British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Coal

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MineralsUK
Centre for sustainable mineral development

Mineral profile

Definition, mineralogy and deposits

Definition and characteristics

Coal is a combustible rock, composed of lithified plant remains. It consists of macerals[1], minerals and water. It is formed by the alteration of dead plant material that initially accumulates as a surficial deposit of peat and is then buried beneath layers of younger sediment. As the temperature rises, due to increasing depth of burial, the initial peat may be sequentially altered by the process of coalification through brown coals, which include lignite and sub-bituminous coal, to black coals or hard coals that comprise bituminous coal, semi-anthracite and anthracite.

Coalification involves the loss of water and volatile components in the form of carbon dioxide and methane and an increase in the carbon content, from about 60 per cent in peat to more than 90 per cent in bituminous coal and 95 per cent in anthracite. Calorific value[2] also rises from about 15 megajoules per kilogram (MJ/kg) in peat, through 25 MJ/kg in brown coal to 35 MJ/kg and more in bituminous coal and anthracite. The position of a specific coal in the classification sequence is described as its rank, and represents the degree of coalification. For example, anthracite is classed as high rank whilst conversely lignite is classed as low rank.

Composition and mineralogy

Coals are typified as either humic[3] or sapropelic[4]. Humic coals are divided into the lithological types: vitrain, clarain, durain and fusain, which differ in their maceral content, texture and fracture characteristics. Sapropelic coals are typically fine-grained and homogenous. They include types known as cannel coal and boghead coal. The composition of the mineral content of coal varies; however, 60 to 80 per cent of the total mineral content is usually made up of clay minerals (commonly illite and kaolinite). Other significant constituents may include; iron disulphide (pyrite), calcium sulphate (gypsum), calcium carbonate (calcite) and sodium chloride (halite).

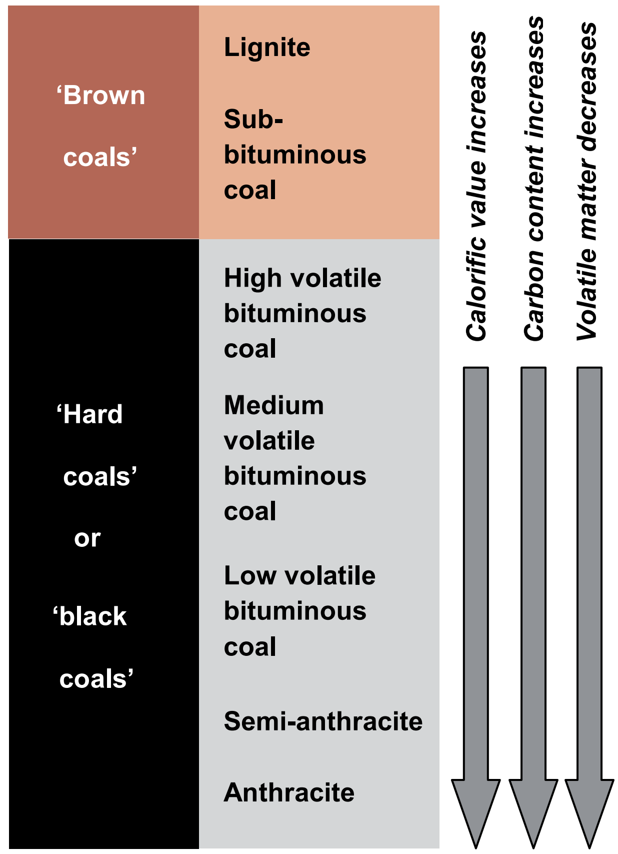

Figure 1 Coal classification (simplified).

Figure 2 Coal awaiting processing.

[1] The basic organic constituent of coal made up of the remains of dehydrogenate plant material
[2] Calorific value is the amount of energy released by the burning of one kilogram of coal
[3] Predominantly composed of the woody remains of mixed plant debris
[4] Predominantly composed of the wax-rich remains of plant spores and algae

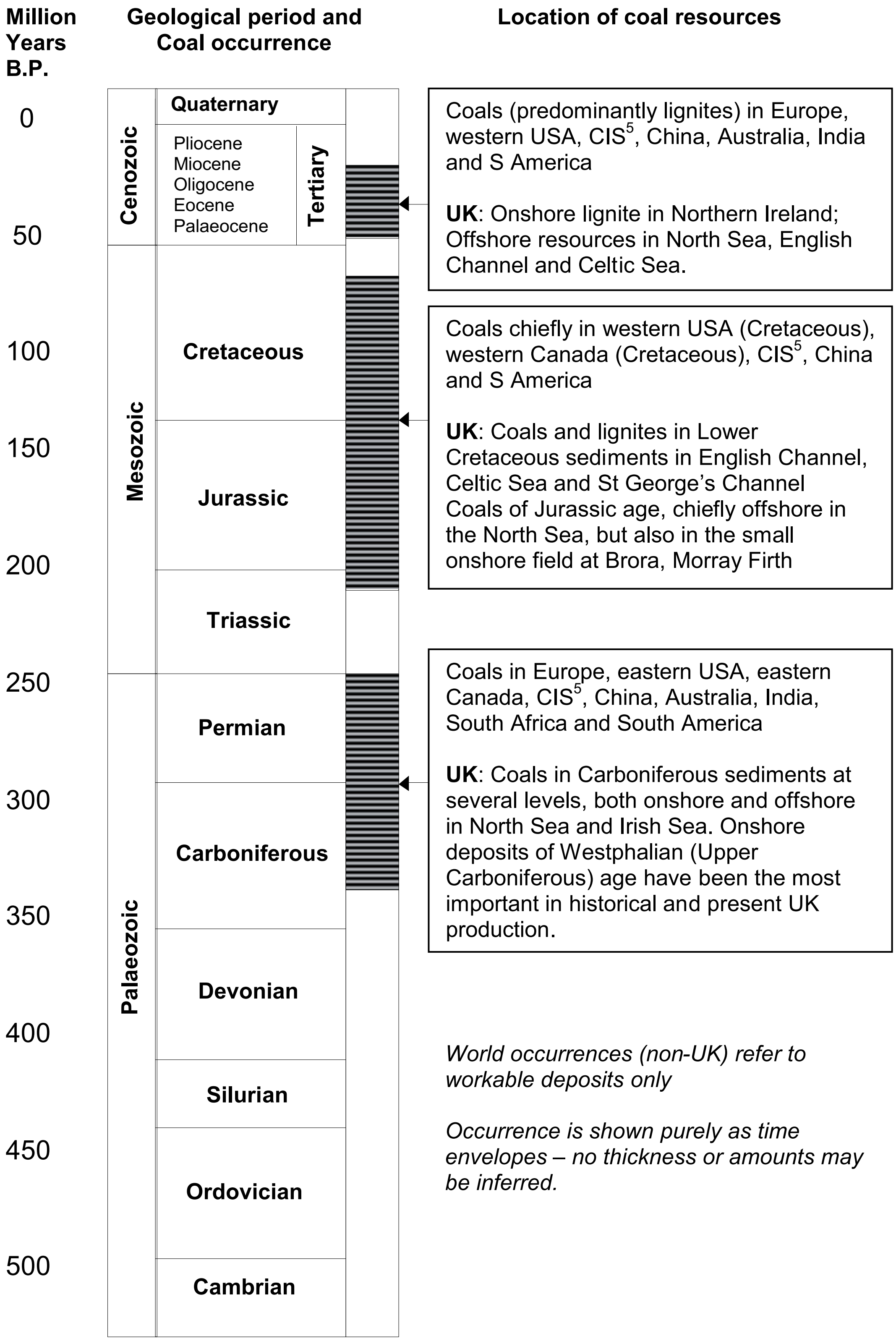

Figure 3 Occurrence of coal in the stratigraphic column.

[5] Commonwealth of Independent States – a loose term representing the bulk of the countries that formerly comprised the Soviet Union: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan (correct as at March 2010).

