of intent has been signed with a Chinese integrated utility and chemical manufacturer to build a plant in the Inner Mongolia Autonomous Region. This will produce K-Fuel using local lignite as feedstock. Two proposed sites are being evaluated. Originally developed at Stanford Research Institute in the USA, K-Fuel technology uses high pressure and temperature steam to convert lignite. The treatment increases CV and reduces moisture content and pollutants.
- **Golden Concord Project**
  US-based Synthesis Energy Systems (SES) has formed a joint venture with China Coal Chemical (Xilin) Co Ltd (Golden Concord) to develop a series of lignite gasification plants to be located at mines in Inner Mongolia. Syngas generated will be used for methanol production (>225 kt/y).

Table 16 Examples of upgrading and lignite-to-chemicals projects and proposals (5th Advanced Coal Chemical Summit, 2009)

Project/proposal	Comments
Baiyinhua Lignite Upgrading Trial Project	Capacity of 3 Mt/y
Chifeng Lignite-to Methanol-Project	Cost of RMB 8 billion
China Ocean-wide Holdings Coal-Based Methanol/Methanol to Olefin Project	Cost of RMB 22.8 billion
China National Offshore Oil Corporation (CNOOC) Coal-Based Natural Gas Project	Cost of RMB 30 billion
Chuncheng Group Lignite Dryness Project	Capacity of 5 Mt/y
Datang Duolun Coal-to-Olefin Project	
Datang Guoneng Lignite Dryness Project	Capacity of 5 Mt/y
Datang Coal-Based Synthetic Natural Gas (SNG) Project	Cost of RMB 24.7 billion
Dongsuqi Lignite Dryness Project	Capacity of 4.5 Mt/y
Huaneng Yimin Lignite Upgrading Project	Capacity of 5 Mt/y
Inner Mongolian Tongliao Lignite Processing Project	Capacity of 6 Mt/y
Lu Liang County Lignite Mining Project	Capacity of 0.3 Mt/y
Mengyuan Lignite Upgrading Project	Capacity of 3 Mt/y
Northern Power Lignite Upgrading Project	Capacity of 4 Mt/y
Shenhua Hulunbeier Lignite Upgrading Project	Capacity of 1.53 Mt/y
Tongliao Lignite-to-Ethylene Glycol Project	Cost of RMB 10 billion
Xilinguole Lignite-based SNG Project	Cost of RMB 1.5 billion

- **SES-YIMA** Coal Industry Group project, Henan (Hai Hua plant)
  SES has a second joint venture with the Chinese government-owned YIMA Coal Industry Group Co Ltd. The company aims to develop coal-to-methanol plants in Henan. Government approval is currently awaited. Phase I of the project will comprise a gasification facility, feeding syngas to a 500 kt/y methanol plant. Several coals will be used including a reactive subbituminous coal containing ~33% ash from YIMA's Yaojin mine. Late in 2009, the Hai Hua plant was operated successfully. The gasification technology used (U-Gas) has also performed well with lignite from the Baiyinhua region of Inner Mongolia, and coals with 45% ash content.

8 Southeast Asia

This region comprises the countries of Brunei, Indonesia, Kampuchea, Laos, Malaysia, Myanmar, Singapore, Thailand, Vietnam and the Philippines. Apart from Kampuchea, Singapore and Brunei, coal is currently produced and/or consumed in all of these. However, Indonesia and Vietnam are the only coal exporters. Most countries produce hard coal although Thailand produces only lignite and Laos and Myanmar produce both types. Coal production in the region has increased significantly during the past decade, attributable mainly to increased output from Indonesia.

In the longer term, lignite use in Southeast Asia could rise significantly. Although the region's reserves of hard coal and lignite are similar, potential resources comprise 80% lignite and 20% hard coal. The bulk of these are located in Indonesia, Vietnam and Thailand. Under the IEA's most recent Reference Scenario (OECD/IEA, 2009), coal production in the region rises by over 75% by 2030 to 486 Mt/y, with the role of lignite increasing significantly. Because of its high moisture content and low CV, use would largely be by domestic utilities, allowing hard coal to be exported (Fenwick, 2010).

8.1 Indonesia

Indonesia is rich in lignite and high moisture subbituminous coals but lacks significant reserves of bituminous coals and anthracite. Lignite and subbituminous coal deposits are found on the islands of Kalimantan and Sumatra. The former is the main hub of production for coals of internationally tradeable quality whereas Sumatra is the key resource for low rank and high moisture coals, predominantly for domestic markets. There are also further smaller deposits on Sulawesi and Papua. Compared to world standards, coals produced are low in sulphur and ash, but can also be low in heating value due to high moisture content; this is especially so for deposits found in Sumatra. Low sulphur coals from Kalimantan are shipped regularly around the world, often for blending with higher sulphur coals from other sources.

The reserves of coal in the country as a whole are difficult to quantify with any certainty, with figures ranging from 4.3 to 7 Gt of mineable (economically recoverable) reserves (Baruya, 2009). For instance, the World Energy Council (WEC, 2009) suggests total proven coal reserves amounting to 4328 Mt, comprising 1721 Mt of anthracite + bituminous coals, 1809 Mt of subituminous coal, and 798 Mt of lignite. Thus, around half of Indonesian coal reserves are considered to be of lignite-subbituminous quality. The major Indonesian coal-producing companies are shown in Table 17.

The quality of Indonesian coals varyies, and it is not unusual for the properties of some lignites to overlap with those of poorer quality subbituminous coals. Some subbituminous coals can have a moisture content of between 10% and 35%. In addition, in some cases, their CV can be as high as some bituminous coals. Lignites generally have a moisture content between 35% and 70% and a CV below 15 MJ/kg (Baruya, 2009; APEC, 2008).

Since 2000, overall Indonesian coal production has risen dramatically. During this period, lignite production has increased steadily. In 2008, output comprised 246 Mt of hard coal plus 38 Mt of lignite (OECD/IEA, 2009) (Figure 20).

Coal is important to the national energy supply and at present ~20% of total coal output is used within the country. In 2008, coal demand was ~31 Mt for power generation and 6 Mt for cement manufacture. Historically, these two sectors have dominated domestic coal consumption and this is likely to continue. Indonesia has ~6 GW of generating capacity fuelled by subbituminous coals. Most major power plants are at minemouth locations. Some power generation coals have moisture contents similar to those of lignite, but have higher CVs.

Table 17 Major Indonesian coal producing companies (Baruya, 2009)

Company	Main mine location	Production, Mt, 2007	Resources, Mt	Main coal types produced
PT Adaro Indonesia	South Kalimantan, Borneo	36	2069	Subbituminous
PT Berau Coal	East Kalimantan, Borneo	12	2927	Subbituminous
PT Kideco Jaya Agung	East Kalimantan, Borneo	21	3772	Subbituminous
PT Arutmin Indonesia (BUMI Resources)	South Kalimantan, Borneo	15	3726	Bituminous, subbituminous
PTBA (Tambang Batubara Bukit Asam Tdk)	South Sumatra, West Sumatra	11	3726	Subbituminous, lignite
PT Kaltim Prima Coal (BUMI Resources)	East Kalimantan, Borneo	39	3726	Subbituminous
PT Indominco Mandiri (Banpu)	East Kalimantan, Borneo	12	284	Subbituminous
PT Gunung Bayan Pratama Coal (Bayan Resources)	East Kalimantan, Borneo	8	n/a	Subbituminous

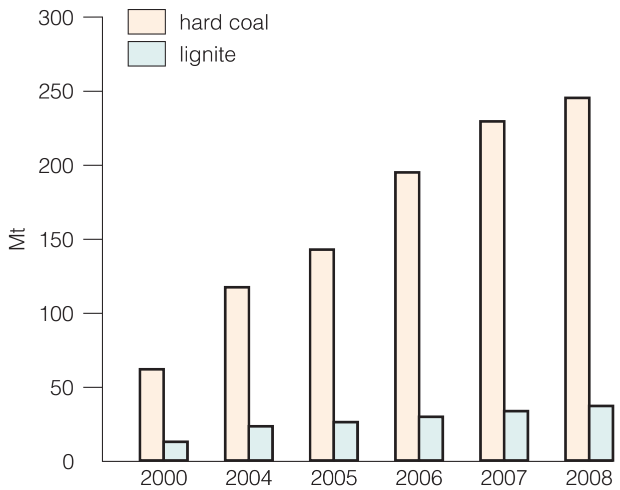

Figure 20 Indonesian hard coal and lignite production (OECD/IEA, 2009)

