

World coal resources

At a time when the international community must face the key challenges posed by global warming as well as sustainability in general and many of our fellow citizens have come to look unfavorably upon fossil energies, the world is still heavily dependent on these energies to cover growing global energy demand. With proved reserves equivalent to more than 120 years at the present rate of extraction, with a better worldwide geographical distribution than petroleum, coal seems like an especially secure energy. While the renewable energies are showing rapid growth but still only represent a small proportion of the world energy mix, coal was the energy whose consumption grew at the fastest rate and for the sixth consecutive year. This gives cause for concern when one realizes that coal is also the most environmentally harmful energy at local level (its extraction generates pollution) and globally (its combustion emits CO₂). So how is it possible to reconcile the apparently irreconcilable, especially when, in some countries, coal represents the bulk of the energy resources? Since it is impossible to do without coal, the solution is to develop new “clean coal” technologies, among which the capture and storage of CO₂ looks like a promising pathway. In the process, it will be necessary to overcome major technical, economic and social challenges.

Mankind has been using coal longer than any other fossil fuel. Today, it is the world's Number Two source of primary energy with 27% of demand (Figure 1). According to the baseline scenario used by the IEA in its World Energy Outlook 2009, the consumption of coal is expected to rise by 1.9% per year between now and 2030, by which time it should account for 29% of global primary energy requirements. This may seem paradoxical in light of current efforts to reduce greenhouse gas emissions, knowing that the combustion of coal emits 1.3 times more CO₂ than oil and 1.7 times more than gas.

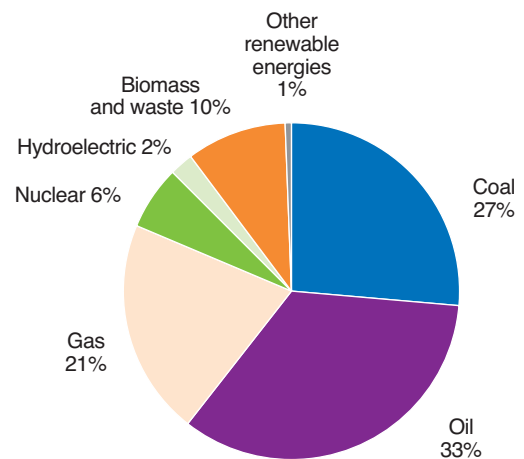
Three-quarters of all coal produced is used to fuel power or cement plants. It is also vital in the steel industry, because it enters into the composition of steel. In addition, coal has found new outlets such as the production of synthetic fuels using Coal to Liquids (CTL) and Coal Bed Methane (CBM) technologies.

A few important reminders

Coal is a complex natural resource, formed from organic matter that undergoes a series of complex

transformations when it is deposited, then buried beneath sedimentary layers. This is known as coalification. A great many factors are involved in these two stages and have a direct impact on the intrinsic characteristics of the coal and on the characteristics of the

Fig. 1 - World primary energy demand, in 2007 (12 Gtoe)



Source: IEA/WEO 2009

World coal resources

deposits (e.g. the architecture, thickness and continuity of coal-bearing layers) and therefore on their economic value. For more information, see the Panorama 2008 article that explores these matters in greater detail.

Among all of the parameters available to describe coal, the “rank” of the coal (its maturity) is always taken into consideration when evaluating the coal wealth of a country (Figure 2). Coal is categorized as follows, proceeding from the lowest rank to the highest:

- lignites, which have low calorific values (between 5.5 and 14.3 MJ/kg). Their use is restricted to the production of electricity. Lignites represent 17% of world reserves,
- subbituminous coals (8.3 to 25 MJ/kg) and bituminous coals (18.8 to 29.3 MJ/kg). Both subbituminous and bituminous coals are suitable for producing electricity and blast furnace coke, as well as for the CTL process. They represent 82% of world reserves,
- anthracites, which have a higher calorific value (30 MJ/kg), are used for residential and industrial purposes and only represent 1% of world reserves.