Deposits

Coal deposits are characteristic of thick non-marine sedimentary basins that have dominated certain areas of the globe at different times in the past, but especially in the Carboniferous and Permian periods. Coals of this age comprise the bulk of present world reserves of black coal. Brown coals, which include lignite, are more typical of (but not confined to) sedimentary basins dating from the Tertiary period that have not, in general, suffered deep burial. However, certain Tertiary coals, e.g. in Colombia, are of high rank due to high temperatures produced by local geological conditions.

Individual coal layers, known as seams, may vary in thickness from a few millimetres to tens of metres. They are characteristically tabular or lenticular in form and extensive in area but may be interrupted by features such as sand-filled channels that were cut into the peat immediately after its deposition, and by later structural features such as faulting and folding. Coal seams rarely comprise more than five per cent of the sedimentary sequence in which they occur, and their thickness may be only one tenth of the original (peat) thickness, before coalification.

Extraction methods and processing

Extraction

Coal is mined by both underground and open-pit methods. Underground mining involves chiefly two methods, longwall mining where mined-out areas are allowed to undergo controlled collapse as mining proceeds and room and pillar mining where pillars of coal are left in place to support the excavation.

Deep underground mines normally use a variant of the longwall method where a panel of coal (a defined area of the seam) is accessed by driving parallel tunnels within the seam along two sides of the panel, and joining these by a further cut at right angles that becomes the working face. A continuous mining machine then cuts coal by repeated passes along the working face, which either advances from (longwall advance) or retreats towards (longwall retreat) the mine access shafts or declines. Coal is normally removed by conveyor belt along the lateral tunnels. The roof in the working area is supported by hydraulic props and shields that are removed sequentially, allowing the roof to collapse as the working face is moved. Depending on seam thickness, practically all the coal in a panel may be removed by this method. More than one panel may be worked in a mine at the same time but typically only 50 per cent of available coal in an underground mine is recovered.

Waste rock in the mined coal is disposed of on an adjacent tip. In many parts of the world, waste tips are now landscaped and vegetated to reduce environmental impact.

The room and pillar (also called pillar and stall) mining method is used generally at shallow depths, where it is desired to avoid disturbance at the land surface. Extraction from the rooms proceeds on a rectangular plan and up to 60 per cent of the coal may be taken, leaving pillars to support the roof. A competent roof rock is a pre-requisite but an optional final phase is to rob the pillars until the roof collapses. The method is now very little used in Europe, but is important in other parts of the world.

Open-pit mining, also called opencast or open cut mining, is essentially a quarrying method. It is viable where a seam is relatively near the land surface, or where a pit can expose a number of seams within an acceptable depth – normally up to 100 metres in the UK, but exceptionally to 200 metres. The rock that lies above and between each seam (the overburden and interburden) is excavated and stored nearby and the coal seams exposed, including seams that would be too thin to remove by underground mining, are extracted. Both capital and working costs are far less for open pit mines than for underground mines and at the end of the pit's life it is normally back-filled using the overburden and the area is restored to other uses. In older mining districts, e.g. the UK, open pit mines sometimes overlap with areas formerly worked by shallow room and pillar methods. The floor of a deep open pit may

Figure 4 A continuous miner used for driving underground roadways to access reserves up to a kilometre deep in British coal mines. Picture courtesy of MRP Photography.

also be the starting level for underground mining using a decline for access (as at Margam, South Wales).

Highwall or auger mining is a hybrid method used to maximise the output of an open pit. It involves the use of remotely-operated cutting or boring machines that excavate slots or tunnels in the seam exposed at the foot of the highwall (the final wall in an open pit). It is effectively a way of mining underground, to a limited extent, using surface operators.

Illustrations, diagrams and photographs of different mining methods can be found in Thomas, 2002.

Processing

Run-of-mine coal normally requires treatment before marketing as it frequently contains unwanted impurities. The processing depends on the properties of the coal and the intended use.

The coal is crushed and this may be all the processing that is required or it may be separated by size to go on for further beneficiation. The most widely-used method is treatment in an oscillating column of water, where the unwanted rock fragments sink faster than coal; such plant is normally known as a washery. Alternative treatments for cleaning coal include use of a heavy medium such as a suspension of magnetite in water and froth flotation where the coal is finely crushed. Other methods using water are also used.

Specification and uses

Specification

The fundamental division of bituminous coal by end-use, and thus also by trade category, is into thermal or steam coal, used for burning in power stations and in other industrial and domestic uses, and coking or metallurgical coal, used in the steel industry to de-oxidise iron ore in the blast furnace. The properties that determine the economic viability and end-use category of coal are its rank (degree of coalification), chemistry and physical properties. Ultimately the ex-mine price for steam coal is based chiefly on its net calorific value (NCV).

The most basic properties of coal in respect of its use are its content of moisture, volatiles, ash and fixed carbon. These properties together determine its rank. Moisture, either uncombined or combined with minerals, absorbs heat during combustion and creates handling problems; ash (the mineral-derived residue after combustion) reduces calorific value and may cause slagging and fouling problems in boilers. The total content of moisture, volatiles and ash is the reciprocal of fixed carbon content and thus high values

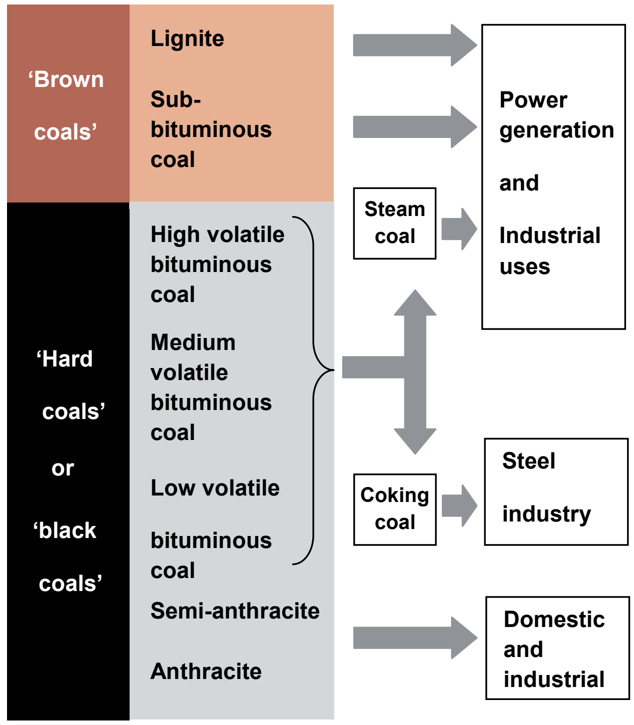

Figure 5 Coal uses; by coal type

of any or all of them reduce the calorific value and the carbon content of coals. Also significant are the contents of hydrogen, oxygen, nitrogen and sulphur. Nitrogen and sulphur, which is present both as iron pyrites and as organic sulphur held in the coal itself, are important because of their possible contribution to atmospheric pollution in the form of nitrogen oxides and sulphur dioxide respectively. Chlorine may be present in amounts that cause corrosion in boilers, and phosphorus is undesirable in coking coals due to its effect on steels.

Combustion tests are vital in deciding the optimum use of a coal. They consist of determinations of

- calorific value
- ash fusion temperatures
- caking tests, which quantify the swelling and agglomeration properties of coal on heating, with air excluded
- coking tests, which examine the volume changes, texture and strength that result on heating a coal sample to produce coke.

Relative density determinations indicate the heavy media to be used in coal preparation. Other important physical properties are hardness, abrasion index and particle size.

As a generalisation, the range of properties necessary in a coking coal are much more tightly constrained than those required for a steam coal. Power generation plant can be designed specifically to burn a particular type of coal (including peat) but the same degree of flexibility is not found in blast furnace design.

A number of coal classification schemes that relate to use, rather than science, have been devised in different countries. In general most are based on coal rank, often expressed as content of volatiles, sub-classified by calorific value, ash content, sulphur content and other variables. The scheme used by the British industry, pre-privatisation, runs from class 100 (anthracite) with volatile content to nine per cent or less, to classes 400–900 (high-volatile bituminous coals), with volatile content generally above 32 per cent. Lignite is not included. Other major schemes are those of the American Society for Testing and Materials (ASTM) (http://www.astm.org) and the UN Economic Commission for Europe (UNECE) (http://www.unece.org). There are broad similarities between all major schemes.

