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## Clean Coal Conversion:

### Road to Clean and Efficient Utilization of Coal Resources in China

Zhang Yuzhuo
President, Shenhua Group

**The World Bank Decision on Coal Funding Must Be Made to Work**

**Does Coal Have a Long-Term Future in Europe?**

**Shenhua's DCL Project: Technical Innovation and Latest Developments**

# Coal and Civilization

Liu Baowen
Executive Editor, *Cornerstone*

In the recorded history of mankind, the evolution of civilization cannot be separated from two major aspects—the development and utilization of tools and natural resources. This has been the case in both the East and the West, whether at the early stages of formation or during the more advanced development of a civilization. As a natural resource, coal has played a central role in the advancement of civilization. Especially since the first Industrial Revolution began in the 1760s, coal has become an indispensable material base, and necessary to guarantee the continued evolution of human civilization, contributing to quality-of-life improvements and industrial progress in an increasingly prominent manner. Without the progress of the coal industry, there would not be such splendid civilization and cultural prosperity as is currently found in the world. Today and into the foreseeable future, coal is and will be a principal source of energy, which is needed to provide a foundation to sustain the advancement of human civilization.

With the development of modern industrial civilization that was derived from the exploitation and application of fossil energy with coal as the mainstay, we are undoubtedly confronted with unprecedented challenges: the clean and efficient production and conversion of coal, which is a challenge for the coal industry, and the need to reduce carbon emission and improve environmental protection, a challenge for related sectors. Considering the perspective of the advancement of the whole of human civilization, these challenges are relevant and will continue to exist well into the future. On the other hand, these challenges are global, pressing issues that have a vital influence on the rise and fall of human civilization. To address these challenges, therefore, collaboration is necessary to find solutions for the coal industry. The coal industry has been making progress based on technology and management, which will both be necessary to tackle these challenges. The process of tackling challenges also is a chance to take advantage of opportunities—to promote what is beneficial and abolish what is harmful, and to achieve breakthroughs. Although it is a tedious process, there awaits a bright future for industrial and environmental progress.

One potential solution that could lead to cleaner coal conversion and also reduce the carbon footprint of the transportation sector is the use of coal as a feedstock through conversion into liquid fuels and chemicals. The low contents of carcinogenic aromatics and essentially zero sulfur contents of liquid fuels produced through indirect liquefaction make these fuels inherently much cleaner than crude oil-derived liquid fuels. Incorporation of CCS, biomass coprocessing, and/or polyproduction can lead to liquid fuels with carbon footprints that are small fractions of those for crude oil-derived products. This means that CTL processes could enable potentially huge roles for coal in a carbon-constrained world by reducing the carbon intensity of transportation fuels.

Although the first commercial CTL plant was successfully established in South Africa by the 1980s, subsequent low oil prices quelled further deployment of this capital-intensive approach to providing liquid fuels. Recently, however, high oil prices as well as political unrest in oil-rich regions have led to renewed interest in CTL. China is leading the way in making progress toward clean coal conversion. The articles published in this issue focus on clean coal conversion and its effect on the future of coal-based energy from this perspective in the hopes of sparking a more extensive and deeper debate.

# CONTENTS













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**Editorial Office**
Shenhua Science and Technology Research Institute Co., Ltd 006 mailbox
Shenhua Science and Technology Park,
Future Science & Technology City,
Changping District
Beijing 102211, China

Phone: +86 10 57336026
Fax: +86 10 57336014

Email: cornerstone@shenhua.cc (Chinese)
Email: cornerstone@wiley.com (English)
Website: www.cornerstonemag.net

# Clean Coal Conversion:

**By Zhang Yuzhuo**
President, Shenhua Group
Academician, Chinese Academy of Engineering

In 2012, global coal consumption increased by 2.5%, far less than the average growth rate of 4.4% over the past decade although it remained the fossil energy source undergoing the most rapid growth in consumption. In addition, in 2012 coal accounted for 29.9% of global primary energy consumption, the highest percentage since 1970.[1] For the foreseeable future, the role of coal as an important global energy source, especially in non-OECD countries, will remain unchanged.

As a principal non-OECD country, China's coal-dominated energy mix will remain unchanged in the near term. At the same time, China's impact on global coal production and consumption patterns will continue to increase. In 2012, the net growth in global coal consumption came exclusively from China, and, for the first time, coal consumption in China exceeded half of total global consumption. China's coal utilization level relates not only to the healthy development of its own economy and society, but also has a significant impact on the development of the world's economy and environment. Advancing clean coal conversion to facilitate a revolution in energy production and consumption, and thereby achieving the harmonious development of energy, economy, and the environment, is the only way to

# Road to Clean and Efficient Utilization of Coal Resources in China

achieve clean, efficient utilization of coal in China as well as throughout the global energy system.[2]

## OVERVIEW OF THE CLEAN COAL CONVERSION INDUSTRY

The coal conversion industry emerged in the 1950s, and chemicals production from coal at the commercial scale commenced during the 1990s. Since 2000, a continuous rise in the international price of crude oil and an ongoing increase in environmental global awareness have once again drawn significant attention to coal conversion, with a particularly strong emphasis on *clean* coal conversion. This has facilitated a fervor of coal conversion activity in China. Homegrown technologies have emerged based on research and development (R&D). Examples include packaged technologies such as Shenhua's direct coal liquefaction technology, a coal-to-methanol-to-olefin technology (Dalian Institute of Chemical Physics of the Chinese Academy of Sciences), and a multi-nozzle coal/water slurry gasification technology (East China University of Science and Technology), as well as unit technologies such as methanation, coal-to-chemicals catalysts, and large-scale methanol synthesis. Plants that have been completed include the Shenhua Ordos 1080-ktpa (kilo tonnes per annum) direct coal liquefaction plant, three 160–180-ktpa indirect coal liquefaction plants, three large coal-to-olefin plants, one 200-ktpa coal-to-monoethylene glycol (MEG) plant, and several large coal-to-methanol and methanol-to-methyl ether plants with advanced gasification technologies. Four new coal-to-gas projects have been constructed. This progress has led to the formation of a commercial clean coal conversion industry enabled by coal gasification and based on C1 chemical technology to synthesize various low-carbon chemical products and clean petroleum substitutes (i.e., synthetic fuels); the industry is based on the philosophy of low-carbon, clean, and highly efficient energy utilization.[3–5]

## THE EVOLUTION OF CLEAN COAL CONVERSION

### Coal Liquefaction

Coal liquefaction falls into two categories: direct and indirect liquefaction, both of which have been developed and commercialized in China.

For direct coal liquefaction, industrial-scale production was realized in Germany during World War II. After the first oil crisis, countries such as the U.S. and Japan successively developed many direct coal liquefaction technologies, with the largest pilot plant having a capacity of 600 t/d (tonnes per day). With an eye on its own industrial development needs, Shenhua Group in China independently developed the Shenhua Direct Coal Liquefaction Process and established the only 1080-ktpa direct coal liquefaction facility in the world. This facility was formally placed into commercial operation in January 2011; as of the end of June 2013 it had produced more than two million tonnes of synthetic fuel products, while achieving operational excellence. To build upon the commercial operation, further research and development are needed, such as reducing water consumption, improving product yield, reducing emissions, effluents, and wastes, and enhancing the development of premium and high-performance coal-based fuels.

*"For the foreseeable future, the role of coal as an important global energy source, especially in non-OECD countries, will remain unchanged."*

The core technology of commercial-scale indirect coal liquefaction was first mastered in South Africa. Over the last decade, China has made breakthroughs in commercial indirect coal liquefaction through independent R&D. Three 160–180-ktpa indirect liquefaction projects have been placed in operation. Now efforts are being made to speed up the implementation of a large demonstration project, which is focused on solving key technical issues such as the design and manufacturing of large-scale Fischer–Tropsch (F-T) synthesis slurry bed reactors, catalytic oxidation of alcohol byproducts, methane conversion and utilization of synthesis tail gas, production and application of new F-T synthesis catalysts, process optimization and integration of a heat recovery system, and engineering design for major project deployment. Progress is also being made to improve process integration and optimization, further reduce the required unit investment, reduce water and coal consumption per unit product, establish a high-temperature F-T synthesis demonstration plant, and achieve safe and stable long-term operation of large (e.g., >1 MMtpa) plants.

**Shenhua's groundbreaking 1080-ktpa Ordos direct coal liquefaction facility is an example of the major CTL advancements occurring in China.**

## Coal-to-Olefins

Currently, there are two commercial coal-to-olefin technologies: the coal-to-methanol-to-olefin (MTO) process and the coal-to-methanol-to-propylene (MTP) process. Globally, many companies are investigating and optimizing olefin production processes. Today, the most successful include the methanol-to-olefin (DMTO) technology (Dalian Institute of Chemical Physics of the Chinese Academy of Sciences), Sinopec methanol-to-olefin (S-MTO) technology, U.S. UOP/HYDRO methanol-to-olefin (MTO) technology, and the German Lurgi MTP technology. Based on the existing technologies, China has established and put into commercial operation four coal-to-olefin projects, such as Shenhua Baotou's 600-ktpa MTO and Shenhua Ningmei's 500-ktpa MTP. In addition, China is actively pursuing new technologies for the optimization of catalyst production, reduction of water and coal consumption, improvement of production selectivity and yield, etc. Shenhua Group has independently developed a next-generation methanol-to-olefin (SHMTO) technology, and the Dalian Institute of Chemical Physics of the Chinese Academy of Sciences has completed the R&D leading to the second generation of methanol-to-olefin (DMTO-II) technology. Both technologies have been applied at commercial plants that are currently under construction. There are plans for further optimization and improvement of the entire process, including gasification, purification, and methanol synthesis, so as to form a complete process package with intellectual property rights that improves the stability and economics of large plants.

## Coal-to-Gas

Methanation, a key coal-to-gas process, is a mature, proprietary technology currently deployed commercially in China. The first phase, including commissioning, of the Datang Keqi Project, with a capacity of 1.33 billion $m^3$/yr, has been completed, while the second phase, with a capacity of 1.33 billion $m^3$/yr, is nearing completion. The first phase of the Datang Fuxin Project, with a capacity of 1.33 billion $m^3$/yr, has been completed and the commissioning is currently underway. The first phase of the Inner Mongolia Huineng Project with a capacity of 0.4 billion $m^3$/yr and the first phase of the Xinjiang Qinghua Project with a capacity of 1.75 billion $m^3$/yr are also nearing completion. When all the above-mentioned projects are running at full capacity, there are plans in China to further develop, through R&D, the key aspects of the methanation technology, such as improvements in fixed bed gasification pressure, efficient wastewater treatment and reuse, and a portfolio of coal gasification technologies, to demonstrate integrated gas, electricity, and chemical polygeneration and comprehensive peaking-shaving regulation technology and to improve energy efficiency and overall financial return.

## Coal-to-MEG

Coal-to-MEG technology is available in Japan and the U.S. The first coal-to-MEG commercial-scale demonstration project in the world (i.e., Tongliao GEM Chemical 200 ktpa) was built in China and includes several technologies with Chinese intellectual property rights. At the industrial scale, the economic feasibility and actual operation of MEG production through carbonylation and hydrogenation of synthesis gas will be demonstrated. In addition, the focus of R&D includes the scale-up of major equipment, such as dimethyl oxalate synthesis reactors and dimethyl oxalate hydrogenation reactors, optimization of technologies for wastewater treatment and reuse, MEG distillation efficacy and product quality improvements, and identification of other economic and practical coal-to-MEG routes.

### Coal-to-Aromatics

Tsinghua University, Dalian Institute of Chemical Physics of the Chinese Academy of Sciences, and others have developed a coal-to-aromatics technology. Huadian Coal Industry Group Co., Ltd. has constructed and successfully commissioned the world's first 10-ktpa pilot plant. Moreover, efforts will be made to eventually develop the first industrial-scale coal-to-aromatics demonstration project, which will focus on key technologies such as design and enlargement of the methanol-to-aromatics reactor, reaction heat control, engineering optimization, as well as industrial application of paraxylene catalysts.

### Coal-to-Hydrogen

Coal-to-hydrogen is already a mature technology, and is an important means of obtaining a cheap and steady supply of significant quantities of hydrogen. In 2007, Shenhua Group built the world's largest coal-to-hydrogen plant, with a capacity up to 600 t/d, which is mainly used to provide hydrogen for Shenhua's direct coal liquefaction plant.

With a continuous, strong demand for clean fuel, hydrogen cells, hydrogen gas turbines, and hydrogen-powered automobiles are gradually moving toward large-scale commercial production, and hydrogen will become an important source of clean energy. Therefore, coal-to-hydrogen is a viable technology based on the realistic possibility of large-scale commercial operation.

## PROSPECTS FOR CLEAN COAL CONVERSION

Today, the world is increasingly attentive to the development of low-carbon, high-efficiency, and clean energy. The future of energy development lies in the establishment of a new energy ecosystem (a term commonly used in China and elsewhere that refers to an integrated energy system that is in balance with the environment), which will be centered on more efficient utilization of energy (including higher efficiency energy conversion and improved resource utilization), and can be built based on effective integration of various energy sources, so as to form a low-carbon, efficient, clean polyproduction system featuring "near-zero emissions".

Given that coal will continue to play a dominant role for the long term, clean coal conversion is the key to the establishment of the new energy ecosystem. At the same time, attention should also be focused on near-zero emissions during fossil


**Today the Shenhua Baotou MTO Plant produces 300 ktpa of polypropylene and 300 ktpa of polyethylene.**

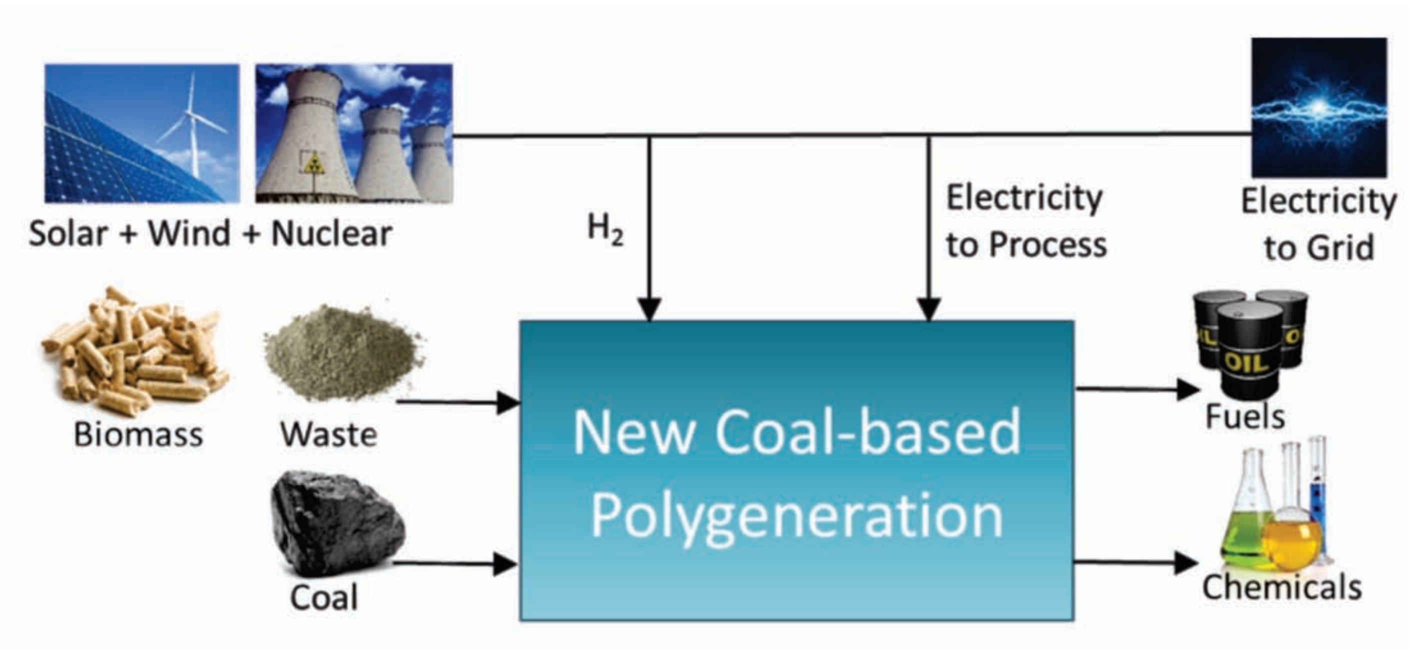


**FIGURE 1. Framework for new coal-based polygeneration**

energy utilization, so as to realize the green and collaborative development of fossil energy, unconventional energy, and renewable energy, as well as advance the energy production and consumption revolution.

To achieve a successful energy revolution in China, a country where energy is dominated by coal, clean coal conversion has been included as an integral part of national energy strategies. The government is working actively to propel independent R&D of associated technologies and equipment, support growth of relevant industries, and establish an energy ecosystem based on clean coal conversion. The prospects for clean coal conversion involve four coal-related shifts, described briefly below.

### Shift from Fuel to a Combination of Fuel and Feedstock

It is critical to continue the research, development, and demonstration of modern coal conversion technologies to achieve clean and efficient coal conversion and utilization. The overall arrangement of the coal-to-chemicals industry must be rationally planned to facilitate the construction and sound development of an integrated large-scale coal-to-chemicals industrial base. In 2012, the production capacity of coal-to-liquid fuels in China increased to 1.6 million tpa, coal-to-methanol increased to 55 million tpa, and coal-to-olefins (ethylene + propylene) production increased to 1.8 million tpa. Coal consumption for coal conversion is projected to reach 40–50 billion tpa in the next 40 years.

In this way, the role of coal is changed. Coal is not merely a fuel, but also a feedstock if we make full use of the C, H, and other elements found in coal for chemical synthesis and their heating value. Once market demands for electricity and heat are met, various clean energies and industrial raw materials, including natural gas, liquid fuels with ultra-low emissions, aviation and specialty fuels, and chemicals, can be produced via coal gasification.

### Shift from a Singular Energy System to a Component in an Integrated Coal–Unconventional Energy–Renewable Energy System

Unconventional energy and renewable energy are vigorously being developed via proactively pursuing hydroelectric power, safely and efficiently developing nuclear power, developing wind power projects in an orderly manner, and accelerating the utilization of solar power. In addition, shale gas, shale oil, biomass energy, geothermal energy, and other unconventional energy sources are also being actively pursued as well as promoting a distributed energy grid, so as to enable unconventional energy and renewable energy to take an increasingly prominent role in the restructuring of the energy mix. Moreover, an in-depth investigation will be completed for energy integration and optimization technologies with the objective of enhancing energy conversion and utilization efficiency—the coupling of shale gas and coal-to-chemicals processing, combining nuclear energy-to-hydrogen and coal polyproduction, combining solar energy-to-hydrogen and coal polyproduction, and combining utilization of coal, waste, and biomass, all of which are shown in Figure 1.

The development of unconventional energy and renewable energy can change the coal-dominated energy mix. It can also bring about multiple possibilities for coal conversion pathways to realize the combined utilization of various energy resources and to establish a new coal-based polyproduction system with more efficient utilization and conversion of energy resources.

*"The development of unconventional energy and renewable energy can change not only the coal-dominated energy mix, but also brings about multiple possibilities for coal conversion pathways …"*

## Shift from High-Carbon Development to Efficient Utilization of Coal with Near-Zero Emissions

It is necessary to develop technologies to control pollutants throughout all coal conversion processes. It is important to implement technologies for efficient and clean combustion, coordinated pollutant control and reuse of wastes, and reclamation of wastes for comprehensively controlling pollutants from coal-fired power plants. Technologies for clean energy substitution/large-scale application, efficient removal of pollutants, and coordinated control of multiple pollutants with byproduct recycling can also be applied to control pollutants from industrial boilers. Similarly, advanced process technologies for efficient removal of pollutants with coordinated control of pollutants with byproduct recycling can be applied for controlling pollutants from industrial kilns. Finally, modern coking pollution control technology includes large-scale application, reclamation, and cleaning. All of the technology pathways are shown in Figure 2.

To achieve improved, cleaner coal conversion, additional R&D and the application of new coal-associated technologies, such as $CO_2$ capture, utilization, and storage (CCUS) and reclamation and comprehensive recycling of wastes or pollutants, will be required to achieve increased commercial deployment of coal conversion. For example, with efficient extraction and comprehensive utilization of aluminum, gallium, germanium, uranium, sulfur, and other resources in coal, the coal and its associated resources can be used efficiently and completely with the realization of near-zero emissions of pollutants.

## Increasingly Intelligent Coal-Based Energy Production and Consumption

It is essential to promote the application of big data, Internet of Things, mobile Internet, and other information technologies

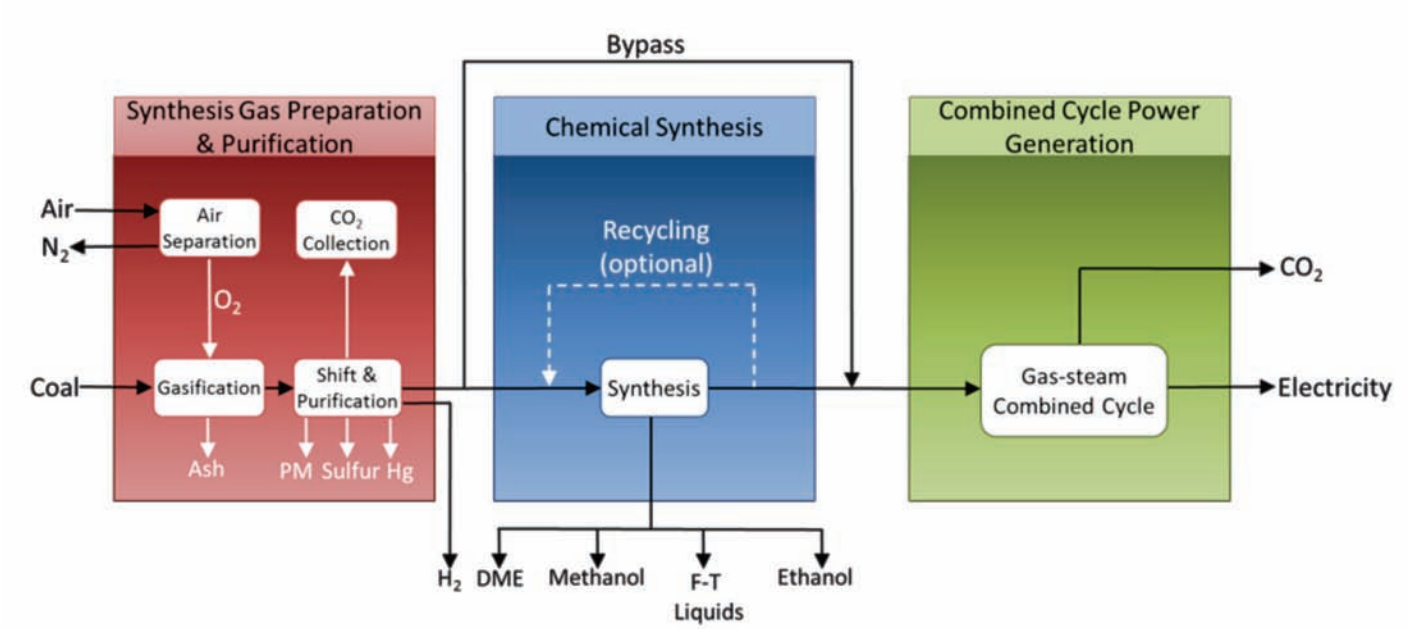


**FIGURE 2. Polyproduction based on coal gasification**

**The first production line of the Datang Keqi coal-to-gas facility has been completed and the second line is nearing completion.**

throughout the process of coal conversion to maximize the intelligent features utilized in clean coal conversion. Increased use of intelligent technology is necessary to realize effective integration of clean and efficient coal conversion with unconventional energy and renewable energy as well to function in real time and adjust for the valleys and peaks caused by dynamic energy consumption. In addition, energy production and consumption with better safety and reliability performance, matching accuracy, and integration are necessary to form a new model such that a low-carbon, efficient, and clean energy system, meeting development needs of our economy and society, is indeed created, which can launch a revolution in the energy industry and transform the development path of society.

