Coal: resources, reserves and production

For the French, whose last coal mine closed in 2004, the "comeback" of coal as a political issue may seem a bit surprising. Even if coal is still used in domestic industry and to produce electricity, it's many years since it was used as the primary energy source for electricity production. This situation, specific to France and certain European countries, is not at all typical of the world situation: in the face of surging energy demand, coal – whose reserves have been estimated by the World Energy Council to cover 145 years of consumption at the current rate – seems to be an energy of the future and an alternative to oil, natural gas and nuclear power for the production of electricity.

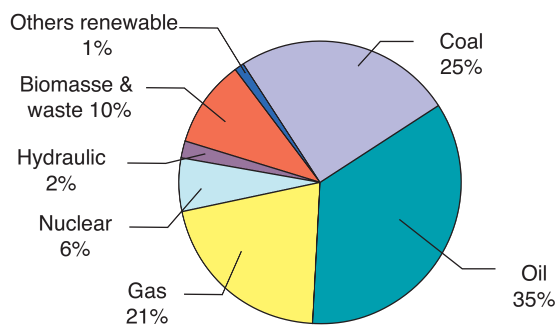
Coal is the fossil fuel that has been longest in use. It drove the first industrial revolution in late 18th century in England and provided the bulk of the energy for the second one at the end of the 19th century. Gradually, its share of world energy supply dropped in favor of oil and natural gas, but it is still the Number Two primary energy in use, oil being Number One and natural gas Number Three. In 2005, coal accounted for one-quarter of world consumption of primary energy.

More than three-quarters of coal demand is from power plants and cement plants, where it is used as fuel. Coal is also vital to the steel industry (it takes 600 kg of coke[1] to make one ton of steel). Coal also gives rise to by-products (the term is "carbochemistry") used in the pharmaceutical industries and chemical industries as dyes industries, plastics and textile fibres, fertilizers, etc. Finally, in some countries, it is used for household consumption (heating, cooking).

Furthermore, new outlets for coal are being developed, such as the production of synthetic fuels — the Coal to Liquids (or CTL — cf. Panorama article), the production of Coal Bed Methane or Coal Mine Methane (CBM and CMM — cf. Panorama article) and the storage of CO_2.

(1) Coke is obtained by distilling coal in the absence of oxygen. It is practically pure carbon. The volatile by-products of coking are also used by the industry.

World primary energy demand in 2005
11.4 Gtoe



Source: AIE WEO 2007

Coal, a complex natural resource...

Coal is stratified sedimentary rock that, after being dried at 110°C, contains at least 50% of organic carbon along with other elements (hydrogen, oxygen, nitrogen, sulfur) and mineral phases constituting the "ash" remaining after combustion of the rock.

Brownish-black to black, it is formed from organic matter that undergoes a series of complex transformations when it is deposited, then buried beneath sedimentary layers. The term "coalification" is used to designate the process that, during burial, produces coals of increasingly high rank: from the peat stage to the anthracite stage, through the stages of lignite and coal.

Most of the coals are formed from higher land plants — they are called humic coals — deposited in swamps or peat bogs. Large coal deposits are composed of this type of organic matter. Another category of coal forms from algal matter generated in an aquatic environment: these are known as sapropelic coals. However, the processes that produce this type of coal do not result into large size deposits. This category represents less than 10% of world reserves.

The oldest humic coals date from the Devonian period, more than 400 million years ago, when appeared vascular cryptograms (e.g. ferns), the first higher land plants. These plants were followed by the Gymnosperms (e.g. conifers) during the Carboniferous period, about 350 million years ago, then by the Angiosperms (flowering plants) at the Cretaceous period, about 140 million years ago. Sapropelic coals can be even older, as some have been found in strata of Cambrian age (540 to 490 million years ago), in Australia for instance. In some cases, like in Siberia, they can be very old: from 1.8 to 3 billion years.

The age of the deposit, which determines plant type, is only one of many factors influencing the final characteristics of coal. The latter result from all of the processes occurring during the deposition and burial of organic matter.