Uses

Electricity generation

Approximately 26.5 per cent of world primary energy consumption is from coal and power generation is the primary use for coal (World Coal Institute, 2009a). Roughly 41 per cent of electricity, worldwide, is generated from coal (World Coal Institute, 2009a) and this may be considerably higher in many individual countries. In China, for example, 81 per cent of the electricity generated is through coal-fired power stations.

The US Energy Information Administration for 2009, predicts that world electricity generation will increase by 77 per cent from 2006 to 2030 with world net energy generation increasing on average by 2.4 per cent per year within that period. In their models, they project that coal will continue to fuel the biggest proportion of power production, rising to 43 per cent of world electricity supply by 2030 (EIA, 2009). Coal's dominance is ensured by sustained high prices for oil and natural gas making it a more economical option. This is especially true for coal-rich countries such as China, India and the United States. However, international agreements on reducing greenhouse gas emissions could change this predicted outlook (EIA, 2009a).

Steel

Almost two thirds of world steel production is made from iron produced in blast furnaces which use coal, mainly in the form of coke. Coke is made from coking coals, which are characterised by their chemical and physical properties: they are low in sulphur and phosphorus, liquefy when heated in the absence of air and solidify into hard, porous lumps. The lumps of coke are produced by processing coal in a series of coke ovens with oxygen-deficient atmosphere in order to concentrate the carbon. By-products of this process include gas, which may be used as fuel in the plant, and tar and chemicals which may be further processed for sale. The coke has a high energy value and provides the permeability, heat and gases which are required to reduce and melt the iron ore, pellets and sinter consumed in iron making. Another method, less used, is pulverised coal injection, which can utilise a wide range of coals, including the less-expensive steam coal. Most of the balance of world steel production is produced from scrap in electric arc furnaces, and it follows that much of the electricity for this process is produced from coal.

Liquid fuel

Liquid fuels derived from coal are sulphur-free and have low levels of nitrogen oxides and particulate matter. Coal may be converted into liquid fuel (and other products such as waxes, lubricants and chemicals) by two methods: direct liquefaction, where coal is dissolved in solvents at high temperature and pressure; and indirect liquefaction, which gasifies the coal to produce a syngas which is then condensed over a catalyst (the Fischer-Tropsch process). The Fischer-Tropsch process produces a clean, high-quality product whilst the liquid fuel produced through the direct process requires further refining. The process of indirect liquefaction has been known since the 1920s, and in the Second World War, Germany produced significant quantities using this method. Recently, however, this process has been widely publicised in the media through news of developing and potential projects in China and the USA and concerns regarding security of oil supply.

Shenhua Group Corp. is China's biggest coal producer and began China's first plant turning coal into liquid fuels, to augment its output of gasoline and diesel, at the end of 2008. The plant is capable of producing one million metric tonnes of fuel per annum. The Shenhua Group is the only Chinese company authorised to develop coal-to-fuels plants in the country in an effort to conserve coal resources (Bloomberg, 2009).

Sasol operates the world's only commercial, coal-based synfuels manufacturing facility at Secunda in South Africa, producing synthesis gas (syn gas) through coal gasification and natural gas reforming. Sasol has plans to work with India to exploit its coal reserves to boost the domestic supply of liquid fuels. In 2009, the company, in joint-venture with Tata, was awarded long-term access to a portion of the North Arkhapal and Srirampur coal block, an estimated 1.5 billion 'tons' of coal (Sasol, 2009).

Other uses

Coal is used as an energy source in cement production – a process that requires a large amount of energy. The coal consumed in cement production is half the mass of cement produced. Coal may also be gasified to produce a combination of hydrogen and carbon monoxide, which may be used for a range of purposes such as industrial heating, electricity generation and manufacture of chemicals. It is the source of numerous chemicals, as by-products, which are used in soap, pharmaceutical products, solvents, plastics, dyes and synthetic fibres. Coal is used in alumina refineries and in the production of activated carbon, carbon fibre and silicon metal.

World resources and reserves

The term 'resources' represents the quantity of coal present in known deposits, but takes no account of whether they are economic to extract, or technically feasible to recover. By contrast the term 'reserves' represents that part of a coal deposit which is both technically and economically recoverable. Reserves may be either 'proved' (also known as measured) or probable (also known as inferred), with the former estimated to a greater degree of confidence than the latter (World Coal Institute, 2009b).

Worldwide, coal is the most abundant of the fossil fuels, and its reserves are also the most widely distributed. Coal reserves are recoverable in approximately 70 countries, with the USA, Russia, China and India having the largest reserves.

According to the (US) Energy Information Administration 80 per cent of the world's recoverable reserves are located in five regions: the USA (28 per cent), Russia (19 per cent), China (14 per cent), other non-OECD Europe and Eurasia (10 per cent) and Australia/New Zealand (nine per cent). Estimates for total world reserves are in the region of 929 billion tonnes (EIA, 2009b).

However, the World Coal Institute estimates that there are over 847 billion tonnes of proven coal reserves worldwide and that this is sufficient to last for 130 years at current rates of production. Discovery of new reserves, development of new mining techniques and economic factors may extend this timescale (World Coal Institute, 2009b).

Country	2004	2005	2006	2007	2008
China	1960	2205	2373	2536	2622
USA	1009	1026	1055	1030	1066
India	413	437	462	491	527
Russia	282	299	310	314	326
South Africa	243	244	245	248	252
Indonesia	132	153	194	217	225
Germany	208	203	197	202	192
Poland	161	160	156	146	144
Kazakhstan	87	86	96	98	111
Turkey	47	64	64	78	89

Table 1 Total coal production (million tonnes) for top 10 producing countries.
Source: World Mineral Statistics database, BGS

World production

Coal remains the most used fuel for electricity generation in North America and in the most populous countries of Asia. The (US) Energy Information Administration forecasts world coal consumption will almost double in the period 2006-2030 (EIA, 2009b).

In 2008, world coal production was 6619 million tonnes; this is an increase of 204 million tonnes, or three per cent, compared to the previous year. The top 10 producing countries are shown in Table 1 and Figure 6. China continues to be the largest producer with 2622 million tonnes, which is almost 40 per cent of total world

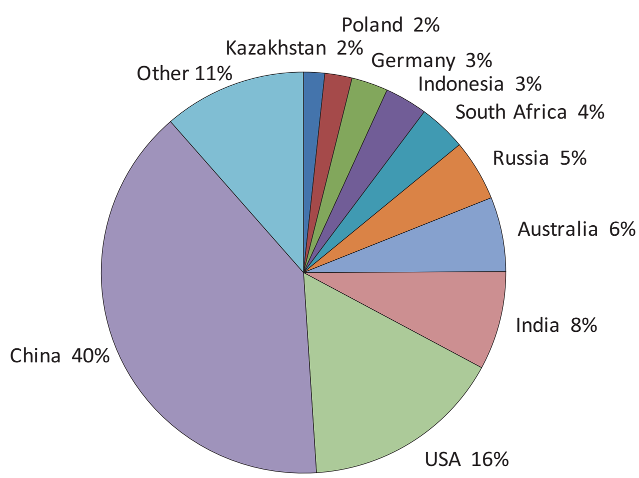

Figure 6 World coal production 2008, all types of coal by country.
Source: World Mineral Statistics database, BGS

Coal

Company	Production (million tonnes)	Main locations
Coal India	404	India (fiscal year 2008-9)
Peabody	255	USA, Australia, Venezuela
Shenhua Group	169	China
Arch Coal	137	USA
Datong Group	122	China
BHP Billiton	116	Australia, Colombia, South Africa, USA
Anglo American	100	Australia, Colombia, South Africa
Siberian Coal Energy	96	Russia
Xstrata	86	Australia, South Africa

Table 2 Selected major coal producing companies in 2008 This table is not comprehensive.
Source: Individual company websites

production. Between 2004 and 2008, China's production increased by 34 per cent, although the rates of increase have reduced over that period. The USA remains the second largest producer of coal with 1066 million tonnes, with India third at 527 million tonnes. These represent 16 per cent and almost 8 per cent of total world coal production respectively (British Geological Survey, 2010).

