



## Technology to clean up coal for the post-oil era

February 6, 2007

**During the transition to the solar age an energy gap will have to be filled.** The thirst of populous emerging economies for energy and the industrial countries' sustained need for energy will ensure a further rise in demand. However, it looks as if the supply of oil, and later also natural gas, will not keep pace with this demand. Only by leveraging every possible means will it be possible to compensate the imbalances emerging on the horizon.

**Coal can change from pariah to paragon of virtue.** Coal offers great potential as a substitute for oil and natural gas in the medium term, but so far its versatility has been underestimated. Going forward, coal could attract more attention in all three major energy sectors – power generation, the heating market and transport – provided that the right technologies delivering higher efficiency and lower environmental burdens take root.

**Environmental risks emphasise need for "clean coal".** Global warming is one of the biggest dangers facing human existence on earth, and combatting this danger is therefore one of the greatest challenges. Since coal causes 40% of global CO<sub>2</sub> emissions, only advanced technology can pave the way to a better future. Therefore, a "yes to coal" will always come with strings attached. The required quantum leaps in technology could, however, open the doors to the global mass markets.

**Immense global potential for innovative clean coal technologies.** With oil currently trading at around USD 54/bbl, coal-to-liquid technology is already an interesting alternative from a purely commercial point of view. Plans are afoot to invest USD 10 tr in power generation plants worldwide. The need for investment is very high not only in emerging economies like China but also in Europe and particularly in Germany, where the effects of the law to phase out nuclear power will unfold fully in the years ahead. CO<sub>2</sub>-free coal-fired power plants could become a milestone on the way to a better energy future in spite of their additional fuel consumption. However, achieving nationwide solutions will require a considerable amount of time and funding.

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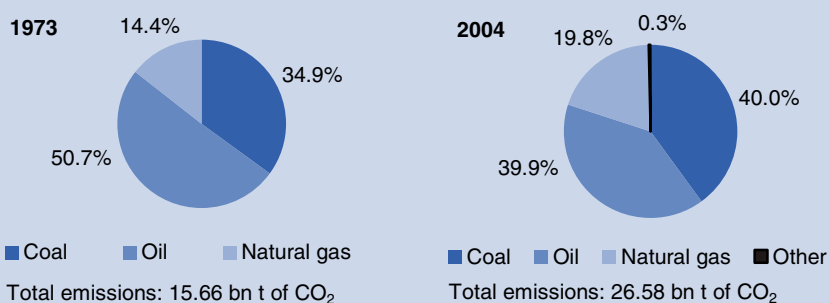
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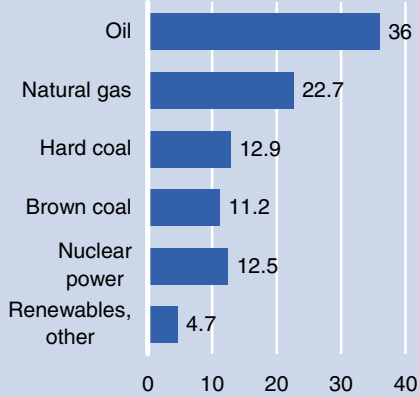
### Coal's contribution to global CO<sub>2</sub> emissions has increased

Share of energy source in CO<sub>2</sub> emissions



### Coal accounts for 1/4 of primary energy consumption in Germany

2005, %

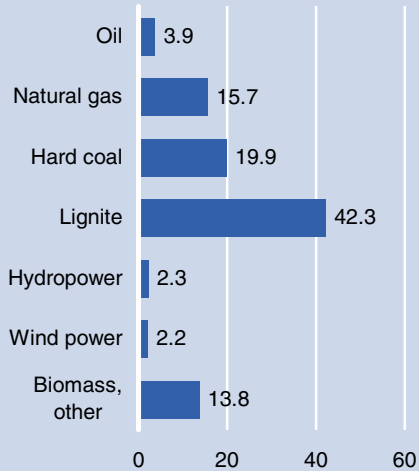


Source: AG-Energiebilanzen

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### Lignite important for primary energy generation in Germany

2005, %



Sources: AG-Energiebilanzen; GVSt, Steinkohle Jahresbericht 2006

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## Coal will gain significance in the post-oil era

Nothing says that our global energy future has to be dark, depressing and hopeless. Worldwide prospects for energy after the petroleum age<sup>1</sup> are actually quite good, but only if all possible levers are used. These include steps – apart from urgently needed conservation and efficiency-enhancing strategies – to diversify the range of energy carriers with an even greater drive to mobilise renewable energies and to continue developing potential alternative technologies.