Among the factors that play a key role during the deposition of organic matter, we might mention:

- The climate, which also determines the type of plant and of peat bog;
- The biological and chemical processes involved in plant decay and decomposition, which require the presence of oxygen and micro-organisms in the environment and are regulated by the alkalinity or acidity of the water available;
- The mineral matter absorbed by the plants, whether it was present in the soil, dissolved in the water of the swamp or borne by the wind; these parameters depend on the geographical and hydrological deposit conditions and on the volume of sediments brought to the environment.

These factors determine:

- The regional distribution;
- The architecture, thickness and continuity of coal bodies;
- The type of coal, in terms of the maceral[2] composition and the quantity of mineral matter associated with the organic matter (quartz, argilaceous minerals, pyrite, calcite and siderite);
- The presence of trace elements (e.g. arsenic, cadmium and mercury), their concentration and their vertical and lateral distribution;
- Their petrophysical properties (porosity and permeability).

All of the chemical and physical processes involved in coalification is governed by the increase in temperature and, to a lesser extent, by that in pressure, both constrained by the geodynamic and tectonic conditions characterizing the region concerned throughout its history. In the course of this process, the organic matter gradually loses its water and hydrogen-rich volatile elements, becomes enriched in fixed carbon and generates gases in large quantities, some of which remain trapped within the rock, due to its very low permeability. Long known, these gases are difficult to exploit. A distinction is made between coal bed methane (CBM), which is the total quantity of methane present in the coal, and coal mine methane (CMM), which is the quantity of gas actually extracted from the mine. Miners are all too familiar with mine gas, which represents a fraction of the CBM.

... whose value depends heavily on its characteristics

The use of a coal and its value are determined by its properties:

- Rank (its degree of maturity) is the key parameter used in estimating reserves. Coal is classified as follows, proceeding from the lowest rank to the highest:
  - Lignites present a low calorific value (5.5 to 14.3 MJ/kg) and their use is restricted to the production of electricity. They represent 17% of world reserves;
  - Sub-bituminous coals (8.3 to 25 MJ/kg) and bituminous coals (18.8 to 29.3 MJ/kg), both of which are suitable for electricity production, blast furnace coke and the CtL process. They represent 82% of world reserves;
  - Anthracites have a high calorific value (30 MJ/kg) and are used for household and industrial purposes. They only represent 1% of world reserves.

(2) Macerals are particles of organic matter inherited from the remains of plant parts.

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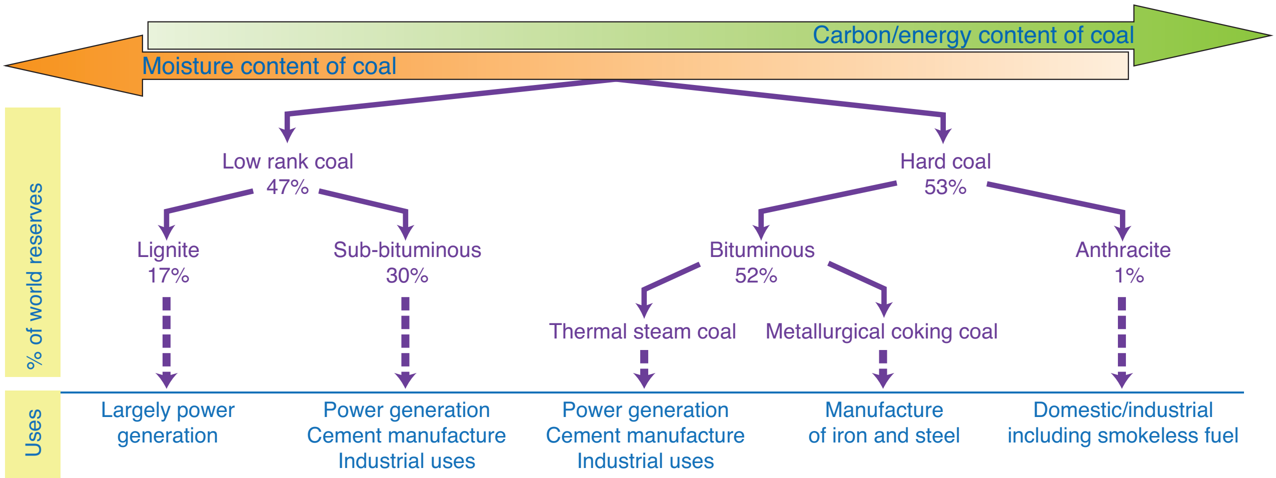
Types of coal