## CONCLUSIONS

Considering that China's energy mix is dominated by coal, great efforts are being made to develop clean energy options to accompany the global tide of low-carbon development. Clean coal conversion can lead to the realization of the transformation from high carbon, to low carbon, to carbon-free coal utilization with broad prospects for technological and commercial markets in the future. It is expected that China's clean energy development route will be focused mainly on the acceleration of clean coal conversion. There are several pathways for clean coal conversion, including increasing integration of coal and unconventional energy and renewable energy, development of coal-associated resources (e.g., CCUS and other technologies), and making the full industrial chain of clean energy more intelligent through technology. All these options are also essential to meet energy demand, optimize the global energy mix, and sustainably and soundly develop the global economy of future.

Shenhua Group, the world's largest coal-based energy supplier and the leading coal conversion technology developer, will, via independent innovation and industrial upgrading, remain committed to R&D and the implementation of clean coal conversion. Shenhua Group is also committed to promotion of an intelligent clean energy system featuring near-zero emissions, so as to make unremitting progress for not only the development of the global energy industry, but also a brighter future for society.

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# The World Bank Decision on Coal Funding Must Be Made to Work

**By Benjamin Sporton**
Deputy Chief Executive, World Coal Association

Despite the immense challenges of delivering energy to the 1.3 billion people who lack it, the World Bank's recent decision to limit financing for coal-fired power plants could risk limiting the use of one of the most affordable and effective tools for combatting energy poverty.[1] The bank's decision to limit funding for coal to all but rare circumstances, with a deliberate switch to gas as a preferred energy source, will place new hurdles in the path to development for many of the world's poorest countries. Despite the bank's leadership arguing that affordable energy is needed to help end poverty and to build prosperity, it seems to believe this is achievable without coal, one of the most affordable energy sources available.


**Under the leadership of Jim Yong Kim, the World Bank has recently announced that it will limit financing for coal-fired power plants except in rare circumstances.**
*Photo:* Hindustan Times via Getty Images

It is for this reason that the bank's decision must be made to work. Although the new framework is a clear shift against coal, it leaves the door open in some circumstances. The bank's board will be under immense pressure from environmental groups to abandon coal completely and the campaign against coal funding by multilateral development banks won't stop with this decision. Instead, what will be important is how the decision can be operationalized with a view to achieving economic development and addressing concerns about climate change in an integrated way.

*"Despite the bank's leadership arguing that affordable energy is needed to help end poverty and to build prosperity, it seems to believe this is achievable without coal, one of the most affordable energy sources available."*

## HEADING IN THE WRONG DIRECTION

The decision comes as the World Bank, like many other international institutions, increasingly focuses its work around climate change, perhaps beginning to risk their development mandate. The bank says its focus on climate arises from an assessment that the consequences of climate change would impact most on poorer countries and that climate change will hinder economic development. These points do have merit, but the policy decision ignores realities about energy impacts on development.

As the Center for Global Development highlights, "no country has yet to demonstrate a development approach that does not rely on either fossil fuels or nuclear power, or a natural endowment of geothermal or hydroelectric energy, for the bulk of its generation."[2] That means in the vast majority of scenarios fossil fuels are the only option. Very few countries have significant natural endowments of geothermal or hydro and very few developing countries are able to look to nuclear for a number of reasons, not least because of cost factors. This leaves a choice between coal and natural gas in most scenarios, and in its new directions paper the World Bank has turned to gas.[1]

In doing so, the bank has ignored the realities of development across the globe in the past 30 years—a story most revealingly told in China, where coal has been the major energy source fueling the industrial development that has raised over 660 million people out of poverty. Without poverty reductions in China, 80% fueled by coal, global poverty has actually increased over the past 30 years. The bank has also ignored evidence from the International Energy Agency (IEA), which sees a significant role for coal in on-grid electrification and only a limited role for gas.[3]

The bank argues its decision is based on concerns about climate change and has increased its focus on gas as the answer to energy access. However, unabated gas is not the solution to raising global energy access, to meeting the challenge of climate change, or to ensuring secure, reliable supplies of energy.

While it might seem counterintuitive, the prospect of multilateral development banks backing out of funding for coal could have unintended consequences. A number of examples of countries pursuing coal to meet their energy needs are explored below, and in some cases they could go ahead with coal projects regardless of whether the bank is involved or not. The risk, however, is that without bank involvement, cheaper, less efficient, and more polluting technologies might be used because they are all that can be afforded in the absence of concessional finance or loan guarantees. It will be important for the bank to recognize this as it implements its new policy framework.

## MAKING THE NEW PARADIGM WORK

Despite the headlines heralding the World Bank's move away from coal, the reality is more nuanced. Perhaps conscious of striking a more realistic balance between development and climate objectives, the bank recognizes it will need to support coal in some scenarios, essentially a "with regrets" approach. In its framework for assessing climate impacts,[1] scenario 2 specifically envisages situations where energy access is a priority and where lower cost but higher emission technologies may be needed. In this scenario the bank is clearly leaving a door at least slightly ajar for greenfield coal projects, or as it says "only in rare circumstances".

Beyond consideration of greenfield projects, the World Bank highlights the potential of efficiency improvements at existing coal plants as being one of the most cost-effective ways of reducing emissions, an area in which they intend to operate.

There are many countries, however, where coal is the only realistic solution to addressing the energy challenge. As the IEA demonstrated in its 2011 *World Energy Outlook*, coal will provide more than half of the on-grid electricity needed to meet its own modest energy-for-all goal.[3] Much of this will be delivered in countries representing an arc through developing Asia, beginning

**A shopkeeper carries his rented lantern during a blackout in Karachi, Pakistan.**

with Uzbekistan in the west through Pakistan and India and then into Southeast Asia and including some of the most dynamic economies in the world. Around half of the world's 1.3 billion people without access to electricity live in the region. A recent study shows the sheer scale of demand for coal-based electricity in the region. Outside of India and China, around 100 GW of coal-fired plants are planned, but on their own these two countries plan an additional 500 GW each.[4]

Many of these countries have significant coal reserves available for domestic production or can easily and affordably import coal from nearby markets. Already utilizing coal to at least some degree, many of these countries have coal infrastructure in place or can easily develop it. Very few have the necessary infrastructure to support significant growth in the gas sector, even in the medium term. For almost all these countries the role to be played by renewables will be limited to off-grid and mini-grid solutions.

If serious progress is to be made for economic development, that leaves coal as the clear choice when considering the energy needs associated with developing and growing modern economies in those countries. Those that do already rely on coal to some degree will likely continue to do so in the future. The bank will also have an important role in helping replace aging power plants with more efficient and cleaner 21st-century coal technology.

## SOME EXAMPLES

In this region, Pakistan is one country that is taking decisive steps to improve its energy situation by accessing its coal reserves. Around half of Pakistan's population live without access to electricity and installed capacity is around 100 MW per million of population (compared to around 2800 MW in the U.S.). Pakistan's government is planning more than 7 GW of new coal power in the near term, much of it intended to replace reliance on expensive aging oil power plants. Pakistan has extensive reserves of coal, estimated at around 170 billion tonnes, in the Thar Desert, which can help fuel its economic development. Even more importantly, the Ministry of Water and Power says switching to coal will help save around US$26 billion in fuel costs over the next 15 years.

**After training, apprentices can be qualified to work at the Medupi power plant.**

*Photo:* Hitachi Power Africa Pty. Ltd.

However, the demand for coal-fired electricity extends well beyond Asia. Southern Africa in particular has significant coal reserves, which are being used to bring electricity to countries with major energy access challenges. South Africa itself is a good example, where more than a quarter of the population live without electricity access. It is also the recipient of the World Bank's most recent funding for coal, a project that drew significant controversy. The 4800-MW Medupi power station has received more than US$3 billion in funding from the bank and, according to Eskom, the project operator, will directly grow South Africa's economy by approximately 0.35% a year. The Medupi coal power station will be the first in Africa to use supercritical technology, employed in most high-income countries for new coal power generation. Using these efficient technologies does make a significant difference in reducing emissions from coal power plants—a pointer to the fact that the bank's involvement can help see cleaner, more efficient technologies deployed. The project is a clear demonstration of how the bank has effectively already been applying its climate-conscious framework to decisions about funding for coal—and demonstrates how climate and development priorities can be implemented in an integrated way.

## THE IMMEDIATE TEST TO COME

If implementation of the World Bank's new policy is the question, then we will not have to wait too long for the answer. The test will come in Kosovo where the government hopes to build a new 600-MW lignite plant. The bank will soon be in the position of needing to decide whether to provide loan guarantees to enable the project to go ahead.

There is already significant opposition to the project from environmental groups in Kosovo, Europe, and elsewhere. If the bank does decide to support the project it will surely come in for criticism. However, such a decision would show how recent policy changes can be made to work. Speaking recently about the Kosovo question, the bank's president, Jim Yong Kim, spoke surprisingly strongly about the importance of its development

**The harsh winters in Kosovo (Prizren shown here) mean that access to reliable energy is critical.**
*Photo:* Diedon Maloku

and humanitarian roles. "The climate change and the coal issue is one thing," he said, "but the humanitarian issue is another, and we cannot turn our backs on the people of Kosovo who face freezing to death if we don't move in."[5]

The Kosovo project would see the replacement of a Soviet-era coal plant, considered to be the biggest point-source of pollution in Europe, with a much more modern and reliable plant, capable of significantly improving energy supplies in the country. Kosovo is one of Europe's poorest economies. The high cost of accessing its unreliable electricity leaves its population of almost two million locked into a struggling economy with unemployment at around 45%, with little hope of finding warmth through harsh winters.

The Kosovo example clearly fits within the World Bank's scenario 2 where coal projects should be considered eligible for funding. According to its own analysis, the proposed new plant "is the least expensive thermal option, even when the relatively higher environmental costs are priced in,"[6] meaning that the plant beats the bank's clearly defined preference for gas when other energy sources are not suitable.

If the Kosovo project is ultimately supported by the World Bank, then there is a real prospect that recent policy changes can be made to work. It will demonstrate that in situations where lack of energy constricts development and coal is the preeminent choice, based on a range of criteria to address that challenge, then the bank may be willing to act. It may show that a more reasonable balance can be struck between climate and development objectives.

If the World Bank takes this lead, then it is likely that other development banks will take a similar approach.

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# Energy Literacy:

## Why Telling the Story of Coal in Australia Is Important to Its Long-Term Success

**By Nikki Williams**
Former CEO, Australian Coal Association (now merged with the Minerals Council of Australia)

The year 2013 is a pivotal time for the Australian coal industry. As this issue of *Cornerstone* is published, a national election has recently been concluded. Whichever political party takes office, the new government will be responsible for setting the nation on a different, more prudent, cohesive, and productive course. For coal, Australia's second-largest export industry, it is vital that economic, taxation, regulatory, and budget policies provide the framework to strengthen coal's productivity and international competitiveness. Environmental regulations and energy and climate change policies must be designed so that they underpin—rather than damage—the future of coal as an export industry.

Amid the noise of electioneering and with such big-picture policies under the microscope, it has been difficult to focus attention on the topic of energy literacy, even though it is vitally important to the public debate about Australia's future. A clear understanding of coal, and knowledge of issues around energy security and climate change, is needed among Australians if the coal industry is to secure ongoing support from the community and sensible policies from government. Currently, the reverse holds true. The community has limited understanding of the myriad of issues affecting the future of coal; and what knowledge it does have is largely being provided by governments and bureaucracies which themselves often lack insight into the sector. A case, perhaps, of the blind leading the blind.

**Coal supplies approximately 75% of Australia's grid electricity, supporting modern infrastructure in cities such as Brisbane.**

***"A clear understanding of coal, and knowledge of issues … is needed among Australians if the coal industry is to secure ongoing support from the community and sensible policies from government."***

This blindness is perplexing given the centrality of coal to Australia's economic success. Since coal was discovered in the late 18th century, it has provided Australia with competitively priced electricity, ensuring a solid foundation for a globally competitive industrial base, and contributed to the manufacture of the steel and cement needed for the construction of a growing nation. Today, coal is Australia's second-largest export commodity; the coal economy is worth around AUD$60 billion (2011–2012) and employs directly and indirectly some 180,000 people. Importantly, coal-fired energy supplies 75% of the nation's grid electricity. Australia's coal exports are helping to fuel countries around the world that need affordable and reliable energy to light their homes and offices and to build the critical infrastructure that underpins economic growth. There is a direct nexus between the rate of electrification of a society and its level of poverty. Eradicating energy poverty has become one of the most important pillars of global efforts to bridge the gap between the first and fourth worlds. It is for this reason that global coal use is projected to continue rising.

So why then do we need to tell the story of coal?

## DEMONIZING COAL

The emergence of climate change as an issue in the 1990s put the Australian coal industry under an intense spotlight and led to serious questioning of the industry's role. The emissions generated from the production and utilization of coal have led to an unsettling picture of coal as a dangerous source of climate change. This picture has replaced the traditional understanding of coal as an invaluable mineral. Activists have launched a coordinated, sophisticated, but shrill anti-coal campaign that knowingly peddles misinformation about, and fear of, coal. Regular media stunts and protests continually muddy the waters and, in the absence of clear statements from political leaders, these simplistic and untruthful views are given higher profile than they merit. The coal industry has been easy to demonize by activist groups because of poor understanding of how energy is produced and the challenges involved in simultaneously meeting energy demand and abating greenhouse emissions.

A sensible debate is difficult, if not impossible, in the current Australian environment. The government's poorly framed and communicated policies have contributed to the problem. Government policies have been pitched so as to create the perception that all renewable energy sources are inherently “good”, all coal is “bad”, and gas is somewhere in between (often failing to recognize that gas too is a fossil fuel that will become part of the climate change problem by 2017). This one-dimensional characterization means that low-emissions technologies that apply to fossil fuels, notably carbon capture and storage (CCS), are not regarded as part of the solution to lowering emissions. The widespread view of coal—as an industry of the past and irrelevant to our future—has emboldened activists to openly campaign for the immediate closure of the industry.

***“A sensible debate is difficult, if not impossible, in the current Australian environment.“***

Another contributing factor is the dislocation between climate change and energy policies in Australia. These policies should be intimately entwined, but energy policy has been a poor cousin to climate policy, with low priority given to energy security, affordability, and Australia's position as a global energy exporter. The major political parties have been fundamentally at odds over approaches to energy and climate change policy. They have not seen it in their interest to broaden and deepen the public conversation about energy. Indeed, highly polarized, almost tribal calls to action have provided fertile ground for myths to mushroom.

**Australia’s elected officials have a responsibility to address energy policy in a prudent, effective manner.**

## ENERGY LITERACY AND THE STORY OF COAL

The task for Australian governments, alongside the fossil fuel sector, is to start explaining the full breadth of the impacts of climate policies, the sources and costs of future energy options, and the technologies that support them. A sound foundation of energy literacy is needed so that Australians can have an informed debate about the challenges that lie ahead.

The term *energy literacy* is understood by those involved in the energy sector. It would be wrong to assume, however, that there is a universal understanding of its meaning. At its most elementary level, energy literacy connotes knowledge of energy: the energy facts of life. This refers to basic content knowledge around energy use and generation; how much energy is used by individuals, sectors, or nations; and where the energy comes from: fossil fuel or other forms. Content knowledge includes a grasp of straightforward energy terminology, such as units of measurement for energy and greenhouse gas emissions.

A higher level of literacy means the comprehension of energy issues, which goes beyond knowledge alone. It requires the skills to assess information, judge its significance, and use it to consider a problem, debate the merits of alternative options, and propose a solution. This grasp of energy information is critical to conducting a sophisticated debate about the coal


**A Greenpeace ship sails in Sydney Harbor before heading to the Great Barrier Reef in Queensland, Australia, where activists boarded a coal carrier to protest against Australia's coal exports.**
*Photo:* Corbis Images

industry, energy policies, and low-emissions technology solutions to carbon abatement.

With energy knowledge comes the ability to analyze the issues that surround energy and its generation, energy-intensive manufacturing, coal in the economy, and the related aspects of climate change and carbon abatement. The objective of energy literacy initiatives is to create an energy-literate individual who has the capacity to understand the scale and dimension of the challenges that lie ahead for Australia, and the world, as the transition to a low-carbon economy progresses. An energy-literate community is better prepared to influence government to develop policies and solutions that reflect community goals. It has the power to drive change in democracies such as Australia's.

The task of improving energy literacy begins with "telling the story" of coal. The story starts with the facts about coal and its role in bringing prosperity to the nation. The production and utilization of both metallurgical and thermal coal contribute in many ways that are not recognized. The AUD$3 billion a year paid in royalties to state governments by the industry, for example, helps to support state services including schools, hospitals, and police forces. A further AUD$10 billion is paid in direct and indirect taxes to the federal government and AUD$5 billion is paid in wages to the many people working directly in the coal industry. The benefits of coal mining are vital to the life of rural and regional Australia, where most mines are located. The coal industry is a major export earner, contributing directly to the standard of living of all Australians. The jobs of the 1.1 million Australians who work in energy-intensive manufacturing depend on reliable and competitively priced electricity, which is provided by coal. Coal is also the critical ingredient for steel and cement production. The story of coal involves many strands because coal's place in Australia's economy and society is multi-dimensional.

***"The task of improving energy literacy begins with 'telling the story' of coal."***

The story of coal needs to be told so that citizens can embrace and absorb the facts about energy, energy security, and climate change in Australia. This would mean that Australians would understand how electricity is generated; who uses energy, in what amounts, and when; sources of Australia's carbon emissions; what the alternative sources and costs of energy available in Australia are; what energy sources will work most efficiently in the Australian environment; and the array of low-emissions technologies needed in the energy mix of the future. The energy facts about coal will enable analysis of the issues. Key framework issues involve an appreciation of the size and dimension of the emissions abatement challenge; how Australia can safeguard coal as a major export industry given the contribution of greenhouse gases to climate change; how Australia can maximize the benefits of Australia's rich coal reserves; and how coal can play its part in nation building in Australia, and in developing countries, through energy poverty alleviation.

Energy "illiteracy" ultimately creates unrealistic expectations of how easy it is for Australia to transition to a low-carbon economy. It further leads to the damaging view that renewables are the only solution to reducing emissions, a conclusion which excludes the necessity to develop CCS and other low-emissions technologies as part of the energy mix. Energy illiteracy has already led to needlessly expensive investments. The Australian electricity sector and those industries which rely on affordable energy (like aluminium smelting, for example) are becoming increasingly uncompetitive: a fact now dawning on Australians as they face exponential increases in their electricity bills.

## POLICY CHANGE IN AUSTRALIA

A key reason for improving energy literacy is to drive robust and strategically formulated government policy. Governments, in democracies such as Australia, respond to and reflect community sentiment. Lack of community knowledge can, and has, hindered proper policy development. To date, Australian governments have done little to assist community understanding of the enormity of the challenges that lie ahead in Australia's energy transformation.

In the lead-up to Australia's election, the incumbent Labor Government has already changed its climate change policy. In 2012, Labor launched its climate change policy through a group of measures called the Clean Energy Future Package. Its centerpiece was the introduction of a fixed carbon price of AUD$23/tonne. In July, however, the fixed price period was truncated and the floating price changed to take effect in 2015, in a more rapid transition to an Emissions Trading Scheme. The design of the Labor carbon pricing scheme has always damaged the competitiveness of the Australian coal industry not only because it is the highest in the world but because it uniquely taxes the mining, rather than only the combustion, of coal. No Australian coal competitor faces such a carbon tax quantum.

In presenting Australians with the “clean energy future”, the Labor Government promoted the idea that lowering Australia's greenhouse emissions would involve a simple and painless shift to renewable energies. The policy documents and public collateral have been resplendent with images of wind turbines and blue skies. At a policy level, coal is specifically excluded from receiving any funding for R&D, regardless of the fact that three-quarters of Australia's electricity is generated from coal. Such a policy approach reflects a pro-renewable and anti-fossil fuel ideology. Creating policy on this basis is all the more remarkable and irrational when Australia is such a resource-rich, coal-reliant economy.

One element of government policy is called the Renewable Energy Target (RET), which mandates that 20% of Australia's electricity should be sourced from renewable energy by 2020. The RET was introduced to encourage the generation of electricity from renewable sources and reduce greenhouse emissions in the electricity sector. The impact of the RET, however, has been

**Nikki Williams, former CEO of the Australian Coal Association, which has now been incorporated into the Minerals Council of Australia, strongly advocates improved energy literacy.**

to contribute to increases in the price of electricity (now being seen in consumer and business electricity bills) and distortions of the energy market. The RET has effectively forced the highest cost, most mature renewable technologies into the energy supply. The RET is now discouraging investment in base-load power and electricity that can manage demand during peak periods. With Australia’s carbon tax now in place, the RET is increasing the cost of achieving Australia's target for carbon abatement. Unfortunately, the RET is not driving any reductions in emissions.

The RET policy, together with the Clean Energy Future measures, are examples of how poor energy literacy has seen incorrect perceptions entrenched. In this case, renewable solutions are believed to be the “best”. However, Australians are unaware of the high cost of the RET and the impact of a growing share of inherently intermittent renewables on grid stability. Australia must have supplementary, traditional base-load back-up to support renewables. As an island nation, with a virtually linear grid, Australia—unlike Europe—cannot call on neighboring countries to supply base-load power when needed. Australia's geography, its network of coal-fired power generators, its electricity distribution, not to mention extensive coal reserves, mean coal-fired generation is the lowest cost and most reliable source of electricity. These issues are fundamental to policy but are ignored in the debate.

## USING ENERGY LITERACY TO IMPROVE POLICIES

A high level of literacy means that people will have the knowledge and the skills to think critically about energy challenges so as to make informed judgments and decisions. The story of coal needs to be told in a new, more complete way, once the facts and issues have been explained and understood. The story should unfold logically, leading to the understanding that CCS is a critical low-emissions technology that must be deployed in the future. In short, the coal story could look something like the following:

- Coal is needed to meet Australian and world energy demand.
- CCS is critical to Australia abating carbon emissions from coal and gas while providing crucial electricity and nation-building materials.
- A rapid move away from coal will damage Australia's energy security and reduce the wealth that coal contributes to the economy and every Australian.
- Activists campaigning against coal in Australia are jeopardizing Australian jobs and economic competitiveness along with efforts to give the world's poorest people access to affordable electricity and an improved quality of life.