Coal India, a company wholly owned by the Government of India, was the world's largest producing company, by a large margin in 2009 (Table 2). It is the largest employer in India, with almost 409 thousand people (Coal India, 2010). Peabody, the world's largest private sector coal company, has many operations in the USA, operates ten surface and underground mines in Australia and a subsidiary owns a share of the largest coal mine in Venezuela (Peabody, 2010).

World trade

The main coal-exporting countries are Australia (261 million tonnes), Russia, South Africa, Columbia and China.

The quantity of coal that is traded is relatively small compared to the amount consumed as many of the large

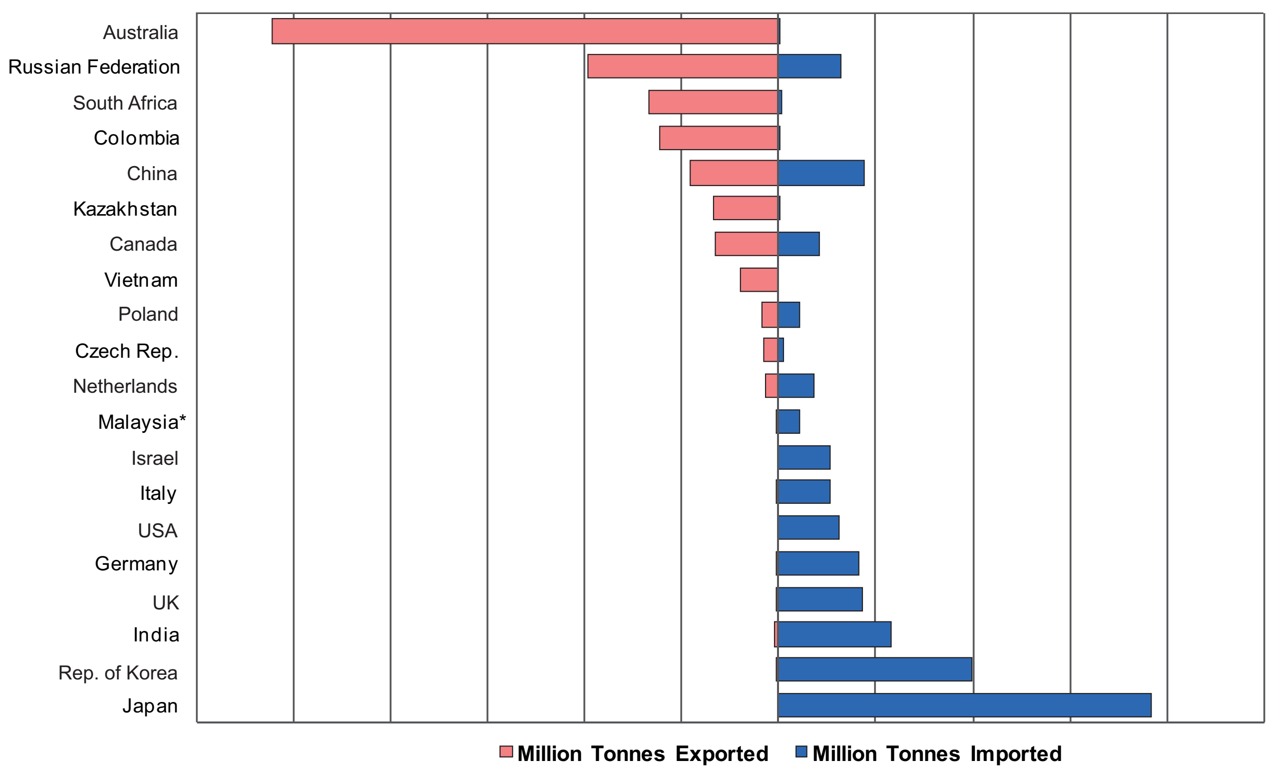

*Figure 7 Major coal importing and exporting countries 2008. *Import data for 2007.*
Source: UN Comtrade database, BGS World Mineral Statistics database.

consumers have indigenous coal resources. The major importing countries in 2008 are Japan (192 million tonnes), Republic of Korea and India. World trade in coal is predominantly hard coal (black coal) and, as a proportion of total coal trade, steam coal accounts for around 72 per cent of the total and coking coal for 28 per cent.

The proportions of steam coal and coking coal within total trade vary sharply from country to country. Among coal exporters, USA and Canada provide chiefly coking coal; while other exporters provide chiefly steam coal. Among importers, the majority import chiefly steam coal but coking coal makes up a high proportion of total coal imports to Japan, Republic of Korea and India.

Prices

The pricing of coal is complex, since the price of a shipment of coal is based on coal type (steam, metallurgical, etc.), net calorific value and content of impurities such as sulphur. Additionally, the cost of transportation comprises a large proportion of the delivered price of coal. A selection of typical prices is shown in Figure 8.

Coal is chiefly sold under long-term contracts that fix the price of coal over the term of the contract, usually with an escalator based on inflation. Also, there is a well-established world spot market for coal that is the source for most quoted spot prices. Some organisations, such as the globalCOAL RB Index, base their price on a basket of different coal-type prices and incorporate bid/offer data. The 'free on board' (F.O.B.) price of steam coal in international trade, in terms of globalCOAL's RB Index, increased from $20 per tonne in July 2001 to $77.56 per tonne in December 2009.

Coal prices are lower and more stable than oil and gas prices, most notably since 1999, and the World Coal Institute predicts that it is likely to remain the most affordable fuel for power generation in many developing and industrialised countries for several decades.

The coal prices dramatically increased in 2008 in response to disruptions of supply at some of the world's most important coal producers. These included China, who suffered some of the heaviest snowfalls in decades, power shortages in South Africa and flooding in Australia (BBC, 2008).

Focus on Britain

Resources

Coal resources in England, Wales and Scotland that have been mined in the past, or are being mined at present and which will be accessible to conventional mining

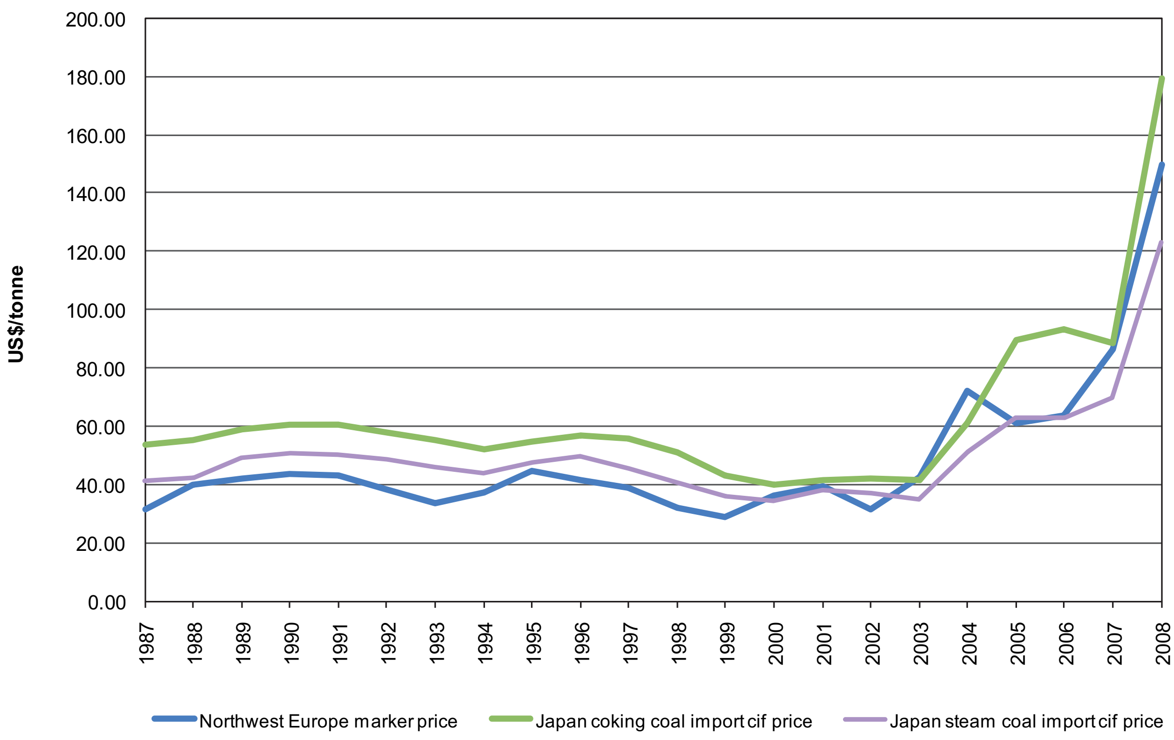

Figure 8 Coal prices 1987 to 2008.
Source: BP Statistical Review of World Energy 2009
Note: cif = cost+insurance+freight (average prices); fob = free on board.