Source: WCI

In the U.S. classification presented here, the lignites and the sub-bituminous coals are referred to as "brown coal" and the bituminous coals and anthracites are known as "hard coal". Other classifications exist, including the German one, whose categories are not exactly the same as in the U.S. system. The energy value of coal can vary within a broad range:

- The ash content and trace elements (type and concentration), directly related to the presence of the mineral phase in the coal, have an impact at industrial level (furnace efficiency, type of boilers, removal processes) and at environmental level (toxicity of gaseous effluents).

  Essential for iron and steel production, coke is made from bituminous coal which has physical properties such that it softens, liquefies and resolidifies into hard but porous lumps when heated in the absence of oxygen. In addition, the coal must have low phosphorous, sulfur and ash contents.
- The petrophysical properties and the maceral composition affect the adsorption and desorption capacity of coal, hence its capacity to produce CBM and to store CO_2;
- The regional distribution as well as coal body architecture, thickness and continuity have a direct impact on operating conditions and the economic value of the deposit, as well as on the estimation of gas volumes and CO_2 storage potential.

In conclusion, even if rank is the parameter that is always used to estimate a country's coal wealth, one should not lose sight of the fact that other characteristics of coal can subsequently affect exploitation, particularly as regards environmental constraints, which have become increasingly prevalent.

Resources and reserves

There are a number of classifications that vary in complexity, i.e. in the level of detail, reflecting the fact that many geological and economic criteria are involved in the decision to exploit a coal deposit or not.

According to the definitions of the World Energy Council (WEC), the term resources corresponds to the volumes of coal still in place at a given time and considered to be technically extractable – meaning coal deposits located at the maximum depths (generally up to 1,800 m) compatible with the technical means of extraction and presenting veins that are sufficiently thick (at least 35 to 80 cm, depending on the type of coal). They may be proved, indicated, or inferred, depending on the degree of uncertainty. Proved resources correspond to coal whose maturity (rank), grade and quantity have been determined based on reliable geological data and supported by measurements and analyses. Indicated and inferred resources include the quantities that may exist in as-yet unexplored extensions of known deposits or in undiscovered deposits in known mining areas, but also quantities estimated on the basis of geological conditions recognized as being favorable.

Reserves are those resources whose exploitation is economically viable at a given date. Proved recoverable reserves (or simply proved reserves) mean those proved resources that can be recovered in future under existing and anticipated local economic conditions, using current technology. To these reserves must be added the "estimated additional" recoverable reserves, which correspond to the volumes in place whose exploitation in future is thought to be reasonable on the basis of available geological and technical data.

Proved recoverable reserves are used to classify countries and construct scenarios for the future. Proved resources, a number that must be taken with a much higher degree of caution, gives one an idea of coal's potential.

Six countries dominate the coal scene

Total world coal resources, all categories combined, may come to more than 1,000 billion tons (Gt) of proved resources, to which one might add 1,770 Gt of estimated additional resources. These resources are abundant, but these figures should be taken with a great deal of caution. According to WEC, the data are incomplete, therefore not necessarily representative of each region.

However, one can give credence to figures published by some of the countries that are also the richest in reserves. The United States possesses the largest resources in the world by far. In early 2006, the WEC member committee from the United States announced proved coal resources in place of 447 Gt (54% of bituminous coal, 37% sub-bituminous coal and 9% lignite), to which one might add 1,100 Gt of estimated additional resources.