The importance of the energy literacy endeavor was finally acknowledged by government less than a year ago. In developing a new energy policy in 2012, the Labor Government identified energy literacy as important to advancing policy and gaining community support for energy initiatives. This view was supported by academics, industry groups, energy providers, retailers, and consumer groups in their submissions. The government expressed the challenge in this way[1]:

> *Australia must have a mature, informed and ongoing public dialogue on our energy future, the transition to clean energy, and ways to reduce our greenhouse gas emissions.*
>
> *As a society, we face potentially difficult decisions about the pace and strength of our efforts, the environmental, social and economic impacts, and the policies that will be needed to drive the transition.*

The Australian coal industry intends to reinforce this view in the coming years in its work with all levels of government. A partnership is needed between governments, industry, stakeholders, and the public to improve national energy literacy. The community needs facts, not myths, to underpin its understanding of the opportunities and challenges that lie ahead. Through better energy literacy, governments would be supported to set policies that reflect broad economic, environmental, and energy objectives. Energy literacy is an untapped resource for Australia which requires urgent attention and national support.

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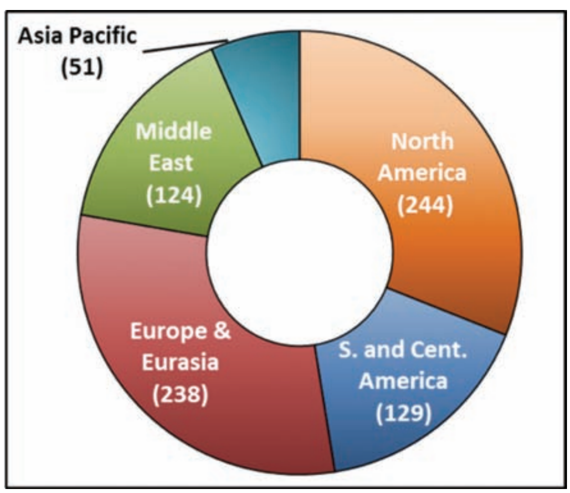
# How Long Will Global Coal Resources Last?

Already well established, the international coal trade will continue to grow in importance as some regions produce their proven reserves of coal faster than others. The figure at the right was reproduced using data from the BP 2013 Statistical Review. In the figure, the years of production that can be sustained at current rates are shown in parenthesis. Note that, at current production rates, North America has 244 years of proven coal reserves and Europe and Eurasia have 238 years. The Asia Pacific region, which includes Australia, China, and India, has only 51 years of proven coal reserves at current production rates. Actually, the coal reserves in the Asia Pacific are higher than any other region, but production has increased dramatically in this region recently, leading to coal being the fastest growing fossil fuel. Examining the reserves-to-production ratio highlights the increasingly important role that the international coal trade could play in the future.




*Source*: 2013 BP Statistical Review (www.bp.com)

# Winning Public Support for the Future of Coal

By Robin Batterham
Kernot Professor of Engineering,
The University of Melbourne

The International Energy Agency has projected that coal use will continue to grow and will overtake oil as the most used energy source as soon as 2017.[1] In the first article of this two-part series, the importance of innovation was highlighted as a necessity to keep the coal industry competitive.[2] However, even if the coal industry maintains financial competitiveness, it must also maintain the public license to operate, which could be threatened by the perception of a lack of sustainability.

## MAINTAINING THE PUBLIC LICENSE TO OPERATE

In many countries mining and sustainability are viewed as impossible to reconcile. This is, however, an illogical position and we are best to start from the original Bruntland definition[3] of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It is all about present needs and the needs of future generations. Given that coal will be abundantly available for the next few hundred years, whether coal as a resource is exhausted is barely relevant in terms of the needs of future generations. What is important, however, is that existing mines treat sustainability in an integrated manner, not just as a public face to environmental efforts, which is too easily dismissed as "green wash".


**Can a low-emission coal-fired power plant, such as Boundary Dam with CCS, be considered sustainable similar to renewable energy sources?**

> ***"Lower emission power generation is what the world needs, not renewables per se. Under this mantra coal can rightly claim an ongoing role."***

Maintaining the public license to operate with coal requires attention to three points:

- The need for low-emission energy is growing.
- Coal use will ultimately decline when replacements are seen as more sustainable.
- Current operations must focus on sustainability.

### The Need for Low-Emission Energy, *Not* for Renewables

Globally there has been quite extraordinary support from governments around the world, almost without exception, to increase the amount of renewables used for power generation. The Organization for Economic Co-operation and Development (OECD) has reviewed the numerous schemes in place and shown that some are far more effective economically than others at phasing in renewables.[3] In short, the value of the massive cost to the public of feed-in tariffs and renewable energy certificates is questionable; Johnstone[3] shows convincingly that the general innovative capacity of a country is a far more powerful predictor of implementation of low-emission technology than feed-in tariffs or mandated levels of renewables.

The fact that the public and governments have focused on renewables instead of low-emission energy puts the coal industry in a difficult position. The response of the industry must be to emphasize that coal can also be a low-emission energy source. By adopting this position, coal can be seen as just as worthy as any other technology, at least for the present.

For existing power plants and their supply chains, the opportunities for emission reduction lie mainly in the upstream processing (mining, coal cleaning, and transport) and in carbon capture, use, and storage (CCUS). For new power plants, far more opportunities for emission reduction exist, as the Chinese have demonstrated. The economic drivers are there for new plants (minimize cost of coal) and for existing upgrades; what is needed is a price on carbon that encourages emission reduction rather than more renewables per se.

A more unified voice from the industry would help; in particular, one emphasizing that lower emissions are the target and there are many paths to achieve this—more power from the same amount of coal, energy efficiency employed more widely, and renewables. The debate must be shifted from *"we dream of 90% renewables"* to *"we dream of 90% emission reduction".*

If we talk of clean coal we often cause confusion, because some may believe that coal is inherently not clean, just as some see mining as essentially nonsustainable. My suggestion is to avoid, wherever possible, using the term *"clean coal"* and opt for *"lower emission coal"*.

## The Ultimate Future for Coal

This is a touchy point for the industry, especially those parts that have achieved significant emission reductions already and are working hard on CCUS with emission reduction targets of 90% versus present levels. I suggest, however, that the coal industry could and should adopt the position that *"in the longer term, coal use will decline when replacements are seen as more sustainable".* By admitting that coal use will ultimately decline, much of the sentiment and protest currently leveled at the industry is deflected. By dwelling on the importance of sustainability, this approach emphasizes present needs and the intent not to compromise the needs of future generations. As we explored in the first part of this series, the coal industry exists within a highly competitive environment, and accepting that others may, in the long run, out-compete us is hardly novel. The key is that we keep coming back to the pillars of sustainability: the people in our industry, the wider community, the environment, and economics.

It is inevitable that coal will only ever be one of the sources for power generation. This is quite an advantage in that it reinforces that there is legitimacy in other approaches. Choices should flow from sustainability assessments, not emotional beliefs that one form of power supply is superior to others. As an example, consider the recent decision to alter the power mix in Germany. Leaving aside their aspirational target of 90% renewables by 2050, the power mix in Germany is already at the point where the only reason widespread brownouts have not occurred in southern Germany is that power from the north is transmitted to the south courtesy of spare capacity in adjoining countries (hardly sustainable!) and that major power users in industry are required to shed load at certain times (again hardly sustainable economically). All of this has occurred where a feed-in tariff has distorted prices markedly, but has not resulted in a sustainable photovoltaics industry. When government initiatives are driven by emotion rather than sustainability, one should expect strange outcomes.

## *The Sustainable Mantra for Coal*

All of this argues against trying to push the mantra of "clean coal" and instead adopting two clear, positive points:

- Coal can deliver lower emissions sustainably.
- Coal use for power will cease when replacements are seen as more sustainable.

## *Hybrid Solutions as Part of Sustainability*

One of the more obvious ways for coal-fired power stations to reduce emissions is to work with hybrid solutions, e.g., rapid heat-up to allow better load following when wind and solar drop off. A consortium of companies, researchers, and government are exploring this option in northern Germany. Thus far, it has demonstrated great potential. In a similar vein, rapid start, rapid ramp rate coal-fired plants, such as the direct injection coal engine, could potentially offer a means to support greater proportions of renewables in a grid in the same way that open-cycle gas turbine plants can support renewables, potentially at a lower cost than with gas.

The review article by Huang Qili from Issue 1 of *Cornerstone* concludes with a section on the use of coal with renewable energy as hybrid power generation options.[4] There are, of course, many demonstration-level plants operating around the world pursuing this opportunity. Most concentrate on solar heating boiler feed water to intermediate temperatures, thereby avoiding steam bleeds in the turbine train.

Further alternatives include cofiring of biomass together with coal. This was also included in the recent article by Edward Rubin.[5] Experience with this around the world is also considerable, and the challenges here are largely economic rather than technological. Agricultural and other biowastes can be pelletized with fine coal or used directly. The obvious challenge is that thermal capacity is generally down-rated so that there has to be a price on carbon or some savings in eliminating the waste to make the project economically feasible.

A more economic route is likely to be the use of geothermal heat directly in existing coal-fired power stations. The idea is not new,[6] but it has quite some advantages since there is no new technology involved on the power station side. One merely bypasses the existing boiler feedwater heaters and runs the boiler feedwater through heat exchanges fed by a geothermal loop. The footprint required is low and the technological risk to the power station is minimal in that, as a retrofit, the plant would retain the ability to return to its original configuration. From the geothermal side, it simplifies things considerably in that temperatures of 150°C would be more economical than the present targets of 180°C or higher. This means that drilling costs could be reduced as target temperatures might be achieved at 3-km depth rather than 4–5 km. This is especially relevant where there are thick coal seams, as is often the case near power stations. Such coal seams act as thermal blankets because the conductivity of coal is almost an order of magnitude lower than that of most rocks. In addition, geothermal that can tap into existing infrastructure is obviously far more economic than having to build stand-alone power plants plus transmission lines.

Overall, hybrid solutions offer practical and potentially economic ways to demonstrate that coal can deliver lower emissions in a sustainable manner.

## Focusing on Sustainability

The third necessary element of maintaining a license to operate is that present (and future) operations have to demonstrate that they are focusing on sustainability. Sustainability must permeate every part of a business if it is to meet the multiple objectives of social well-being, environmental stewardship, and economic prosperity, both during the life of the mine and after closure. It is also not about single projects or even what a single company can do on its own. As soon as stakeholders beyond the company are involved, as they must be, life gets complicated.

There is much good practice within the industry already and the sharing of this practice is highly desirable. The better performers focus in four directions.

### *Sustainability for People*

Maintaining the health, safety, and well-being of workers is, for many, the highest priority. The notion of zero harm is now widespread. Employment opportunities for indigenous communities and other special groups are also a key priority.

### *Sustainability for the Environment*

Environmental stewardship must be a core value of a company and actions should be visible. Minimizing the impacts and risks associated with operations is the starting point. Further extension is practiced to improve operations and to tackle long-term legacy issues well beyond that required by regulations. A risk-based approach such as the International Standard ISO 14001 ensures that environmental risks are assessed and controlled, and performance is continually improved.

### *Sustainable Economic Performance*

The economics of an operation must be positive. Sustainable development is not possible without sustainable economics. Innovation, as discussed in the first article of this series, plays a key role in ensuring sustainable economics.

### *Sustainability for Wider Stakeholders*

The Rio Tinto Iron Ore Sustainability Report summarizes well what is needed[7]: "We strive to develop enduring relationships with our neighbors built on mutual respect, active partnerships, and long-term commitment. We seek to understand the social, environmental, and economic implications of our activities on our host communities. We work collaboratively with communities and stakeholders."

> ***"The debate must be shifted from* 'we dream of 90% renewables' *to* 'we dream of 90% emission reduction'.*"***

To make these four key elements work for most companies, it is necessary to be very analytic in understanding the different needs of the external stakeholders and to accept that it is not possible to satisfy all needs simultaneously. The situation has been well summarized recently by Reggio and Lane, as is shown in Figure 1.[8]

Much is happening on the sustainability front in the coal industry that suggests that this part of the license to operate is achievable for the foreseeable future.

Engagement with the wider community is time consuming and ongoing. Some agreements take years and then must still be seen as working documents. There is a valuable lesson in how two countries have approached the permanent storage of

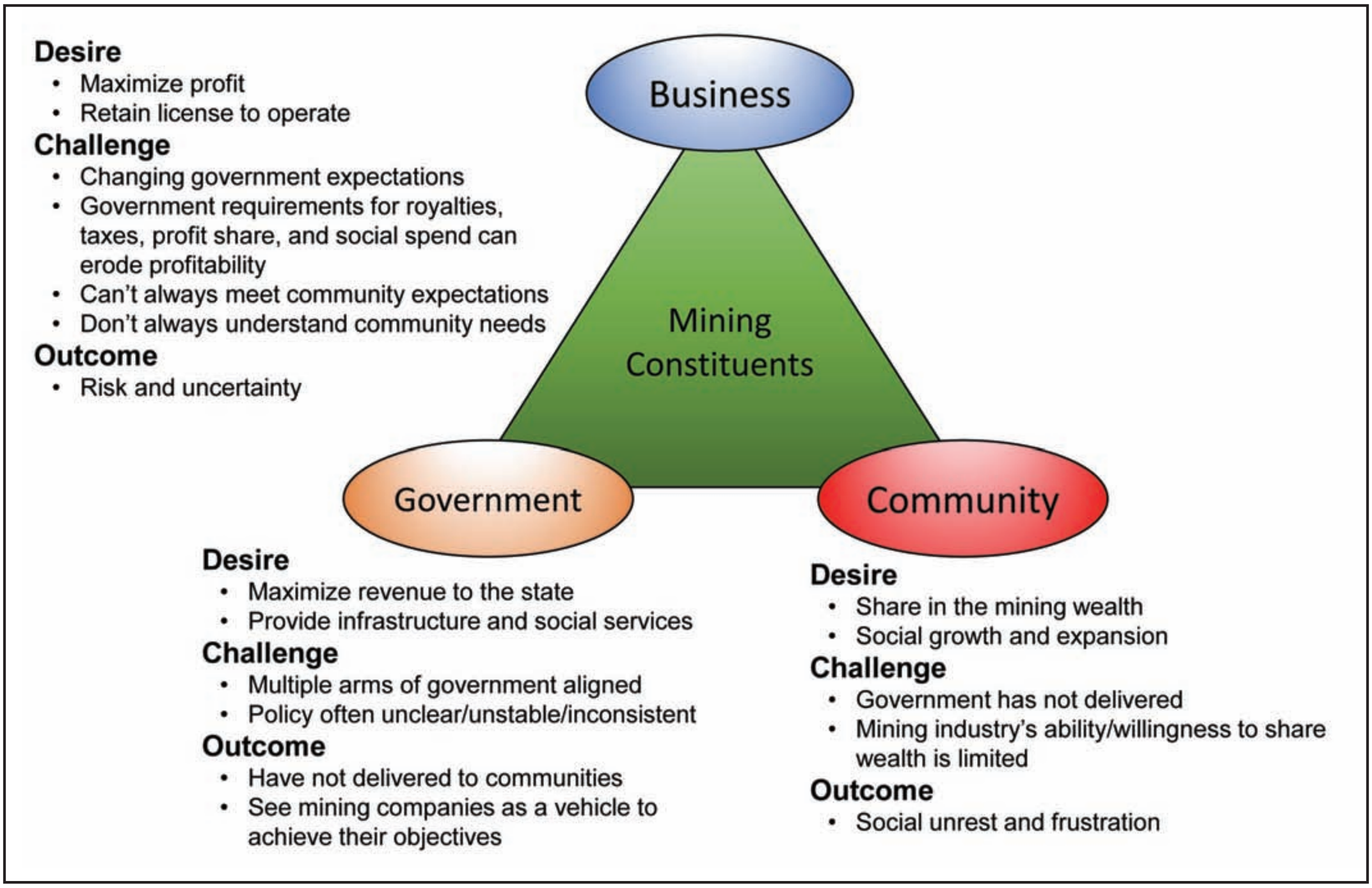



**FIGURE 1. Understanding the stakeholders[8]**

nuclear waste with very different results. In Sweden, an antinuclear country, negotiations started in 1983 with full consultations. Agreement was reached for a repository in 2009. In the U.S., Yucca Mountain was selected without a similar level of consultation. Despite billions of dollars spent on the technical aspects of Yucca Mountain as a permanent repository, agreement on the site has yet to be achieved.

## WILL THE COAL INDUSTRY LOSE ITS LICENSE TO OPERATE?

In this article three key elements have been suggested. On the sustainability front, there is solid evidence of strong performance and an awareness of the challenges by many parts of the coal industry. In the other areas of coal being seen as delivering lower emissions and of moving out of power generation when replacements are seen as more sustainable, there is still a long way to go.

Lower emission power generation is what the world needs, not renewables per se. Under this mantra coal can rightly claim an ongoing role. Coal is part of the solution.

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The author can be reached at r.batterham@unimelb.edu.au.

# German Federal Energy Policy:
## Party Platforms

**By Nicholas Newman**
Contributing Author, *Cornerstone*

Germany is the biggest energy market in Europe. It ranks fourth in the world for consumption of coal and sixth in consumption of oil and natural gas. In terms of electricity generation, the country has an installed capacity of 165 GW, of which 88.4 GW is thermal, 12.1 GW is nuclear (nine reactors), 29 GW is wind, and 24.9 GW is solar PV (at end-2011).[1] Imports account for two-thirds of Germany's energy consumption.

Germany's federal election was held on 22 September 2013. During campaigning all the political parties supported the country's dash toward renewables and the promise, following the Fukushima disaster, to close all nuclear power stations by 2022. Nevertheless, there is an increasing realization that the Renewable Energy Sources Act of 2000, which promised 20 years of guaranteed prices and priority access to the power grid together with the promised closure of 16% of the country's electricity capacity, has created unintended consequences of price distortions, surging costs, and the threat of blackouts. Because renewables are dispatched first regardless of price, the very success of renewables has meant that the spot price of electricity has fallen to a level at which modern natural gas power plants have become uncompetitive with coal-fired power plants. The consequence has been increased coal-based power generation, fueled by imports of cheap American coal, rising emissions in 2012, and German household bills rising rapidly to around 40–50% above the European Union average. The business sector is counting the cost of Germany's green policies, with applications for exemptions from the renewable energy charge rising to nearly half a million (*Der Spiegel*, 15 July 2013)[2], loss of international competitiveness, and threats to shift operations abroad. This dawning reality of green energy at very high cost versus jobs and households' standard of living is the central dilemma facing the political parties that form the next coalition government.

**Germany's policy of dispatching power from renewable energy, such as these wind turbines near Lauterbach, before other sources of electricity regardless of market price has had the unintentional effect of squeezing out natural gas and increasing power generation from coal.**

> *"The business sector is counting the cost of Germany's green policies with … loss of international competitiveness, and threats to shift operations abroad."*

### POLITICAL BACKGROUND

There are six political parties in the Federal Parliament known as the Bunderstag. Currently, Chancellor Merkel leads a governing coalition comprising her party, the Christian Democratic Union (CDU), and her allies, the Christian Social Union (CSU) and the Free Democratic Party (FDP). The current opposition consists of the Social Democratic Party (SPD), The Left (Die Linke), and The Greens (Die Grünen). The recent election results could lead to a coalition, led by Chancellor Merkel, made up of both left-of-center parties, including the SPD and The Greens, and right-of-center parties, the CDU, and CSU. Because of the tradition of coalition government, party leaders have to form alliances and make compromises to ensure membership in the eventual governing coalition. It is not surprising that each party's election platform manifesto is opaque and differentiation is minimal—for the parties are appealing not only to the national voting public, but to business and industries' sectors as well as state governments. In these circumstances few parties or candidates offer a distinctive position on energy policy, let alone its essential components.

## THE PARTIES AND THEIR ENERGY POLICIES

### Power Prices

German consumers' electricity bills are 40–50% above the EU average of €0.165 per kilowatt-hour in order to pay for government subsidies for renewable energy as well as the cost of exemptions granted to approved industrial high-energy users and local taxes. The realization that a list of 1550 firms that are exempt from paying the green subsidy includes golf clubs and coal mines, and a claim by Felix Mathes, an analyst at the Öko-Institut, that "at least half the companies don't belong on this list"[3] have shocked long-suffering householders and small businesses. In this election year, Chancellor Merkel has promised to reduce the US$24 billion per year green subsidy and tweak the feed-in tariff to reduce price distortions arising from the huge expansion of renewable power and priority access to the grid. The opposition The Greens estimate that exempt companies will save up to €4 billion (US$5.3 billion) while electricity bills for private energy customers and smaller businesses will increase by a corresponding amount. The European Union's Competition Commissioner, Joaquin Almunia, believes that such corporate exemptions from the green subsidy charges contravene EU Competition Law. In response to this and to voter disquiet, Chancellor Merkel has announced that she is willing to amend entitlements for corporate exemptions. The FDP recognizes the need for affordable power prices while saying nothing about remedies; the SPD supports energy price regulation and cost limits.

**Chancellor Merkel will lead a broad coalition as a result of the 2013 elections; this coalition will be facing major challenges related to the energy sector.**
*Photo:* Wikimedia Commons

***"German consumers' electricity bills are 40–50% above the EU average of €0.165 per kilowatt-hour in order to pay for government subsidies for renewable energy as well as the cost of exemptions granted to approved industrial high-energy users and local taxes."***

### Coal Power

Alongside renewables, Germany is making a dash for coal, with eight new coal power stations with a combined capacity of 5800 MW, enough to provide 7% of Germany's electricity needs, opening in 2012–2013. By 2020, another 12 new coal-fired power stations with sufficient capacity to supply 19% of Germany's power needs are planned.[4] This threat to the environmental agenda led The Greens to declare their wish to see an end to coal-based power generation as soon as possible and a change in the law to prevent the construction of new brown coal mines. The other parties are more equivocal, tending to be supportive toward coal power—not opposing new coal power stations, but insisting that they be of the latest in environmentally friendly technology and capable of being fitted with carbon capture and storage technology, when it became commercially feasible. Specifically, "the CDU supports coal power as a method to balance out power fluctuations. The SPD tends to be ambivalent about coal power, thanks in part to its links to the coal and steel lobby in the country," says Dr. Claudia Kemfert, Deutsches Institut für Wirtschaftsforschung e.V. (DIW Berlin; German Institute for Economic Research).[5] The SPD party candidates in North Rhine-Westphalia and Brandenburg are pro-coal because they represent coal-mining regions while the SPD candidate of Hessen opposes coal generation, in part, because Hessen has no coal mines and no coal-fired generation plants.

## Nuclear Power

All the party manifestos support the objectives of shutting down and decommissioning Germany's nuclear power sector by 2022. The CDU manifesto includes a policy to improve nuclear safety at Europe's remaining nuclear plants; the SPD proposes that Germany withdraw government support for construction of new nuclear power plants abroad. As for The Greens, they propose withdrawing from the EU's EURATOM Treaty. However, the stark economic reality and the fear of blackouts facing the new governing coalition may force a return to the original nuclear closedown schedule set by Chancellor Gerhard Schroder a decade ago. Such a prospect could be likely under a grand coalition. Merkel controls her own party, and the SPD would probably endorse what was their own policy. Business and the unions would also be on board. That would give the nuclear plants at least another decade to operate beyond 2022.