Although the value of a coal depends primarily on its rank, one should not lose sight of the fact that other characteristics have an impact on its utilization, such as ash content, the presence of sulfur or that of trace elements.

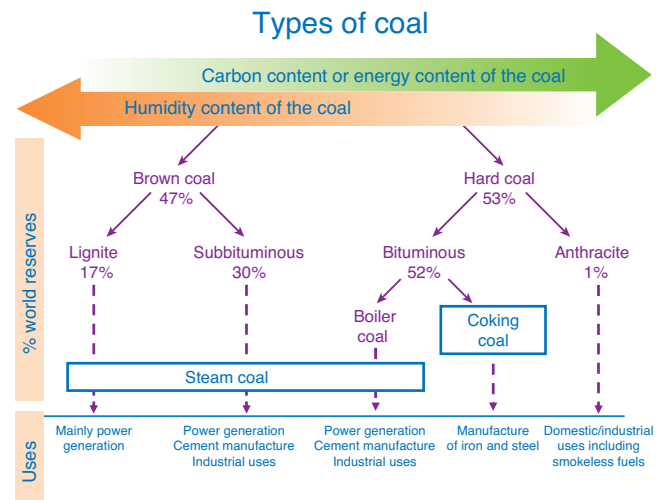
Resources and reserves: questionable data

According to the definitions of the World Energy Council (WEC), resources correspond to the volumes of coal that are still in place at a given time and considered to be technically extractable. Resources can be “proved,” “indicated” or “inferred” depending on the degree of uncertainty.

Reserves are the part of resources that are economically minable at a given date. Proved reserves designate proved resources that can be recovered in future under the present and anticipated economic conditions, using existing technologies. To these one should add “estimated additional reserves,” i.e. the volumes in place for which future exploitation can be reasonably expected, based on the geological and technical information available.

Obviously, forecast scenarios must be constructed using data concerning resources and reserves. However, even the WEC says that the quality of data is uneven, depending on the country. Sometimes, no data at all are available. This is especially true of resources. A particularly high degree of uncertainty characterizes data for some key countries, like the Russian Federation and China.

Fig. 2 - Different types of coal and how they are used



Source: IFP, based on World Coal Institute

For instance, China is Number Three for coal resources and possesses the largest coal market in the world. The WEC figure for China is the same as in 1991; curiously, it was not included in the last survey available to date, which was the survey made at year-end 2005 and published in 2007. For recoverable reserves, the situation is less critical in that data are available for more than 70 countries. Although one can consider the statistics put forward for some key coal-producing countries (e.g. the United States, Australia and India) to be reliable, caution should be exercised in some cases:

- when figures are not updated. In China, the figure for reserves is the same as in 1992, although it has been established that 20% of the reserves have been produced and 1 or 2% burned in fires that got out of control,
- when a sharp variation occurs. For instance, South Africa lost more than 37% of its reserves between year-end 2005 (WEC and BP data) and year-end 2008 (BP). The volume extracted during this interval (2.9 billion tons) does not suffice to explain this variation. There is no information to show that “reserves were reclassified as resources”. Indeed, the concept of reserves incorporates economic criteria, such as the price of coal (which is affected by the market and therefore variable by nature) or whether subsidies are implemented or discontinued (Germany is a case in point). When figures vary from one year to the next, it is not always due to the volume produced and it is not always easy to determine the cause.

Since the latest WEC survey will not be published until 2010, we took our figures for world reserves at year-end 2008 from the BP Statistical Review of World Energy June 2009.