Australia is also endowed with non-negligible volumes: 97.3 Gt of proved resources (57% of bituminous and sub-bituminous coal, 43% lignite), not to mention 283 Gt of additional resources.

India reports some 100 Gt of proved resources (96% of which is bituminous coal) and 157.5 Gt of additional resources.

As for the Russian Federation and China, the data are very uncertain. In May 2006, according to information from the Russian ministry of natural resources, proved resources in place were estimated to be 184 Gt and additional resources more than 200 Gt. As for China's estimated resources, the number of 988 Gt was first put forward in 1991 and then again in 2001.

At year-end 2005, proved world coal reserves were estimated to be 847.5 Gt, representing about 145 years of production at the current rate; these reserves are considerably larger than those of oil (40 years) or natural gas (65 years). Compared to other fossil fuels, coal reserves are also more equally distributed across the surface of the earth, because each of the three zones – North America, the Commonwealth of Independent States and Asia/Oceania – holds 27 to 30% of world reserves. The map below compares the geographic distribution of coal, oil and gas.

At year-end 2005, six countries accounted for 82% of world coal reserves: the United States (28.6%), the Russian Federation (18.5%), China (13.5%), Australia (9%), India (6.7%) and South Africa (5.7%). We might also note that Ukraine, Kazakhstan and Serbia hold reserves exceeding 1% of world reserves. About 70 other countries represent, all in all, less than 9%. All of the European countries taken together (including Serbia) only account for 5.2%.

The total of 847.5 Gt can be broken down as follows: 430.9 Gt of anthracite and bituminous coal, 266.8 Gt of sub-bituminous coal and 149.8 Gt of lignite. Both their geographic distribution and the ranking of the six major countries present significant contrasts. The first category (bituminous coal and anthracite reserves) shows the same distribution breakdown as that of coal in the aggregate, but the other two categories do not.

Reserves of sub-bituminous coal are located predominantly in the United States and the Russian Federation which, together, represent 74% of the total, followed by China (13%), Ukraine (6%) and Brazil (3%). With regard to lignite reserves, Germany and Serbia now figure in the top six, which puts Europe in third place behind Australia and the United States for this type of coal.

With 112.3 Gt of bituminous coal, 100 Gt of sub-bituminous coal and 30.4 Gt of lignite, the United States occupies first place for its bituminous and sub-bituminous coal reserves and second place, behind Australia, for lignite. Coal is to be found throughout the country, especially in the west, in the central part of the U.S. (Illinois and western Kentucky) and in the Appalachians.

China ranks second for bituminous and sub-bituminous coal reserves and third for lignite, with a total of 114.5 Gt of recoverable reserves. While there is coal in all parts of the country, three-quarters of domestic recoverable reserves are located in the north and northwest, especially in the provinces of Shanxi, Shaanxi and Inner Mongolia.

Russia possesses 49 Gt of bituminous coal, of which 23% can be mined at the surface and 55% is suitable for coking coal. Three-quarters of the 97.5 Gt of the sub-bituminous coal reserves and 100% of the 10.5 Gt of lignite can be extracted from open-pit mines. Many