## Gas Power

According to Germany's Federal Institute for Geosciences and Natural Resources, there could be between 6.8 trillion $m^3$ and 22.6 trillion $m^3$ shale gas[6] in place. This is enough to substantially reduce Germany's dependence on imports. Environmentalists in both The Greens and The Left parties are seeking a total ban on fracking (a controversial method of gas extraction), regardless of the energy security and economic benefits it promises. The CDU and SPD simply urge a ban on the hazardous chemicals used in fracking.[7] Germany's brewing industry is calling for a ban on fracking until the risk of water contamination can be ruled out.[8] The brewing industry in Germany employs 25,000 people and had worldwide sales of US$10 billion in 2012. Chancellor Merkel, who drank from a liter-sized traditional beer mug during a campaign rally in Munich in May, has agreed to draft legislation to outlaw fracking in some areas. There is growing public opposition to fracking, which forced Chancellor Merkel to put on hold any decision about it until after the election.[9] No party manifesto strongly promotes gas generation. The CDU require gas power plants to balance power fluctuations from renewables while The Greens mention the need for gas as a bridge-technology in the transition to fully renewable power.

## European Emission Trading System

Germany did nothing to prevent the collapse of the European Emissions Trading System (ETS) and support for its reform is mixed. Dr. Kemfert states, "The CDU is very serious about ETS reform, it wants reform of current weaknesses and introduction of more effective incentives," investing the income from emission trading in furthering the renewables revolution.[5] The FDP, which is a pro-business party, opposes the ETS and prefers to leave things as they are. However, the FDP would like the current ETS system extended to include the heat and transport sectors, since this is likely to increase the price of ETS certificates. As for the SPD, they appear to be ambivalent, perhaps in part due to their historic links to the coal lobby. The Greens, which obtained 10% of the national vote in 2009, wish to introduce a yet-unspecified minimum price for $CO_2$ emission trading certificates. The remaining parties have no known views on reform of the ETS system.

## National Grid and Local Grid Infrastructure

Germany will need to spend US$25 billion over the next decade to upgrade its transmission network with 4500 km of high-voltage power lines and 200,000–400,000 km of medium- and low-voltage power lines to accommodate its fast-expanding renewable-energy sector, reports Deutsche Energie-Agentur GmbH.[10] However, delays in decision making in the year's run-


**Rallies held shortly after the Fukushima disaster, such as this one in Munich, led to a formal plan to decommission all of Germany's nuclear power plants by 2022, a deadline that may prove problematic to meet.**

up to federal elections, lack of cooperation between planning authorities, and postponements caused by lawsuits have hindered infrastructure construction. Ilse Aigner, of the CSU,[11] favors a partial nationalization of the country's electricity grid in order to ensure that the massive power lines required for transporting green energy from northern Germany's off-shore wind farms to the industry-heavy regions of the south are finally built. However, German Economics Minister Philipp Roesler, an FDP party member, has rejected nationalization outrightly.

In addition to the differences between the CSU and FDP over partially nationalizing the new high-voltage power grid, the parties can be divided into two camps. The CDU, SPD, and FDP support modernization and expansion of the network infrastructure at all levels including creating the right financial framework to attract investment; The Greens and The Left[12] support investment focusing on local grids in order to encourage decentralized energy supplies. In addition, The Greens favor all new 110-kV lines being buried in areas of natural beauty, thereby raising the projected costs of this essential work.

## Competition

The Green Party criticizes a lack of competition in the German electricity market. At the wholesale level, renewables enjoy priority access to the national power market, despite being more expensive than both coal and natural gas power. The FDP and The Left party appear to have well-developed policies to promote much needed real competition in energy markets. The other parties favor local competition, by promoting the establishment of local groups of households and businesses jointly setting up local power-generating companies as a method of increasing price competition and attracting local investment.

## KEEPING OPTIONS OPEN

It is clear that all the parties were keeping their options open until after the election for fear of losing votes and allies, yet all, including the CDU, need to maintain their "green" credentials. No politician seems willing to go back on the promise to close down nuclear plants by 2022. Nevertheless, Chancellor Merkel, who will lead the next government, recognizes the trade-off in policy options by saying, "we have to take care that, notwithstanding the need to make progress on environmental protection, we don't weaken our own industrial base."[13] It was on these grounds that she blocked the EU's decision to tighten car emission standards.

It is clear that energy prices are a major issue for both households and business, and Merkel has offered measures to limit future increases. It would not be surprising if, because of potential decommissioning costs, the new governing coalition extended the life of existing nuclear plants. Such a policy shift would dampen the prospects of coal-fueled power stations. More significantly, there is an acknowledgment of the need for leadership and centralization of energy policy. The Left party now calls for a master plan for the energy sector; the SPD favor the creation of a dedicated Department of Energy, and the Green party itself proposes a new government-owned company to lead, plan, coordinate, and implement energy policy.

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The author can be reached at www.nicnewmanoxford.com.

# The Future of Lignite in European and German Energy Policies

**By Hubertus Bardt**
Head, Environment, Energy, Resources Research Unit
Cologne Institute for Economic Research

**Jennifer Striebeck**
Researcher, Environment, Energy, Resources Research Unit
Cologne Institute for Economic Research

Energy policy and environmental policy go hand in hand at the European Union (EU) level. With the adoption of the ambitious 20-20-20 targets in 2009 a clear policy statement has been made by 27 EU member states: calling for a 20% cut in emissions of greenhouse gases by 2020, compared with 1990 levels; a 20% increase in the share of renewable sources in the energy mix; and a 20% cut in energy consumption.[1] Even though a pioneering EU Emissions Trading Scheme (ETS) had already been launched in 2005, the new target set in 2009 demands changes to the ETS in order to reach the ambitious $CO_2$ reduction goal.[2] Concerning the two remaining objectives of a 20% increase of the share of renewables in the energy mix and a 20% decrease in energy consumption, member states pursue diverse strategies with traditionally different energy portfolios at hand. Undoubtedly, the German energy policy has been among the European leaders in environmentally friendly energy policies. However, with the political decision in 2011 to transform the German power sector from a nuclear- and fossil-based system to renewables within four decades, its role as pioneer has been reemphasized.[3] The ambitious goal to transform the German energy system—commonly referred to as *Energiewende*—raises many technical and regulatory questions. Furthermore, it challenges all conventional and, to date, extensively used energy sources such as lignite.[4]

**Although German brown coal mines provide an affordable, secure energy source in Germany, the role of lignite in the future is uncertain amid the country's ambitious $CO_2$ emissions reduction goals.**

> ***"The ambitious goal to transform the German energy system … challenges all conventional and, to date, extensively used energy sources such as lignite."***

## GERMAN ENERGY POLICY AND ENERGIEWENDE

Electricity generation in Germany has traditionally been based on three pillars, as shown in Figure 1. In 2012, lignite was the major source for electricity generation with a contribution of 25.7% of the total. Hard coal and nuclear power generated 19.1% and 16.1%, respectively. In the early 1990s the importance of these three energy sources in the energy mix was even more significant as each resource accounted for more than 26%. Since then, the volume of electricity produced from natural gas has risen sharply, and amounts to 11.6% of total power generation today. Meanwhile, renewable energy sources have become a new pillar of German electricity generation. Between 1992 and 2011 the share of renewable energy grew from 3.8 to 22.1%.

During the past decade the German energy sector was exposed to several significant policy changes, implying new framework conditions for energy production. However, there is a clear trend in terms of orientation toward environmental goals, mostly related to the reduction of greenhouse gas emissions in electricity generation. The most environmentally motivated innovations are summarized in Table 1.

With the German government's decision in spring 2011 to phase out nuclear energy, the framework for German power generation changed abruptly. In light of the nuclear accident in Fukushima, eight German nuclear power plants were shut down: temporarily at first, and then eight months later the shutdowns were made permanent. The remaining German nuclear power plants are scheduled to be shut down by 2022.[7]

The federal government has put forward ambitious objectives for the expansion of renewable energy sources in Germany. According to those objectives the share of wind, solar, biomass, and other renewable energy sources should increase to 80% by 2050, with intermediate targets of 35% renewable energy by 2020 and 50% by 2030. Thereby the development toward an environmentally friendly energy policy in Germany will be continued and reinforced. After an increase of over 16 percentage points in the last two decades, the goal through 2050 is a further increase of about 60 percentage points; however, this target is also based on reduced consumption and production levels. Reduced electricity consumption due to increased efficiency and a rise in electricity imports are therefore assumed to facilitate the increase in the share of electricity production from renewable energy in Germany.

***"With the German government's decision in spring 2011 to phase out nuclear energy, the framework for German power generation changed abruptly."***

## COAL IN A CHANGING ENVIRONMENT

The German Energiewende, with its focus on renewable energy, will bring new challenges for conventional sources, such as the challenge lignite faces to remain Germany's most important domestic resource for energy production. However, lignite can still play an important role even in an energy system largely based on renewable energy. Different scenario calculations lead to various results regarding the expected energy mix in 2030. The respective scenarios are based on the phasing out of nuclear power and the extensive development of renewables. It is anticipated that for the next decade the importance of brown coal will remain quite stable; subsequently it is assumed that the role of lignite in the German energy mix will be stable or decreasing. The different calculations imply a lignite share of 12.5–23% of the electricity mix in Germany by 2030. The lead scenario of the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety anticipates that in 2030, one in eight kWh

**TABLE 1. Key measures toward an environmentally friendly energy policy in Germany**

| *Year* | *Measure* |
|---|---|
| *1991* | Feed-in tariffs for electricity from renewable energy |
| *1998* | Energy and Electricity Tax Act |
| *2000* | Renewable Energy Act (EEG) (amended several times) |
| *2005* | Introduction of European $CO_2$ emissions trading |
| *2010* | Energy concept with lifetime extension of existing nuclear power plants |
| *2011* | Final shutdown of eight nuclear power plants and shortening the maturities for the remaining power plants |

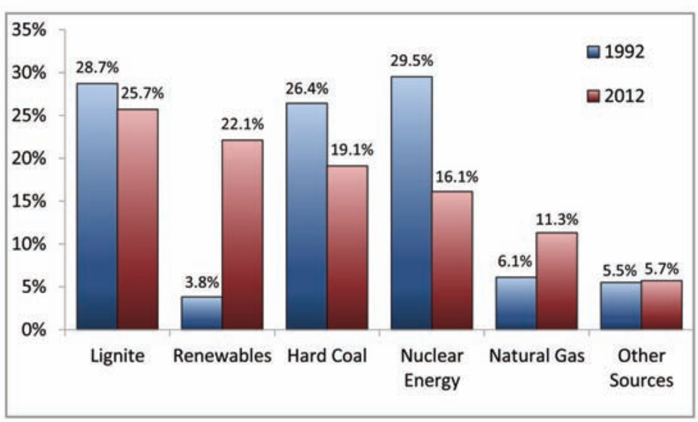


**FIGURE 1. Contributions of energy sources for electricity generation in Germany[5,6]**

will still come from lignite power (see Figure 2).[8] Brown coal can not only make an important contribution to energy security, but is also a convenient and cost-efficient way of generating electricity. Even at a $CO_2$ emission allowances price of €20/tonne,[A] lignite remains—besides nuclear power—the cheapest source of electricity generation. Other fossil energy sources cost 15 to 50% more.[9] Wind, biomass, and photovoltaic energy are significantly more expensive. Unlike oil or hard coal, the price of lignite is not based on competition in international markets where resources from different providers are being traded. Since long-range transport of lignite is not economical, the user of the coal remains bound to the seller, and vice versa. Hence, even if this does not affect the price of electricity, because other power sources are determining the price, the integration and coupling of lignite mining and electricity production lead to cost savings for the lignite industry and thus lower the overall macroeconomic generation costs.

The major challenge regarding the use of lignite for electricity production in the future energy mix is the reduction of greenhouse gas emissions associated with the combustion of coal. First of all, electricity generation from lignite implies relatively high costs for the purchase of emission rights, which decreases economic competitiveness. Hence, if emission certificates become very expensive, the use of brown coal for electricity generation might become uneconomical. Furthermore, due to greenhouse gas emissions, social acceptance of the construction and operation of coal-fired power plants is low. Modernization of the power plant portfolio might serve as a quick, and at the same time economical, solution to reduce emissions from lignite. This will not only contribute to the completion of the power supply in the German energy mix, and therefore secure a stable power supply, but will also contribute to climate protection. However, whether this will be an efficient climate protection measure depends on

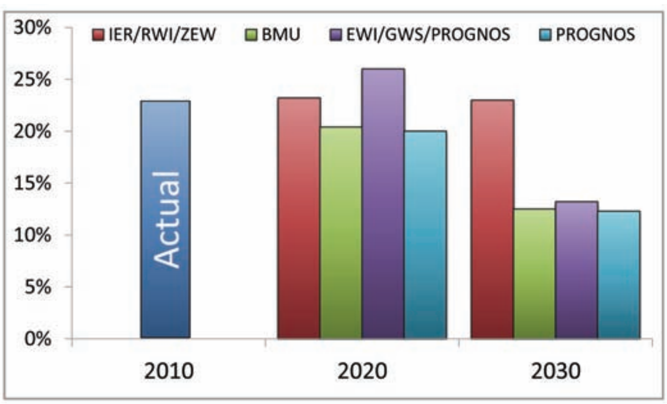


**FIGURE 2. Share of lignite in gross electricity generation: actual value for Germany in 2010, different scenario calculations for 2020 and 2030**[4,8,10–12]

the cost ratio, which is determined by emission trading and its associated price for emitting a tonne of $CO_2$. Modern brown coal power plants can achieve efficiencies of 43% or more. Older power plants which are now going to be shut down, after 40 years of operation, only achieve efficiencies of approximately 32%. By replacing old power plants with modern plants, efficiency could therefore be increased by more than 10 percentage points. This would also lead to significant reductions of $CO_2$ emissions. Based only on power plant efficiency improvement, emissions could be reduced by a quarter. In the future new power plants are expected to reach efficiencies of 45% or more, which corresponds to emissions reductions of at least 30% compared to older power stations. With these kinds of savings, a contribution to climate protection could be made. Ultimately, the issue of economical optimization will determine the future types of power plants.

*"Modernization of the power plant portfolio might serve as a quick, and at the same time economical, solution to reduce emissions from lignite."*

## TOWARD A NEW ENERGY MIX: REGULATION VS. MARKET

In general, the role of the state in the design of the energy mix is arguable. The major question is whether the market or the state should be responsible for the selection of primary energy sources. Certainly, the state has to define the objectives of energy policy. Nevertheless, which energy mix is actually capable of guaranteeing security of supply, economic efficiency, and environmental protection cannot be specified by centralized regulation. Regarding the choice of technology, state neutrality should prevail and market processes should determine which sources of primary energy serve best to achieve these objectives. This can only be attained through a market-governed process of trial and error. The state's role primarily should be to set a consistent regulatory framework that ensures the consideration of environment-related goals. Only stable framework conditions can ensure efficient investment decisions and lead to a well-established energy supply structure in the long run.

The European Emissions Trading Scheme (ETS) provides the decisive means to account for greenhouse gases in the range of primary energy sources for electricity production in the EU.

Within the ETS a market price is assigned to each tonne of $CO_2$. Therefore, a company can either generate electricity with a particular fossil-fueled power plant, and must buy the appropriate allowances for it, or it may dispense with the production of electricity and sell the certificates at the stock market. Which technology is used is therefore determined by the respective cost structures. Depending on the distribution of the costs of the emissions of different technologies, one or the other alternative may be favored. In the case of lignite, all emission rights have to be bought and these must cover all direct emissions from the combustion processes. This combines high initial investment, low running costs, and relatively high costs of emissions trading. Compared to natural gas, electricity generation from lignite is economically beneficial only at higher production volumes—if the fuel price differential is not compensated for by higher costs of emissions.

By setting a clear limit to emissions, the ETS endorses the pursuit if its climate protection objectives. The price mechanism ensures that the most efficient way of reducing greenhouse gas emissions is used, and thereby promotes an economical approach toward climate protection. However, the politically motivated restrictions on emission sources currently lead to lower efficiency. The consequence is that economic costs are generated without positive effects for the climate. Currently, emissions of a single plant are irrelevant to climate change in emissions trading, because the additional emissions in one place are compensated by additional savings elsewhere. From this logic, it follows that rather high emissions from lignite power plants are compatible with climate protection, as long as they can be operated profitably under the terms of emissions trading. This is ultimately dependent on the price of emission rights and thus the upper limit of total emissions.

## CONCLUSIONS

Lignite will continue to play an important role in ensuring the power supply in Germany. As a cheap domestic energy source, it contributes to lower electricity costs and ensures the security of supply. The German Energiewende and the associated greater emphasis on climate change issues in electricity generation imply a particular challenge for lignite in the long run—especially in the framework of the European ETS. However, it would be premature to predict the end of lignite as an energy resource for German electricity generation. It will be rather crucial to combine the advantages of lignite with the requirements of the future. This especially demands the modernization of power plants and the investment in more efficient and climate-friendly technologies. Greater power plant flexibility could enable lignite to remain an important element in Germany's future energy system where it can be used as a complement to and backup for fluctuating renewable energy sources. Within the framework of the ETS with its specified caps for emissions, the use of lignite will lead to price changes and to emission reductions elsewhere. Which technology will lead to $CO_2$ savings is, therefore, left to the actors on the market.

## NOTES

A. Since the introduction of the EU ETS in 2005 the prices for EU allowances have declined constantly. In 2013 the prices for a tonne of $CO_2$ sank below €5/tonne due to an oversupply of allowances. With the decision in June 2013 to "backload" certificates, an increase of carbon prices is expected; however, the future price level remains uncertain.

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The authors can be reached at bardt@iwkoeln.de and striebeck@iwkoeln.de.

# Coal Conversion to Higher Value Hydrocarbons:
## A Tangible Acceleration

**By Serge Perineau**
President, World CTX

Converting coal into petroleum looks like a new alchemy to our fellow human beings, most of whom remain unaware it is possible. Given the availability of coal and the scarcity of oil in many regions of the world, however, several nations and companies have shown great interest in this industry, leading to tangible developments since the beginning of this decade.

Until 2009, commercial experience was limited to that of one company, Sasol, in South Africa for liquid fuels, and Dakota Gas, in the U.S., for natural gas. As a result of a tremendous research effort, demonstration plants have proven the viability of different technologies with near-commercial capacities and, today, more plants are being constructed than ever before. Considerable information on coal conversion has been made available under World CTX's impetus, allowing benchmarking with other energy routes in terms of logistics, environmental impact, and economics. This article puts coal conversion in this perspective and provides an overview of present industrial developments.

**The Great Plains Synfuels Plant in North Dakota, U.S., has been producing natural gas from coal for over 25 years.**

### CTL, CBTL, AND OTHER ACRONYMS

CTL (coal-to-liquids) generally refers to the conversion of coal (including lignite) or petroleum coke into liquid fuels. Biomass is often associated with the coal. Some projects are referred to as CBTL (coal/biomass-to-liquids), but the simpler expression CTL is often maintained for CBTL projects. In this article, CTL encompasses both CTL and CBTL. It is important to clarify that BTL (biomass-to-liquids) is not considered within the scope of CBTL. The respective models of BTL and CBTL are fundamentally different, mainly due to the capacities of the units, which are significantly smaller for BTL than for CBTL. In addition, due to the image of BTL in public and political circles as a fully renewable, green energy source, BTL can enjoy subsidies that CTL cannot.

The principle of converting coal to liquid fuels is the same as converting it to other high-value hydrocarbons, as all processes consist of transforming molecules contained in coal and adding hydrogen to them.

***"As a result of a tremendous research effort, demonstration plants have proven the viability of different technologies with near-commercial capacities…"***

### CTL: ALREADY A LONG STORY…

CTL was first carried out at the beginning of the 20th century in Germany, where two technology routes were developed and patented: the "indirect route" by Franz Fischer and Hans Tropsch and the "direct route" by Friedrich Bergius. However, these processes became uncompetitive with the discovery of large and easy-to-produce quantities of crude oil in the 1950s. Later in the century, in order to secure its petroleum requirements, South Africa began an ambitious industrial CTL program, which resulted in several decades of global leadership.

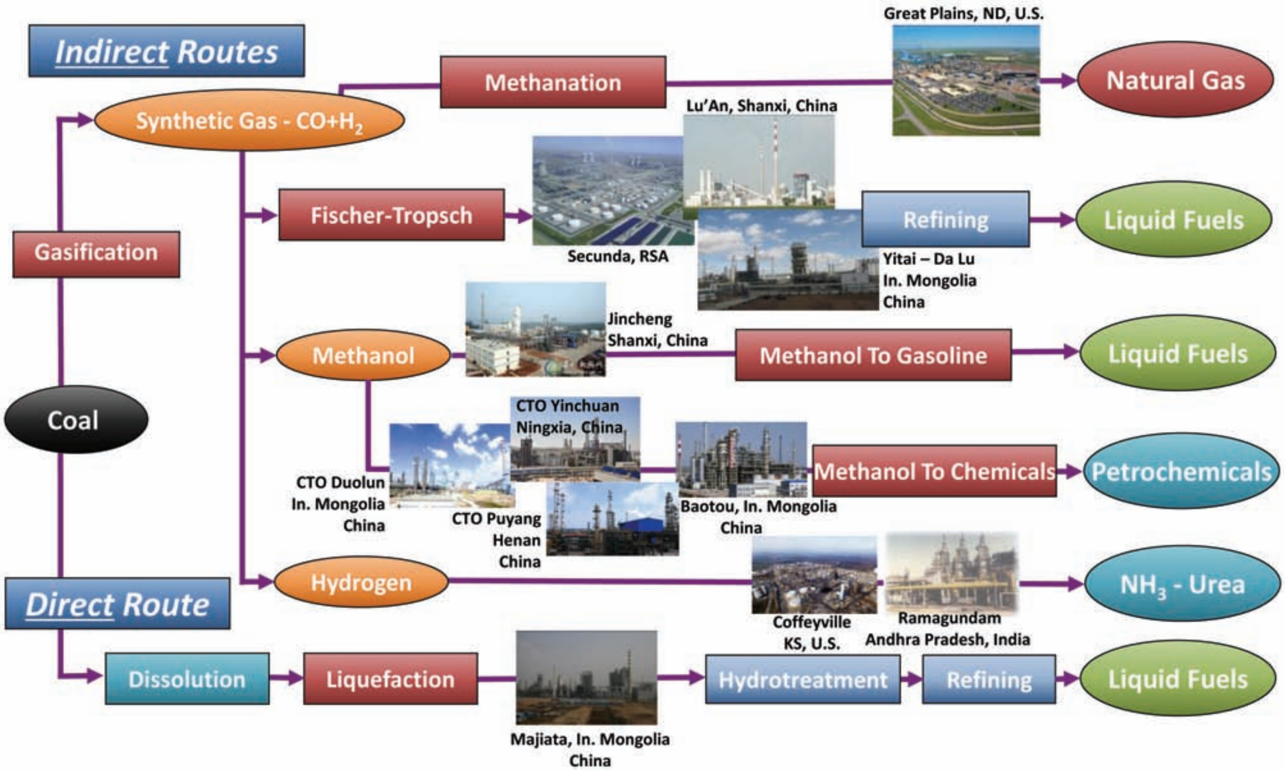


**FIGURE 1. Coal conversion pathways and technologies, with pictures of operational plants**

The oil shocks in the 1970s and 1980s spurred the U.S. to invest billions of dollars in research in CTL and to build the first coal-to-SNG (substitute natural gas) plant in North Dakota; then lower oil prices in the 1990s led to reduced attention in the area. The increase in the price of crude oil at the beginning of the 21$^{st}$ century generated new interest in CTL, particularly in China and the U.S.; projects were launched in both countries. These projects resulted in demonstration plants in China, whereas in the U.S. new environmental policies and the development of shale gas (and potentially gas-to-liquids units) have slowed the pace of progress. Today, seven conversion plants are commercially operating in China and 100 projects are being carried out globally (see the cover story in this issue for a more detailed discussion).