World coal resources

Coal reserves are fairly evenly distributed worldwide, but with a few dominant countries

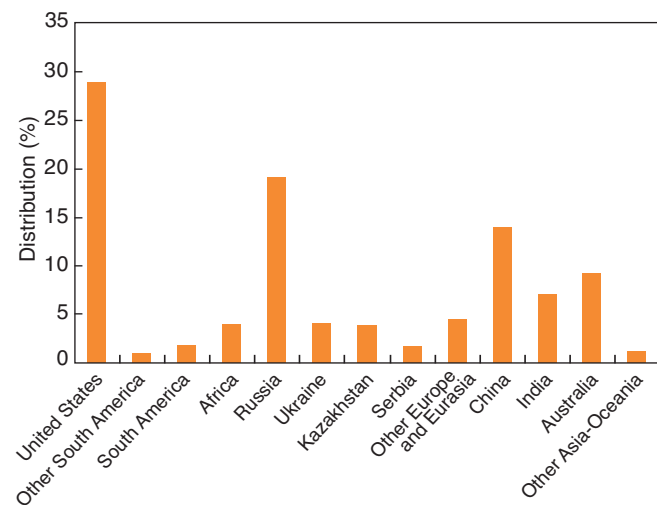
Proved coal reserves at year-end 2008 stood at an estimated 826 billion tons (Gt), representing about 122 years of production at the current rate. These numbers should be compared with the estimates published at year-end 2005: 847.5 Gt and 145 years. The data available do not provide an explanation for this decline of more than 21 Gt.

Coal is the most broadly distributed energy in the world. According to WEC survey data for about 70 countries, world reserves are concentrated in thirds. One-third is located in North America (29%), dominated by the United States; one-third in Eurasia (34%), dominated by Russia to which one can add Ukraine, Kazakhstan and Serbia; and one-third in Asia-Oceania (31%), where the reserves in China alone are equal to the sum of the reserves in India and Australia. Africa represents less than 5% of the total, with the bulk of the coal wealth to be found in South Africa. South America holds only 2% of world reserves (Figure 3).

Five of the nine countries mentioned represent 78% of total reserves: the United States (28.9%), Russia (19%), China (13.9%), Australia (9.2%) and India (7.1%). South Africa (3.7%) now ranks behind Ukraine (4.1%) and Kazakhstan (3.8%) but ahead of Serbia (1.7%). The other sixty countries account for less than 10% of the total. Europe, including Serbia, contains only 5.1% of world reserves.

The total of 826 billion tons (Gt) breaks down into 411 Gt of hard coal (anthracite and bituminous coal) and 415 Gt

Fig. 3 - World distribution of recoverable coal reserves, year-end 2008

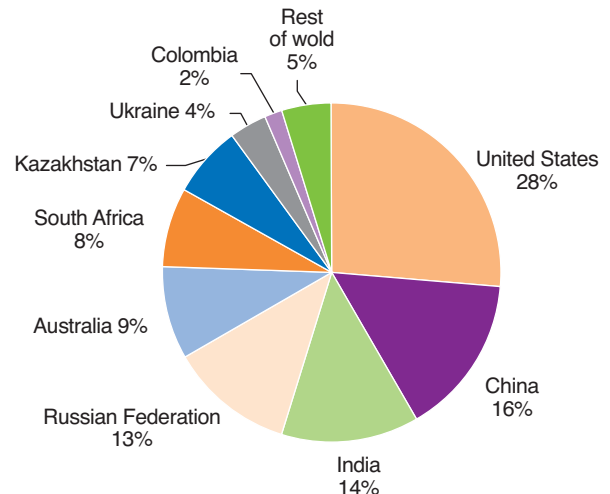


Source: BP Statistical Review 2009

of brown coal (subbituminous coal and lignite). With this subdivision, the geographic distribution and country rankings change, mainly for brown coal. Lignite-rich Germany as well as Brazil, with its abundance of subbituminous coal, outrank South Africa and Kazakhstan, which have little or no brown coal (Figures 4 and 5). According to the statistics published at year-end 2005 (but not available at year-end 2008), Europe ranked third for lignite, after Australia and the United States.