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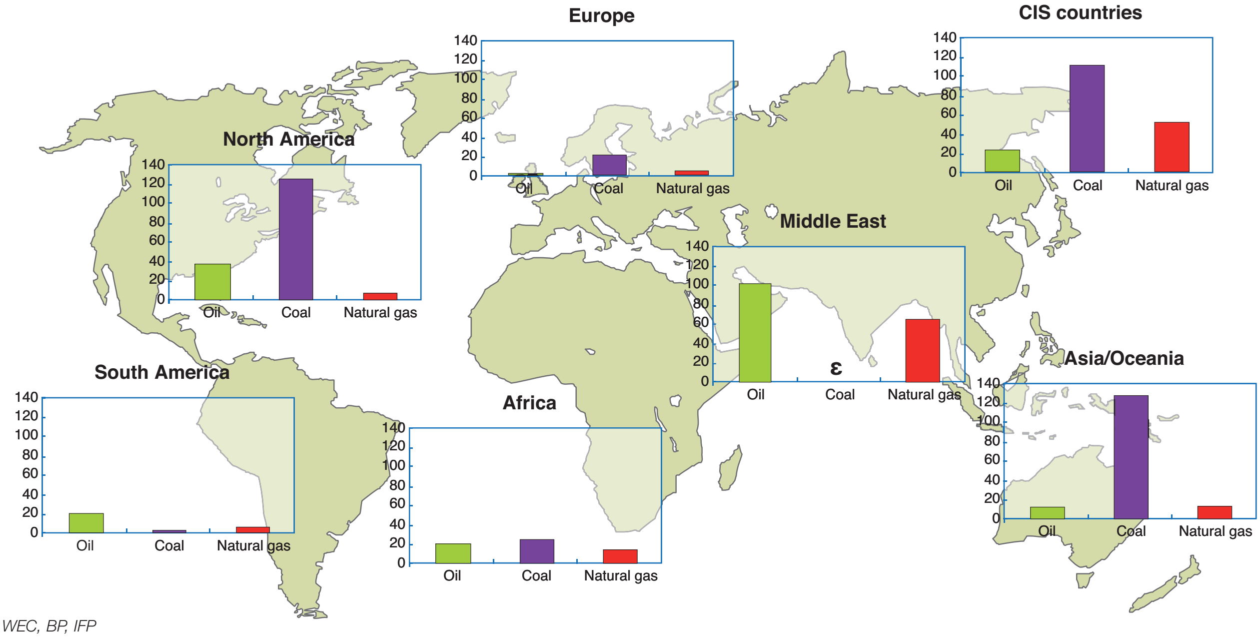
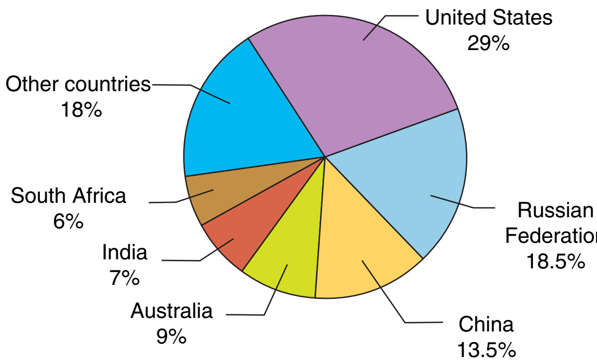
World reserves of fossil energies (Gteo)

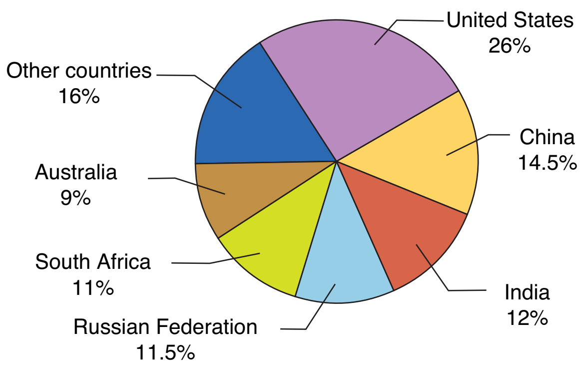


Source : WEC, BP, IFP

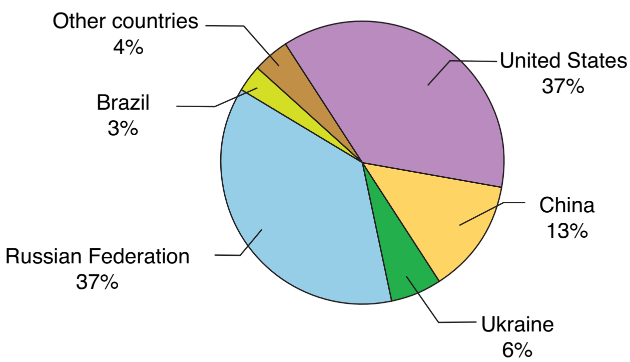
Geographical breakdown of recoverable reserves (year-end 2005)