In public debate about our energy options after the petroleum age virtually no consideration is given to coal or else it gets very bad reviews. In the developed countries, coal is usually considered synonymous with a dangerous climate killer; in the developing countries, for inhuman labour conditions in the mining industry (the talk is of “blood coal”). At best, coal is given credit for its valuable contribution to energy security during the industrialisation era.

## From pariah to paragon of virtue

Today, coal is used in the industrial countries above all as a source of fuel for generating electricity, for the heating market and for metal production. In the emerging economies, coal is still used in some places to fire steam engines. Going forward, coal could attract much more attention in all three major energy sectors – power generation, heating and transport – provided that the right technologies with higher efficiency levels and a low environmental impact take root. In this sense, the versatility of coal has been underestimated.

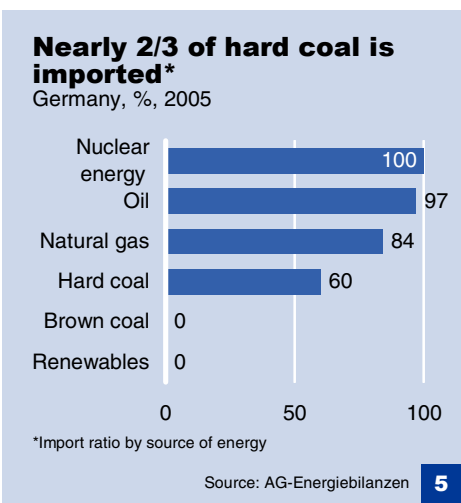
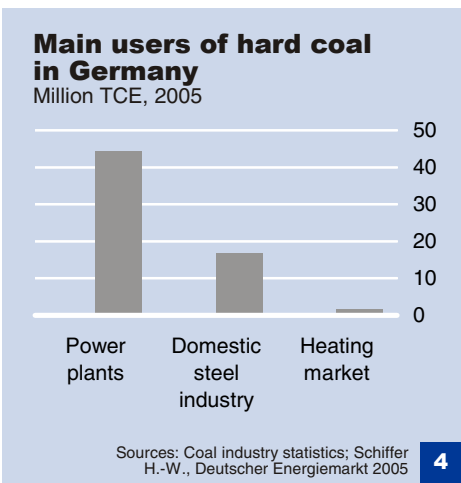
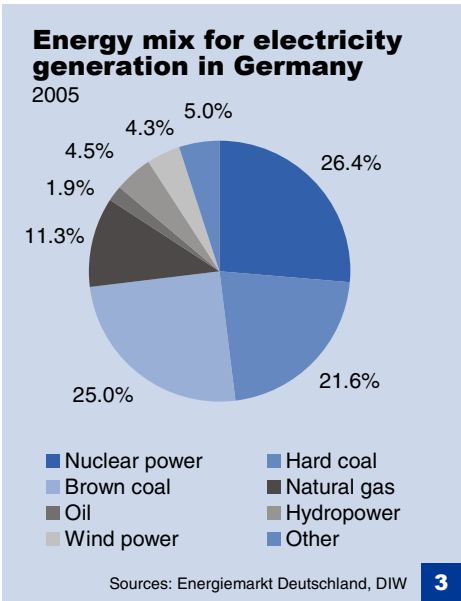
As a substitute for the hydrocarbon fuels oil and natural gas, which will become increasingly scarce in the relatively near future, coal offers considerable potential for improving our energy structures in future – at the national, European and global levels. At heart, the main issue is the transition period during which first oil and later also natural gas will become very scarce and expensive while renewables are not yet able to shoulder the main burden. However, only advanced technologies and innovations will be able to pave the way for coal into a better future. In this respect, the “yes to coal” will always come with strings attached.