techniques in the future are almost exclusively of Upper Carboniferous age (300–330 million years old) and are commonly known as the Coal Measures in England and Wales. Resources of coalbed methane (CBM) that may be developed in the future are also contained exclusively in Carboniferous coals.

In Northern Ireland there are extensive deposits of lignite. A considerable amount of data on these deposits has been compiled in recent years and as a consequence the Department of Enterprise, Trade and Investment for Northern Ireland has suspended the issue of further prospecting licences. This situation will be reviewed in three years (DETI, 2010).

Hard coals of Upper Carboniferous age occur in discrete areas (coalfields) that tend to be on the flanks of upland regions in England and North Wales, are confined to the Midland Valley in Scotland and underlie a dissected plateau in South Wales. Anthracite occurs only in the western part of the South Wales Coalfield. Of the coalfields that have been worked, only that in Kent is completely concealed by younger rocks. The English coalfields extend below the land surface to 5000 m below sea level (concealed coalfields) and also extend far into the offshore basins on the UK continental shelf, particularly in the southern North Sea.

Hard coals and lignites of Mesozoic ages also occur under the continental shelf and to a limited extent onshore. Coal deposits of Upper and Middle Jurassic age (140–180 million years old) are widespread in the North Sea, the Cleveland Basin, the Moray Firth and the East and West Shetland Basins and occur to a limited extent onshore. Local use has been made of the Jurassic deposits near Brora, on the Moray Firth. Coals in Wealden sediments (early Cretaceous, 120–140 million years old) occur particularly in the English Channel Basin and in basins in the Celtic Sea and St. George's Channel.

Lignites of Palaeocene to Miocene age (5–65 million years old) are prominent in the northern North Sea, where individual seams may be up to 30 metres thick, and also occur to the west of Shetland. Eocene-Oligocene lignites (25–55 million years old) also occur in basins in the St. George's Channel, South Celtic Sea and English Channel. Potentially important onshore deposits occur around Lough Neagh in Northern Ireland and there are minor deposits in the Bovey Tracey and Petrockstowe basins in Devon.

Detailed information may be found in the Coal Resources Map of Britain, which was produced in 1999 jointly by the Coal Authority and the British Geological Survey (http://www.bgs.ac.uk/mineralsuk/mines/coal/home.html) and which is also available on CD-ROM.

Coal-related resources of other minerals comprise deposits of fireclay and secondary aggregates from coal mine waste tips. Fireclays (sedimentary mudstones) were formerly important as refractory raw materials but are now chiefly used for facing bricks and pavers. They only occur in close association with coal seams; their resources are thus essentially coincident with shallow coal resources and their production is highly dependent on the future of opencast coal mining. However, only 20 per cent of opencast coal operations actually recover fireclay and there is a danger that fireclay resources are being irrevocably lost where they are discarded as waste rather than being stockpiled. Coal waste tips are now frequently reworked both to recover coal and secondary aggregates, and to effect environmental improvements in local regeneration schemes.

Reserves

Reserves are that part of a resource that are economically viable and that may be legally extracted at the time of determination. Normally, in any one mine new reserves are delineated and proved as existing reserves are used up; some UK coal mines had productive lives of more than a hundred years. The end of a mine's life is the point at which it is no longer economic to extract coal, even though it may remain available to be mined.

The Coal Authority (see below) stated in its 2008-09 annual report that, in March 2009, there were 125 million tonnes of licensed coal at licensed operating underground mines. Underground mining usually extracts just above 50 per cent of the total volume of available coal. Available coal in licensed opencast operations was 42 million tonnes. Opencast mining often recovers nearly 100 per cent of available coal. A further 293 million tonnes of licensed reserves was located in closed operations and 133 million tonnes had conditional licences.

Structure of the industry

The UK coal industry was, with minor exceptions, nationalised in 1947. It passed back into private ownership in 1994. The principal coal producer is *UK Coal plc*, which accounts for about 44 per cent of total GB coal output and operates the four large deep mines producing in England, together with four English surface mine sites working in March 2009. *H J Banks & Co Ltd, Holgate Aggregates Ltd* and Shires Developments Ltd are the other surface mine operators in England. Other underground mines in England are operated by *Eckington Colliery Partnerships, J Flack Ltd, Maltby Colliery Ltd, Powerfuel Mining Ltd* and a number of individuals.