8.1.1 The power generation 'Crash Programme'

In 2004, Indonesia adopted a National Coal Policy which sought to promote the development of its coal resources in order to meet growing domestic requirements and to increase coal exports. The government has since committed to reducing the country's high dependence on imported oil by gradually increasing the share of coal to at least 33% of the total energy mix in 2025 (APEC, 2008). As Indonesian oil and gas reserves have decreased, coal has assumed a more important role within the power sector. This has been boosted as new large coal reserves have been discovered in recent years,

As a consequence of growing demand outstripping capacity, Indonesia has suffered frequent blackouts and supply interruptions. The country's high dependence on oil for power generation has meant that associated costs have increased significantly. To overcome this, the government charged PLN to undertake a 'crash programme' to build new coal-fired power plants with a total capacity of 10 GW. Some 7 GW of this capacity (including 3 x 600 MW, 7 x 700 MW, and 7 x 300–400 MW) will be built in Java. From 2010 onwards, the government is implementing its plan to convert oil-fired power plants (7.75 GW) into coal-fired units and to build 10 GW of new coal-fired capacity. The intention is that this will reduce fuel import dependency and address the country's soaring electricity demand. It is anticipated that the total coal demand for the revamped power sector will rise to ~72 Mt by the end of 2010. In 2015, it will be 86.5 Mt, increasing further to 95–118 Mt by 2025. Most of this coal will comprise indigenous lignite and subbituminous coals. It is anticipated that once, on line, this new capacity will overcome the shortfall for at least several years. To guarantee electricity supply in the following years, a second 10 GW Crash Programme may follow.

The current Crash Programme is under way with projects such as the expansion of the existing Paiton power plant (Paiton III). This is a new 815 MW supercritical PCC unit scheduled to start up in 2012. As elsewhere in the region, this will be fired on local subbituminous coals. The steam turbine and boiler will be supplied by MHI and construction undertaken by TOA Corporation of Japan. Power from the plant will be sold to Indonesia's state-owned power utility, PT PLN (Persero) for 30 years.

8.1.2 Non-power coal use

At present, the largest coal-consuming non-power sector is cement manufacture. This is almost totally reliant on domestic coal for its energy. Alongside this, about 20% of national coal output is used by various industries that include textiles, pulp and paper, the metals industry, and smaller-scale applications such as briquetting. However, for more than a decade work (in collaboration with Japan) has been under way examining the potential for the liquefaction of Indonesian coals. In recent years, this work has moved up the political agenda as oil prices have risen and Indonesian oil import dependency has increased. Both coastal and inland minemouth CTL plant locations have been considered (Silalahi and others, 2005). A target has been suggested to replace 2% of the country's oil consumption by 2025 via the liquefaction of low grade coals (seven modules, consuming 25 Mt/y of coal). It is suggested that the first such plant could be built by 2016 (Tirtosoekotjo, 2006).

For some years, Japan and Indonesia have also been co-operating on a project to upgrade low-rank Indonesian coals (the Upgraded Brown Coal Project – UBC). In 2008, a large-scale demonstration and development project was launched at the Satui coal mine in South Kalimantan (METI, 2008). In the UBC process, low-rank high-moisture coals are dewatered using an oil-based process. This significantly increases the coal's CV. The Japanese Ministry of Economy, Trade and Industry (METI) are actively supporting the project.

Coal gasification is also under consideration for producing SNG (to replace natural gas) and for the production of syngas as a feedstock for the production of fertilisers, methanol, chemicals and transport fuels.

8.1.3 Coal exports

The country is currently the world's largest exporter of thermal coal (followed by Australia and China). There are currently 17 exporters (each with exports in excess of 0.5 Mt/y) of steam coal. In 2007, Indonesian producers shipped 165 Mt of coal, roughly 30% of global seaborne thermal coal supply (Ewart and Vaughn, 2009). In recent years, more than 75% of the country's coal output has been exported; in 2007, some 164 Mt were exported from a total production of 212 Mt. Export volumes have increased year on year (in 2000, 56 Mt were exported). Current port export capacity is 220 Mt/y. However, because of the increased domestic demand resulting from the Crash Programme, exports may be capped at 150 Mt/y at some point.

Major export markets include Japan, Taiwan, South Korea, Hong Kong, India and other southeastern Asian countries and Western Europe. Indonesia currently supplies more than 30% of the Pacific Basin market. Around two thirds of the country's export coals are produced from around two dozen mines in South Kalimantan. Typical quality specifications for export thermal coals are shown in Table 18.

Table 18 Typical quality specifications for Indonesian export thermal coals (Ewart and Vaughn, 2009)

Quality parameters (as-received basis)	Bituminous coals	Subbituminous coals
Moisture content, wt%	10–12	24–38
Ash content, wt%	2–12	1.5–7.5
Volatile matter, wt%	31–42	28–37
Sulphur content, wt%	0.1–0.95	0.07–0.9
CV, MJ/kg	22.2–28.1	17.2–21.7

The country's large deposits of subbituminous coal are unusual in that they contain lower ash and sulphur levels than the world average. Export coals often border on low-mid rank subbituminous; some have heating values of ~21 MJ/kg (similar to some Indonesian lignites).

8.2 Thailand

The country has proven reserves of between 1354 Mt and 2 Gt. It is estimated that around 1 Gt could be economically viable; potentially, there could be up to 75 years of reserves available. Deposits are spread across more than thirty basins in the northern and southern parts of the country. However, over 80% of proven resources are in the north. The biggest individual reserves are in the northeast region, in the Mae Moh and Li Basins. There are significant reserves at Songkhla (>100 Mt) and Surat Thani (~150 Mt). Most of these reserves comprise high-sulphur lignite, with smaller amounts of subbituminous coal (Kessels, 2010).

The Thai coal industry is dominated by two key players, although the majority of coal is produced by the Electricity Generating Authority of Thailand (EGAT). Until recently, the other player was Banpu, with a combined capacity of 3.3 Mt/y of lignite. However, due to depletion of reserves, mining operations in Thailand ended at the end of 2008.

Much of Thailand's lignite is produced from the Mae Moh opencast site, the country's largest lignite mine. It is also the largest tertiary coal deposit in Southeast Asia. The site is operated by EGAT and produces nearly 52 kt/d of lignite, with an annual production of 16–17 Mt. This represents >80% of Thailand's total coal production (Marston, 2003). The mine is expected to remain in operation until at least 2028.

The Thai government is currently examining options to diversify the country's energy supply; one option is to increase the use of coal. This would increase energy security and help reduce imports of natural gas. Thailand has a total installed power generating capacity of 25.6 GW. Some 15 GW of this is operated by EGAT, the company generating around half of the country's electricity. Overall, some 70% of Thailand's power is produced from natural gas although only around 13 years of proven reserves remain in the Gulf of Thailand. This has increased the incentive to use greater amounts of coal for power generation. Many power stations are currently fired on imported hard coals although the largest, EGAT's 2.63 GW minemouth Mae Moh power plant, uses domestic lignite sourced from the adjacent mine. This is the largest coal-fired power plant in Southeast Asia, generating 15% of the country's total electricity from ten operational units. Annually, around 15 Mt of lignite is consumed. This is effectively all of the daily output from the Mae Moh mine (Simachaya, 2008).

As a consequence of the high sulphur content of Thai lignite, it seems unlikely that any new coal-fired plants will make use of indigenous lignite, but will opt to fire imported hard coals (Kessels, 2010). The properties of Thai lignites can vary significantly. However, average parameters include an ash content of between 2% and 45%, moisture content between 3.3 and 41%, and sulphur content of between 2.4% and 24%.

Non-power lignite consumption includes the Thai cement industry, steel production, paper and pulp manufacture, and small- and medium-sized factories. Most lignite for these applications is supplied from mines other than Mae Moh. In 2008, 16.3 Mt of the 18 Mt of lignite produced in Thailand was used for power generation, 1.74 Mt for cement manufacture, and 630 kt by other users. By 2021, total coal demand is forecast to increase to 28.3 Mt for power generation plus 19.7 Mt for industrial use.