## Coal is a pillar of the energy mix in Germany

Nearly 83% of Germany’s primary energy consumption in 2005 was based on fossil fuels. When the contributions from hard coal and brown coal (lignite) are taken together, their combined share (24%) is slightly higher than that of natural gas (23%). In volume terms, only oil (36%) is more significant. For generating secondary energy in the form of electricity, the contributions from hard coal and brown coal (22% and 25%, respectively) are surpassed only by that of nuclear energy (26%). Combined, though, hard coal and brown coal clearly account for the lion’s share at nearly half of the total.

In terms of primary energy generation, lignite is the biggest domestic source of energy in Germany. In 2005 lignite delivered 54.8 m tonnes of coal equivalent (TCE), or 42% of the total energy generated in Germany (129.7 m TCE). Next in line were hard coal and natural gas. With lignite output of 178 m t in 2005 Germany is the world’s biggest producer, accounting for nearly one-fifth (19%) of

<sup>1</sup> See Auer, Josef (2004). Energy prospects after the petroleum age. Deutsche Bank Research. Current Issues. December 2, 2004. Frankfurt am Main.



global production. The deposits are concentrated in three areas: the Rhineland, Lausitz and other parts of east Germany. Because raw brown coal has a high water content of 55% on average and a relatively low heating value, transporting it over fairly long distances is of no commercial interest. Therefore, 92% of the domestic output is used in nearby plants for generating electrical power or heat for district heating purposes. There is no import dependence for lignite whatsoever.

Unlike the lignite industry, which receives virtually no subsidies, the existence of hard coal mining in Germany has been propped up by government funding for years. Without this protection hard coal would no longer rank second for primary energy generation in Germany. Nevertheless hard coal extraction declined from 149 m t in 1957 (useable output) to 25 m t in 2005, i.e. by 83%.

The much higher energy content of hard coal vis-à-vis brown coal makes the transport of this energy carrier commercially feasible over great distances as well. International trade in hard coal benefits from the fact that this source of energy is available in abundance at relatively low cost worldwide. It is no wonder that the German import ratio has been climbing steadily for years and already reached about 60% in 2005. Hard coal consumption came to about 63 m TCE in Germany in 2005. The main users are power generating stations (70%), the steel industry (27%) and the heating market (3%).

Germany's imports of hard coal harbour no cluster risk since they come from a diverse range of countries. More than 80% of the coal imported in 2005 came from Germany's main suppliers: South Africa (25%), Poland (20%), the CIS (16%), Colombia (12%) and Australia (9%). Another 14% came in roughly equal measures from Canada, the US, China and Norway. While shipments of hard coal from Australia and China need up to three months, deliveries from Poland and Russia can reach the German market in two months including lead times. All in all, the coal imports are sourced from an adequately diversified variety of regions. Supply disruptions in individual countries could be compensated relatively easily – unlike with natural gas. At last reading the cost of import coal (delivery to German border) was EUR 59.75 per tonne, i.e. far less than German coal (EUR 160).

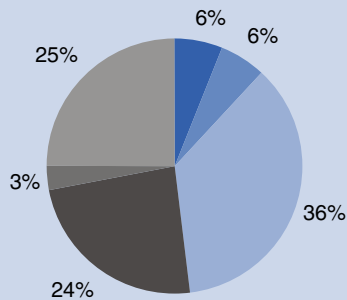
### Hard coal of key importance to global energy supply

In total, coal covers 28% of world demand for energy, which ran to about 15 bn TCE in 2005. Actually, the hard coal and brown coal shares are strongly asymmetrical, as lignite contributes only 3 percentage points. Over seven-tenths of global hard coal output is used to generate electricity, meaning that it covers 35% of world electricity demand, while lignite accounts for only 4%. As with all other sources of energy, production and consumption of coal have been climbing for decades, though significant shifts are to be seen on the user side. The growing demand for iron and steel benefits the coking coal segment. Steam coal is attracting more orders from power stations but losing significance in the heating market.