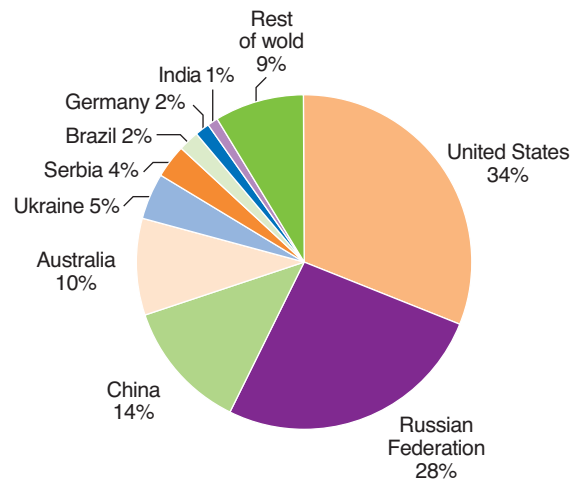
In North America, 98% of the reserves are located in the United States, by far the most coal-rich country in the world. At year-end 2005, its proved resources stood at an estimated 447 billion tons (Gt): bituminous coal (54%), subbituminous coal (37%) and lignite (9%), to

Fig. 4 - Geographic breakdown of recoverable reserves of hard coal, year-end 2008



Source: BP Statistical Review 2009

Fig. 5 - Geographic breakdown of recoverable reserves of brown coal, year-end 2008



Source: BP Statistical Review 2009

World coal resources

which one might add large additional resources exceeding an estimated 1,100 Gt. Its total reserves at year-end 2008 stood at 238 Gt, down by 4.5 Gt compared to year-end 2005 due to production. Coal is broadly distributed throughout the country: in the northwest in the Fort Union area (lignite), in the Rockies (mostly subbituminous), in the central states of Illinois, Iowa and eastern Kansas (mostly bituminous) and in the Appalachian Mountains (bituminous and anthracite).

Canada contains 0.8% of world reserves, which are concentrated in the west in the provinces of Alberta and (southwestern) Saskatchewan and in the Yukon Territory. They consist in nearly equal parts of bituminous coal, subbituminous coal and lignite.

With reserves of 108 billion tons (Gt) of brown coal and 49 Gt of hard coal, Russia ranks respectively second behind the US and fourth behind the US, China and India. Its proved resources may amount to 184 Gt and its additional resources 200 Gt, but the data are attended by great uncertainty. Nearly one-quarter of the bituminous coal can be surface mined and 55% is coking coal. The bulk of the subbituminous coal and lignite is suitable for open-pit mining. In 2003, the country numbered 92 underground mines and 119 open-pit mines. Many basins contain coal: the Moscow, Donetz and Pechora Basins in the European part of Russia; the Kuznetsk and Kansk-Achinsk Basins in western Siberia; and the Lena and Tunguska Basins in eastern Siberia. The Kuznetsk Basin alone holds the majority of proved reserves and represents more than half of Russian production.

Ukraine possesses 18.5 billion tons (Gt) of reserves containing subbituminous coal and lignite, fifth in the world for this type of coal. It also possesses some 15.5 Gt of bituminous coal. Most of the deposits are located in the Donetz Basin in the eastern part of the country. Ukraine totals about 200 mines whose operations are affected by structural problems: until 2004, Ukraine reported the highest accident rate of any country except China. The fact that electricity production is relying on natural gas to an increasing extent has caused many mines to close.

Kazakhstan contains the largest reserves in Central Asia with 31.3 billion tons (Gt) of which 90% consist of bituminous coals and anthracite. More than 90% of national electricity is produced from coal.

Europe only represents 5% of world reserves with, in order of decreasing importance: Serbia (13.9 Gt in 2005), Poland (7.5 Gt), Germany (6.7 Gt), Czech Republic (4.5 Gt), Greece (3.9 Gt) Hungary (3.3 Gt) and Bulgaria (2 Gt). The reserves in Serbia are composed of 99% lignite, the largest in Europe. All of the deposits are

surface mined. The lignite is mainly used to produce electricity. Germany, too, possesses large reserves of lignite and ranked first in the world until 2002 with 43 billion tons. But when it discontinued state subsidies, profitability fell below the breakeven point at most of the mines in the country and reserves were revised sharply down: -85% for lignite and -99% for hard coal. Poland stands second in Europe for reserves (6 Gt of hard coal and 1.5 Gt of lignite), and is the only European exporter. Coal represents 93% of the primary energy produced and 70% of consumption.