8.3 Malaysia

Malaysia's coal reserves are located primarily in Sarawak and Sabah, with smaller deposits in Selangor, Perlis and Perak. Total estimated resources stand at between 1000 and 1483 Mt.

Sarawak has the largest coal deposits, with total resources estimated at 1228 Mt; these range from anthracite to lignite. Other deposits are on peninsular Malaysia (17 Mt subbituminous coal), and Sabah (238 Mt of bituminous + subbituminous coal). At present, coal production is limited largely to subbituminous coals from Sarawak, the bulk of production coming from an opencast mine in the Merit-Pila coalfield of western Sarawak. The coalfield is the largest in Malaysia with an area of ~260 km^2 and is located in Kapit area of Sarawak. It holds more than 400 Mt of coal resources. In recent years, the field has been producing up to 780 kt/y. The mine is operated by the country's biggest individual coal mining company, Global Minerals (Sarawak) Sendirian Berhad (GMS) who produce *MeritCoal*, a subbituminous coal (B rank) with very low sulphur content. It is also low in nitrogen and ash. The coal is supplied to local generators but has also been exported to countries that include Bangladesh, Taiwan and Japan. In 2008, total national coal production amounted 1.06 Mt (OECD/IEA, 2009).

In terms of the country's electricity requirements, Malaysia's coal resources are considered as strategic, and are being actively promoted as a fuel of choice for power generation. This will help free up more natural gas for export. Additionally, the country currently relies heavily on imported supplies of coal from China, Indonesia and Australia. The increased use of indigenous supplies would help reduce import dependency. Coal has been identified as part of Malaysia's fuel mix strategy and forms part of the long-term development of a sustainable energy supply for the country. Under the Ninth Malaysia Plan, there will be a steady decrease in the use of natural gas and a corresponding increase in the use of indigenous coal.

A significant proportion of the country's coal output is used by the power generation sector. The bulk of the subbituminous coal produced is used to fire the 210 MW Kuching power plant in Sarawak. However, at present much of the coal-fired power sector continues to rely on imported supplies. The country's overall coal consumption has been increasing steadily for some years since 2002, growing at the rate of 9.7%/y. This has been covered mainly by increased imports. In 2005, 12.3 Mt of hard coal were imported, increasing to 14.9 Mt in 2006 and 15.8 Mt in 2008. Total coal consumption in 2008 was ~17 Mt (OECD/IEA, 2008). Total coal consumption for electricity generation is projected to reach 36 Mt/y by 2020 (Othman and others, 2009).

8.4 Vietnam

The Vietnamese economy is predicted to grow four or five fold during the next two decades and energy consumption is expected to rise accordingly. A wide range of coals is available for potential exploitation. Every coal rank is found in Vietnam, from the large amounts of anthracite already mined, to bituminous and subbituminous coals, lignite, and peat. The Vietnamese coal mining industry has recently been well explored by Baruya (2010).

Vietnam has two main coalfields, only one of which is currently in commercial operation, namely the Quang Ninh anthracite basin. This has proven reserves of ~10 Gt and supplies coal for both domestic and export markets. During the past decade, output has risen dramatically. The second coalfield is a major basin in the Red River Delta which contains very large deposits of subbituminous coals and lignites discovered during oil exploration activities. To date, some exploration and surveying has been undertaken although no commercial mining operations have yet started. The country is seeking foreign investment to develop the field and it is anticipated that production will be developed during the coming decade or so (Khiem, 2005). Thus, there could be a major shift to the use of indigenous lignite in the coming years, particularly as Vietnam's electricity demand continues to increase (Fenwick, 2010). However, Baruya notes a number of possible impediments that may hamper development of the Red River deposits. These include issues of extreme depth and difficult geological conditions of some reserves.

The country's coal mining industry is owned and operated by the state coal mining company, Vinacomin. Vietnamese hard coal production is currently around 40 Mt/y, about 15.5 Mt of which is used domestically. The balance is exported. During the past few years the country has also produced ~1.8 Mt/y of lignite (OECD/IEA, 2009). Since 2004, hard coal exports have increased substantially, reaching 25 Mt in 2009, an increase of 30% over the previous year. China was the largest export market, followed by Korea, Japan and Thailand. However, exports look set to be capped as domestic requirements continue to increase. Electricity demand has been increasing sharply by 17–20%/y, and predictions suggest that, at some point, the country will become a net coal importer. According to the Ministry of Industry and Trade, in the period up to 2025, Vietnam will need to add 4 GW/y of generating capacity. As hydropower resources have been nearly fully exploited, and natural gas supply is limited, the country will need to focus on coal-fired capacity, hence the growing interest in its subbituminous-lignite deposits. In the near term, the country may have to resort to coal imports to fire some of its proposed new power plants.

Vietnam's power sector has a total generating capacity of ~12.5 GW and annual electricity production is in excess of 60 TWh. Hydro accounts for 42% of this total, natural gas for 42% and coal for 14% (ASEM, 2009). Although the country has relied heavily on hydropower, in the future a combination of nuclear power and coal-fired plants is expected to account for a growing proportion of total electricity production. Further increases in hydropower seem unlikely as most sites are already being exploited, and gas and oil reserves are limited. Consequently, the country plans to increase its dependence on nuclear and coal-fired capacity. There are plans to build 13 nuclear reactors by 2030, with a combined capacity of 15 GW. Coal-based capacity was boosted recently by the announcement in December 2010 that Doosan Heavy Industries is to build two new power plants, each of 1200 MW. Further orders are expected. Electricity demand is forecast to increase at a yearly rate of 9–10% during the period 2011-25. The structure of the power sector is forecast to change as more coal is used to generate 49% of the country's electricity in 2015, 55% in 2020, stabilising at 68% by 2025. The resultant domestic coal demand is expected to be (Van Can, 2007):

- 2010 – 29–32 Mt/y;
- 2015 – 47–50 Mt/y;
- 2020 – 69–72 Mt/y;
- 2025 – 112–115 Mt/y.

It is expected that coal imports will become necessary post-2015 to meet this demand.

8.4.1 Lignite use for power generation

There are a number of lignite mines operating mainly in the province of Lang Son that supply local power plants. Several of these are based on the use of CFBC technology and are using, or when fully developed, plan to use, local lignite. The first CFB-based plant came on line in 2004, supplied by one of the Lang Son mines. This is the 100 MW Na Duong Power station, Vinacomin's first thermal power plant. This was constructed to take advantage of the local lignite, supplied from the long-established Na Duong opencast mine. The lignite supplied has an ash content of between 20% and 40%, sulphur content of 2.5% to 6.2% (typically 5.4%), and a CV of 10.4 to 18.4 MJ/kg (LHV). The plant uses two

50 MWe Foster Wheeler *Compact* CFB units, sulphur emissions being controlled via limestone injection (Duc Thao, 2004; Baruya, 2010). Other CFBC-based projects include the newly completed Campho Thermal Power Station in Quang Ninh Province (4 x 150 MW, fired on 40% ash waste coal slurry and coal dust), the (2 x 50 MW) semi-anthracite-fired Cao Ngan plant that came on line in 2006, a 440 MW project at Maokhe, and a 220 MW project at Sondong (Truc, 2009).

In the future, there is expected to be increasing focus on the large lignite/subbituminous coal deposits of the Red River Delta, still largely untapped. Although still somewhat speculative, reserves here have generally been estimated at ~210 Gt, although other reports suggest a lower total of around 30 Gt (Baruya, 2010). Vinacomin suggests a resource of 250 Gt, of which, 1.5 Gt within a 25 km^2 area is considered as proven (Truc, 2009). Truc also notes the existence of large peat deposits in the Mekong Delta (10 Gt, with 0.2 Gt regarded as proven).