The globally rising demand for hard coal has boosted growth in international trading. In 2005 around 16% of global hard coal output was marketed outside the country where it was mined. Only 10% is transported by land means, with the other 90% being transported by sea.

**Oil predominant in global primary energy consumption\***

2005: 15 bn TCE



\*without bio-mass

- Nuclear energy
- Hydropower + other
- Oil
- Natural gas
- Brown coal
- Hard coal

Sources: BP Statistical Review of World Energy, Juni 2006, BGR, DB Research calculations

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**Versatile coal: Capital intensive and fiercely competitive**

Coal figures strongly in substitution competition with practically all other sources of energy. Since considerable time and expense are needed to adapt energy infrastructure, the individual sources of energy do not compete with one another directly. Coal only becomes competitive after its energy has been converted in power generating stations to the secondary energy carriers electricity and heat or in refining facilities to the form of coking coal, briquettes or dust. This competition is ultimately played out at the user level, where energy is required for process heat, air conditioning, lighting, and mechanical purposes such as mobility, production processes and consumer electronics. Ultimately, the end-users of energy are industry, households, government facilities and private transport companies. For them, the initial energy plays more of a subordinate role; what is much more relevant is the price of a specific energy service.

In the medium to longer run, though, the demand for coal is also a function of the capital invested, for capital-intensive investment will determine the technology of energy conversion and thus ultimately also energy demand. For example, modern coal-fired power stations need less energy input to produce electricity than they used to thanks to technological improvements and higher efficiency.

**Coal – challenge for German energy policy**

Before and after the last world war, coal played an important role in energy policy. The traditional objectives of energy policy have had a varying degree of relevance over time, though.

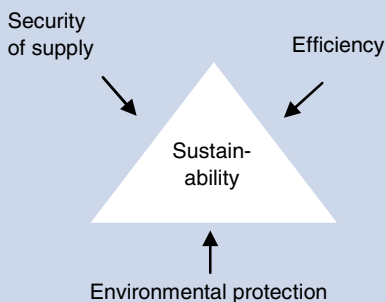
After the war it was initially an advantage to be able to tap the locally abundant deposits of brown coal and hard coal as a source of energy. There is no denying that domestic coal did much to shore up Germany's energy supply during those first few decades. It provided employment and enabled the development of modern industrial structures to boost Germany as a production location.

The economic efficiency of supplying energy with coal raised more and more questions over the years though and was regularly the subject of bitter political conflicts – especially when it was a matter of continuing or adapting support programmes. This scarcely applies to lignite, for it can be procured in Germany at low cost. By contrast, domestic hard coal has been at the centre of controversy: deposits in geologically unfavourable locations and ever deeper mines have led to very high costs by international standards. Hard coal producers in Germany have simply been unable to match the cheap world market price. Over time, the annual subsidies have gone into the billions, sparking a political rethink. Politicians have now reduced their arguments “only” to whether it is a good idea to maintain a domestic “hard coal base” for critical supply situations or whether it would be more practical to shut down all hard coal operations altogether. The issues – besides regional, labour-market and social considerations – are future financing (federal states and/or federal government) and business strategy (floating Ruhrkohle on the market, for instance).