The African coal-producing countries are dominated by South Africa, whose resources total 110 Gt. According to some estimates, national reserves have fallen from 48 Gt in 2005 to 30 Gt at year-end 2008. They consist of bituminous coal that is sulfur-poor but presents a high ash content. Most of the 70 mines, 44 of which are underground, are located in the Transvaal and the northern part of the Karoo Basin. Three mines account for 70% of the reserves. Coal represents 88% of national primary energy consumption and is used to produce 90% of the electricity. It is also the raw material that covers nearly one-third of liquid motor fuel requirements *via* the CTL process. While the use of coal is expected to keep increasing over the next few years, the uncertainty that, according to the South African Department of Minerals and Energy, surrounds the volumes of economically extractable reserves, raises doubt as to whether the economy can long continue to depend massively on coal without taking into consideration the environmental problems posed by its use.

Asia is dominated by two "giants": China and India. China ranks second for its bituminous coal reserves and third for its subbituminous coal and lignite reserves, with recoverable reserves totaling 114.5 billion tons. In 2003, the number of mines came to an estimated 23,700. All parts of the country are endowed with coal deposits, but 83% of high-grade reserves are to be found in the north and northwest, especially in the provinces of Shanxi and Shaanxi and in Inner Mongolia. On the other hand, reserves are relatively rare in the southeastern provinces, which are major consumers.

The reserves in India (54 billion tons), mostly bituminous coal, put the country in third place behind the United States and China for this type of resource. There are also 4.6 Gt of lignite. Revised up again since January 2007, proved resources stood at nearly 102 Gt of bituminous coal on April 2008, to which one can add 124 Gt of indicated resources and 34.5 Gt of inferred resources. These values cover deposits located to a depth of up to 1,200 m. Two-thirds of the mines are underground, one-third are surface mines. The eastern half of the country

World coal resources

holds 77% of the bituminous coal reserves. The bituminous coal and lignite are of mediocre quality (high ash content and low calorific value), which means that India cannot export its coal but must import this raw material in growing quantities.

Indonesia also possesses substantial proved resources which, according to estimates, come to nearly 12.5 Gt. This includes 4.3 Gt of recoverable reserves (40% subbituminous coal, 32% lignite and 28% bituminous coal). In general, Indonesian coal offers a medium calorific value (21-29 MJ/kg) and is high in volatile matter and low in both sulfur and ash, which makes it one of the cleanest coals in the world.

The last powerhouse is Australia, sitting in fourth position (9.2%). Its reserves (39.2 Gt) of bituminous and subbituminous coals are located mostly in New South Wales (42%) and Queensland (53%). It also has lignite reserves (37.4 Gt) located exclusively in the state of Victoria. National resources have been estimated at 97.3 Gt to which one might add 283 Gt of additional resources. Half of the bituminous coal and all of the lignite reserves can be surface mined. The coal is of excellent quality, with a high calorific value and low levels of sulfur, ash and other impurities.

Asia: the largest theater of operations for the coal industry

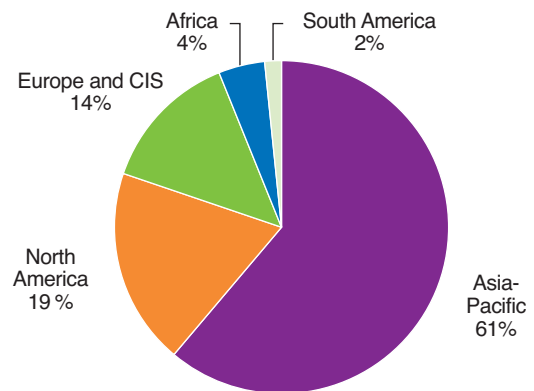
Asia-Pacific, Number One producer

In 2008, world coal production totaled 6.8 billion tons (Gt), up steadily since 2000. China was the Number One producer by far with 42% of extracted volumes. The United States came in second with 18% of world output, followed by Australia (6.6%), India (5.8%), Russia (4.6%), Indonesia (4.2%) and South Africa (4.2%). The top seven producers accounted for 85% of world production (Figure 6).