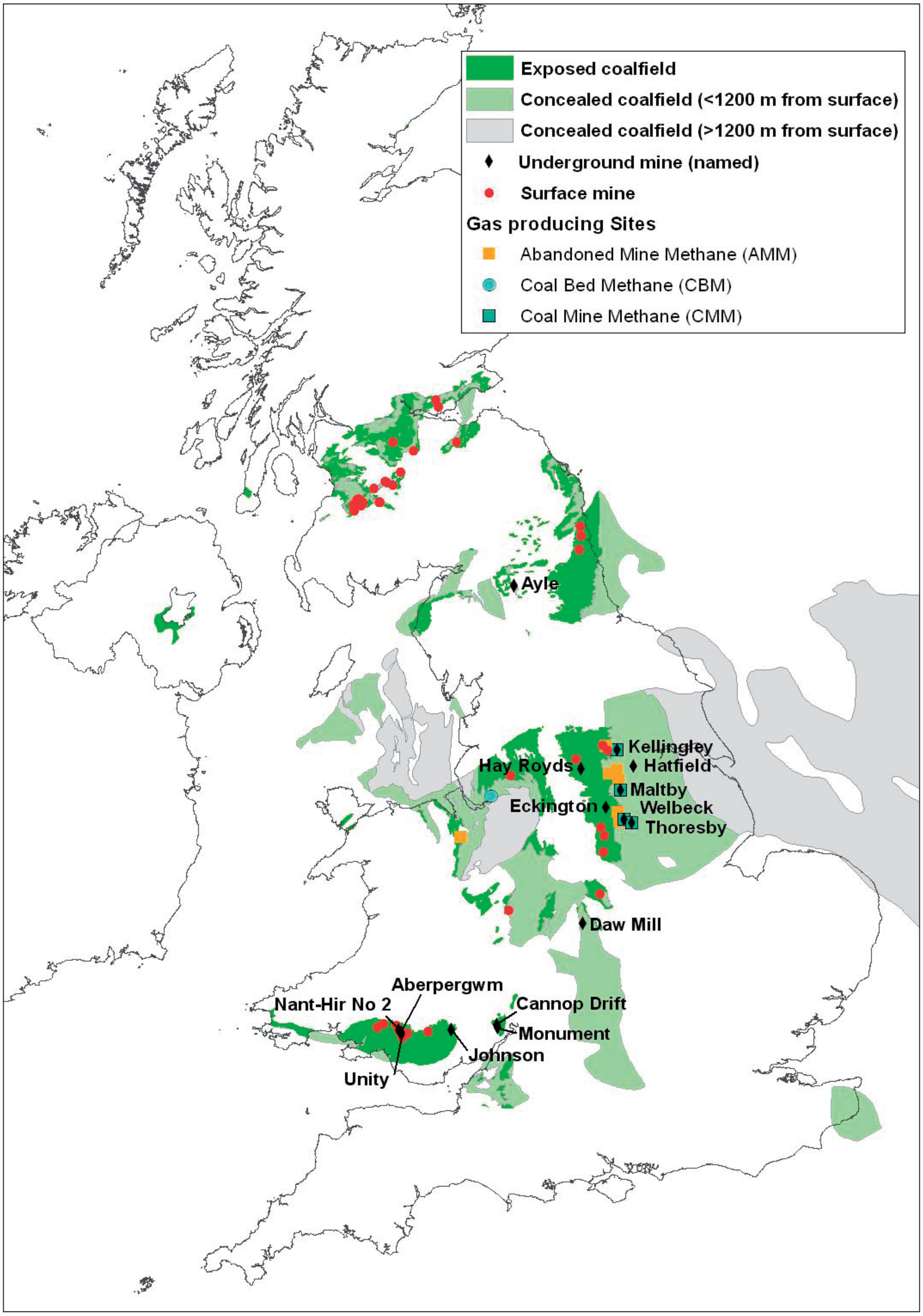

Figure 9 ***Distribution of coal resources in the UK, including producing and developing mines (March 2010).***
Source: BGS and the Coal Authority. OS topography © Crown Copyright. All rights reserved. 100017897/2010

In Scotland, no underground mines remain. One company, *Scottish Coal Company Ltd*, operates twelve of the 19 surface mine sites working in March 2009. Other Scottish sites are operated by *ATH Resources, Kier Minerals Ltd* and *Hall Construction Services Ltd*.

In Wales, there are three collieries, operated by *Blaentillery Mining Partnership, Energy Mining Ltd* and *N H Colliery Ltd*. Three other mines are in development. There were six surface mine sites operating in March 2009, of which three are operated by Celtic Energy Ltd. The others are run by Bryn Bach Coal Ltd, *EnergyBuild Ltd* and *Miller Argent (South Wales Ltd)*.

Governmental policy and sponsorship responsibility for the coal industry now lies with the Department of Energy and Climate Change (www.decc.gov.uk). The Coal Authority (www.coal.gov.uk) owns coal mineral assets on behalf of the state and regulates the industry. It was set up and assumed its functions in 1994 as a Non-Departmental Public Body responsible to the Secretary of State for Trade and Industry. Its principal activities are:

- licensing coal mining operations and making available rights in relation to unworked coal;
- settling subsidence damage claims not falling on coal mine operators;
- managing property, and the historical liabilities, arising from ownership of the coal reserves and underground workings, including responsibility for dealing with minewater pollution issues in areas of former coal mining;
- providing access to its archive of coal mining plans and to geological data.

Most of the Authority's geological borehole logs (data) are now lodged with the British Geological Survey (www.bgs.ac.uk).

For coal, as with other minerals, the Mineral Planning Authorities (County Councils, Unitary Authorities and National Parks) are responsible for granting planning permission for developments. The Mines Inspectorate (http://www.hse.gov.uk/mining/) of the Health and Safety Executive (HSE) has responsibility for encouraging and enforcing the effective management of health and safety within the mining industry.

Production

Production of coal in the UK peaked in 1913 at 287 million tonnes. Since 1981 it has fallen steeply from 128 million tonnes to 17.8 million tonnes in 2008-09. In 2001, production was exceeded by imports for the first time. Table 3 shows underground and opencast production by individual country for the last five financial years. Underground production in Scotland ceased in 2002. As shown in the table, the largest contributors to total output are underground production in England (44 per cent) and opencast production in Scotland (33 per cent).

Consumption

In 2008, 36 per cent of the electricity generated in the UK (energy supplied basis) came from coal and this accounted for 83 per cent of coal consumed in the UK. An increase

Table 3 Production of coal (thoudand tonnes)
Source: The Coal Authority, 2009

	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009
ENGLAND					
Underground	11 082	9 759	7 710	7 327	7 887
Opencast	2 720	1 204	1 018	1 811	2 162
Sub total	21 542	10 964	8 729	9 138	10 049
WALES					
Underground	431	558	440	168	125
Opencast	1 426	1 210	1 252	1 082	1 694
Sub total	1 857	1 768	1 691	1 250	1 820
SCOTLAND					
Underground	-	-	-	-	-
Opencast	7 632	7 739	6 143	5 921	5 960
Sub total	7 632	7 739	6 143	5 921	5 960
UNITED KINGDOM	23 291	20 470	16 563	16 310	17 829

Table 4 Consumption of coal by end use 2008 (thousand tonnes)
Source: DECC, 2009
Notes: The term "Transformation" refers to the consumption of coal in the manufacture of other types of fuel or energy; these are separated underneath.
"Energy industry use" refers to coal used during extraction.
"Final consumption" refers to coal used directly as fuel by industry or domestic customers; these are separated underneath.

	2003	2004	2005	2006	2007	2008
Transformation	**60 093**	**57 631**	**59 406**	**65 146**	**60 434**	**55 621**
Electricity generation	52 464	50 444	52 084	57 363	52 558	47 801
Heat generation	622	478	453	457	456	458
Coke manufacture	5 729	5 487	5 564	5 929	5 933	5 875
Blast furnaces	882	865	1039	1 121	1 242	1 170
Patent fuel manufacture	396	327	266	276	245	317
Energy industry use	**6**	**8**	**6**	**4**	**5**	**5**
Final consumption	**2 924**	**2 810**	**2 437**	**2 301**	**2 433**	**2 586**
Iron & steel	-	-	-	-	1	1
Other industries	1 857	1 846	1 791	1 704	1 759	1 872
Domestic	1 043	941	614	561	648	684
Other final users	25	23	32	20	14	14

in gas prices led to coal-fired generation becoming more competitive, and, combined with an upturn in UK steel production, consumption of coal rose.

Towards the end of 2008, however, the worldwide economic slowdown had an effect on coal prices and continued to negatively influence the market value of coal in 2009. Demand for coal fell and production levels followed, compounded by the over-production in 2007 and 2008 which had resulted in excess coal stocks. Furthermore, trade in coke fell because it is used in the production of steel, which was also significantly affected by the global downturn (British Geological Survey, 2010).

Trade

Imports of coal have been rising steadily for the past decade and are three times higher than in the mid 1990s. In 2001, imports exceeded domestic production for the first time, due to a demand level that was higher than expected, and problems at some UK mines. In 2008, UK imports are more than double the indigenous production (see Table 5). The main sources of imports were Russia, Colombia, South Africa, USA and Australia. (DECC, 2009a).

Table 5 UK supply of coal 2008 (thousand tonnes) on a country of origin basis
Source: DECC, 2009
Notes:
"na" = data not available
"–" = zero
"European Union" includes coal from outside the EU routed through the Netherlands.

	Bituminous		Anthracite	Total	% of UK supply
	Steam Coal	Coking Coal			
Total UK Production	na	17 604	na	18 053	28.8
Imports					
Russia	21 193	-	34	21 709	34.6
Columbia	5 294	-	16	5 363	8.6
South Africa	4 249	-	32	4 281	6.8
USA	2 792	1 472	-	4 264	6.8
Australia	699	3 203	-	3 902	6.2
Indonesia	2 162	-	-	2 162	3.5
Canada	-	1 378	-	1 396	2.2
China	-	-	-	108	0.2
European Union	933	-	52	1 149	1.8
Other Countries	59	-	11	208	0.3
Total Imports				44 613	71.2
Total Supply				62 666	