**Environmental objectives are the Achilles' heel**

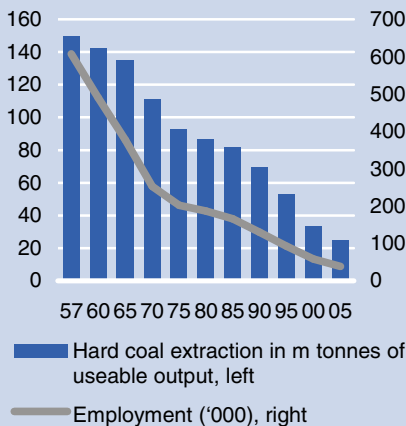
The actual Achilles' heel of using coal is the negative externalities that go with it such as spoiled landscapes and – of far greater

**Triangle of objectives in energy policy**



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### Germany's hard coal industry in decline



Source: GVSt, Steinkohle 2006

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#### Definitions:

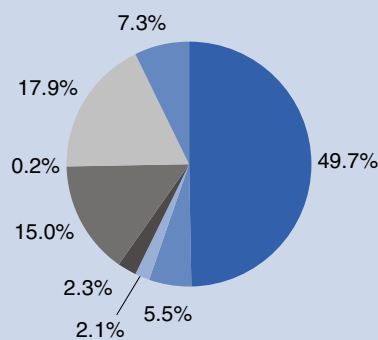
**Reserves** are deposits of raw materials used as energy sources that can be tapped in commercially feasible volumes at current prices and with current technology.

**Resources** are proven quantities of energy sources that for technical and/or commercial reasons are currently not yet exploitable, as are unproven quantities of energy sources which it may be geologically possible to exploit in future ("yet to find").

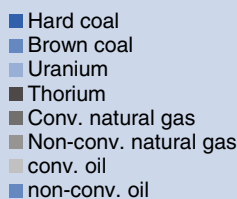
Source: BGR

### Dominance of coal in global energy reserves\*

2005: 1,290 Gt TCE



\*Non-renewable sources of energy



Source: BGR

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significance on a world scale – the gases emitted when both types of coal are burned.

What was regarded just a few decades ago as a doomsday phobia can – in view of countless scientific studies and publications – no longer be dismissed out of hand: there is an unambiguously positive correlation between the consumption of fossil fuels, the emission of greenhouse gases and the warming of the earth's climate. Since the use of coal produces the most greenhouse gases, it receives particularly strong criticism and is opposed most vehemently. From a climate point of view, lignite gets worse marks than hard coal, but hard coal is of much greater relevance for energy supply worldwide.

### Environmental risk emphasises need for "clean coal"

Global warming is one of the biggest dangers facing human existence on earth, and combatting this danger is therefore one of the greatest challenges facing mankind. Fossil fuels, especially those that pose the greatest threat to the earth's climate, will only have a future if they can be reinvented from an ecological standpoint. Coal accounts for 40% of global output of carbon dioxide (CO<sub>2</sub>). The "bridge to the future" must therefore lead to "clean coal", which if possible has to be climate neutral and thus acceptable to the public at large. If "King Coal"<sup>2</sup>, the mythical figure of the coal-mining saga, stops wearing a black robe in future and instead dons an environmentally-friendly white robe, his days will not be numbered and he may go on to prosper the second time round.

Until renewable sources of energy are finally mature and established enough to shoulder the burden of the world energy supply largely on their own, the purified "clean coal" may develop into one of the biggest sources of hope for a more secure energy supply. Notwithstanding, it would help if it were possible to boost the pace at which renewables are being developed.

### Large reserves and resources of coal around the globe

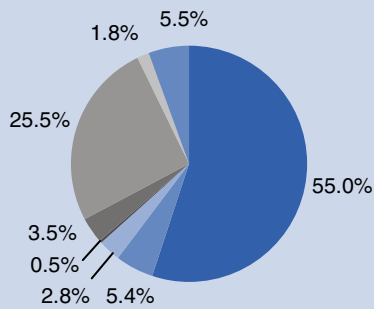
According to statistics from Germany's Federal Institute for Geosciences and Natural Resources (BGR), coal accounts for 55% of the global reserves of all non-renewable sources of energy, coming ahead of oil, natural gas and uranium. In terms of volume, hard coal makes up nearly 50% of the reserves, so it is much more important than lignite at 5.5%. The dominance of coal becomes even more apparent when you look at the potential resources, i.e. the volumes that are not yet commercially feasible at present. In this case, the breakdown for coal is 60% of total resources, with hard coal contributing 55% and lignite some 5%. Next in line come natural gas (including non-conventional types), oil and uranium.