In the first half of 2009, the key market players responded to lower demand by scaling back coal production and postponing many projects to boost capacity (especially Australia and Russia). China also restructured its coal mining acreage by closing the smallest extraction sites, which reduced production capacity.

Regarding the mining companies, coal mining production was dominated by large, highly diversified international conglomerates such as BHP Billiton, Rio Tinto, Vale Do Rio Doce, China Shenhua, Anglo American and Xtrata. These companies produce other mineral commodities in addition to coal, such as precious and base metals, including iron. Their control over the production of both

Fig. 6 - World coal production, in 2008 (6.8 Gt)



Source: BP Statistical Review 2009

coal and iron gives them power over the steel-making industry.

Australia and Indonesia, top exporters

Australia represents 28% of the international coking coal trade. It exports mainly to Asia, supplying nearly 70% of Asian coking coal imports. This dominance is likely to last: Australia is developing its internal transport and port infrastructure (e.g. at Koorangana Island and Dalrymple Bay) to augment export capacity. The country possesses abundant reserves of good quality that can be extracted at relatively low cost.

Indonesia dominates the steam coal export market. It will have to make a major effort to keep exporting at this level, especially as regards infrastructure and internal transport costs. The country will also have to show that it can attract foreign capital to stimulate domestic exploration and develop new mines. However, domestic demand is growing fast, which will necessarily limit its export capacity.

China dominates the market

The world's top two coal producers, China and the United States, are also the biggest consumers (42.6% and 17% of world consumption), followed by India, Japan, Russia, South Africa, Germany and South Korea. Global coal consumption rose by 3.1% in 2008, the smallest increase since 2002. China alone accounted for 85% of the increase (its demand has doubled since 2000). One key recent development is that China has become a net importer, which is likely to revolutionize the coal market. In 1993, that is what happened to the oil market when China became a net importer of oil.

World coal resources

Coal prevails on the Chinese energy landscape, contributing nearly three-quarters of the electricity production. The reasons are that coal reserves are abundant, can be extracted at low cost, and ensure a greater degree of national energy independence (China is not well endowed with hydrocarbons in light of its requirements). In addition, China represents half of the world's production of steel, which is a highly coal-intensive industry.

Asia, top importer

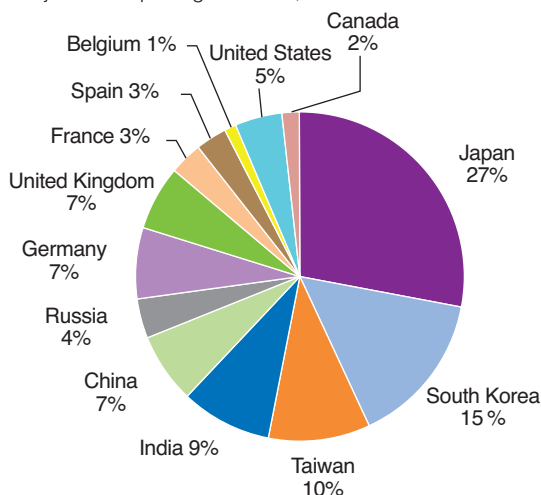
Asia accounted for 70% of world coal imports (Figure 7). Japan was the Number Two steel producer behind China, but its coal production is insignificant. The country is the foremost world importer of steam coal and imports the quasi-entirety of its requirements, mostly from Australia.

South Korea and Taiwan also cover the bulk of their coal requirements by means of imports. This trend is expected to intensify: projects are currently underway to boost capacity to generate electricity from coal.