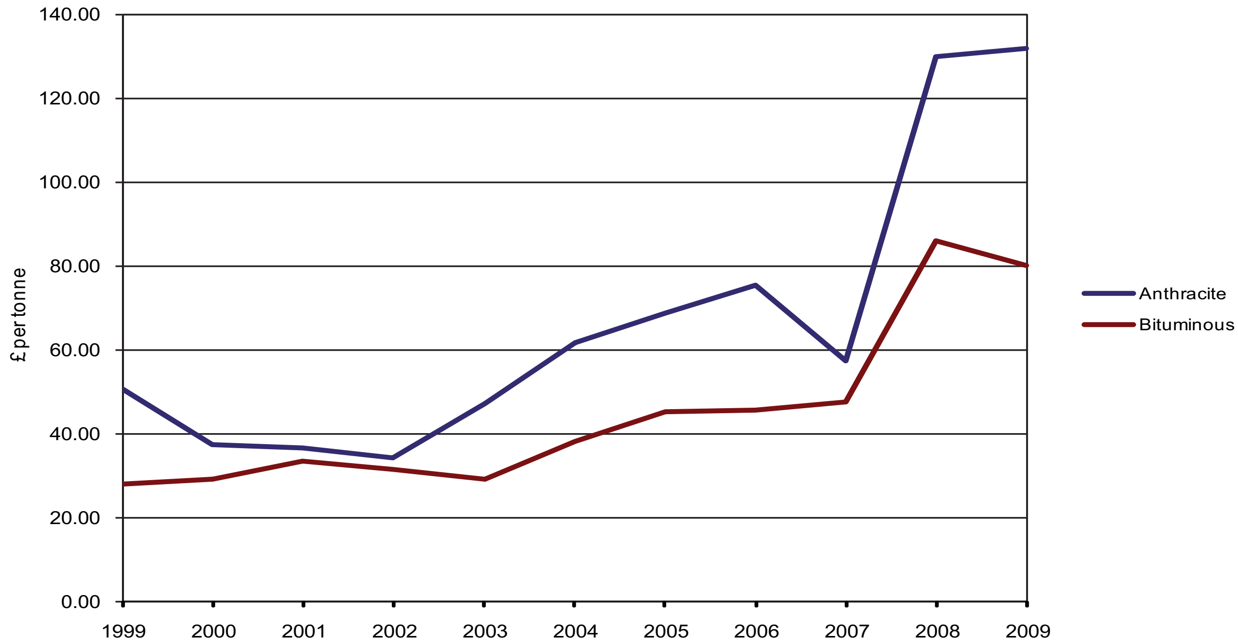

Figure 10 Average import prices for coal in the UK, Jan 1999-Nov 2009.
Source: HM Revenue and Customs, 2010

Prices

Prices for imported bituminous coal are shown in Figure 10.

Coal produced in the UK faces competition from imported coal on the basis of both price and quality. The prices of coal internationally have soared in recent years, in response to increased demand from developing nations such as China, India, Indonesia, Russia and Kazakhstan. In these countries coal is required especially for electricity generation, and in the steel industry which is increasing due to demand for infrastructure and buildings. The economic recession towards the end of 2008 slowed this trend and continued to influence the market value of coal into 2009 (British Geological Survey, 2010).

The trend of substantial increases in the world price of coal since 2005 has meant that domestic producers are now better placed to sell their product in competition with imported coal, taking advantage of lower transportation costs. Coal is also relatively inexpensive compared with other fuels such as oil and gas and so remains competitive.

Issues

Steam coal imports to UK are now much higher than home production and thus electricity generation in the UK is becoming increasingly dependent on imported coal (Table 5). Approximately 75 per cent of imported coal is used in electricity generation (DECC, 2009a).

The review of UK energy policy, 'The Energy Challenge', published in July 2006, proposed action to secure the long-term future of UK coal production and power generation. The Coal Forum was convened as part of this energy review to bring together coal-fired generators, coal producers and suppliers, power plant suppliers, trade unions, small businesses and other parties in order to discuss important issues. The forum will facilitate dialogue within the industry and work to ensure that we have the right framework, consistent with our energy policy goals, to secure the long-term contribution of coal-fired power generation and optimise the use of economical coal reserves in the UK. (DTI, 2006).

The forum has produced reports on security of supply, the Energy Gap, climate change and global warming, the environmental impact of coal use and produces periodic reports on its work (The Coal Forum, 2010).

The issue of security of supply of energy has attracted the attention of the European Commission (EC); it has concluded that the Union's dependence on external energy supplies will rise from 50 per cent in 2000 to 70 per cent of the total by 2030 if trends continue. Following the expiry of the European Coal and Steel Community (ECSC) regulations on 23rd July 2002 the EC's new coal State aid regulation (2002-2010) provided the UK with the flexibility to pay investment aid to mines that were thought to have a viable future. This Investment Aid Scheme was the subject of a consultation exercise, the results of which were considered by the then Department of Trade and Industry (DTI) now the Department of Energy and Climate Change (DECC). This report was completed in December 2002 and as a result UK Coal received £51.8 million to support investment in its remaining seven deep coal mines following the closure of the Selby Complex. A further £6 million was awarded to four other mines in England and Wales. The DTI also commissioned an independent study (IMC Group Consulting Ltd, 2002) of the remaining reserves at existing deep mines to identify where investment support might be best directed.

The most serious environmental objection to the use of coal lies in its potential to produce atmospheric pollution in the form of sulphur dioxide, which causes acid rain, and the greenhouse gases carbon dioxide and nitrogen oxides. Most of the potential sulphur dioxide emissions can be removed by desulphurisation plant integral with the power stations. Sulphur dioxide emissions from UK power stations have reduced by 87 per cent since 1990 largely as result of many coal-fired power stations retro-fitting flue-gas desulphurisation equipment. A useful by-product of this process is synthetic gypsum which can be used in the manufacture of plasterboard and similar products (AEP, 2010).

In the UK the DTI's Cleaner Fossil Fuels Technology programme (formerly the Cleaner Coal Technology Programme) will be replaced by a Carbon Abatement Technologies (CAT) programme. This will run for ten years, with a review after five years, and will cover all fossil fuels, with the aim of lowering carbon dioxide emissions to atmosphere by a variety of strategies, including Carbon Capture and Storage (CCS) technologies (DECC, 2010).

The EU Energy Review, 'Energy for a Changing World', was released early in 2007. It states that coal and gas, together accounting for 50 per cent of the EU's electricity supply, will remain an important part of the energy mix (EU, 2007). The International Energy Agency (www.iea.org) predicts that coal use in power generation will double by 2030, therefore development of clean coal and carbon capture and storage is crucial. The EU plans to establish a favourable regulatory framework for its development, to invest more in research, to incorporate carbon dioxide capture and storage into the EU Emissions Trading System, and to take international action.

Participation in the European Emissions Trading Scheme (ETS) is mandatory for all UK electricity generators who use fossil fuel, including coal. ETS, which came into effect in 2005, aims to reduce the EU's carbon dioxide emissions. Coal is a high carbon fuel and coal-fired stations emit roughly twice the level of carbon dioxide as Combined Cycle Gas Turbines per unit of electricity generated). The price of carbon within the ETS is likely to be a major influence on future demand for coal by UK generators. In addition, the UK Climate Change Act 2008 sets legally binding emission reduction targets for 2020 (reduction of 34 percent in greenhouse gas emissions) and for 2050 (reduction of at least 80 percent in greenhouse gas emissions), and introduces five-yearly carbon budgets to help ensure those targets are met.

The ETS carbon price and UK carbon reduction targets clearly have major implications for the long-term use of coal for electricity generation. Future demand will depend increasingly on the viability of commercial-scale carbon capture and storage (CCS). Although the UK Department of Energy and Climate Change (DECC) has initiated a competition to design and build a commercial-scale post-combustion CCS scheme associated with a coal-fired power plant by 2014, considerable uncertainties remain regarding costs. Future decisions on investment in the development of UK coal resources will have to be made against this regulatory background and, until at least 2014, uncertainties about the commercial viability of CCS.

This commitment is likely to have significant effect on the future usage of coal in the UK by making CCS a commercially viable technology and ensuring that coal can contribute to the low carbon economy.

Serious coal-related pollution in the UK at present is that caused by minewater leaking out of abandoned mines and carrying heavy suspensions of iron oxide in acidic solution. The Environment Agency and Coal Authority have commissioned a study into how groundwater refills in coalfields that are now closed, and to assess the environmental risk that these pose for the future. To date, 53 coal minewater treatment plants in the UK prevent over 1800 tonnes of iron entering water courses.The plants manage over 140 000 cubic metres of minewater each day and have helped to protect over 200 kilometres of rivers and streams (Environment Agency, 2008).