One advantage of coal is that it offers the greatest range of global reserves among the fossil fuels. The "static range", i.e. the quotient of current reserves to annual output, came to over 212 years for lignite at the start of 2006, and 153 years for hard coal. By contrast, the ranges for oil (42 years) and natural gas (63 years) are much smaller. The reserves findings alone point to a relatively high performance capability for coal. Experience tells us, though, that the ranges represent only a snapshot of the situation, since the numerator and the denominator vary over time owing to techno-

<sup>2</sup> See Macalister, Terry (2006). Brave new world for King Coal as it tries to clean up its act. The Guardian. February 21, 2006. Wodopia, Franz-Josef (2006). Kommt „König Kohle“ zurück? Energiewirtschaftliche Tagesfragen. Vol. 7.

**Coal accounts for 60% of global energy resources\***

2005: 6,489 Gt TCE



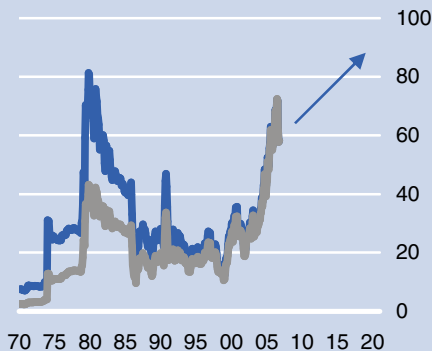
\*Non-renewable sources of energy

- Hard coal
- Brown coal
- Uranium
- Thorium
- Conv. natural gas
- Non-conv. natural gas
- conv. oil
- non-conv. oil

Source: BGR **10**

**Rising price of oil signalling end of era**

Real and nominal oil price\*, USD/bbl



\*Average of Dubai, WTI, Brent

- real
- nominal

Sources: HWWA, MWV, OECD, DB Research estimates **11**

logical progress, new finds, price changes and growth of global demand.

If the conventional and non-conventional resources are added to the reserves, the ranges increase. However, while this then boosts the ranges for oil and natural gas to only 120 and 200 years, respectively, the range for brown coal extends to 1,300 years and hard coal to around 1,000 years. The figures for the fossil-based hydrocarbons oil and natural gas, in particular, suggest that supply is secure when in fact it is not, for it is scarcely likely that non-conventional resources can be activated technologically and economically in the foreseeable future.

Not only the large proven reserves and potential resources among the fossil fuels argue for an even greater role for coal in the coming decades and centuries. The generally global distribution of coal deposits is also a point in its favour.

**High oil prices turn coal into an alternative fuel**

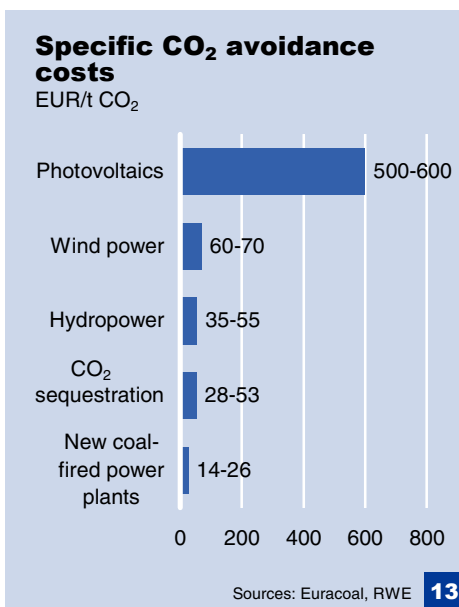
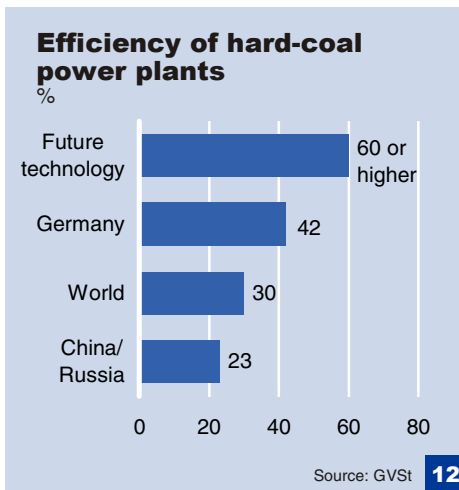
The search for alternatives to conventional fuels did not seem to be an urgent task in late 1998 when a barrel of oil cost less than USD 10. Not quite 10 years later, with oil going for an annual average price of USD 65 in 2006 (i.e. an increase of more than 500%), sentiment is reminiscent of the gold rush days. The most prominent participants in the contest for the fuels of the future have long since entered the race. Mass markets are awaiting the winners:

- First-generation bio-fuels are increasing in popularity in the most diverse countries of the world, such as Brazil, the US and Germany. In Brazil, they have long since become commercially competitive. Research on the second generation, the synthetic bio-fuels (biomass-to-liquids, or BTL), is continuing briskly.
- Natural gas has been a common fuel in some countries for years. More appears to be possible if the catalytic conversion of natural gas proves able to secure the availability of a synthetic fuel, so-called GTL (gas-to-liquids), on an industrial scale. GTL and BTL will mean fewer emissions and higher efficiency.
- By means of liquefaction (coal-to-liquids, CTL), coal may directly replace oil even as a fuel. Thanks to higher reserve and resource ranges, coal as a substitute would clearly have an advantage over fuels based on natural gas.

What would appear to be a technological sensation for the younger generation has basically been the state of the art for years. The direct liquefaction of coal was first put into practice at the beginning of the past century. In 1925, Franz Fischer and Hans Tropsch discovered an indirect liquefaction method, one which still bears their names: Fischer-Tropsch synthesis. This means that coal can in principle be liquefied both directly and indirectly. All three basic processes – coal hydration, coal extraction and petrol synthesis – were developed in Germany.

Before the second world war, Germany sought to achieve energy autarchy. Towards the end of the war it had 27 liquefaction facilities, 9 being Fischer-Tropsch indirect plants and 18 direct liquefaction plants. They covered 90% of domestic fuel demand. After the war the technology fell out of favour in Germany as it was sidelined by a different energy policy and low oil prices.

Coal liquefaction currently plays a commercial role in South Africa, which established and fostered a CTL industry in the 1950s that covers about 60% of domestic demand. The US also uses CTL



technology. As of late the world's biggest coal producer, China, is also planning to engage in CTL with the erection of its first large-scale facilities. The three countries all have abundant deposits of coal that can be exploited at low cost. In the long run, though, these should only be activated if technological advances are able to keep the environmental impact in check.

The US, which has traditionally favoured technological solutions to problems, launched initial programmes for modern CTL technology in the mid-1970s. The initiatives of the US government and the Department of Energy (DOE) cover a broad range extending to the president's latest hydrogen initiative, for hydrogen can also be generated via coal liquefaction. Stimuli for CTL solutions are also coming from the Department of Defense (DOD), since they will enable the military to enjoy a secure supply of fuel and propulsion agents without being dependent on imports.

Most US programmes target CTL technologies becoming competitive at oil prices of around USD 25-30 per barrel. In the early days, though, the price of oil was much lower. With oil currently trading at around USD 54/bbl, CTL is an interesting alternative from a purely commercial point of view. The commercially feasible costs for CTL lie in a range of USD 40-50.<sup>3</sup> From a macroeconomic standpoint, the result is not as good of course because of the higher costs of CO<sub>2</sub> emissions. But if these problems are solved, e.g. by means of sequestration, coal would be a source of hope for the fuel market in the post-oil era.

### New power generation technology for fewer emissions

A total of USD 10 trillion is expected to be invested in power generating plants around the globe up to 2030, with over USD 2 trillion being invested in China alone. The need for investment is very high not only in the emerging markets but also in Europe and particularly in Germany, where the effects of the law to phase out nuclear energy will become truly noticeable in the years ahead.