Investigations carried out by Vinacomin suggest that a production of 9–10 Mt/y from the Red River Delta could be achievable for a considerable period. According to its *Master Plan for Coal Development*, during the period 2010-15, Vinacomin aims to obtain a clearer estimate of the Red River reserves, and to have the first coal mine in operation in the region. In 2009, an interministerial council agreed to recommend Government approval for a plan to exploit these reserves, with commercial mining beginning in the 2020s. In the interim, Vinacomin will test and evaluate underground mining techniques and also explore the possibility of adopting underground gasification. It is planned to test both technologies simultaneously at various depths. The first test project is scheduled to begin in 2010 in Khoai Chau, Hung Yen. It is expected that exploration and assessment work of the delta basin will be completed by 2015. It seems likely that, in the future, greater use will be made of the country's lignite deposits, mainly for power generation. Some of the subbituminous coals have a respectable calorific value of 25–26 MJ/kg, are low in sulphur, and are suitable for thermal power generation and metallurgy. Given these qualities, they are comparable to some Indonesian coals, hence there may be the potential for some of the better quality Red River deposits, eventually to be developed for both domestic use and export.

In a recent development, Environmental Clean Technologies (ECT) of Australia has signed a licensing agreement with Vietnamese company Thang Luong Investment and Joint Stock Company for the use of its lignite dewatering technology, known as Coldry (*see* Section 6.1.2).

8.5 Laos

Laos has reserves of hard coal (mostly anthracite) and lignite, scattered through various coalfields in many parts of the country. Coal deposits have been confirmed in numerous locations in the provinces of Oudomxay, Saravan, Sayabury, Vientiane, and Xiengkhouang. Total proven reserves of bituminous coal are estimated at between 100 Mt and 347 Mt (USGS, 2008) although exploration of other potential sites is continuing. Currently, annual production is around 130 kt. This is used mainly in local industries although some is exported.

Anthracite and lignite are currently produced from a handful of mines. Typically, the state-owned Agriculture Industry Development Enterprise produces ~35 kt of anthracite from its operations in Vangvieng in Vientiane Province. Anthracite is used locally, mainly for cement production, whereas the lignite is exported to Thailand (USGS, 2008). The country's main energy resource is lignite, with the major deposit located at Hongsa in the north-west region. Proven reserves amount to 810 Mt, of which >530 Mt are considered to be economically recoverable. This lignite has a CV of 8–10 MJ/kg and sulphur content of 0.7–1.1%. It is estimated that output from these reserves would be capable of sustaining a 2 GW power project (ADB, 2009a). In the Luangnamtha Province, the Viengphoukha mine produces ~222 kt of lignite.

Lignite consumption within Laos is set to increase as the result of a new mining and power generation project being developed. In 2007, Ratchaburi Electricity Generating Holding, Thailand's leading IPP, announced that it would invest in the proposed 1878 MW Hongsa lignite-fired power plant. This plant will be owned jointly by Banpu Power Co (40%), Ratchaburi (40%), and Lao Holding State Enterprise (20%). A second joint venture has been established to develop a coal mine at the Hongsa deposit in Sayaboury Province. This will be owned jointly by Banpu and the Government of Laos. The newly-created Hongsa Power Company will operate the power plant and Phu Fai Mining the associated lignite mining operation. The plant is scheduled to come on line in 2013. The Hongsa power plant will start supplying electricity to Thailand by 2015. Under the terms of an MoU, the Electricity Generating Authority of Thailand (EGAT) has agreed to purchase 1473 MW from the plant. Annual lignite consumption will be 13 Mt. During the current 25-year concession the plant is expected to consume more than 320 Mt of lignite.

8.6 Myanmar

The country has numerous coal deposits spread throughout the country. Most are along the Ayeyarwady and Chidwin River Basins and in the southern part of the country. According to the Myanmar Ministry of Energy, there are a total of 16 confirmed major coal deposits, all of which are either subbituminous coal or lignite. At present, although mining is carried out in ten locations, only a few mines are producing on a significant scale. These comprise the state-owned deep Kalewa mine (reserves of 87.8 Mt subbituminous) and opencast Namma mines (reserves of 2.8 Mt lignite). Output from these two mines has been increasing for some years. In the private sector, the Mawdaung opencast mine in the Taninthayi Division exports coal to Thailand. Other private mines in Shan State are operated by local producers, supplying local needs. The country's other coalfields are located in remote regions and currently lack the infrastructure needed to move the coal to major consuming centres cheaply.

There are plans to increase production from the Kalewa mine, potentially to300 kt/y. This is dependent on the development of a 66 MW power plant project and a 500 kt/y cement plant. If this proceeds, 66 MW will be produced initially, increasing to 120 MW during phase II. Promotion of rural electrification, supplied by coal-fired plants, may also be increased.

The main domestic coal uses are currently for small scale power generation, mineral processing, and sponge iron production, in almost equal proportions (Thein and Myint, 2008). In 2007-08, total national coal production was 1.12 Mt (including 328 kt lignite) (OECD/IEA, 2009). Of this total, 869 kt was consumed domestically and 229 kt exported. Although modest, output is forecast to continue increasing; by 2012-13 it is expected to be 1.74 Mt, rising further to 2.33 Mt in 2015-16, 4.59 Mt in 2020-21, and 5.65 Mt in 2030-31(Myanmar Ministry of Energy, 2008a).The increased amount of coal expected to be used by both the power and industry sectors will require more intensive exploration efforts to fully identify coal reserves. Development of these projects would benefit from direct foreign investments and technology transfer initiative such as clean coal technologies (Myanmar Ministry of Energy, 2008b).

8.7 The Philippines

The country has a total of 236 Mt of proven recoverable coal reserves. This comprises 22 Mt of bituminous coal, 70 Mt of lignite and 144 Mt of subbituminous coal (184 Mt resources) (WEC, 2004). A combination of indigenous and imported coal is used to fire power plants and supply various industrial applications. In 2008, indigenous coal production amounted to 2.36 Mt (OECD/IEA, 2009). This came from a number of sites although the biggest individual producing area was Semirara Island, Antique. This produces around 90% of the country's total output. The main coal-producing areas include Zamboanga (103 kt/y), Surigao (51 kt/y), Cebu (41 kt/y), Batan Island, Albay (24 kt/y), and Negros (15 Mt/y). Coal reserves in the Cotabato Basin are potentially substantial, although have not

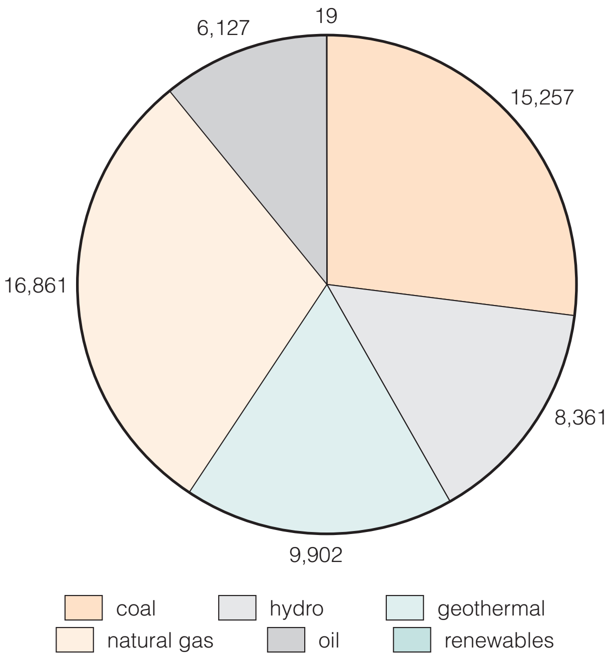

Figure 21 Power generation in The Philippines, GWh (Oca, 2007)

yet been fully explored. The largest individual coal producer is Semirara Mining Corporation (SMC). This produces >90% of the country's total coal output via its opencast operations.

In 2008, national coal demand rose to 12.2 Mt, although only roughly a third came from indigenous resources. The balance was imported from China, Indonesia, Australia and elsewhere. Power generation remains the largest coal-consuming sector (>10 Mt/y), followed by cement manufacture (>2 Mt/y). Coal-fired power units range between 50 and 700 MW. Some are fired on indigenous coals and others on imports. A breakdown of the country's electricity generation is given in Figure 21.

Local coal has begun to play a greater role in the country's electricity sector with a number of new projects coming on line or in development. In 2007, the 232 MW Mindanao power plant in Villanueva, Misamis Oriental came into full commercial service. It was built by Steag of Germany under a BOT agreement. It has a 25-year power purchase agreement with state-owned National Power Corp and has been providing 16% of Mindanao's electricity, reducing the reliance of oil-based plants from ~30% to 13%. In March 2010, in order to help alleviate local power shortages, it was announced that Evonik Steag (with local partners Aboitiz Power Corp and La Filipina Uygongco Corp) was considering enlarging the plant by a further 100 or 200 MW.