The future of fireclay production in the UK is linked to that of opencast coal mining; fireclay resources are essentially coincident with shallow coal resources and their production is highly dependent on the future of opencast coal mining. However, only 20 per cent of opencast coal operations actually recover fireclay and there is a danger that fireclay resources are being irrevocably lost where they are discarded as waste rather than being stockpiled.

Alternative technologies

Alternative or clean coal technologies reduce the environmental impact of coal by increasing the efficiency of its conversion to energy and by reducing harmful emissions, notably of carbon dioxide and sulphur dioxide.

The DECC (formerly DTI) is supporting a programme of research and development into carbon abatement technologies (The Coal Authority, 2001). Information on this and comprehensive DECC publications on all these topics may be found at The Coal Authorities website: www.coal.gov.uk/

Methane

Methane was, and in some parts of the world still is, notorious as the cause of disastrous explosions in coal mines. However, methane derived from coal is recovered commercially from old mines and from unworked coal seams. Methane and water are the main by-products of the natural process of coalification. Methane is adsorbed on to internal free surfaces in the coal and is also held in the natural fracture system (the cleat) of the coal bed. Through this natural process, theoretical stored methane contents can be up to 34 cubic metres per tonne in saturated anthracitic coal, although in Britain this volume appears to peak at about 20 cubic metres per tonne. The volume of methane generated exceeds the storage capacity of the coal, and excess gas migrates to other reservoirs or is lost to the atmosphere.

Coal Mine Methane (CMM)

After an underground coal mine has been abandoned methane released from the remaining coal accumulates in the voids (the gob) of old workings, diluted with air to the extent of methane concentrations of between 25 per cent and 70 per cent. This can be commercially recovered, as coal mine methane (CMM), when recovered from operating mines or abandoned mine methane (AMM), from abandoned mines.

Coalbed Methane (CBM)

Methane in unworked seams is known as coalbed methane (CBM). Recovery techniques involve entering the coal by boreholes (wells), then using water pressure to fracture the coal by making use of its natural fracture system. The borehole is cased off and the casing is perforated opposite the coal seam. Tubing is inserted inside the casing and the well is pumped to lower the pressure in the coal seam. This causes methane to diffuse through microscopic pores in the coal into the network of fractures and from there into the wellbore. At first it is produced as a mixture of water and methane, which is passed through a separator. The gas is dried and sent for use and the water is sent for treatment, if required, before disposal. In a number of important physical properties the UK CBM resources differ from those in the USA but it is clear that the resource is large and has been

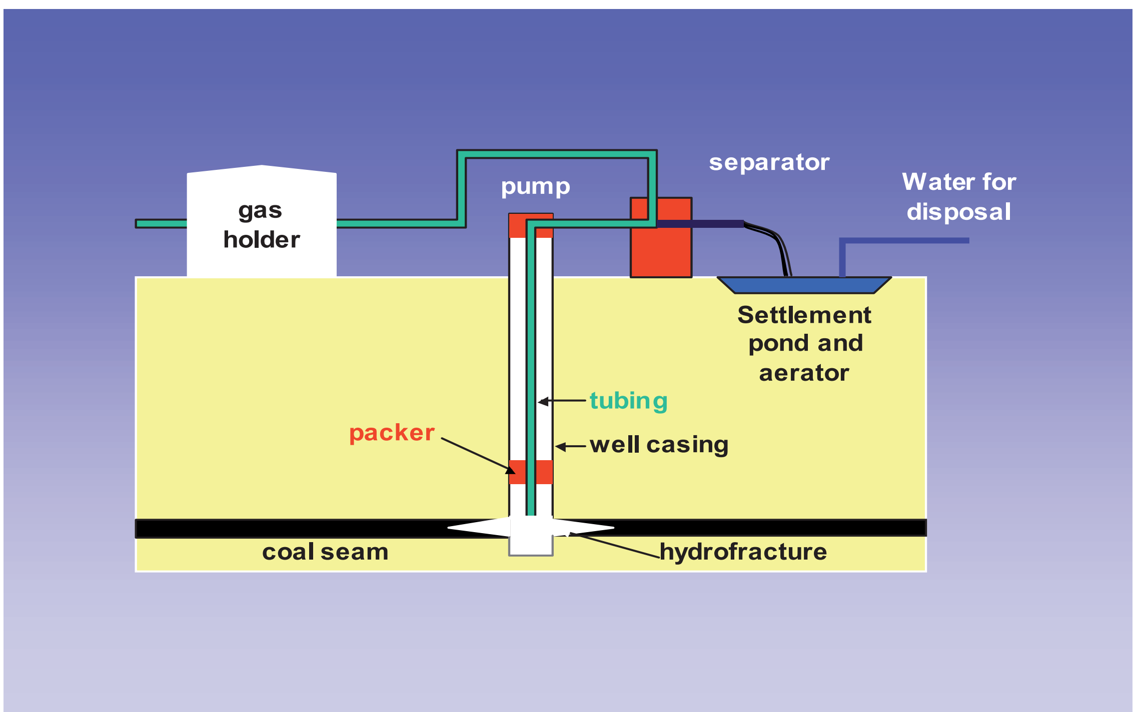

Figure 11 The coalbed methane concept

the subject of a quantitative assessment project undertaken by the BGS. As well as estimating the size of the resource, this project has assessed the resource density.

The first commercial production of coal bed methane, contributing to the national grid has was announced by Island Gas (partner Nexen) in June 2009. Electricity is generated from coal bed methane at their pilot Doe Green site in Cheshire. Wood Mackenzie, in a recent report, estimates that coal bed methane production in the UK could become commercial given current and projected natural gas prices. The same report estimates that the Cheshire Basin has potential reserves of 4 trillion cubic feet (Li, 2009).

Underground Coal Gasification (UCG)

Another prospect for the future is underground coal gasification (UCG). In this process, which is at the development stage, coal is accessed by means of very accurate controlled directional drilling and is then subject to a controlled burn that proceeds towards the recovery borehole, producing a usable gas combustion product. A DTI feasibility study in 2004 concluded that UCG in association with carbon capture and storage has the potential to contribute to the UK's energy requirements. In the light of concerns about energy supply, this method of producing fossil fuels is gaining further popularity. The DTI concluded that the UCG process has potential for UK coal reserves, particularly when considered against the massive offshore coal resource, which may be amenable to UCG. A programme of studies, funded by the DTI, was undertaken to critically assess the commercial feasibility of UCG. A UCG-CCS study under the Firth of Forth in Scotland is hoped to provide insights into processes to unlock the vast coal reserves under the North Sea and lead to the first commercial UGC licence granted in the UK (Underground Coal Gasification, 2009).

Manufactured gas from coal

For approximately 100 years from the middle of the nineteenth century, coal was heated in the presence of steam to make coal gas or town gas. This was the chief source of gas for industrial and domestic consumption. It was almost entirely displaced by the production and supply of natural gas from the 1960s onwards, but it is now being re-assessed and developed with new technology in the light of forecasts of dwindling availability of natural gas. The best-known technology is the Integrated Gasification Combined Cycle (IGCC) system. This has been developed to demonstration stage. It involves the use of synthetic gas in a combination of gas and steam turbines with the exhaust gas from the former then being used in conventional steam turbines. It has the potential to achieve significantly higher efficiencies, with lower environmental pollution, than conventional technology but it is a complex process with high capital costs.

In February 2009, Powerfuels plc were granted consent by the Department for Energy and Climate Change (DECC) for the first large-scale IGCC plant at Hatfield Colliery. The plant, which will be fitted with CCS technology, will be built in two phases: the first phase will be to construct a combined cycle gas turbine (CCGT) facility which will be powered via a natural gas pipeline from the National Transmission System. However, in phase II this plant will be converted to a full IGCC facility using synthetic gas manufactured from the remaining coal resources within the Hatfield colliery. Construction is scheduled to start in 2010 with completion expected in 2015.

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