For investments, not only the direct costs but also the implications for the world climate will increasingly gain importance. This holds all the more so as over the past 30 years the share of CO<sub>2</sub> emissions from coal has risen from 35% to 40% – with total emissions rising by 70% globally. Since natural gas will grow more and more expensive in tandem with oil and since the delivery streams apparently already harbour risks, the potential for innovative clean coal technologies is immense. The efficiency of coal-fired power stations in the EU rose by one-third over the past three decades. Modern hard coal stations can achieve a score of 45%. The replacement and modernisation of old generating plants in the industrial countries and above all in the emerging markets alone would noticeably reduce the dangers for the climate. The specific CO<sub>2</sub> avoidance costs attainable with new power plants are lower than with many other strategies.

One much more revolutionary project is a plan to develop emission-free coal-fired generating plants. Upstream and downstream CO<sub>2</sub> sequestration, for which there are several different methods, aims for climate conservation. There are diverse alternatives for subsequent CO<sub>2</sub> storage, e.g. disused mines, oil and natural gas caverns that have been pumped empty or special geological

<sup>3</sup> See IEA Coal Industry Advisory Board (2005). Meeting our energy needs – driving forward coal's role in a clean, clever and competitive energy future. Workshop report. Paris.

**Hard coal widespread throughout the world**

2005

	Extraction	Consumption
World (Exajoules)	122.6	122.4
	%	%
Europe	4.0	8.8
CIS	8.2	6.3
Africa	4.6	3.7
Middle East	0.0	0.3
Austral-Asia	59.3	56.4
North America	22.5	22.5
Latin America	1.4	0.7
OECD	32.8	37.2
EU-25	3.6	7.7
OPEC	3.3	0.8

Sources: BGR (2005), DB Research calculations

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formations such as saline aquifers. As things stand today, such storage methods still harbour significant risks, though. This is why additional research is urgently needed. And the costs to be incurred until serial production is possible are not insignificant.

The initiatives for CO<sub>2</sub>-free coal-fired power plants are widespread. The US is giving all-out backing to the development of a zero-emission power plant with the FutureGen project. The EU is doing much to support innovative technologies for sequestration. In Germany, RWE says it will build the first industrial-scale, CO<sub>2</sub>-free coal-fired power plant by 2014. Furthermore, Vattenfall Europe plans to set up a CO<sub>2</sub>-free pilot plant based on lignite.

The current investment boom in Germany for new coal-fired power plants is partly the result of the climate protection privileges that the federal government granted in the framework of the second National Allocation Plans for emission rights for the years 2008 to 2012 (NAP II). The streamlining of the NAP II as a result of recent EU criticism has done virtually nothing so far to change the environmental subsidies. Truly CO<sub>2</sub>-free coal-fired power plants will probably not be available for serial production before 2020. If the technology can clear the hurdle, Germany's mechanical engineering and plant construction sectors stand to benefit even more than hitherto from the soaring global demand for investment. The European Commission is considering whether it should permit only CO<sub>2</sub>-free power stations after 2020. It will take even longer than that before all the existing coal-fired power plants are emission-free.

Despite new technology the disadvantages inherent in the cost of mining hard coal in Germany will not be eliminated even during the post-oil era. The outlook for German hard coal will thus continue to hinge on the subsidies granted by politicians. By contrast, lignite will remain an efficient source of energy for domestic supply for decades following the oil boom thanks to modern technology.

**Conclusion: Versatile coal will be key in the interim**

Coal will have good prospects if efforts to engineer its transformation into a clean energy source with a neutral impact on the climate are successful. Abundant deposits and the favourable global distribution will enable a relatively secure energy supply in Germany and the world, particularly when oil and later also natural gas have become scarce and thus expensive. The transition period in which coal may be the only answer could be limited, though. But this would require fast progress on renewable energies as well as on hydrogen research. Breakthroughs of backstop technologies such as nuclear fusion need much more time. Until then, transformed, more environmentally-friendly use of coal will be of the essence.

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