Coal use looks set to increase further as a number of new coal-fired power plant projects are currently at various stages in their development. Some are likely to use indigenous coal and others, imported supplies. These comprise:

- The *Isabela Coal Mining and Power Plant Project*. The state-run Philippine National Oil Company-Exploration Corporation (PNOC-EC), in conjunction with San Miguel Corporation, is developing a lignite mine plus a 50 MW CFBC minemouth power plant project near Cauayan City, Isabela. The opencast mine has estimated mineable reserves of ~25 Mt. The power project may be enlarged to 100 MW at a later date. Discussions are ongoing between PNOC-EC and San Miguel regarding partnership arrangements. The power plant could be constructed jointly, or SMC could supply coal for an SMC-owned plant;
- Kamanga power station. This is a proposed 200 MW station in the coastal town of Maasim, Sarangani Province. The developer is Conal Holdings, a JV between Electricity Generating Public Company Limited of Thailand and the Alcantara Group. Sultan Mining and Energy Development Corporation will supply coal for the project;
- Calaca coal-fired plant. Trans-Asia Oil and Energy Development Corporation are developing a 270 MW project in Batangas. Initially, it will be 135 MW, but if demand is sufficient, it could later be doubled. The company is negotiating with a Chinese equipment supplier for the plant's construction. The project is expected to be completed by 2013;
- Naga 200 MW CFBC power plant in Cebu. Developed by SPC Power Corp (KSPC), a JV comprising KEPCO Philippines Holdings (a wholly-owned subsidiary of KEPCO) with Salcon Power. The plant is expected to supply power to six electric cooperatives that have signed power sales contracts amounting to 120 MW. Doosan Heavy Industries is constructing the plant. The project's first 100 MW unit is on track for completion in 2011, with the second coming on line in 2012. Coal is expected to be imported Indonesian subbituminous;

- San Miguel Corporation has recently acquired a number of mines with a view to ramping up the generating capacities of its planned coal-fired plants in Mindanao, an area that continues to experience power shortages. The company is also characterising coal reserves in the region and plans to construct a 300 MW minemouth power plant in General Santos City. This would need about 750 kt/y of coal.

It is considered that various parts of the country have coal reserves that would be adequate to supply the needs of major power plants for the next 25 years. These include deposits in Isabela (lignite) with a potential of 150–300 MW, Cagayan (lignite) with at least 100 MW, Surigao Del Sur (lignite and subbituminous) with 300 MW, South Cotabato (subbituminous) with 300–900 MW, and Zamboanga Sibugay (bituminous) with ~200 MW

Apart from power generation and industrial applications, local lignite and/or subbituminous coals are also the focus of attention for a proposed coal-to-liquids project (the Philippines Coal Hybrid Liquefaction Project), based on the use of Headwaters indirect coal liquefaction technology. To date, a pre-FEED assessment has been undertaken; this confirmed that the process was techno-economically suitable for Philippine coals. Should the project proceed, the next step will be the construction of a Fischer-Tropsch Process Demonstration Unit. A proposed commercial-scale plant would produce >60,000 bbl/day of ultra-clean, liquid transportation fuels, and also generate 67 MW of power that could be exported to the national grid. Based on initial studies, the total coal feed rate would be ~26,200 t/d of (as-received) lignite, and 7130 t/d of subbituminous coal. Successful plant development could cut the country’s dependence on imported oil by at least 20%, producing ultra-clean fuels costing 40% less than equivalent imported petroleum products. It could also act as a CTL hub for Southeast Asia, given the country’s strategic proximity to coal shipping routes, indigenous (largely untapped) coal resources, and other coals from the region.

9 South and Central America

South and Central America contain a total of 19.89 Gt of proved recoverable coal reserves. Some 12.07 Gt are of subbituminous coal and 124 Mt are of lignite (WEC, 2004). Reserves are spread throughout a number of countries although most are concentrated in just a handful. For instance, most of the continent's subbituminous coal is located in Brazil, with most lignite in Ecuador and Peru.

9.1 Argentina

Although Argentina is a significant energy producer and a net energy exporter, it has limited coal reserves. Its energy resources are dominated by oil and natural gas, with coal playing a minor role in the national energy mix. Only one of the country's power plants is coal fired. Argentina has proved recoverable coal reserves amounting to 424 Mt, all of which are subbituminous (WEC, 2004). Almost all confirmed reserves are located predominantly in two locations: the mothballed Pico Quemado mine in Rio Negro Province (estimated reserves ~75 Mt), and the Rio Turbio mine in Santa Cruz Province. However, recently, further coal reserves have been identified in the Laprida and Lamadrid districts of Buenos Aires Province.

The only significant coal mine (Rio Turbio) lies close to the border with Chile. This is state owned and supplies coal mainly for power generation (shipped to the 350 MW San Nicolás power plant near Buenos Aires), metallurgy and other minor uses. Some coal is also used on site. At present, coal's contribution to the Argentine economy remains small. However, a new power generation project is being developed by Yacimientos Carboníferos Río Turbio (YCRT) close to the Rio Turbio mine and future coal production is expected to increase to 1 Mt/y. This new 240 MW plant is using two Foster Wheeler CFB boilers, the first such units to be built in Argentina. It is expected that these will supply about 1% of the country's electricity (fed to the grid) and will contribute towards diversifying the Argentinean energy mix.

9.2 Brazil

Brazil imports a considerable amount of metallurgical coal for its steel industry, although to date, coal mining and coal-fired power generation have remained relatively small scale. However, this situation may change as the country capitalises further on its indigenous coal deposits. Most of these are of low quality.

Brazil has the largest coal reserves in South America (BP, 2009). In 2007, the WEC estimated that the country had just over 17 Gt of coal reserves in place although other estimates suggest that the total could be closer to 32 Gt. Around 42% were categorised as proven recoverable reserves amounting to 7.068 Gt (WEC, 2007). This is made up predominantly of subbituminous coal and lignite, although individual deposits vary in both quality and quantity. The main deposits are located mostly in the southern states of Rio Grande do Sul, Santa Catarina and Paraná. It is estimated that a significant proportion of the country's reserves could be exploited through opencast operations. At present, around 65% of Brazilian coal production is obtained via surface mining.

Almost all of Brazil's current coal output is classified as steam coal; most of this (>85%) is used as power station fuel and the remainder by industrial plants. Much of the coal is characterised by high ash and sulphur content, as well as low calorific value. The country's steel industry is expected to remain the largest domestic coal consumer for the foreseeable future although, owing to the lack of suitable indigenous supplies, the sector relies almost entirely on imported metallurgical coal from the USA, Australia, China, Canada and South Africa. Around 70% of this is used for coke production. Overall, Brazil is Latin America's largest coal consumer.

For several years, Brazilian coal production has been steady at around 5.7–5.8 Mt/y (OECD/IEA, 2009). The leading coal producer is Copelmi Mineraçao, which holds the concession for >3 Gt of coal in several areas of the State of Rio Grande do Sul and currently achieves a production of more than 2 Mt/y of raw coal. The other major producer is Companhia Riograndense de Mineração (CRM). In total, there are around 15 coal producing companies currently active in the country. For some years, the Brazilian Banco Nacional de Desenvolvimento Economico e Social (BNDES) has been developing plans to expand the country's coal industry. BNDES hopes that its proposed programme will ultimately make Brazil self-sufficient in coal, eventually becoming a net exporter (Clough, 2008).