## ENERGY SECURITY

The comparative availability of crude oil, natural gas, and coal on a global basis is universally known. Access to adequate petroleum products is critical to the independence and development of countries, because it is linked to needs for transportation and defense—where liquid fuels cannot be substituted, at least in the medium term. Although reserves and resources of fossil energy are often discussed on a global basis, their geographical repartition holds strategic importance, as conventional crude oil and natural gas are generally located far from the regions with the highest energy consumption, while coal and lignite are fully available in most of them.

*"The increase in the price of crude oil at the beginning of the 21$^{st}$ century generated new interest in CTL, particularly in China and the U.S."*

## LOGISTICS

In remote places rich in coal, transportation can be expensive or sometimes impossible without heavy investments in railways. Converting this coal to liquid fuels or gas then makes sense, for either local consumption or transportation by pipe, which requires less capital expenditure and has lower operating costs than railways.

## TECHNOLOGIES

Coal can be converted to liquid fuels under several processes, essentially (i) the indirect route and (ii) the direct route. These pathways are represented in Figure 1, with pictures of commercial and demonstration plants, which have capacities between 2000 and 20,000 bbl/day.

The first route is referred to as "indirect" because a first step consists in producing an intermediate: synthetic gas (syngas), composed of carbon monoxide and hydrogen. In the second step, syngas is used as a feedstock in four main different processes:

- Fischer–Tropsch synthesis: liquid fuels are synthesized from the molecules of carbon and hydrogen contained in syngas
- Methanol-to-gasoline: methanol is synthesized from syngas and converted to gasoline
- Production of petrochemicals: once methanol has been synthesized, chemical derivatives are produced as in conventional petrochemical industry
- Methanation: methane (SNG) is synthesized from the molecules of carbon and hydrogen contained in syngas

In the direct route, coal is pulverized and mixed in recycled slurry in which hydrogen is added under pressure; Shenhua is operating the only demonstration-scale plant.

Both indirect and direct routes have respective advantages, in terms of versatility and choice of outputs (more diesel or more naphtha). Most projects today are based on indirect processes, mainly due to the higher level of knowledge accumulated by experience and research; this was the case at least until Shenhua's Direct CTL plant was placed into operation.

## SUSTAINABLE DEVELOPMENT: TWO LEVELS OF ANALYSIS

CTL is a chemical step included within a long energy channel. It is important to assess its environmental footprint at local and global levels. Local relates to the environmental impact at the place where the material is mined, converted, and consumed; global is linked to the greenhouse effect.

### Local Footprint

The environmental impact of coal mining is important to manage, but is outside the scope of this article. The second step is precisely CTL, which has similar characteristics to chemical and refining operations. Water requirements can be a concern. Studies are being made to decrease water needs, but scarce availability can make projects impossible in some areas. The solid wastes generated by CTL processes are similar to those produced by power plants and used in the same applications. The treatments of gaseous and liquid effluents are similar to the ones applied in the refining industry and do not raise particular questions.

The third and last step is the consumption or combustion of the fuel. As CTL fuels result from a synthesis process, they are significantly cleaner, notably in terms of sulfur, than conventional fuels produced from crude oil. Vehicles using these fuels then generate cleaner emissions, which benefits air quality, notably in cities.

*"CTL is a chemical step included within a long energy channel. It is important to assess its environmental footprint at local and global levels."*

### Global Footprint

The global footprint is a major stake for any energy channel. Coal, the most carbonaceous fossil fuel, is the raw material for CTL, which means that the starting ratio of carbon versus hydrogen is the largest. Therefore, for a given amount of energy production, the $CO_2$ emissions are higher with coal than with natural gas or petroleum. In addition, CTL, as an intermediate process between mining and final combustion, features energy consumption which also results in $CO_2$ emissions.

It is useful to compare the net $CO_2$ emissions of a liquid fuel produced from coal to those of a conventional fuel. This is done in WTW (well-to-wheels) analyses, where the total greenhouse gas generation is analyzed: primary extraction (i.e., coal mine vs. crude oil well), transportation of primary feedstock, conversion/refining, transportation of finished product, and final combustion. The WTW analyses implemented by several research centers and institutions have generated consistent results. In this article, we include the results based on previous publications from the Princeton Environmental Institute (U.S.), recognized for its contributions to coal and biomass mixed conversion improvement. The results of the Institute's analysis are summarized in Figure 2.[1]

### Global Footprint Mitigation

As shown on the left side of Figure 2, greenhouse gas emissions

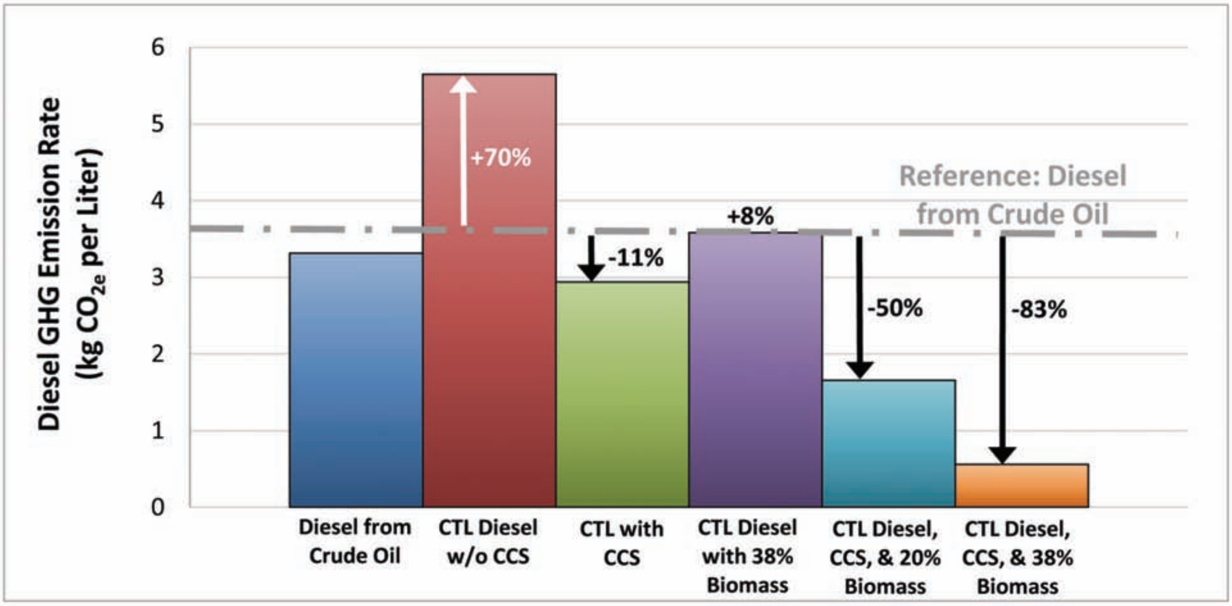


**FIGURE 2. Greenhouse gas emissions (kg of $CO_2$ equivalent per liter of diesel fuel) for different CTL diesel options compared to oil-derived diesel[1]**

are 70% higher with CTL diesel than conventional diesel. Researchers are focused on two routes to mitigate the global footprint of coal conversion.

### *Carbon Capture and Storage (CCS)*

CCS consists of purifying, compressing, and storing the $CO_2$ underground. For this analysis, CCS is applied to the $CO_2$ produced in the CTL plant.

CCS is often seen as a non-feasible technology, mainly due to the current economics. To date, this may be true for air-fed power plants where $CO_2$ needs to be separated from nitrogen after combustion; analyses have shown that 80–90% of the costs are based on that separation called "capture". CTL offers a valuable advantage in this field: Because no nitrogen enters the plant, $CO_2$ emitted by CTL processes is free of nitrogen, so that capture is not necessary. The cost of CCS is then bearable, as has been demonstrated during operation and over a decade of $CO_2$ sales at the SNG plant in North Dakota (U.S.), where the major part of the $CO_2$ is exported for enhanced oil recovery. When $CO_2$ has an economic value, CCS then becomes "carbon capture, utilization, and storage" (CCUS). Research is also being conducted on $CO_2$ as a raw material for chemicals.

The comparison summarized in Figure 2 demonstrates that, thanks to CCS, the WTW footprint can be reduced by 11% compared to conventional diesel.

*"$CO_2$ emitted by CTL processes is free of nitrogen, so that capture is not necessary."*

### *Biomass Addition*

The carbon contained in biomass comes from the atmosphere. Therefore, the greenhouse gas footprint of consuming biomass feedstock is negligible. When CTL diesel is produced using coal and biomass, the aggregate greenhouse footprint is decreased. When CCS is implemented, the carbon coming from the biomass, thus from the atmosphere, is finally sequestered, resulting in *negative* net $CO_2$ emissions: This is the exact contrary of venting the $CO_2$ associated with hydrocarbons produced from underground to the atmosphere. Figure 2 includes the $CO_2$ emissions for various cases of biomass addition with or without CCS.

Three key points related to biomass addition must also be considered:

- By guaranteeing a high temperature, coal improves the yield of biomass conversion compared to BTL.
- Biomass collection is restricted to a limited area to keep

logistics cost effective and reasonable and also to limit the associated carbon footprint (a 200-km radius is often quoted).
- There are some technical problems associated with gasifying both coal and biomass, in terms of process and equipment, but solutions are being developed.

### *Polygeneration*

The electricity required to operate the CTL plant is usually generated on site using coal. Electricity generation can be installed with capacity significantly higher than the CTL plant needs, resulting in an operation referred to as polygeneration. Polygeneration allows optimizing the plant operation, which implies reduction of costs and additional benefits in terms of carbon footprint. These additional benefits, which can be allocated to both outputs in several ways, are not quantified in Figure 2.

### *Simulation Results*

As is shown in Figure 2, liquid fuels produced from coal in a CCS-equipped CTL plant generate approximately 11% less $CO_2$ per liter of fuel compared to conventional fuels produced from crude oil, although $CO_2$ emissions are 70% higher if CCS is not applied. The addition of biomass to coal brings significant reductions, especially if combined with CCS: The carbon footprint is then reduced by almost 50% in the case where 20% of feedstock is biomass. If 38% of the feedstock is biomass and CCS is applied, the $CO_2$ emissions for diesel are reduced by 83% compared to diesel from crude oil.[1]

## ECONOMICS

CTL is recognized as a capital-intensive industry, with capital expenditures expressed in billions of dollars. Reported investment costs are between US$80,000 and US$120,000 per daily barrel installed.

Competitiveness is commonly expressed with the price of crude oil equivalent. Given the level of capital expenditure, the calculation of this equivalent price is contingent upon the method through which the cost of capital is taken into account. Crude oil price equivalent will also depend on the price of coal, power (bought or sold by the plant), manpower, and other classical parameters in the industry. As a result, figures should be considered with caution. It is generally accepted, however, that prices of crude oil equivalent vary between US$60/bbl and US$90/bbl.

The return on capital engaged in CTL projects will primarily depend on the price of crude oil and the cost of construction associated with the cost of capital. The cost of construction and the cost of capital are known when a project is decided. However, the volatility of the price of crude oil will remain over the coming decades, which often makes project financing difficult.

## DEVELOPMENT

In the last five years, major technology improvements have been achieved and several coal conversion units have been started. Many coal-rich countries and mining and oil companies conduct technical programs in their own research centers, often through international cooperation. Subjects include the optimization of the processes described earlier and catalysts, as well as new areas such as catalyst improvement, underground coal gasification, plasma gasification, CTL+algae systems, and $CO_2$ utilization. Also, through various publications and conferences such as the World CTX (www.worldctx.com), the conversion industry monitors the results obtained in demonstration plants, which are accumulating tens of thousands of hours of experience.

In terms of industrial development, South Africa, with a 160,000 bbl/day capacity, has been the only country producing fuels from coal for decades. China is now by far the most active country in developing new projects. CTL production in China, begun in 2009, has reached 29,000 bbl/day in four plants and is expected rise to more than 310,000 bbl/day by 2016.

SNG production has been limited to North Dakota up to now, with 4400 $Mm^3$/day capacity. Coal-to-SNG units are being constructed in Korea (1900 $Mm^3$/day) and in China (with four units totalling 86,000 $Mm^3$/day capacity all of which are complete or nearly complete). India is active as well, with a coal gasification plant to be operational in 2013 to replace imported natural gas.

The production of methanol and derivatives from coal is also developing, principally in China. Starting gradually in 2009, the production of monoethylene glycol on one side and olefins for

**Experts gather annually to discuss industry updates at the World CTX conference.**

polyethylene and polypropylene on the other side is now reaching capacities of 1.7 million tons per annum.

These investments in production units are complemented with important supporting capital expenditures, such as a new CTL-devoted catalyst production facility with an annual 48,000 tons capacity (12,000 tons in phase 1, under construction) and the pre-approved Xinjiang-Guangdong-Zhejianga pipeline crossing China from west to east for transporting SNG with an 82,000 $Mm^3$/day capacity.

Numerous less-advanced projects are being pursued in other countries such as Australia, Colombia, Indonesia, Mongolia, Russia, and the U.S.

## CONCLUSION

As coal is fully available in most energy-consuming regions, CTL will remain driven by energy security concerns and logistics gains. Greenhouse gas emissions are a key environmental issue. Technology improvements, CCS, and the addition of biomass open up opportunities for mitigating the carbon footprint in a more efficient way than conventional liquid fuels. Various technologies have proved their viability, opening the way to the construction of many units, most of them located in China.

Coal conversion is capital intensive. Once the cost of construction and financing is known, project profitability will be subject to the volatility of crude oil prices and the cost of coal. With crude oil price around US$90/bbl–US$100/bbl, CTL is competitive. Further improvements will result from the intense research being actively pursued. This development and the lessons from demonstration plants in China are paving the way for this industry's present development. International cooperation has played, and will continue to play, a key role in progress related to technology, the environmental footprint, and the competitiveness of CTL.

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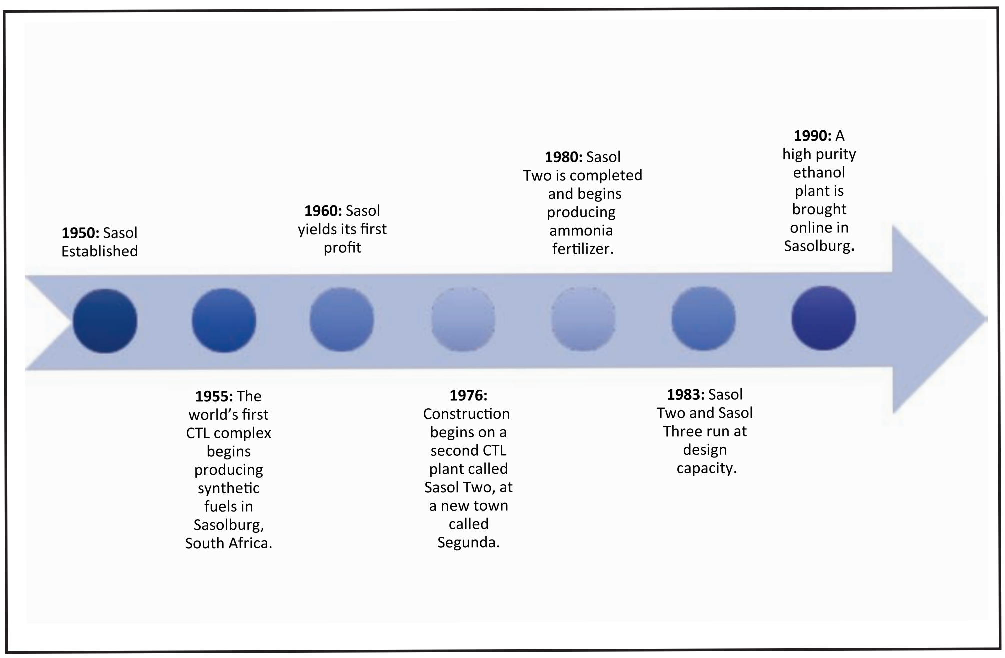
The author can be reached at management2013@worldctx.com.


# A Timeline for Commercial CTL Deployment

Three CTL plants located in South Africa have been in operation for decades. During their lives they have produced everything from formula car racing fuel to fertilizers, plastics, explosives, and much more. Sasol built and commenced operation of the world's first CTL plant in the 1950s, but an ever-changing global market has spurred many innovations over the years. The first CTL plant was named Sasolburg and is located approximately 80 km south of Johannesburg–this plant is still in operation today and is fully dedicated to chemicals production. The timeline to the right captures some of the major events related to Sasol's CTL industry.




*Source*: www.sasol.com

# Energy Players in the 2013 Fortune Global 500

**By Han Yue**
Manager, Shenhua Science and Technology Research Institute Co. Ltd

**Dong Juan**
Manager, Shenhua Science and Technology Research Institute Co. Ltd

**Chi Dongxun**
Director, Shenhua Science and Technology Research Institute Co. Ltd

In July 2013, *Fortune* released its annual Global 500 list, which reflects, to some extent, business paths of specific enterprises, while also providing a glimpse into global industrial development patterns and economics. A growing number of Chinese enterprises are listed in the Global 500, demonstrating China's increasingly significant status in the international economic landscape. Despite some residual negative impacts of the global economic downturn and a continuous drop in bulk commodity prices, enterprises in the energy sector managed to safeguard their critical role as major players contributing to global economic growth, among which coal enterprises in particular enjoyed robust growth.

**Energy enterprises are increasingly represented in the Fortune Global 500.**

*"Enterprises in the energy sector managed to safeguard their critical role as major players contributing to global economic growth, among which coal enterprises in particular enjoyed robust growth."*

## CHANGES IN THE GLOBAL 500 RANKING WITH DECLINED PROFITABILITY

Royal Dutch Shell, Wal-Mart, and Exxon Mobil continued to occupy the top three slots in the 2013 Global 500, with Royal Dutch Shell winning the top slot for another consecutive year. The U.S. was the leader in terms of number of enterprises listed, with 132, equaling that of the previous year. Next was China, with 95 on the list, 18 more than last year. The slot for second runner-up was taken by Japan with 62 enterprises listed in the Global 500, a decline of six as compared with last year.

The 2013 gross operating revenue of the Global 500 was US$30.305 trillion, representing a year-on-year increase of 2.77%. Gross profit dropped by 5.47%, to US$1.541 trillion, compared to the previous year, while the profit margin stood at 5.08%, down 8% from the previous year's 5.53%. In spite of the increase in operating revenue of the Global 500 in 2013, a substantial decline was observed in both profit and profit margin. Due to the adverse impact of the sustained slump of the global economy and weak growth on overall operations of global enterprises, profitability was undermined. The revenue threshold for joining the ranks of the 2013 Global 500 was US$23.2 billion, an increase of US$1.2 billion since 2012. However, the rate of increase decreased from 12.6% in 2012 to 5.3% in 2013.

## MORE ENERGY PLAYERS WITH A SHARP DECREASE IN OVERALL PROFITABILITY

The number of energy enterprises, including oil and gas companies, mining enterprises engaged in the coal industry, and power-producers listed on the Global 500 increased from 93 in 2012 to

96 in 2013, accounting for 19.2% of the Global 500. The number of companies in the oil and gas sector dropped from 58 to 56, yet still accounted for 58.3% of the total energy enterprises. Enterprises engaged in the mining and coal sector increased from 11 to 16, among which five were newcomers; note that all of these newcomers were Chinese coal enterprises. Several WCA members such as Glencore Xstrata, BHP Billiton, Shenhua Group, Rio Tinto Group, Xstrata (now merged with Glencore), and Anglo American also made this year's list. Mining and coal sector companies on the list are shown in Table 1.

Overall, the profit margin of energy enterprises declined in varying degrees. The oil and gas and power sectors suffered a sharp decline in both operating revenue and profit. Enterprises in the mining and coal sector also encountered a large decline in profitability, with a 73.4% decrease in profit margin from the previous year. Unlike the oil and gas and power sectors, however, these mining and coal companies realized a significant increase in operating revenue, highlighting an obvious imbalance between increased revenue and decreased profit within the industry. Severe as the situation may be, several enterprises in the mining and coal sector also managed to maintain a favorable profit margin, e.g., BHP Billiton 21.35%, VALE 11.55%, and Shenhua Group 11.28%, demonstrating robust resistance to risk by maintaining a competitive edge in challenging times.

## FUTURE OUTLOOK

### Chinese Enterprises Will Increasingly Impact and Change Global Economics

The global economy has entered a new round of structural adjustment since the global financial crisis, and the emerging economies, led by China, have risen rapidly to become the leaders fueling the world's economic recovery. Nevertheless, the momentum of growth of emerging economies has slowed under the on-going negative impacts of the global economic downturn. Out of the 2013 Global 500, China ranked among the top global economies in terms of the number of listed enterprises and newly listed enterprises. Chinese enterprises also demonstrated sound potential for future development in terms of business performance, far beyond the overall business performance of the Global 500. From a long-term perspective, the global economy will return to a growth path after step-by-step adjustments.

**TABLE 1. Mining and coal companies in the Fortune Global 500**

| *Ranking* | *Company* | *Operating Revenue (US$ billion)* | *Profit (US$ billion)* | *Country* |
|---|---|---|---|---|
| *12* | GLENCORE XSTRATA | 214.44 | 1 | Switzerland |
| *115* | BHP BILLITON | 72.23 | 15.42 | Australia |
| *178* | SHENHUA GROUP | 54.52 | 6.15 | China |
| *195* | RIO TINTO GROUP | 50.97 | -2.99 | UK |
| *210* | VALE | 47.69 | 5.51 | Brazil |
| *311* | JIZHONG ENERGY GROUP | 35.32 | 0.06 | China |
| *360* | XSTRATA | 31.62 | 1.18 | Switzerland |
| *373* | SHANDONG ENERGY GROUP | 30.71 | 0.95 | China |
| *399* | ANGLO AMERICAN | 28.76 | -1.49 | UK |
| *403* | SHANXI COKING COAL GROUP | 28.65 | 0.001 | China |
| *404* | HENAN COAL & CHEMICAL | 28.64 | -0.44 | China |
| *407* | YANGQUAN COAL INDUSTRY GROUP | 28.58 | 0.03 | China |
| *415* | KAILUAN GROUP | 27.84 | 0.12 | China |
| *430* | LUAN MINING GROUP | 27.11 | 0.002 | China |
| *432* | DATONG COAL MINE GROUP | 26.98 | -0.07 | China |
| *435* | SHANXI JINCHENG ANTHRACITE COAL MINING GROUP | 26.76 | 0.33 | China |

**Increased industrialization and improved energy access will ensure continued demand for energy, safeguarding the position of many energy enterprises in the Global 500.**

During this course, even if China's economic growth slows from its previous level, it will still sustain robust growth and continue its leading role as a major impetus for global economic growth. Chinese enterprises will also influence and change the competition patterns of the world economy through continuous development, constantly enhancing China's influence on the world economy.