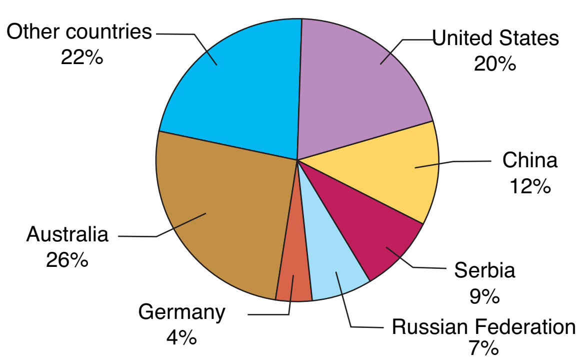
Geographical breakdown of bituminous coal and anthracite reserves



Geographical breakdown of sub-bituminous coal reserves



Geographical breakdown of lignite reserves



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.

Australia comes fourth with bituminous coal reserves (including sub-bituminous coal) totaling 39.2 Gt, mainly located in New South Wales and Queensland, and lignite reserves of about 37.4 Gt exclusively located in the state of Victoria; half of the bituminous coal and all of the lignite reserves could be exploited using open pit mines.

The reserves in India are primarily composed of bituminous coal. With reserves of 52.2 Gt, India ranks third behind the United States and China for this type of coal. The largest deposits are located in the eastern half of the country, where 77% of reserves are to be found. Unfortunately, this coal as well as the lignite (less than 4.3 Gt in reserves), used mainly to produce electricity, are low grade with a high ash content and a low calorific value.

In South Africa, the bulk of reserves is composed of bituminous coals (48 Gt) located mostly in the Transvaal and the north part of the Karoo Basin. The coal is low-sulfur but has a high ash content.

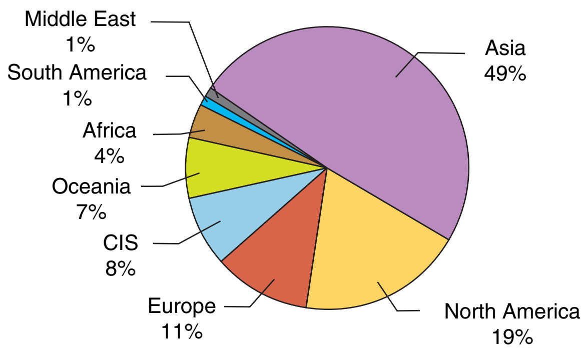
Ukraine contains 16.5 Gt of sub-bituminous coal reserves, Number Four in the world in this category. One should also add about 15 Gt of bituminous coal. The majority of these deposits are located in the Donetz Basin.

Serbia possesses the largest lignite reserves in Europe, 13.5 Gt, which represent 98% of domestic production. All deposits are worked at the surface.

Germany contains large lignite reserves – located in the Rhine region – and until 2002, was Number One in the world with 43 Gt. These reserves were lowered to 6.6 Gt in 2004 by German authorities. Ditto for its hard coal reserves, lowered from 23 to 0.183 Gt in 2004, a drop of 99%. The reason for these decreases is that the coal reserves in subsidized mines were excluded after subsidies were discontinued. Three-quarters of the hard coal is mined in the Ruhr, at depths greater than 900 m.

The countries with the largest reserves are also the biggest producers. According to the World Energy Council (WEC), world coal production stood at 5.9 Gt in 2005. China is by far the top world producer with 37.1% of extracted volumes, and the United States stands second with 17.6%. Next come India, Australia, Russia and South Africa, accounting respectively for 7.3%, 6.4%, 5.1% and 4.2% of production. The top six producers represent three-quarters of world production.