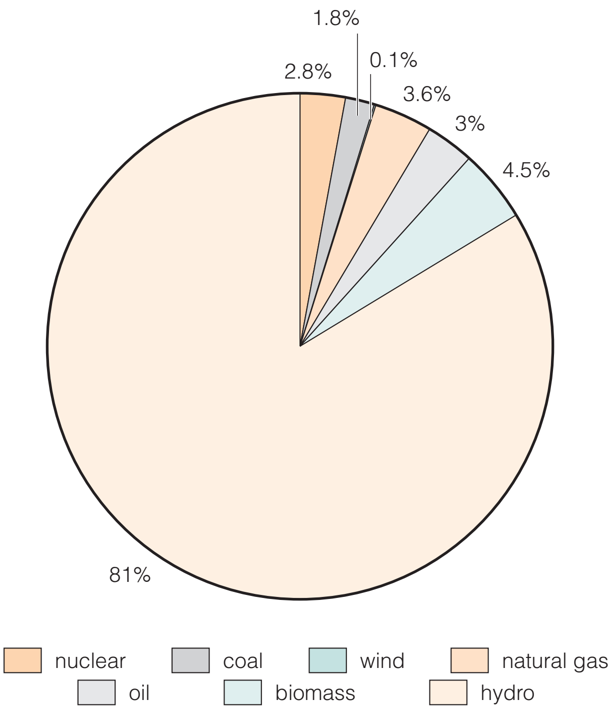

Figure 22 Makeup of Brazilian power sector, 2010

After steel production, the power sector is the second (but much smaller) coal-consuming sector. Indigenous coal is used mainly for electricity generation, with the balance used by various industries that include petrochemicals, pulp and paper, food production, and ceramics. Brazil depends heavily on hydropower for most of its electricity, and coal contributes only around 2% (Figure 22).

There are currently eight power plants fired on indigenous subbituminous coal, with a combined capacity of 1455 MW. Individual unit size varies and coal consumptions range between 0.3 and 1.74 Mt/y (CoalPower). However, it is forecast that this will change as coal-fired capacity continues to increase. The Brazilian Federal Energy Research Office has planned for an expansion of coal power to 6 GW by 2015, bringing coal's share to 5% of the total. Since 2000, local coal production has increased significantly, largely to meet the needs of new power projects.

After nearly two decades without any new coal-based power projects in Brazil, 2005 heralded the start of a number of new projects and proposals. Since then, Eletrobás' subsidiary CGTEE (with CRM) has expanded coal-fired capacity from its Candiota site. This has included a US$285 million investment in the 350 MW Candiota III plant (also known as Presidente Medici – Phase C), due for completion in 2010. About 80% of the plant's equipment was supplied by the Chinese company Citic International Contracting, and the project financed by the Chinese Development Bank (Patel, 2010). This may be followed by a second project. A further US$20 million has been invested in increasing output from the adjacent mine.

There are also a number of other new coal-fired projects that have been proposed or are being developed. These include the following (Vasconcelos, 2009):

- the 350 MW Jacuí I plant, to be located in the municipality of Charqueadas, Rio Grande do Sul. Coal will be supplied by CRM's Mina do Leão II mine. The consortium developing the project includes Andrade Gutierrez, Siemens, BBP Environment, Alstom Power, and MDU Resources;
- CGTEE is building a 350 MW plant in the south of the country, scheduled for start-up in 2010;
- Vale, the largest Brazilian mining company, is building a 600 MW plant in the north, scheduled for start-up in 2012;
- a joint-venture comprising MPX and Energias do Brasil is building a 720 MW in Pecem Port, near Fortaleza. Phase I start-up is scheduled for 2012;

- MPX is building the 700 MW Porto do Açu project in Rio de Janeiro; Phase I is due to come on line in 2012. A second 700 MW expansion project is also planned;
- MPX plans to build two new units (2 x 360 MW) in 2013 and 2014 in Itaqui Port, near Sao Luis;
- Tractebel Energia plans a new 340 MW plant, scheduled to start up in 2012.

If all these proceed, national coal requirement will increase significantly.

9.3 Chile

Chile has substantial reserves of subbituminous coals, estimated at around 1150 Mt (WEC, 2004). Coal is produced only in the Lota/Coronel area and in the extreme southern part of the country. There are only two commercial mines in operation, although new developments are currently under way. At present Chile imports most of the coal needed for power generation from Columbia and Australia. However, the *Riesco Island Project* is expected to reduce the level of imports by up to 30%.

The Riesco is the country's biggest and most important individual deposit. This has subbituminous reserves in excess of 300 Mt, although these could be as high as 670 Mt. There are three main deposits, namely Río Eduardo, Elena and Estancia Invierno. The Riesco project is based on these proven deposits and involves the development of mines and the construction of a mechanised transport and sea export facility. Stage I of the project (4 Mt/y opencast production) is due for completion by 2011 (Mining Technology, nd). The coal will be shipped to power plants in urban areas in the northern and central regions of Chile. Currently, some of these fire combinations of subbituminous and imported bituminous coals. Further developments are expected to push output up to 6 Mt/ by 2013. Apart from the power sector, imported hard coal is also used in smaller amounts, mainly for coke oven operations and cement manufacture.

Coal is currently supplied to a number of the country's power plants. Some use combinations of bituminous and subbituminous coals, whereas others (such as the 266 MWe New Tocopilla co-generation plant) are fired solely on Chilean subbituminous coal. Some Chilean coal is also exported. For instance, the 454 MW Guayama CFB-based power plant, developed in Puerto Rico by US-based AES Corporation (the island's first coal-fired power plant) uses Chilean subbituminous coal. Two CFB boilers were supplied by Alstom Power. The plant is well equipped with emissions controls systems that include SNCR.

9.4 Colombia

Colombia has significant coal deposits spread across eight regions. Most of the country's coal reserves of 6814 Mt have been confirmed as of bituminous quality, although 380 Mt of this is classified as subbituminous (BP, 2009); for instance, some of the reserves in the Alto San Jorge field in Córdoba have been classified as subbituminous. No lignite has been identified.

After Brazil, the country has the second largest reserves in South America, concentrated mainly in the Guajira peninsula in the north and the Andean foothills. Recent years have seen hard coal production increase steadily, rising from 38.2 Mt in 2000, to 78.6 Mt in 2008 (OECD/IEA, 2009). There are plans to eventually expand production to ~100 Mt/y. The biggest individual production site is currently the Cerrejón Zona Norte (CZN) project, the largest coal mine in South America and reputedly, the largest opencast coal mine in the world.

Nearly all coal production is exported. Generally, the quality is good, with low sulphur content. However, at the moment, coal does not play a major role in Colombia's energy production, with only around 5% of total output consumed within the country.

9.5 Ecuador

Although the country has proven (lignite and subbituminous) coal reserves totalling 24 Mt, currently, these are not being exploited (WEC, 2004). At present, Ecuador is neither a coal producer nor consumer.

9.6 Peru

Peru has a total of 1060 Mt of proved coal reserves distributed throughout much of the country. These comprise 960 Mt of anthracite-bituminous coals, plus 100 Mt of lignite (WEC, 2004). The largest coal deposits are at Alto Chicama (the Northern Anthracite Field – the most significant reserve), Cuenca del Santa, and the Goyllarisquizga and Hatun Huasi coal basins in the Cáceres Region. Historically, coal mining operations have been relatively small, with Peruvian mining companies being unable to meet the country's coal demand. However, in 2008, foreign investment was made in the sector via the takeover of Peruvian company Sudamericana de Carbon (SDC) by Canadian mining company Vena Resources. SDC specialises in the exploration, development and mining of (predominantly) anthracite.

The rank of Peruvian coals is highly variable. Thus, coal types include anthracite, bituminous and subbitmunious coals and lignite. The latter two are found in Cenozoic basins. In 2006, total coal production amounted to ~30 kt although at the time, the estimated coal demand was >1.3 Mt/y.

Peruvian coals are used for various industrial applications such as brick making, cement manufacture, filter production, and domestic heating. Some is also briquetted. However, coal may soon also be used for power generation. In March 2010, Refill Energy of the USA announced a US$10 million contract with Nueva Esperanza, a company that holds extensive coal mines and reserves in Peru. Under the terms of the contract, Nueva Esperanza will acquire 49% of Refill's wholly-owned subsidiary Green N-ergy, which holds exclusive worldwide licence and marketing rights to Refill Energy's stratified downdraft gasification and reactor technologies. The flagship project will be the construction of a 200 MW coal-based power plant in the country. The particular coal type selected has not yet been revealed.

10 Russia and former Soviet states

10.1 Russia

At 3928 Gt, Russia has one of the biggest coal resources in the world. Reserves recorded in the state balance that have been explored and studied to at least a reasonable degree and are the most promising for development amount to 192.3 Gt. A further 75.8 Gt is more speculative. BP suggests that Russia has proven reserves of subbituminous coal and lignite amounting to 108 Gt (97.47 Gt of subbituminous coal + 10.45 Mt of lignite) (BP, 2009). Other estimates are similar; for instance, Crocker and Kovalchuk, suggest that lignite accounts for 52.9% (101.7 Gt) of total Russian coal deposits, hard coal for 43.6% (36.6 Gt), and anthracite 3.5% (6.7 Gt) (Crocker and Kovalchuk, 2008).