## Energy Enterprises Have an Unshakable Position

Due to the negative impacts of the global economic downturn and the continuous drop in bulk commodity prices, business performance and profitability of enterprises in the energy sector decreased substantially. However, the increase in the number of energy enterprises listed in the Global 500 and the energy enterprises' share of 60% of the top 20 spots on the list may support the fact that, as an indispensable material base necessary for human survival, economic growth, and social progress, the energy sector will continue to play a significant role in the future. While the scarcity of energy reveals its long-term value, the long-term and sustainable growth of energy enterprises can be expected due to their unshakable vital position in the global economic development pattern.

## Coal Enterprises Enjoy the Potential for Expansion

Some experts project that the coal industry will find itself in a state of gradual decline due to the effect of policies related to greenhouse gas control, a move toward renewable energy, etc. However, Japan's Fukushima nuclear disaster has led some countries to change course back toward increased coal-fired power generation, demonstrating the value placed on safe, cheap, and widely available coal resources. Coal will continue its significant role in the long run, and coal enterprises will enjoy the opportunity to expand business, but how to achieve sustainable development is a question faced by coal enterprises worldwide. As is evident from the number of newly listed coal enterprises, and their considerable operating revenues, among the 2013 Global 500, there is a great deal of robust momentum. However, in the context of slowing global economic growth, excess capacity of the international coal industry, intensified competition in global markets, and an on-going decline in coal price, the substantial decrease in both profit and profitability of coal enterprises cannot be ignored. Mining and coal enterprises should fully utilize their inherent advantages and play a leading role within the industry based on mutual collaboration, so as to strengthen confidence and promote the sustainable development of the coal industry.

The authors can be reached at hanyuea@shenhua.cc and dongjuan@shenhua.cc.

# Does Coal Have a Long-Term Future in Europe?

**By Daniel Gros**
Director, Centre for European Policy Studies

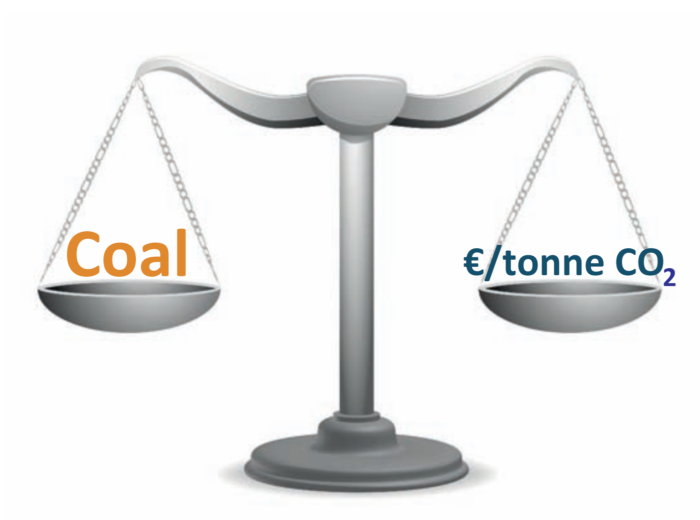
**Jonas Teusch**
Researcher, Centre for European Policy Studies

In Europe, natural gas had been eating away market share from coal for several decades, as illustrated in Figure 1. However, coal has recently made a surprising comeback, regaining market share since 2010. As the figure also shows, the opposite has happened in the U.S. where the relationship between coal and gas consumption was rather stable until about 2005, but the shale gas revolution has since led to a sharp decline in the consumption of coal relative to gas.

A first point is thus that the “comeback” of coal in Europe constitutes the mirror image of the strong decline in the U.S.

Even more importantly, the short-term reversal of the European trend in favor of coal needs to be viewed in the context of the uncertain long-term future stemming from coal’s significant carbon footprint.

In power generation, responsible for three-quarters of EU coal consumption, the main competing generation sources are either about half as $CO_2$-intensive (natural gas) or essentially $CO_2$ free (nuclear and renewables). As the EU is committed to reducing $CO_2$ emissions by 80–95% through 2050 (compared to 1990 levels), coal-fired power generation units would largely need to be phased out unless coal can be decarbonized.




**A moderate price on $CO_2$ could encourage investment in CCS without endangering coal’s competitiveness vis-à-vis natural gas.**

Carbon capture and storage (CCS) is the only feasible way to largely eliminate $CO_2$ emissions from coal. But it is still far from clear whether CCS will turn out to be a commercially viable option: Aside from financial viability, a number of challenges must be overcome, including transport and storage issues as well as public opposition to CCS. What is clear, however, is that some sort of $CO_2$ price is essential to trigger investments in CCS. From this perspective, recent developments are alarming. The EU Emissions Trading Scheme (ETS)—the EU’s flagship policy instrument to reduce the EU’s greenhouse gas emissions cost-effectively—has proven unable to provide a sufficiently high, stable, and predictable price signal to attract market-based investments in low-carbon technologies such as CCS. In addition, a structural reform that would reinvigorate the EU ETS seems highly unlikely in Europe’s current political climate.

*“The EU Emissions Trading Scheme … has proven unable to provide a sufficiently high, stable, and predictable price signal to attract market-based investments in low-carbon technologies such as CCS.”*

## EXPLICIT VS. IMPLICIT $CO_2$ PRICES

The oversupply of allowances that led to the collapse of the EU ETS is due partially to the economic crisis, which has reduced demand for fossil fuels below expectations. Another important reason is that European policy makers were—and still are—not willing to rely solely on the ETS to steer the transition to a low-carbon economy in Europe. Instead, they have adopted additional measures, most notably increased support for renewables and

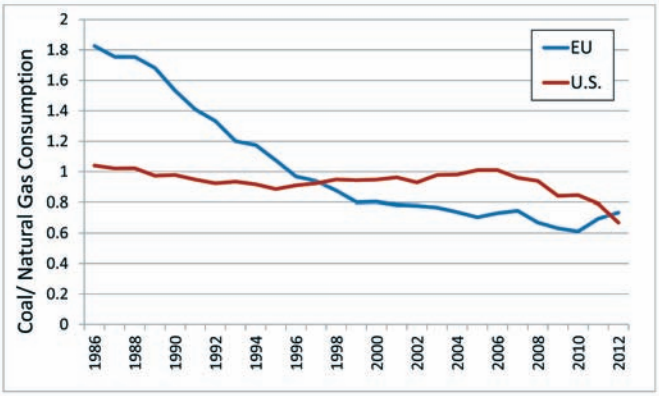



**FIGURE 1. Coal vs. gas: The longer term trend**

*Source*: Authors' elaboration based on BP 2013 data[1]

energy efficiency. Whereas these complementary measures also aim to drive decarbonization, they are interacting in sometimes undesired ways, undermining the visible price signal provided by the EU ETS.

Thus, instead of having a single and explicit price for $CO_2$ all across the EU, there are now a number of different implicit $CO_2$ prices. For example, as stipulated by the EU Directive on the promotion of the use of energy from renewable sources, individual EU member states have implemented national support schemes for renewables. Each national support scheme effectively leads to a different implicit $CO_2$ price, varying by member state and renewable technology, as shown in Table 1.

The order of magnitude and the range between the estimates is striking. Even for wind, generally the most competitive renewable, the implicit $CO_2$ price was more than 10 times higher than the explicit $CO_2$ price provided by the EU's current ETS (which is about €4/tonne). Solar was more than 100 times as expensive, in terms of $CO_2$ emissions avoided, than the current ETS price. This result—that the implicit $CO_2$ price of renewable incentives

**TABLE 1. Implicit $CO_2$ price of renewable energy incentives in select EU member states (€/tonne of $CO_2$, 2006–2012)**

| *Country* | *Wind* | *Solar* | *Explicit ETS $CO_2$ Price (yearly averages, 2006–2012)* |
|---|---|---|---|
| *Germany* | 56 | 574 | 0.74–23.03 |
| *Italy* | 169 | 972 | |
| *Spain* | 86 | 539 | |

*Source*: Marcantonini[2] for implicit prices; European Energy Exchange for explicit prices (www.eex.com/en).

exceeds by far the explicit price via the ETS—was true even when the ETS price was somewhat higher than today's €4/tonne. Even at the prices of some €20/tonne, as has been observed in the past, the renewable support implied a much higher carbon price.

The EU is not the only part of the world which sees such a large disparity between implicit and explicit $CO_2$ prices. In California's Emissions Trading Scheme, the majority of emissions reductions are achieved by complementary policies. Other U.S. states do not have an explicit $CO_2$ price at all, but rely entirely on standards and other traditional forms of regulation. As any visible carbon price seems to be politically unacceptable in the U.S., one would expect the imbalance toward implicit $CO_2$ prices to increase in the future. And, indeed, as voiced by a leading exponent of the U.S. coal industry in the inaugural issue of *Cornerstone*, it is expected "that a standard for $CO_2$ emissions will come".[3]

Does this imbalance between explicit and implicit $CO_2$ prices play out in favor of coal or does it put the future of coal in Europe's energy mix at risk? This comes down to the question of how coal is affected by the various carbon prices, in comparison to its main competitors in power generation. In the EU, coal, which accounts for about one-quarter of electricity generation, mainly competes with natural gas, which has a similar, but somewhat smaller share in power generation, as well as nuclear and renewables.

## COAL VS. GAS

On the face of it, the present state of EU climate policies works out well for coal. Since mid-2011, coal-fired power plants are generally more competitive than natural gas-fired plants and could thereby regain market share. This spread has further increased in early 2013.[4] The trend is also evident in the consumption patterns of coal and gas depicted in Figure 1. While EU gas consumption declined by 2.3% from 2011 to 2012, coal consumption increased by 3.4%.[1]

The significant gain in competitiveness of coal is due to two main reasons. First, coal benefits from the relatively low $CO_2$ price. Second, coal import prices have fallen as U.S. coal producers have had to look for other markets, since natural gas has reduced the role of coal in the U.S. energy mix as a side effect of the U.S. shale gas revolution.

The $CO_2$ price at which production costs for coal- and gas-fired power plants would be equal depends on the efficiency of the power plants and the relative prices of both coal and natural gas. At the commodity price levels of early 2013, a very efficient gas-fired power plant (58% efficiency) would already have been competitive with an old inefficient coal plant (28% efficiency) at an ETS price of €10/tonne $CO_2$, as shown in Table 2. A modern and efficient coal plant (42%), by contrast, would outcompete rather inefficient gas-fired generation capacity (41%) up to a $CO_2$ price of €85/tonne. If both coal- and gas-fired power plants are rather efficient (42% and 58%, respectively), a $CO_2$ price of €38 would be the point at which coal and gas production costs are equal.

Currently, coal is generally the most competitive fossil-fuel-fired source of power generation in Europe. To what extent this remains so in the future depends on both $CO_2$ and commodity price developments.

The relative price of coal (to natural gas) has decreased in Europe, while the U.S. has seen the opposite trend, as shown in Figure 2.

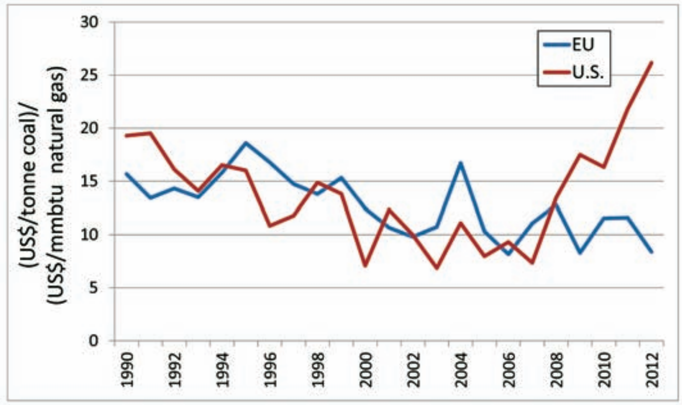



**FIGURE 2. The relative prices of coal and natural gas, 1990–2012**

*Source*: Authors' elaboration of BP 2013 data.[1]

The level of $CO_2$ prices hinges upon political choices made by policy makers. Here, the lack of a higher explicit $CO_2$ price benefits coal in the short term. However, it is doubtful whether the present situation allows for a future for coal in the EU's electricity mix. Without a higher $CO_2$ price, companies have little incentive to invest in CCS or alternative technologies. And unless coal will be decarbonized, it will have to be phased out at some point if the EU is to meet its decarbonization objectives. Without an explicit and technology-neutral $CO_2$ price, it seems likely that coal will eventually silently be phased out through targeted government actions such as standards or a coal tax. An explicit $CO_2$ price would also have the advantage of providing auctioning revenues which could be used to fund CCS projects, further supporting the decarbonization of coal.

Auctioning revenues have been very limited so far, as most allowances have been allocated for free and the carbon price is presently very low. But these revenues could increase significantly in the future as the share of auctioning increases every year (free allocation will be completely phased out by 2027). EU member states enjoy considerable discretion when it comes to spending the auctioning revenues, but the EU ETS Directive requires that at least half of the revenues be used for measures to mitigate climate change. Member states could thus, for instance, invest this money in CCS demonstration projects. Additional funding is available through the NER300 programme managed by the European Commission, also financed through auctioning revenues.

**TABLE 2. $CO_2$ prices resulting in equal production costs for different coal- and gas-fired power plants**

| *€/tonne (t)* | *Coal (28%, 1.1t)* | *Coal (36%, 0.96t)* | *Coal (42%, 0.9t)* |
|---|---|---|---|
| *Gas (41%, 0.45t)* | 40 | 67 | 85 |
| *Gas (49%, 0.41t)* | 23 | 44 | 57 |
| *Gas (58%, 0.38t)* | 10 | 27 | 38 |

*Source*: IEA 2013[4]

Notes: Prices as of early 2013: gas, €26/MWh; coal, €10.5/MWh (including €1/MWh transport costs to plants). Numbers in parentheses refer to assumed plant efficiency and $CO_2$ emissions per MWh electricity.

A substantial price on $CO_2$—say, initially in the range of €20-30/tonne—could thus be the key to preserve the future of coal in Europe. It would provide the auctioning revenues necessary to support and develop CCS while not making coal uncompetitive against gas in power generation. In the longer term, coal with CCS could then become a low-carbon alternative and compete with renewables and nuclear in a world where decarbonization is driven by increasing explicit and visible prices on $CO_2$.

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The authors can be reached at danielg@ceps.eu and jonas.teusch@ceps.eu.

# Shenhua's DCL Project: Technical Innovation and Latest Developments

**By Shu Geping**
Chief Engineer,
China Shenhua Coal to Liquid and Chemical Co., Ltd.

Direct coal liquefaction (DCL) is the most effective approach for the production of liquid products from coal; the energy conversion efficiency can be 60% or greater. DCL also offers important strategic and practical benefits to China in regards to solving problems such as shortages of petroleum resources, balancing the energy mix to rely more heavily on strategically secure coal reserves, as well as a sustained, steady growth of the national economy.

The Shenhua DCL project is a commercial-scale demonstration project that is the first in the world to adopt modern DCL technology; the project is based on creativity and exploration and is demonstrating the promise of the technology to the rest of the world.

## TECHNICAL INNOVATION IN THE SHENHUA DCL PROJECT

### Development of the Core Process and Initial Scale-Up

#### *Advancement of the Shenhua DCL Process*

The Shenhua DCL process, see Figure 1 for the process schematic, is the most critical technology within the entire project. The capacity of the project is 30 times larger than any other DCL units operating now or in the past.

**The Shenhua DCL project is the largest DCL project in the world.**

*"The Shenhua DCL project is a commercial-scale demonstration project that is the first in the world to adopt modern DCL technology."*

Compared with existing processes both in China and abroad, the Shenhua DCL process is clearly more advanced based on the following features:

1. Largest capacity of any single production line: The liquefied coal processing capacity of the single-production line in the Shenhua DCL process is 6000 tonnes/day of dry coal, whereas the capacity of the largest production line abroad is only 2500–3000 tonnes/day of dry coal.

2. Superior synfuels yield: The high-performance solid catalyst used in the Shenhua DCL process means that less catalyst is required and the yield of distilled synfuels is greater than that of the DCL processes abroad that operate under the same conditions.

3. Improved stability: The overall stability of the Shenhua DCL process is greatly superior to that of DCL processes abroad.

4. The Shenhua DCL process is a proven process: the first in the world to have undergone verification at the bench scale, pilot scale, and demonstration at the megaton industrial scale. Thus China has become the sole nation with a megaton-scale proven DCL technology.

#### *Preparation of the DCL High-Performance Catalyst*

The DCL high-performance catalyst is one of the critical technologies responsible for increasing the coal conversion rate and product yield as well decreasing the severity of DCL process operating conditions (i.e., temperature and pressure can be significantly lower when the catalyst is employed).

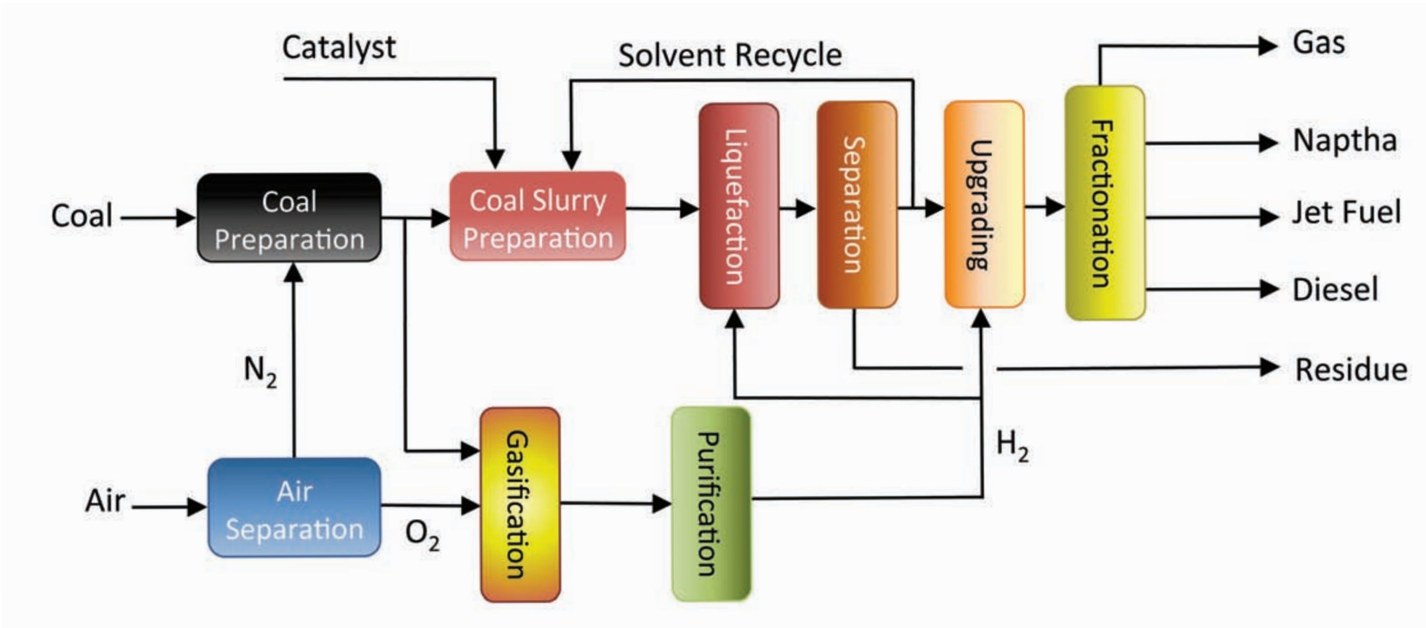


**FIGURE 1. The Shenhua DCL process, shown in the schematic above, is the most critical technology within the entire project.**

The Shenhua Group and the China Coal Research Institute, financially supported by the 863 Program of the Ministry of Science and Technology, jointly developed the DCL high-performance catalyst. During laboratory-scale research, the process and key operating parameters were defined, solutions were developed to avoid unintended reactions, and control parameters were developed for the precipitation and oxidation process. A continuous test unit with a production capability of three tonnes per day of catalyst was constructed. Subsequently, a unit for continuous preparation of the 863 catalyst (named after the program under which it was developed) to provide catalyst for the pilot-scale DCL demonstration was constructed in the Shenhua pilot-scale R&D center. For the DCL demonstration project the catalyst production process was proven after it was scaled up by a factor of 1000 times.

### *DCL Synfuels Processing*

Because the properties of DCL-derived synthetic fuels greatly vary from those of conventional petroleum, upgrading of DCL-derived synthetic fuels requires stricter processing conditions compared with conventional crude oil refining. In addition, catalysts and processing techniques must be specifically developed based on the properties of the DCL-derived products and processing techniques. Catalysts developed in China were adopted in Shenhua's DCL project; a new combined process of product refining and product modification was also developed. Thus, liquefied petroleum gas (LPG) has been processed into high-quality diesel and naphtha. The market for these products is favorable, with highly saleable products and byproducts (e.g., diesel, naphtha, and liquefied natural gas).

## Overcoming Hurdles in the DCL Process

### *Reactor Resistance to Mineral Sedimentation*

Globally, mineral accumulation is common in DCL reactors, which is especially prone to occur when high-calcium content coal is used, as is the case for the Shenhua DCL project. To solve the problem of sedimentation, Shenhua first investigated how to solve the problem at the bench and pilot scales. The reactor type and dimensions of the internal components were determined at the bench scale and then at the pilot scale using a 1-m diameter cold-flow model. Sedimentation of the minerals in the reactor is avoided by controlling the superficial liquid velocity, stabilizing unidirectional flow, and forcing full backmixing. As the largest high-temperature, high-pressure hydrogenation reactor in the world, the reactor applied in the commercial-scale demonstration project has an internal diameter of 4.8 m and has given no indications of mineral sedimentation—even after nearly three years of operation.

### *High-Temperature and High-Differential Pressure Relief Valves*

Increasing the resistance to wearing of high-temperature, high-differential pressure relief valves applied in DCL processes is a global problem. In the U.S., six types of relief valves were tested on a 200-t/d unit using the H-Coal DCL technology; the longest service life for the valves was 600 hours. In Japan, synthetic diamonds have been used as valve seats in a two-section throttling valve, and the longest demonstrated service life for such valves was 1008 hours on a 150-t/d DCL unit. There is a clear requirement for extremely strong materials in the DCL process; although it is strong, the flow coefficient of the valve using synthetic diamonds is far below the requirements in the industrial-scale DCL process. Other valves may have a suitable flow coefficient, but are not strong enough for long-term industrial-scale operation.

Collaborating with domestic manufacturers, Shenhua Group developed a high-temperature, high-differential pressure relief valve for DCL based on the four following aspects:

1. Research and develop appropriate pressure-relief valve structures based on hydrodynamics.
2. Change operating parameters to reduce the solid content in the medium.
3. Optimize control methods and increase the service life of the pressure relief valves.
4. Develop superhard materials suitable for long-term, large-scale operation.

The longest service life of the pressure relief valve developed using Shenhua's valve technology is 2500 hours, with more than 3000 hours of operation considered feasible based on the valve condition after disassembly.

### *Coking*

Coking is a problem in most DCL projects. Specifically, in one project outside of China, coking has occurred in the reactors, the coal slurry reheating furnaces (especially the pressure-relief tower reheating furnace), and the high-temperature, high-pressure separator in the 100-t/d DCL unit. The coking severely affects operation. Preventing coking in the three major vessels is a global challenge. However, coking is not a problem in the Shenhua DCL project. The main factors that lead to coking were discovered through repeated tests and analysis; the impact on operation has been removed through improvement of design and operating conditions.