Geographical breakdown of the coal production in 2005
5.9 Gt



Source: WEC+IFP

China and the United States, the top two coal producers, are also the top consumers, representing 37% and 17.5% of world consumption. They are followed by India, Germany, Japan, Russia and South Africa. In 2007, it would seem that China, previously self-sufficient, became a net importer of coal. The United States is self-sufficient while India covers 12% of demand with imports and the figure is rising.

What lies ahead for coal?

At the present rate of production, the 847.5 billion tons of proved coal reserves would cover world coal demand for about 145 years. But the situation varies considerably from country to country. At the current rate of production, Chinese reserves would be depleted in about fifty years; the U.S. could still cover more than 230 years of consumption, India about 130 years, Australia and South Africa about 200 years and the Russian Federation more than 500 years. In Europe, the reserves in Poland and Germany only represent 47 and 33 years of production, respectively.

These forecasts are based on the current figures for proved reserves and levels of production. Two important observations are called for:

- First observation: The figures concerning reserves are open to question. Economic criteria are involved in the idea of reserves. In theory, proved reserves tend to decrease when the coal price goes down, because certain mines are no longer deemed profitable. On the other hand, if the coal price goes up, certain resources can be reclassified as reserves. In fact, this has only happened so far in two countries:

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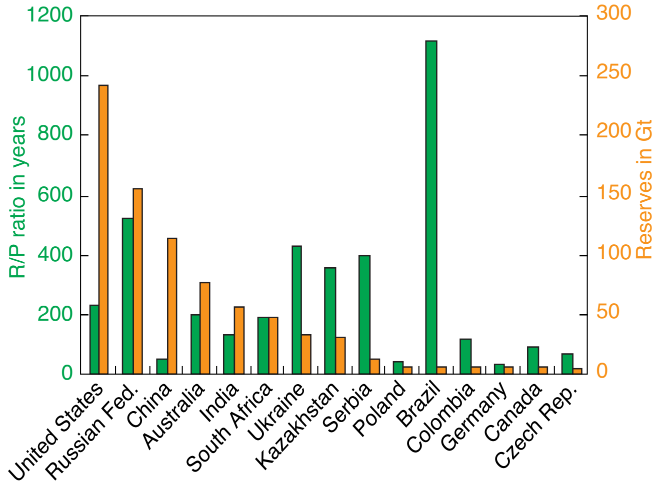
Reserves and Reserves/Production (R/P) ratio for the 15 countries with the most important coal reserves



Source: WEC + IFP

India and Australia, where the reserves of bituminous coal and anthracite were revised upwards by 160% and 30%, respectively, between 1987 and 2005. All other countries individually revised their hard coal reserves downwards, by about 15% worldwide. Sometimes, the adjustment was spectacular such as in Germany, as we have already seen, and Poland. If we consider all coal categories in the aggregate, we find the same overall downtrend: between year-end 2002 and year-end 2005, there was a decrease of 6.8%. This downtrend cannot be attributed to production, whose aggregate value for the same period was low compared to this decrease. Nor can it be attributed, except in specific cases, to a reclassification of reserves to resources because, for an almost identical period (1980-2005), world coal resources were halved.

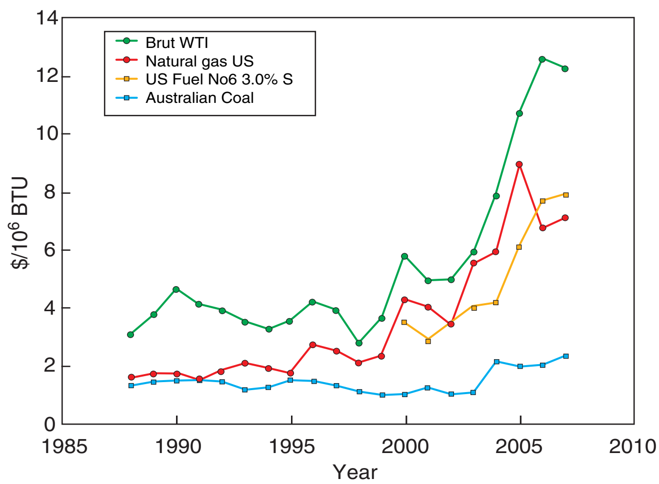
Another problem is that certain figures are not updated. That's true of China: its proved reserves figure has not been revised since 1992, although it has been established that 20% of these reserves have been produced since and that 1 to 2% burned in fires that got out of control. And what is one to make of the information, quoted by the WEC, whereby the reserves in place in mid 2007 amount to about 1,000 Gt in reserves, demonstrated or explored, including all of the degrees of uncertainty between proved and inferred?