India is a major coal producer, but its resources are of mediocre quality. Its master plan for long-term development calls for growing the steel industry, which means importing larger quantities of coking coal.

This year, China, the world's largest producer and consumer of coal, saw a steep increase in coking coal imports. Moreover, the new steel facilities are located near the coast and it is much more profitable to import coal by ship than to transport it by rail from the center of the country. Since the average quality of its coal is relatively mediocre, China imports the high-grade coals that it lacks, i.e. anthracite and bituminous coal.

Fig. 7 - Major coal importing countries, in 2008



Source: IEA 2009

Elsewhere in the world

The United States possesses the largest reserves and ranks second behind China for coal production and consumption. The volume of international trade is low, because the country exports little coal. Productivity is falling at mines and the cost of extracting coal is rising. According to long-term forecasts, demand will rise and the US will become a net importer.

South Africa, a major producer and consumer, depends heavily on coal to cover domestic energy demand. It is also the world's fourth largest exporter, especially of steam coal to Europe and India.

In Russia, the mining industry has been severely affected by the crisis and many projects have been put off. Looking to the long-term, however, the country should increase its capacity to produce and export, especially to Asia. A large number of projects should be mentioned, including the project to extend port capacity at Muchka Bay (Suek and Mechel) and the project to mine the Syradasai deposit (Norilsk and BHP Billiton), expected to yield 12 to 15 million tons by 2015.

South America is the third most prominent exporting region, mostly thanks to Colombia, which has done a great deal to develop its internal transport and port infrastructure. The country is very well positioned to meet steam coal demand emanating from the Atlantic Basin (Europe and the Americas), where it competes with South Africa.

New outlets: CTL

The production of synthetic fuels using Coal to Liquids (CTL) technology offers new outlets for coal. However, the prospects seem limited: not only does CTL yield low energy efficiencies, but it also has a major impact on the environment. As a matter of fact, the use of coal to produce motor fuels is in competition with its use in electricity production, which offers better energy efficiencies (35% instead of 20%). In addition, the CO₂ emissions for the CTL pathway are 2.3 times greater on average than those associated with the production of motor fuels by extracting and refining oil.

The only justification for using CTL, therefore, is to increase the energy independence of countries that are coal-rich but oil-poor (relative to their consumption), such as China or the United States, or countries targeted by an international embargo, as was the case for South Africa.

Based in South Africa, Sasol leads the world by producing 150,000 bbl/d in South Africa. However China has

World coal resources

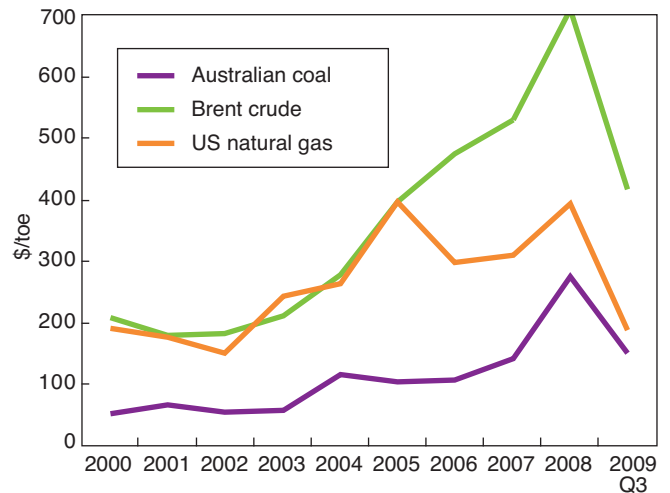
made CTL a national priority and there are numerous projects on the table at both central and provincial level. Shenhua, one of the world's largest coal producing companies and China's largest, aims to produce about 600,000 bbl/d of coal-based fuel by 2020. After announcing several projects in parallel, it undertook two major programs. The first is in Inner Mongolia, where production started in 2007 and should reach full capacity (100,000 bbl/d) in 2010. The second is the Ningxia joint venture formed with Sasol (capacity: 80,000 bbl/d). To limit the environmental impact, Shenhua has allegedly planned to equip its CTL installations with a CO₂ capture and storage system.