**The two samples on the right are the end products of the DCL process.**

## Increasing Equipment Capacity

Shenhua's DCL project has incorporated numerous innovations related to the core process technology, and independent R&D is also being carried out on equipment, such as the reactors, and has led to the recognition of the equipment in the project as the most advanced globally. One example is the development of a DCL reactor with the largest capacity of any single-production line in the world. Other examples include a centrifugal pump and other core equipment that are resistant to wearing caused by solids and also can be used at high temperatures, both of which translate into sound economic benefits.

## Key Environmental Technologies for DCL Emission Reduction

### *Treatment and Conservation of Water*

The typical wastewater from the Shenhua DCL project is high-concentration wastewater; its converted chemical oxygen demand (COD is a common term to determine the degree of pollution) concentration can reach 10,000 mg/L. Therefore, a wastewater processing technology was developed, starting with repeated laboratory tests. Following the laboratory tests, a full wastewater treatment process was developed; the investment in the water treatment facilities for the Shenhua DCL project to date is 890 million RMB, accounting for 7.02% of the total project investment, with the goal of near-zero wastewater discharge.

After the trial operation of the high-concentration wastewater treatment system was completed at the end of December 2008, some unanticipated problems were encountered. Shenhua Group has been vigorously pursuing solutions and improvement measures to solve the problems revealed during unit operation. After more than two years of experimental study, a comprehensive wastewater treatment technology was developed and adopted; the treatment process includes efficient catalysis oxidization, high-efficiency biological filters, ozonation, coagulation of sedimentation, membrane reactor (MBR), ultrafiltration (UF), and reverse osmosis (RO). The retrofit project to incorporate the high-concentration wastewater treatment technology has been initiated. With an investment of 450 million RMB, this wastewater treatment retrofit project has an estimated completion date of October 2013. After completion, high-concentration wastewater

**With a goal of near-zero wastewater discharge, a comprehensive water treatment process was developed for Shenhua's DCL project. Steps within the comprehensive treatment process include (in clockwise order) biological filtering, settling tanks for coagulation, ultrafiltration membranes, and reverse osmosis.**

can be used as inlet water for a desalination processing facility, so as to change the project's philosophy regarding the treatment of wastewater from *recycling according* to *quality* to *multiuse*, and thus truly realize a standard of near-zero wastewater discharge. After the advanced wastewater treatment enters into operation in late 2013, the recycling rate of wastewater will also be further improved. Water consumption as well as the quantity of intake water from the water source can be further reduced, and the ratio of tonnes of water consumed per tonne of synthetic fuels produced can be decreased to less than six.

### *Emissions Reduction through CCS*

Large amounts of $CO_2$ are released during the process of converting coal into synthetic fuels. The goal of carbon emissions reduction can be realized only through the treatment of the $CO_2$. Along these lines, Shenhua Group has constructed the first carbon capture and storage test unit in Asia, through which $CO_2$ released from the DCL hydrogen production facility is captured and then geologically sequestered through injection into a saline reservoir more than 2000 m underground. Through the first half of 2013, the cumulative quantity of $CO_2$ injected over the life of the project was 125,352 tonnes, with each measured operating parameter superior to the design parameters. Monitoring data has been collected from one injection well and two monitoring wells and the injection demonstration has achieved the phased objectives.

## RECENT PROGRESS

Since coal feeding began on 30 December 2008, the Shenhua DCL demonstration project has achieved safe, reliable, long-term operation at full production capacity through a series of technical innovations and breakthroughs as well as equipment breakthroughs and process optimization. Today, the project is making strides toward the target of operation optimization.

In 2012, the DCL unit operated for a total of 7248 hours, with synfuels output of 865,500 tonnes, and a profit and tax of 1.867 billion RMB. By the end of May 2013, the synthetic fuels output was over 400,000 tonnes. The cumulative operation time of the project had reached 302 days (the initial objective was 310 days), with a single continuous operation time of 252 days. The highest load rate was 105% of the design value. The highest product yield was 57%, and the coal conversion rate was 91%.

The Shenhua DCL project can ultimately result in valuable economic


**Shenhua has built fueling stations to sell clean diesel products.**

and social benefits. The project has operated completely under market-based restrictions—raw coal is purchased at the base market rate and products are subject to market-priced sales. The price for diesel is determined according to the price guide issued by the National Development and Reform Commission, and the transfer price of petroleum and petrochemical products is approximately 500 RMB/tonne less than the market retail price. As of 30 May 2013, the DCL project has operated for a total of 22,920 hours, with a synfuels output of 2,580,000 tonnes, sold 2,530,000 tonnes of synfuels products, and paid 2.982 billion RMB in fees and taxes, with an average of 1178 RMB/tonne synfuels paid. The tax payment per tonne of synfuels of the Shenhua DCL project is much higher than that of the average coal-to-chemicals industry or petrochemical companies, thereby making a greater contribution to China's economic growth.

Projections of the economic benefits have been made based on full-load operation and actual production and consumption indices according to product prices based on an international oil price of US$80, and the actual price level of raw materials. This analysis has shown that Shenhua's DCL process can be economically advantageous. The plant will have an even greater profit potential through continued innovation and optimization, which could reduce raw material consumption and improve product yield.

## HIGHLIGHTS

1. The Shenhua DCL project is the first industrial-scale demonstration project in the world based on modern DCL technology. The successful completion and operation of the project has significantly advanced the development of coal liquefaction. Validating operation through the demonstration project has made the technology more mature and has enabled China to lead the world in the application of clean coal conversion and utilization.

2. After safe, stable, optimal, and long-term operation at full capacity, the project has successfully achieved the expected goals with favorable economic returns. Its environment-friendly operation, especially the near-zero discharge of wastewater, has played an important role in the industrial-scale demonstration project.

3. The successful operation and completion of the project can promote the rational utilization of coal resources in western China as well as optimizing the structure for coal utilization industry. The project has importance and significance in promoting local coal processing (i.e., converting coal to synfuels near the mining site) and clean coal conversion, and in improving the value of products of coal conversion.

4. During the implementation of the project, domestic equipment and materials have been adopted that will promote the improvement of equipment manufacturing for the modern coal-to-liquids and coal-to-chemicals industry in China, as well as the advancement of design, integration, and construction capabilities in related fields.

# The Momentum of Chinese-Derived Indirect Coal-to-Liquids Technologies

**By Weng Li**
Director,
National Institute of Clean and Low-Carbon Energy

**Men Zhuowu**
Professorate Senior Engineer,
National Institute of Clean and Low-Carbon Energy

**Bu Yifeng**
Senior Engineer,
National Institute of Clean and Low-Carbon Energy

**Researchers at the National Institute of Clean and Low-Carbon Energy monitor operations of an ICTL project.**

Indirect coal-to-liquids (ICTL) technology consists of a two-step process using coal as a feedstock that is first gasified to produce synthesis gas ($CO+H_2$). The syngas is then converted into hydrocarbon compounds and other products via Fischer–Tropsch (F-T) synthesis.[1–3] The liquid fuels produced through ICTL are environmentally friendly. For example, ICTL fuels contain less sulfur and fewer aromatic hydrocarbons and the cetane number of ICTL diesel can be as high as 70. (The higher the cetane number the better for combustion performance; premium diesel fuels usually have cetane numbers of approximately 60.) The advantage of such a high-quality diesel is that it can be used when there are strict constraints regarding automobile exhaust gases or it can be used as a blending stock to upgrade lower quality diesel. ICTL can also produce higher value products such as wax and lubricating oil.[2,3] Today, the wide array of products that can be made through ICTL is an extremely active R&D area. The core technology of ICTL is undoubtedly the F-T processes. A brief history of its development follows.[3–5]

*"Companies in China have focused primarily on iron-based catalysts, resulting in breakthroughs in many areas that have advanced ICTL technologies."*

F-T synthesis (FTS) was first invented by German scientists F. Fischer and H. Tropsch in 1923. F-T synthesis later became the basis of, and principal step in, ICTL technology. The first commercial-scale ICTL plant was built by Ruhrchemie, a German company, in 1934 and was put into operation in 1936. In 1955, Sasol successfully commercialized the first ICTL plant using a fixed bed reactor in South Africa. After some 50 years of continuous development, Sasol has become the largest producer of ICTL fuels today. The company is able to produce nearly eight million tons of liquid fuels every year. Moreover, Sasol has advanced their technical capabilities for all areas within its ICTL process. One particular achievement worthy of mention is the use of cobalt-based catalysts at commercial scale in F-T technology with natural gas as feedstock. This has inspired worldwide interest in ICTL. Since 1980, China and a few other countries have boosted development and accelerated industrialization of ICTL. International energy companies such as Exxon, Rentech, and Shell all have their own programs to advance the technology toward commercialization. Since the turn of this century, these international companies have mainly focused on cobalt F-T catalysts and gas-to-liquids (GTL) technologies. Taking a different approach, companies in China have focused primarily on iron-based catalysts, resulting in breakthroughs in many areas that have advanced ICTL technologies.

## CURRENT STATUS OF ICTL TECHNOLOGY IN CHINA

### ICTL Development in China

ICTL development in China can be divided into three stages[2]: the first stage was before 1980. During this time, there was little ICTL-related activity in China. The second stage was between 1980 and 2000. During this period, the focus was on the fundamental research necessary to accumulate knowledge and to play catch-up. Only Shanxi Institute of Coal Chemistry (SXICC) of the Chinese Academy of Sciences developed a two-stage process with two different configurations. The first configuration was a modified Fischer–Tropsch (MFT), in which two fixed beds in series were utilized to increase the overall conversion efficiency. The second configuration was a slurry modified Fischer–Tropsch (SMFT), in which a slurry reactor and a fixed bed in series were developed. Both reactor types were tested at the pilot scale. The third stage of ICTL development is the time since the turn of the 21st century. ICTL in China is experiencing a period of fast-paced development, which has made China a global leader in the field of ICTL technologies and their applications.

China's Shenhua Group, a bellwether in China's coal industry, pioneered its modern coal-to-chemicals technologies with a direct coal liquefaction technology as its first project. Following this success, Shenhua Group extended its effort to include most modern coal-to-chemicals technologies, including ICTL. A specialized ICTL research department was formed and a demonstration ICTL plant was successfully operated in 2010. Yankuang Group also founded a research department specifically focused on ICTL and operated a 10-ktpa (kilo tonnes per annum) scale plant in 2004, based on which a megaton process development package (PDP) was developed. SXICC, another major force in the coal industry in China, developed a successful catalyst for ICTL and also was able to mass produce this catalyst. SXICC also formed a partnership with Yitai Group, which is the parent company of Synfuels China. Synfuels was commissioned to conduct research and engineering design on ICTL technology. Sinopec, a petroleum giant in China, is also developing a natural-gas-to-liquids (GTL) technology. Shehua's Ningxia Coal Industry Group, Yankuang Group, Yitai Group, Lu'an Group, and others are either constructing or are planning to construct megaton-scale ICTL plants. The ICTL projects are listed in Table 1. In addition to these major players, some smaller technology companies and institutes in China, such as Shaanxi Gold Nest, are also working on the development of ICTL applications.

**TABLE 1. ICTL projects in China that are planned or have been constructed**

| *Company* | *Location* | *Scale (10 ktpa)* | *Estimated Completion Date* | *Selected Technology* |
|---|---|---|---|---|
| *Shenhua Ningxia Coal Industry Group* | Ningxia Province | 400 | 2016 | Iron-based catalyst, low-temperature Fischer–Tropsch (LTFT), slurry bubble column reactor (SBCR) |
| *Shenhua Group* | Inner Mongolia Xinjiang Province | 100 | Uncertain | |
| *Yankkuana Group* | Yulin Shaanxi Province | 100 | 2015 | |
| *Yitai Group* | Inner Mongolia Xinjiang Province | 180 (first project) | Uncertain | |
| *Lu'an Group* | Changzhi Shanxi Province | 3x50 | 2015 | |

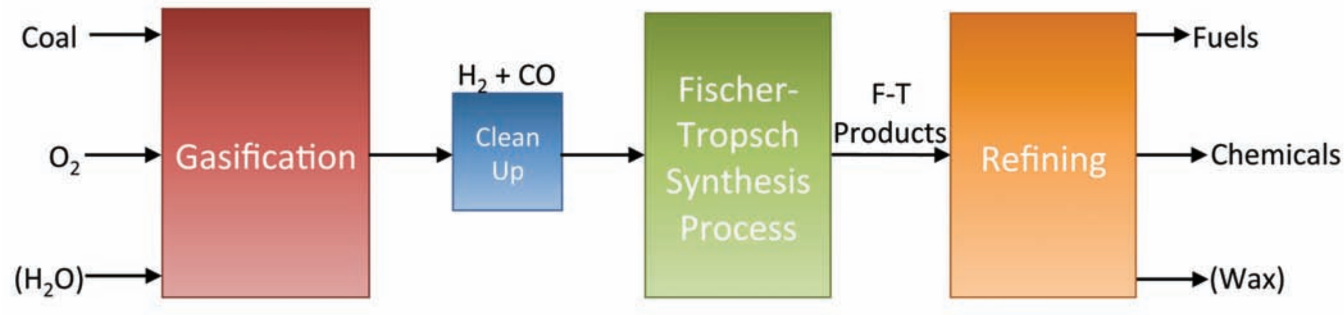


**FIGURE 1. Schematic illustration of a typical ICTL process**

## Key Features of ICTL Technologies Developed in China

A typical flowchart of an ICTL process is illustrated in Figure 1. It can be seen from Figure 1 that the F-T step is the centerpiece of ICTL. In the F-T process, the most important aspects are the catalyst and the reactor type. Catalysts used in the F-T process are developed around transition metal elements such as Fe, Co, Ni, and Ru (iron, cobalt, nickel, and ruthenium, respectively), which have the property of ionizing the CO molecules. In addition, they also exhibit the ability to catalyze the hydrogenation process to extend the length of the hydrocarbons. Among these catalytic metals, Ru exhibits a very high catalytic activity, but its cost is exceptionally high. Ru deposits are rare and for this reason the metal is unlikely to be used as a catalyst in large-scale applications. When Ni-based catalysts are used, they demonstrate a very high selectivity for producing methane as an end product. Ni-based catalysts are more often used in the hydrogenation and methanation processes. The catalysts used in modern F-T processes can be divided into Fe-based and Co-based. Fe-based catalysts are less expensive; metal iron is readily available. They also have a wide operating temperature range for their applications, 200–340°C. Therefore, these catalysts can be made to suit either a high-temperature or a low-temperature F-T process. In addition, they can be manipulated to yield different products. On the other hand, Co-based catalysts exhibit high catalytic activities in the F-T process, but they are more applicable in processes with narrow temperature fluctuations in the 220–230°C range. Cobalt catalytic F-T processes can produce hydrocarbons with a wide range of carbon numbers without producing $CO_2$. Products include a high percentage of saturated hydrocarbons and wax.[2–5]

The reactors used in F-T processes can be grouped into the following categories: fixed bed (FB), circulating fluidized bed (CFB), fixed fluidized bed (FFB), and slurry bubble column reactor (SBCR). The advantages of FB are the ease of collection of the liquid products and easy separation of the heavy hydrocarbons from the catalysts. Its disadvantages are the non-uniform temperature distribution both axially and radially. In addition, construction of FB reactors can be complex, costs are high, and loading and unloading of the catalysts is difficult. A CFB is better suited to high-temperature F-T, leading to products with lower carbon numbers. Turbulence mixes the catalysts and reactant gases in the reactors, which results in effective heat transfer, in turn leading to a more homogeneous temperature profile inside. The uniform temperature distribution allows the control of reaction selectivity (i.e., close control of products). The effective heat exchange also offers the benefit of a smaller heat transfer area, which means a higher capacity with a similar-sized reactor. Its disadvantages include high cost, complicated operations, expensive repairs, and difficult scale-up. The advantages of a FFB are the uniformity in the temperature profile of the same bed, ease of control of reaction selectivity, low equipment cost, and production-targeted fuel products. Sasol's projects in South Africa that were finished in the 1980s all used FFB reactors. The advantages of a SBCR are the homogeneous reactants, homogeneous temperature profiles, low pressure drop (one-fourth of that in a FB), high yields per reactor volume, flexible operations, low operation costs, and the ability to exchange the catalysts while on-line. The shortcoming of the SBCR is the stringent requirements in the separation of the liquid products from the solids.[4–6]

The F-T process can be classified into LTFT (low-temperature F-T) and HTFT (high-temperature F-T) according to the operating temperatures. An LTFT operates in the 200–270°C range and HTFT operates in the 300–340°C range. The F-T process can also be described according to its number of stages. In general, F-T processes have one or two stages. Some researchers believe that a two-stage process can increase the overall conversion and product capacity. However, two-stage design makes the process more complicated and more difficult to operate, so initial investment may also be higher. Different temperature-based processes lead to different product distributions. These in turn have led to several technologies such as Sasol Slurry Phase Distillate (SSPD), Sasol Advanced Synthol (SAS), and Shell Middle Distillate Synthesis (SMDS).[2] The technical details are listed in Table 2.

Because Fe-based catalysts have a greater resistance to sulfur, whereas Co-based catalysts are prone to sulfur poisoning, most Chinese ICTL researchers prefer Fe-based catalysts. A few LTFT processes with SBCR are progressing toward commercialization.

As shown in Figure 1, the following processes are involved in an ICTL technology: coal gasification, F-T product refining, and other technologies. In addition, the composition of the inlet gases and the partial pressure of the effective gas ($CO+H_2$) can influence overall syngas conversions and product yield. For example, the lower the inert gas partial pressure in the fresh syngas, the better for the Texaco gasification technology in an ICTL process. The refining technology for FTS preliminary products is selected to meet the final products requirement. In general, hydrofining is used to deoxidize and to remove olefins and hydrocracking is used to produce diesel.

## China's ICTL Projects

In China, most ICTL technology operators have experience based on technology progression from bench-scale to pilot-scale to large-scale demonstrations. Yanhuang Group achieved a 10-ktpa demonstration plant in 2004. Shenhua, Yitai, and Lu'an constructed a demonstration plant with 160–180-ktpa capacity mainly based on Synfuels China ICTL technology during 2006 to 2009. Also, during the 2006–2009 period, Shenhua independently started and operated a demo plant using its own catalyst and completed a modified ICTL process. Lu'an and Yitai, operated their own demo plants using Synfuel China's technology, including catalyst and technical support. The Yitai Group plant has been operating the longest. With these experiences, China has accumulated abundant experience in the key aspects of ICTL technologies such as F-T catalyst scale-up, commercialized reactors, and various F-T processes. In the meantime, China has also had first-hand experience in industrial scale-up. Table 3 lists some of the technical parameters for the three demo plants.[7]

**TABLE 2. Technical details of different F-T processes**

| *Category* | *Catalyst* | *Reactor* | *No. Stages* | *Product Phases* |
|---|---|---|---|---|
| *LTFT* | Fe, CO | Fixed Bed, SBCR | One, two | SSPD, SMDS |
| *HTFT* | Fe | Fluid bed | One | SAS |

**TABLE 3. Technical parameters for the three current China ICTL demo plants**

| *Parameter* | *Data* |
|---|---|
| Pressure, MPa | ~3.0 |
| Temperature, °C | 250–270 |
| Superficial gas velocity, m/s | 0.10–0.35 |
| $CO_2$ selectivity, mol% | <20 |
| $CH_4$ selectivity, mol% | 1.5–3.5 |

Based on the experiences of operating the demonstration plants, especially the long-term operation by the Yitai Group, the Chinese government approved a four-million-tons-per-year ICTL plant based on homegrown, rather than international, ICTL technologies. The approval allowed Shenhua Ningxia Coal Industry Group to begin construction of the ICTL project in Ningxia Province.

# CHALLENGES

## Resource, Environment, and Industrial Policy Challenges

Generally for ICTL processes, when one ton of synthetic fuel is produced, four to five tons of coal and four to eight tons of water are consumed. Clearly, ICTL has a high demand for coal and water. Therefore, attention must be paid to the availability of coal and water in different regions when planning ICTL projects. China's coal and water resources are unevenly distributed. The coal reserves are centered in the north or mid-west regions such as Shanxi, Inner Mongolia, Ningxia, and Xinjiang provinces, where water resources are less abundant. Some areas have even less water; in these areas, industrial water uses even rely on underground water. Consequently, any ICTL project developer must pay close attention to the efficiency of water use, how much water can be recycled, and the reduction and control of water pollution. At the state level, the central government should carry out the overall planning with a step-by-step, hierarchical coordination strategy to formulate industrial policies to ensure a balance between sustainable development and resource conservation. ICTL also requires a large initial investment and, therefore, necessitates a great deal of support. The investment for a one-million-tpa plant is approximately US$2.5 billion. China's ICTL industry is still in the early stages of engineering development. Although the technology has gone through solid research, development, and industrial demonstration, its further commercialization still faces hurdles due to the upfront investment required. Gasification accounts for over 50% of the total investment. Breakthroughs in this technology will most definitely reduce the financial burden. Improving catalyst performance, optimizing the process parameters, and selectively choosing the materials of construction will undoubtedly reduce the investment required.

### Engineering Challenges

Sasol has acquired a tremendous amount of ICTL experience based on research, scale-up, and operations. Even so, some serious problems arose when Sasol started up the 1400-ktpa capacity Qatar Oryx GTL plant; these problems were resolved by 2009. The take-home message for China's ICTL industry is that engineering scale-up problems are real possibilities. In addition to the accumulation of engineering experience and actual operational experience, simulation is also a powerful tool to predict the possible problems in reactors and throughout the processes.[6,8] The National Institute of Clean and Low-Carbon Energy (NICE) is cooperating with Pittsburgh University and other research institutions in the areas of industrial hydrodynamics, reaction kinetics to improve reactor capabilities, and process simulations to support the megaton ICTL PDP for Shenhua Group.

### Other Challenges

Water produced in LTFT process contains about 5 wt% organic chemicals; for HTFT, this value is even higher. The separation and purification of these organic chemicals for higher value products can improve the overall project economics. Water cleanup is also important for environmental protection. As a result, optimizing the water treatment technologies currently used is critical. Presently, only Yankuang Group has completed comprehensive research in this area; they were able to remove the organic acids using a technology that combined extraction and distillation. However, the largest scale of F-T water treatment in China is approximately 0.2 million tpa, and the project economics are still problematic unless the megaton process is begun in the next few years.[2]

Currently, Co-based catalysts are mainly used for GTL processes. The question remains as to whether they can be used in ICTL. In GTL, the feedstock is natural gas (mainly $CH_4$). The syngas from natural gas has a $H_2$-to-CO molar ratio near two with very low sulfur content, which makes it suitable for Co-based catalysts. On the other hand, the syngas from ICTL has a $H_2$-to-CO molar ratio of less than two with higher sulfur content, even after cleanup, which makes it suitable to Fe-based catalysts. Fe-based catalysts also have an advantage of lower preparation cost. However, Fe-based catalysts require a longer preparation cycle, consume a large amount of water, and can change structure during reactions, which leads to attrition, shorter life, and difficulty in reactivation. Co-based catalysts may be expensive initially, but are more resistant to attrition, have better longevity, trigger simple reactions, and can be reactivated. Co-based catalysts have received greater attention for further research and development efforts.[2,5]

## PROSPECTS

ICTL in China has entered into an industrial-scale era and China has become a global leader of ICTL technology developments and commercialization. Megaton-scale industrial demonstration plants will be constructed and operated in China over the next few years, which will allow the industry in China to continue expanding its experience in ICTL technology. As breakthroughs occur related to Co-based catalysts and problems associated with water constraints and environmental issues are solved, ICTL will find more applications and play an even bigger role in the modern coal-to-chemicals industry.