The country's major coal deposits are concentrated in Siberia (79.4%) and the Far East Federal District (10.5%). Explored and assessed coal reserves are located in 22 basins and 118 separate deposits distributed unevenly across the country. In 2008, Russia produced a total of 247 Mt of hard coal, comprising 182 Mt of steam coal and 65 Mt of coking coal. Lignite output was 76 Mt (OECD/IEA, 2009). Hence, total coal output amounted to 320 Mt. At current levels of production, Russia has 1359 years of lignite reserves and 357 years of hard coal reserves.

10.1.1 Coal production

The Russian system of coal classification differs from most others, such as the ASTM system. Under the Russian system, there are three grades of brown coal (1B, 2B and 3B) – under the ASTM categorisation, 1B equates with lignite A and B; 2B equates with subbituminous C, and 3B overlaps with subbituminous B. Russian 'long flame' D overlaps with subbituminous A. Russian brown coal grades have different moisture contents (1B has moisture >40%, 2B has 30–40%, and 3B is <30%) (Crocker and Kovalchuk, 2008).

Current total Russian coal production is around 320 Mt/y. Although coal is produced in more than 20 basins, the majority comes from seven, three of which lie to the west of the Ural Mountains in the European portion of Russia, and four which lie to the east in the Siberian region of Asia. However, around 90% of all Russian coal is produced in just four major basins. Some 56% is produced in the Kuzbass hard coal basin, 12% in the Kansk-Achinsk lignite basin, 12% in east Siberia and 10% in the Far East. Coal comes from a total of 95 underground mines and 124 opencast sites. For some years, hard coal production has increased steadily, rising from 190 Mt in 2004, to 247 Mt in 2008. During the same period, lignite output rose from 69 Mt to 76 Mt (OECD/IEA, 2009). Most lignite was used for power generation although 12.2 Mt used for heating applications.

Historically, output of lignite has been higher than today's levels. In 1990, some 134 Mt was produced. This fell dramatically, reaching a low of 69 Mt in 2004. Since then, although production has fluctuated somewhat, the trend has generally been upwards (OECD/IEA, 2009). Lignite is currently produced mainly in four basins, namely the Moscow Basin, the Irkutsk Basin, in Sakhalin, and in the Kansk-Achinsk Basin. The latter is the largest producer of lignite in southern Siberia. This has seen considerable expansion due to favourable geologic conditions, thin overburden, and thick coal beds. Virtually all the proven reserves are recoverable by opencast mining. What is claimed to be the largest mine and power generation complex in the world (the Katek Complex) is located within the basin. This complex consists of large opencast mines with productive capacities of up to 60 Mt/y (Lawson, 2002). The basin has balance lignite reserves of 79.8 Gt, some 5.4 Gt of which are at operating opencast mines. In recent years, annual output has been around 38 Mt. A further 16 Mt/y comes from east Siberia, and 15 Mt/y from the Far East. At present rates of production, Russian lignite reserves will last for well over a millennium. Major Russian lignite producers are shown in Table 19.

Table 19 Major Russian lignite producers (2006) (Crocker and Kovalchuk, 2008)

Company	Lignite production, kt
SUEK	43274
Lutek	5525
Priargunskoe	4542
Kansky	3906
Krasnoyarskkrayogul	3600
Amursky	3377
Chelyabinskaya	2978
Sakhalin Coal Company	1243
Volchansky Ugol	1322
Irbeisky	1208
Total industry output	74773

Depending on the source, lignite properties can vary widely. Moisture content can range between 8.3% and 58%, ash content can vary between 3.4% and 51%, and sulphur, between 0.17% and 7.7%. Russian long flame coal D (equates with some subbituminous coals elsewhere) can have a moisture content between 4.6% and 13.3%, an ash range between 6% and 40%, and a sulphur content of between 0.2% and 4.5%.

10.1.2 Coal markets

As elsewhere, the power generation sector is a major consumer of low grade coals. Both electricity demand and generation is increasing in Russia and around a third of total coal output is used for electricity generation and co-generation purposes. Overall, only 17% of the country's electricity is currently produced from coal, compared to the global average of 39%. However, this figure masks huge regional variations in the level of dependence, and coal dominates in the Far East (78%) and Siberia (90%). Essentially, natural gas dominates power generation in western Russia and coal dominates east of the Urals. Lignites are used widely for power generation in the Far East.

A number of major power plants rely on Russian lignite, most located close to the appropriate mines. Some consume between 1 and 2 Mt/y. The characteristics of lignites supplied to power plants can vary considerably. The moisture content of such grades can vary between 13% and 35%, ash content between 4% and 48%, and sulphur content between 0.2% and 2.7%. CV generally falls between 8% and 16 MJ/kg (LHV) (Coalpower). One of the largest individual lignite consumers is the nine-unit Primorskaya power plant in eastern Russia. This uses more than 2 Mt/y of Luchegorsk lignite (39% moisture, 25% ash, 0.2% sulphur, CV of 8.09 MJ/kg).

It was announced in April 2010, that Russia was examining the development of a large scale coal-to-liquids project. The use of indigenous coal in this way would help free up more natural gas for export. Coal producers in several regions, including the Kuzbass in western Siberia, eastern Siberia and the Sakha-Yakutia Republic in northeastern Siberia, are reportedly vying for the plant. If the decision is taken to proceed, construction would take an estimated six or seven years, hence start-up would be post-2016 (Nezavisimaya Gazeta, 2010).

10.2 Commonwealth of Independent States

The political union which formed after the dissolution of the USSR is known as the Commonwealth of Independent States (CIS). Twelve countries make up this union and of these, apart from Russia itself, only a few possess significant coal reserves. Ukraine has the largest, followed by Kazakhstan and Uzbekistan.

10.2.1 Ukraine

Ukraine ranks among the top ten coal-producing countries in the world. It is well endowed with coal, with resources estimated at 52 Gt and total proven reserves of between 33.9 and 34.1 Gt (BP, 2009; WEC, 2004). Some 6.5 Gt are located at active mines. The main coal reserves (45.6%) are concentrated in the Donetsk coal basin. A further 34.2% is located in the Luhansk region, 15.3% in the Dnipropetrovsk region and the remaining 5% is located in the regions of Lviv, Volyn and Kirovograd (Euracoal, nd). Proven reserves of anthracite + bituminous coal are between 15.3 and 16.3 Gt, and reserves of subbituminous coal and lignite between 17.8 and 18.5 Gt; the bulk of this is the former. Proven reserves of lignite amount to 1.93 Gt, with resources of 2.58 Gt (WEC, 2004).

Since the country became independent in 1991, coal production has fallen, although since 2000 it has remained essentially flat at between 59 and 61 Mt/y. During the same period, domestic coal consumption has remained roughly the same at ~37–38 Mt/y. However, under Ukraine's current *Energy Strategy to 2030* strategy, it is envisaged that a series of measures will be taken to increase coal production to 120 Mt by 2015. As part of this, it is planned to reopen more than 40 mines with a total production capacity of nearly 29 Mt/y.

Most of the country's mines are deep, although there are also three opencast sites that produce subbituminous coal and/or lignite. Annual production of lignite is presently between 290 and 300 kt, the bulk of which is consumed within the country (OECD/IEA, 2009). At present rates of extraction, Ukraine's lignite reserves will last for around 1200 years (Crocker and Kovalchuk, 2008). However, for several years, the Ukrainian mining industry has been encouraging the greater development and use of indigenous lignite (Global Power Review, 2008). There are around twenty lignite deposits in the country and some of the most promising for future commercial development lie within the boundaries of the south-eastern part of the Dnieper basin. Of the various lignite deposits within the region, several are not currently being exploited. However, there are approved balance reserves in two areas readied for commercial-scale mining, namely Verhnidniprovska (reserves of ~150 Mt), and Petrykivska (reserves of 75 Mt). Ukrainian lignite reserves have an ash content of between 29% and 46%, and moisture content between 30% and 40%. CV is typically around 12.4 kJ/kg (Euracoal, nd).