In the United States, which possesses the world's largest coal reserves, the development of CTL technology launched under the Bush administration was subjected to a sudden slowdown when Barack Obama came to power and established new priorities for US energy policy. The United States finds itself on the horns of a dilemma: on one hand, CTL would enable it to become less dependent on crude imports from the Middle East, but, on the other, it offers an environmental balance that is no longer acceptable. Implementing CO₂ capture and storage systems would reduce the environmental impact of this technology, provided that the concept of storing CO₂ underground gains social acceptability. The US Department of Energy (DOE) has recently revised estimates of future domestic CTL production down to 200,000 bbl/d by 2030 (AEO 2009).

Prices

Coal has always been cheaper than other fossil fuels (Figure 8). The price of coal registered the largest increase (by a factor of nearly 5) between 2003 and 2008, yet it remained less expensive per unit of energy than oil or natural gas. The trend turned around at year-end 2008 and continued in 2009. Spot prices for gas fell dramatically for several reasons: the economic slump drove down demand for gas, there was a plentiful supply due to the exploitation of unconventional gases in the United States, and LNG-exporting countries boosted their capacity. As a result, the price differential between gas and coal narrowed considerably and coal lost its competitive edge over its main competitor in the electricity production sector. When possible, operators tend to prefer natural gas, which offers the advantage of lower CO₂ emissions. This acts as a drag on coal prices. Furthermore, the fall in prices was also due to a decline in demand induced by the economic crisis.

Fig. 8 - Price trends for fossil-based energies



Source: IFP, based on Platt's

Coal and the environment

The current trend geared towards lowering the environmental impact of industrial activities represents a definite threat to the coal market: it reduces demand for coal. The implementation of environmental regulations, especially those pertaining to greenhouse gas emissions, give market players an incentive to prefer other energy sources, such as natural gas or renewable energies (e.g. in Germany, for instance). In the IEA World Energy Outlook 2009, the alternative scenario (the "450 ppm" scenario) puts coal demand in 2030 at the same level as in 2007. To counter this threat, operators have developed the concept of "clean coal" with a road map in three stages:

- improve energy efficiency at power plants, which reduces demand for coal in the same proportion,
- retrofit old power plants,
- intensify R&D, especially on carbon capture and storage (CCS).

It would appear that the future of coal depends on CCS technology, which would make the use of coal more acceptable from the environmental standpoint. Many projects have been undertaken to install capture units at coal-fired power plants as for example the Vattenfall Schwarze Pumpe pilot in Germany in operation since 2008 or the AEP Alstom Mountaineer Station in West Virginia (United States). Mention should also be made of a European initiative to allocate one billion euros to help finance 12 new CCS projects in Europe in 2010.

Finally, the level of the CO₂ price determined *via* systems like the EU Emissions Trading System or, more generally, the Kyoto mechanisms, will play a decisive role in

World coal resources

the development of this technology. It will also be necessary to ensure social acceptability (by proving that this type of storage is safe). But the system will only work efficiently if the largest consumers contribute to the effort (see the Panorama article "CO₂ markets and the current status of international negotiations").

Conclusion: the outlook for coal

At the current rate of production, the world's proven coal reserves (826 billion tons) would, according to BP, cover world requirements for about 122 years. But the situation varies considerably according to the country. At the current rate of production, the reserves in China will be depleted in about forty years. In contrast, it is thought

that US reserves may cover 224 years of production, reserves in India about 115 years, Australia 190 years, South Africa 120 years and the Russian Federation 480 years! In Europe, the reserves in Poland and Germany would cover an estimated 47 and 35 years of production. However, one should not give these figures more weight than they deserve. Calculated on the basis of current production figures, these projections do not account for future trends of any kind (e.g. the growing impact of environmental constraints on the use of this raw material).

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