Even if one gives credence to the main trends identified here and to country rankings for reserves and resources, these observations throw some doubt on the figures put forward and therefore on coal's longevity in the energy portfolio of the future.

- Second observation: Production is expected to grow. World coal production remained relatively stable in the period 1985-2000, with great disparities in the annual growth rate (ranging from -3.8 to +4.6%), but, since 2003, it has risen at a rate of between 5.2 and 7.7% a year. This is primarily due to high growth in demand from emerging countries such as China and India (cf. Panorama articles *"Coal in India"* and *"Coal in China"*), as well as its low price compared to other fossil fuels that it can replace for specific uses, such as the production of electricity.

  In addition, according to the reference scenario of the International Energy Agency (World Energy Outlook 2007), coal is expected to be the primary energy – not including renewable energies – showing the highest growth in consumption between now and 2030 (+72% from the 2005 level, or 2.2% a year). A trend scenario for the same time frame by the European Commission estimates that coal consumption will increase by about 65%; another, by the US Energy Information Administration of the Department of Energy, foresees a 95% increase. These scenarios indicate that coal consumption would reach between 3.9 and 4.9 Gtoe by 2030 (in 2005, it stood at 2.9 Gtoe).

Fuel prices (per energy unit)



Coal is the primary energy with the highest carbon content, therefore its combustion generates more CO_2 emissions than any other energy. It seems inconceivable that high growth in the use of coal would occur without developing "clean coal" technology to reduce the environmental impact of its use (cf. Panorama article *"Clean coal technologies"*). Alternative policy scenarios have also been developed, based on resolute emissions reduction policies that call for cutting consumption (energy savings) and using energies that emit lower levels of CO_2 emissions. These scenarios see coal demand as growing between now and 2030 at a rate of 1% (EC) to 27% (IEA), in which case consumption in 2030 would be situated between 2.93 and 3.7 Gtoe.

These consumptions in the reference and alternative scenarios represent aggregate consumption of coal between 2005 and 2030 as ranging between 73 and 101 Gtoe, or 18 to 24% of proved reserves in 2005. The response to high demand will therefore probably not be constrained by the volumes of coal reserves, but rather by how far and how fast the extracting industry can boost capacity, especially in the reference scenarios.

Conclusion

Coal is a fossil energy that is:

- Abundant. At the current rate of production, existing reserves could cover 145 years of present consumption. Even if the figures for reserves in some countries must be taken with caution (China, Russia) and production is expected to be rising fast, this is still the mainstream trend;
- Fairly evenly distributed, at any rate, more evenly than for oil and gas. North America, Asia/Oceania and the CIS countries each hold 27 to 30% of existing coal reserves. In this way, coal contributes to the energy independence of major energy-consuming countries like China and the United States;
- Cheaper than other fossil fuels. Between 2003 and 2007, its price has doubled but coal is still nearly five times cheaper than oil and three times cheaper than gas per unit of energy.

Given the current situation – it is difficult for non-producing countries to get access to oil and gas resources, and prices continue to increase – these three characteristics are major assets and explain the recent popularity of an energy that had been thought outdated, as being "from another century".

But coal also is the energy source whose combustion generates the highest levels of CO_2 emissions. CO_2 is known to be a major contributor to global warming, so the use of coal presents a dilemma. It seems inconceivable today that high growth in the use of coal, which is the forecast of many trend scenarios, could occur without completely reviewing how it is consumed.

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