Given Ukraine's high dependence on Russia for its natural gas, it has been suggested that the region's plentiful lignite reserves could be gasified to produce SNG, hence reducing import dependency (Fenwick, 2010), although at the moment there do not appear to be any immediate prospects for this.

10.2.2 Kazakhstan

Kazakhstan contains Central Asia's largest known recoverable coal reserves and has proven reserves of 3.13 Gt of (mostly) lignite and subbituminous coals (BP, 2009). The country accounts for ~20% of the total coal production of the former USSR. There are more than 400 coal deposits of which a third are classified as brown coal or lignite. The two major hard coal producing areas comprise the Ekibastuz and Karaganda basins. The latter has long been the country's main coal supplier, producing up to 50 Mt/y. The Ekibastuz coalfields, which are among the largest in Kazakhstan, lie to the northeast, 200 km from Karaganda. Bogatyr Coal is the largest mining company active in opencast mining in the Ekibastuz basin. Some 70% of its output (~42 Mt/y) comes from its operations in the basin, around half of which is exported (International Mining, 2009). Approximately 30% of Kazakhstan's coal production is exported, mainly to Russia and the Ukraine. The remainder is used in the domestic power generation industry (80% of Kazakhstan's generating capacity is coal based) as well as the iron and steel industries.

Some of the largest lignite deposits are found in the lignite fields of the Turgajskij basin. These include the Orlovskoe deposit, some 380 km west of the capital of Astana, and originally held as the property of the Soviet state. Historically, these deposits have been explored intensely with a view to their use for large scale power generation. To date, this option has not been pursued; however, in 2009, a consortium comprising western investors (represented by Canadian-based Flagship Industries-Charonga) and local partners began the process of re-examining the region's potential with the objective of developing an integrated mine and power plant complex. If the project proceeds, it will provide electricity for the region as well as the southern Urals in Russia.

In 2008, the country produced 104.4 Mt of hard coal, an amount that has grown steadily since 2000. It also produced 4.2 Mt of lignite, most of which was used within the country. Since 2000, lignite consumption has varied between 2.5 and 4.3 Mt/y (OECD/IEA, 2009). In 2008, hard coal consumption was 52.8 Mt.

There are plans for the country's coal production to increase to 100–105 Mt/y by 2015. Although hard coal output currently greatly exceeds that of lignite, the latter is of particular significance in some areas. For instance, the opencast Maikuben West mine is located in the Ekibastuz basin. This has an estimated life in excess of 30 years and supplies ~3.6 Mt/y to local power/co-generation facilities and other industrial plants. Major users include the two Ekibastuz power station (GRES 1 – 4 GW and GRES 2 – 1 GW). GRES 2 supplies ~13 % of the country's electricity. Lignite requirement will increase further at the plant as a third (500 MW) block is to be added to GRES 2. In June 2010 Russia agreed to loan Kazakhstan US$700 million for the project.

10.2.3 Uzbekistan

Uzbekistan has proven coal reserves of around 2 Gt. Hard coal deposits amount to 47 Mt, whereas lignite reserves are almost 1.9 Gt. Bituminous coal is present in two basins, Shargun and Baisun, located in the southern part of the country. Lignite is found in the Angren basin (situated in the Tashkent oblast) which contains proven reserves of 1.9–2 Gt. Most is classified as lignite although there is also some subbituminous coal.

Despite its significant reserves, coal production in Uzbekistan is not substantial as the power generation sector relies heavily on the use of natural gas and oil at present. Coal currently supplies only ~5% of the country's electricity. During the Soviet era, coal production was around 5 Mt/y, whereas more recently levels have been ~2.5 Mt/y (in 2008). Around 97% of output comprises lignite, with bituminous coal accounting for only 3% of the total. All is used in energy production.

At present, nearly all of Uzbekistan's coal is produced by JSC Uzbekugol, with >80% of production coming from the Angrenskiy deposit, the country's largest. Reserves here are estimated to exceed 2 Gt, comprising mostly lignite. Uzbekugol is engaged in mining activities at three lignite deposits (Angrenskiy, Shargunskiy and Baysunskiy). Potentially, at the current level of production, the Angrenskiy deposit could remain active for >400 years. Annually, Uzbekugol produces around 3 Mt of lignite, around 85% of which is supplied to the power sector.

During the past few years, considerable effort has been put into upgrading the Angrenskiy mine, with a view to bringing output up to 6.4 Mt/y by the end of 2010. The project is being financed by a loan of US$120.4 million from China's Eximbank, plus US$34 million from Uzbekugol itself. Modernisation will begin in late 2010 and be completed by early 2012. The work will be carried out by the China Coal Energy Company Ltd (Uzbekistan Today, 2010).

As part of the effort to increase national power output (from 52.3 TWh in 2010 to 80.3 TWh in 2020) the New Angren Thermal Power Plant is being modernised and uprated and will switch from seasonal, to year-round operation. During the first stage of the programme, five existing units will be addressed. Plant capacity will increase to 2.1 GW. This will require 4.2 Mt/y of lignite (ADB, 2009b). In the Sukhardaryinskaya oblast, Uzbekugol also has an operation at the Shargun mine and is developing further mining projects at Baisun.

11 Summary

Current estimates for the world's proven recoverable coal reserves suggest a total of between 1019 Gt and 1025 Gt. Around half of these comprise low value coals, predominantly lignites, subbituminous and high-ash bituminous coals. There are significant reserves of such coals in North America, Europe, and the Asia-Pacific regions. By rank (on a tonnage basis) subbituminous coal accounts for 32% of the world's proven recoverable reserves, and lignite for18%.

For some time, many coal-producing countries have witnessed a steady general decline in the quality of the coal produced and consumed. Often, this is a consequence of the depletion of higher grade reserves and a growing reliance on those of lower quality. Such gradual downward trends in quality can be observed in many parts of the world. Low value coals can take several forms but are generally considered to encompass lignites, plus subbituminous and bituminous coals with high ash and/or moisture contents.

Total proven global reserves of lignite are somewhere between 150 and 283 Gt, although potentially, they could be considerably higher. Lignite is found in many parts of the world, with particularly large deposits in Russia, the USA, Australia, Germany, Greece, the Czech Republic, and Serbia. Global production is currently around 950 Mt/y. At present, twelve individual countries produce more than 20 Mt/y, and each makes an important contribution to national energy supply. The eight biggest lignite producers comprise Germany, Turkey, Russia, the USA, Australia, Greece, Poland and the Czech Republic. Apart from these major producers, there are also many countries where output is less, but nevertheless important, in the respective national energy mix. Lignite is often produced relatively inexpensively from large-scale opencast mines. This usually helps keep down the cost of electricity generation.

Total proven reserves of subbituminous coal are around 267 Gt, with the largest individual reserves located in the USA (the biggest at more than 100 Gt), Russia, China, Ukraine, and Brazil. The bulk of these reserves are located predominantly in the USA and Russia which together represent 74% of the total. Like lignites, the majority is used for power generation and/or co-generation purposes.

High-ash bituminous coals are of particular importance to several major economies. Some bituminous coals can be difficult to categorise. However, generally, lower grades are associated with factors such as low heating value, high moisture content and high ash content. One of the most important economies to rely heavily on low quality bituminous coal is that of India. In this case, the main problem is the very high ash content of most indigenous reserves. Nevertheless, coal's strategic importance outweighs its drawbacks and the country's economy relies heavily on its use for power generation and a range of industrial applications.

Globally, the long-term future of coal-derived energy supplies will include the greater use of low rank and low quality coals, a trend that is already evident in many parts of the world. Increasingly, despite the disadvantages associated with their use, such coals are being utilised for power generation, co-generation, and other industrial applications. In some counties, they form the only significant energy resource available and their use provides a secure source of supply. Even where a country's main source is, at present, imported hard coal, the situation may change as a combination of logistical and production constraints is tightening the global supply, and it is clear that the international market is beginning to accept coals with lower heating value. Increasingly, lower quality coals are being traded and marketed around the world and their use is expected to continue growing for the foreseeable future. This trend may be helped by the ongoing development of various novel drying, cleaning and briquetting techniques aimed at upgrading different low grade and low rank coals in order to improve their properties and increase their value.

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