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The authors can be reached at wengli@nicenergy.com and menzhuowu@nicenergy.com.

# What Would It Take for an Environmental NGO to Accept CTL:

## *An Exclusive Interview with Brad Crabtree from the Great Plains Institute*

**By Holly Krutka**
Executive Editor, *Cornerstone*

**Brad Crabtree, Program Director, Great Plains Institute**

Environmental NGOs have generally opposed the expansion of producing liquid fuels from coal. *Cornerstone* sat down with Brad Crabtree from the Great Plains Institute to discuss what can and should be done to increase acceptance of CTL from an environmental perspective. The Great Plains Institute is a nonprofit organization based in the U.S. Midwest, largely focused on accelerating the transition to a renewable and low-carbon energy mix by 2050 (www.gpisd.net).

Program director at the Great Plains Institute since 2002, Brad Crabtree manages the institute's fossil energy projects. He is a graduate of the Georgetown School of Foreign Service and has an MA in history from Johns Hopkins University. Brad codirects the National Enhanced Oil Recovery Initiative (NEORI), an industry, labor, and environmental coalition convened by GPI and the Center for Climate and Energy Solutions to expand $CO_2$-EOR as a national energy security, economic, and environmental strategy. Brad previously coordinated energy policy advisory groups for the Midwestern Governors Association and codirected Powering the Plains, a regional energy policy project. His background includes energy and environmental policy and project development work in Washington, DC and Brazil and field research in Borneo.

**Q:** ***What do you regard as the most important environmental challenges that must be addressed to enable widespread deployment of CTL technologies?***

**A:** The principal environmental challenge to broader CTL deployment is the greater carbon intensity of liquid fuels derived from coal using traditional CTL processes. Commercially available and emerging transportation fuel options offer lower carbon profiles than conventional CTL, including conventional and some unconventional petroleum and natural gas, petroleum produced through enhanced oil recovery (EOR) using manmade industrial $CO_2$, next-generation biofuels, hydrogen produced in certain ways, and electrification of transport.

The incorporation of additional technically feasible measures into CTL production, such as $CO_2$ capture for EOR, co-utilization of biomass feedstocks with coal, and coproduction of electricity together with liquid fuels, can each incrementally reduce the carbon footprint of final net energy output from a CTL process, resulting in low and even net-negative greenhouse gas (GHG)

**Great Plains SynFuels Plant, operated by Dakota Gas, has been producing natural gas from lignite for over 25 years. Starting in the 1990s, the plant has been selling $CO_2$ for enhanced oil recovery.**

emissions. Such measures will be necessary to overcome environmental opposition to CTL based on relative emissions.

While we would support CTL projects that commercially demonstrate important carbon mitigation strategies, CTL will continue to face general resistance so long as most countries lack comprehensive climate policies to reduce GHG emissions. Technology innovation has made hydrocarbon reserves economically recoverable on a scale that now threatens climate stability, if those reserves are produced and used in conventional ways. In that context, many environmental advocates fear that widespread deployment of CTL will open up the world's vast coal reserves for use in the transportation sector, without broader policies to prevent further and dangerous acceleration of already unsustainable global $CO_2$ emissions.

Conversely, the opening of these unconventional hydrocarbon reserves make advances in carbon capture, utilization, and storage (CCUS) technology that much more critical. CTL, if managed responsibly from a carbon mitigation perspective, could facilitate commercial demonstration and deployment of key CCUS technologies.

Finally, in some industrialized countries, CTL is challenged by growing opposition to the mining and use of coal itself because of the higher carbon footprint of coal without CCUS relative to other fuels and the increasing availability of those alternatives. In addition, failure by some companies to engage in responsible mining practices and end some environmentally destructive types of coal mining undermines efforts by organizations like ours to advance policies and technology demonstration to ensure a viable, low-carbon future for coal.

**Q:** ***What features do you think early mover U.S. CTL projects would have to have in order to minimize opposition to such projects by U.S. environmental NGOs, many of which have opposed any use of coal to make liquid fuels in the past?***

**A:** First, a CTL project would have to commit to capturing 90% or more of its available $CO_2$ and contract to store it in a saline formation or through $CO_2$-EOR. Given CTL's relatively low cost of capture and the need for a revenue stream from $CO_2$, proposed CTL projects in the U.S. already routinely incorporate $CO_2$ capture for EOR into their business model.

Second, given growing environmental concern about overall GHG emissions levels and not just relative emissions, CTL projects should commit to improving substantially on the carbon profiles of conventional petroleum alternatives.

Accomplishing this would require coproduction of electricity with liquid fuels and integration of biomass with coal in the feedstock conversion process, in addition to $CO_2$ capture for EOR. Combined cycle generation of power using unprocessed synthesis gas

**The Great Plains Institute works to protect the environment of the U.S. Midwest and the world by making recommendations to businesses and policy makers.**

and excess saturated steam from the synthesis reactor yields significant efficiency gains, and coprocessing of biomass with $CO_2$ capture allows the permanent capture and storage of photosynthetic carbon from the biomass. Analysis by Robert Williams at Princeton University suggests the technical feasibility of developing a CTL project with coproduction of electricity and use of biomass to achieve very low net $CO_2$ emissions relative to the conventional fossil fuel products displaced.

Finally, demonstrated attention to a sustainable biomass supply would be important. Biomass harvest sufficient to supply a CTL facility would have significant natural resource implications in the area of a plant. However, if properly managed, biomass production can significantly reduce GHG emissions from a CTL project and offer other environmental benefits (habitat, water quality, soil quality).

**Q:** ***What are the most important technical challenges that should be the focus of CTL-related R&D efforts needed to address the environmental challenges?***

**A:** Despite significant commercial experience, skepticism prevails regarding CCUS and other measures to reduce the climate and environmental impact of coal-based energy. Fortunately, the technologies and processes necessary to transform CTL into a very low-carbon and even net-carbon-negative energy system—$CO_2$ capture for EOR, coproduction of electricity with liquids, and co-utilization of biomass—are commercially available today. Thus, the principal focus should not be further research, but rather urgent development and demonstration of a CTL plant that integrates these key features operationally at scale in a commercial setting. Seeing is believing, and the continued absence of a commercially operating low-carbon CTL project reinforces skeptical views of environmental advocates and others. Where research would have great value is in providing comprehensive, independent scientific and technical evaluation of key emission-reducing components of a commercial CTL demonstration project. Evaluation could focus on $CO_2$ capture and security of storage; net carbon balance of the facility's inputs, operations, and product streams; ecological and sustainability aspects of biomass harvest; etc. This would provide objective validation of outcomes for environmental organizations, regulators, policy makers, the media, and the public.

**Q:** ***Do you think there are good prospects for the formation of stakeholder group coalitions that would promote the advancement of environmentally sound approaches to CTL?***

**A:** Several years ago, our organization helped environmental stakeholders in the U.S. Midwest reach agreement on eligibility criteria for CTL-based projects to receive federal tax credits, and those criteria were incorporated into the bipartisan Coal Bridge Energy Act of 2010 authored by U.S. Senators Kent Conrad (D) and Orrin Hatch (R).

However, the fiscal and political context for CTL projects has deteriorated markedly since then, at least in the industrialized world. The U.S. and other mature economies are struggling with deficits and debt, and the emergence of abundant low-cost shale gas and unconventional oil plays have weakened the energy security and economic rationale for CTL. Furthermore, most environmental organizations and other stakeholders that tried to engage the coal industry on an incentive-based approach to climate policy have given up due to the industry's opposition, and they now support more traditional GHG regulation instead.

Still, our experience coordinating a national coalition of U.S. industry, labor, and environmental stakeholders who are working together to expand commercial deployment of $CO_2$-EOR suggests a path forward. Not only does EOR already provide a commercial market for the capture and sale of manmade $CO_2$ to the oil industry, analysis shows that new federal revenue from increased oil production would more than pay for the cost of tax credit incentives to capture, compress, and transport $CO_2$ from industrial facilities and coal plants (both gasification or combustion) to existing oil fields, thus delivering economic, energy security, and climate benefits.

However, for an EOR-based incentive policy for $CO_2$ capture to become political reality will require more than the current handful of coal companies to engage with other stakeholders in supporting needed incentives. It will require the entire industry to make commercial deployment of low-carbon coal technology job number one.

# Emerging Workforce Issues for the U.S. Energy and Mining Industries

**By Cy Butner**
Study Director, Former Senior Program Officer,
National Research Council

**Elaine Cullen**
Vice President,
Safety Solutions International Northwest Operations

**Charles Fairhurst**
Professor Emeritus, University of Minnesota, and
Senior Consulting Engineer, Itasca Consulting Group, Inc.

**Elizabeth Eide**
Director, Board on Earth Sciences and Resources,
National Research Council

## INTRODUCTION

The National Research Council of the National Academies has recently concluded a study of emerging workforce trends in the U.S. energy and mining industries, and the resulting report provides important messages for all of these industries.[1] The study covered oil, natural gas, coal, carbon capture, use, and storage (CCUS), nuclear, geothermal, solar, wind, and nonfuel minerals, along with the electric grid (including the Smart Grid), workforce education and training, workforce safety and health, U.S. federal government workforce issues, and workforce data and data sources. The workforce components in industry, government, academia, and skilled labor at the entry and senior levels were considered. The study focused on the "upstream" portion of the workforce (associated with the production or extractive portion of the industries).

*"The present and future are bright for energy and mining jobs overall …"*

Since no single body collects, analyzes, and reports data on all aspects of the energy and mining workforce, data and information from a range of sources were considered in the NRC report.[1] Where possible, data from federal sources were used, but these data have limitations and data from other sources (including industry, industry associations, professional societies, and academic sources) were used to supplement federal datasets. (The report presents data for each industry and sector, and its appendixes contain an extensive compilation of workforce-related data from federal sources and an overview of these sources.) Although the available data are quite disparate and do not give a complete or precise description of these industries or

**People and technology will be critical to meeting U.S. energy and mining workforce needs.**
*Photo:* Peabody Energy

their workforces, the data and information clearly show the general nature of the workforce and the important trends, issues, and concerns related to it. Following is a summary of the study results.

Energy in the U.S. comes from many sources with established commercial industry bases: e.g., fossil fuels, nuclear energy, and renewable energies. Figure 1 provides the historical and projected energy use by fuel for the U.S. for 1980–2035. Although the use of coal as an energy resource is projected by the U.S. Energy Information Administration (EIA) to decrease slightly from 21% of total U.S. energy use in 2010 to 20% in 2035, coal will remain a sizable segment of the nation's energy portfolio. (New EIA data released after the workforce study was released are largely consistent with these estimates—indicating that coal provided 20% of U.S. energy consumed in 2011 and projecting it to provide 19% in 2040.[2])

## THE BIG PICTURE

The present and future are bright for energy and mining jobs overall, with demand for workers at all levels remaining strong for the foreseeable future. Moreover, these jobs should continue to pay well.

However, two primary factors that cut across the energy and mining sectors do adversely affect their workforces—the aging of the baby-boomer population and the need for workers with science, technology, engineering, and math (STEM) skills. Baby boomers (people born between 1946 and 1964) represent about a third of the U.S. workforce and a large number of expected retirements will occur within the decade. There are not enough

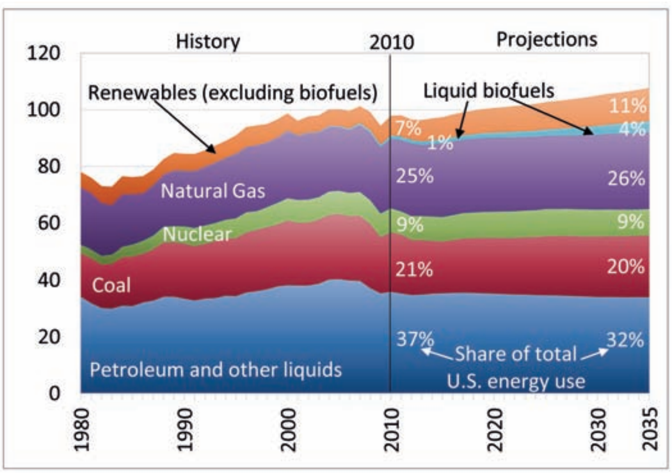


**FIGURE 1. Primary U.S. energy use by fuel, 1980–2035 (quadrillion Btu)**

*Source:* EIA 2012[3]

younger workers in the "pipeline" to replace them. Also, many energy and mining jobs at all levels require STEM skills. This need is increasing as the workplace becomes more complex and technical, and the existing pipeline of STEM-capable students and workers is inadequate to satisfy anticipated needs.

## PROMISING SOLUTIONS

Potential solutions to these problems offer promise. Solutions will need to address the issues of attracting more people into the energy and mining workforce and providing adequate work-force education and training.

Traditional sources of workers will not be sufficient to meet the projected demand. The report outlines the need for urgent and strenuous efforts to attract young and nontraditional workers (ethnic minorities and women) to avoid a workforce shortfall.

Education and training programs are essential if we are to have a workforce of adequate size and ability. It is necessary to bring young people into STEM and technical programs that can lead to energy and mining jobs, beginning at an early age (as early as grade seven). Also, present and future jobs require more education than in the past. Education beyond high school is required for many energy and mining jobs, but a degree from a four-year institution is not required for most. The need for education is increasing and current educational approaches are generally not meeting it. Key components of a more effective education and training system should include community colleges, universities, and education–industry partnerships. There are some very effective programs already underway that target minority portions of the young population and could be expanded and emulated.

The GeoFORCE Texas program at the University of Texas at Austin,[4] for example, is an industry–education partnership that uses a cohort model and focuses on bringing disadvantaged minority students in Texas into the earth and engineering sciences. This program has expanded to the GeoFORCE Alaska program at the University of Alaska Fairbanks.[5] The AfricaArray program at Penn State University[6] also focuses on minority students and seeks to develop a pool of undergraduate and graduate students for the geoscience workforce in the U.S. and Africa using linked research and training programs. The National Science Foundation (NSF) provides another example through its support of Advanced Technological Education centers and projects at selected community colleges. These centers focus on particular industries or sectors, perform industry–educator analyses of the required skills and competencies, and aid other colleges in the development of curricula aligned to the skills requirements.[7] With their ability to quickly adapt to changing conditions and to work with industry to closely align a curriculum with industry

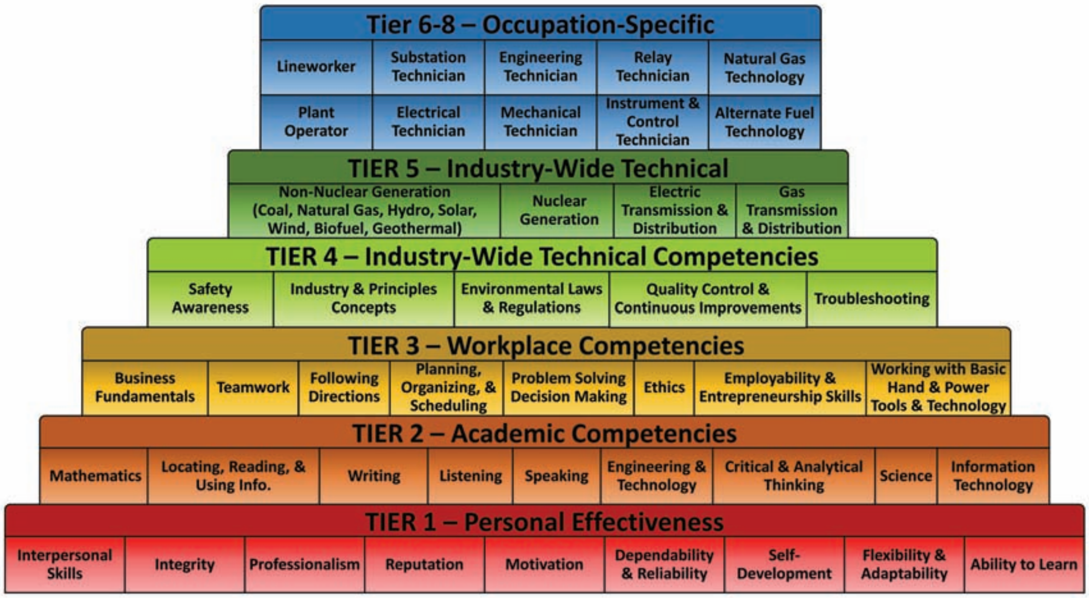


**FIGURE 2. Energy industry competency model: Generation, transmission, and distribution**

*Source:* CEWD 2010[8]

needs, community colleges are providing new, additional pathways for workforce education and certification. Also, in partnership with universities and colleges, community colleges can serve as a pathway to four-year institutions by providing remedial and entry-level education to prepare students for the higher level of undergraduate study. Going forward, it will be important for universities and community colleges to expand partnerships, and critical for committees of experts to be engaged in aligning programs of study with industry requirements.

Partnerships among industry, educational institutions, and educators, especially at community colleges or in the first two years of higher education at four-year institutions, are critical to the future of U.S. energy and mining. They create competency-based educational pathways to industry careers by aligning programs of study with industry requirements.

Competency models exist in manufacturing (which is closely aligned with the energy industry) and in several energy sectors, and there is great potential for extending such models into all of the energy and mining industries. In competency models, basic skills are building blocks to industry careers. As skills are learned at distinct levels, certification can be provided and students can move to higher skill levels and greater achievement. Needed skills can be learned in secondary or community college programs, and lead to high school and/or college credit and degrees and to industry-granted skills certifications that map to career and educational pathways. Figure 2 shows a competency model developed by the Center for Energy Workforce Development (CEWD) for energy generation, transmission, and distribution.

Universities are also an essential part of workforce development. Specialized programs at the bachelor's and master's levels are needed, especially for mining, petroleum engineering, and geosciences. For years, university geoscience and petroleum engineering departments, faculty, and undergraduate enrollment had been decreasing, but these trends have reversed in the last few years. Mining and mineral engineering programs and faculty have experienced a long decline in numbers, and the U.S. graduates a nonsustaining number of mining engineers. Shortage of faculty is a serious problem in all of these disciplines, which impacts the oil and gas, mining, and geothermal workforces. An increase in industry and government funding for academic research would attract and train students and strengthen faculty.

A possible solution to advancing science and engineering, along with enhancing student enrollment, in mining, petroleum, and geological engineering in the U.S. could be the establishment of interdisciplinary graduate Centers of Excellence in Earth Resources Engineering at major research universities. Such centers could bring attention to the technical challenges faced by the extractive industries, offer more holistic earth resources curricula, and develop the professional expertise needed by these industries. These centers would complement the classical programs of the U.S. schools of mines (some of which may establish centers, either alone or with other universities). The report notes that establishing such centers now could ensure the U.S.'s position as a technological leader in mining engineering.

## WHAT ABOUT THE COAL AND HARD-ROCK MINING WORKFORCE?

The U.S. Bureau of Labor Statistics (BLS) reported average annual U.S. employment in 2010 for coal mining as about 81,100 and about 8100 for support activities for coal mining (totaling around 89,200, all in the private sector).[9] The U.S. Mine Safety and Health Administration (MSHA) reported a 2010 U.S. total operator employment of about 89,200 and total contractor employment of about 46,300, for a combined total of around 135,500.[10] The BLS data undercount employment largely due to limitations associated with the North American Industry Classification System (NAICS) taxonomy they use, which results in undercounting contractor employment.

BLS projects coal mining employment (excluding support activities) to decrease to 77,500 by 2020.[11] In comparison, EIA projections show that total U.S. employment in coal mining could be around 86,500 in 2020, 115,700 in 2030, and 128,600 in 2035.[12] As Figure 3 indicates, EIA projects that domestic coal production, as an energy source, is expected to decline through 2015, after which production is expected to grow at an average annual rate of 1.0% through 2035.

For nonfuel mining, BLS reports a 2010 U.S. workforce of about 128,000 (all in the private sector, except for about 270 in local government) and BLS projections suggest a net increase of 3300 private-sector jobs by 2020 in metal ore mining and nonmetallic mineral mining and quarrying.[14] MSHA reports a 2010 U.S. employment of about 160,100 for nonfuel mining operators and about 65,500 for nonfuel mining contractors (totaling around 225,600).[15]

For mining, an aging workforce and international competition for talent are driving a pending workforce crisis for professionals and workers, and an existing crisis for mining faculty in the U.S. The mining workforce is older than the overall U.S. workforce, with more than half of the mining sector expected to retire by 2029. This large number of anticipated retirements presents challenges for ensuring safety and health and for replacing lost experience in the workspace.[16] Also, many university faculty in mining engineering will be eligible to retire by or around 2020.[17] With low production of Ph.D. graduates, this could lead to programs losing faculty positions. The relative absence of consistent federal research funding at mining schools has made the situation worse. Moreover, changing U.S. demographics are expected to cause a workforce shortage that probably will not be offset by anticipated increases in mining production efficiencies (from automation or technological advances, for example). Australia has demographics and production characteristics similar to the U.S. and offers evidence for an emerging U.S. mining workforce shortage.

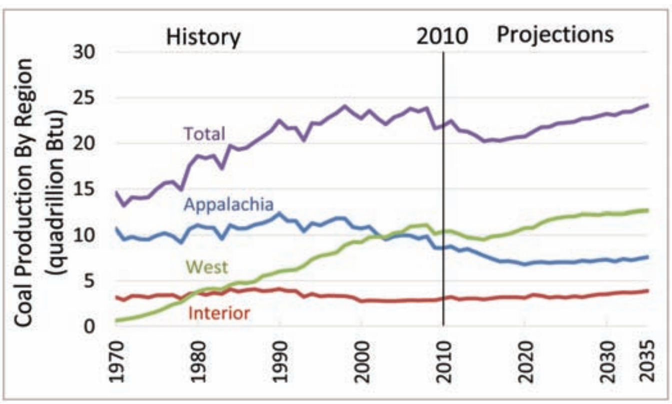


**FIGURE 3. Coal production by region, 1970–2035, reference case (quadrillion Btu)**

*Source:* EIA 2012[13]

Workforce safety and health are important considerations for the mining industry. Several key factors require consideration. The training of new workers is critical, and mentoring and knowledge capture for use in training are necessary. As the workplace becomes increasingly diverse, an important consideration is that supervisors and managers will need training in leading and communicating with a diverse workforce. Effective communication is key to maintaining a safe work environment.

Data indicate that workers with less than one year of experience or who are over 55 years of age are more likely to suffer occupational injury and death than other workers. In mining, the worker population is bimodal, with many workers in two high-risk groups—the young and the aging. With the mining sector facing many expected retirements, the gap between new and experienced workers is expected to grow. Injury and fatality rates are anticipated to increase as a result.

MSHA reports that of the 21 coal miners killed in 2011, 10 had one year or less of experience at the task they were doing.[18] Inexperience is not related to age alone (workers can change professions late in life), but it is most often a factor for new, young workers.[19] An analysis of metal/nonmetal mining fatalities between 2002 and 2006 revealed that workers between 17 and 24 years of age had the highest fatality rate among all age groups of miners who did similar tasks and workers over 55 years of age ranked second.[20]

## CONCLUSIONS

Along with the U.S. workforce challenges come opportunities. Growth in the energy and mining sectors and many pending retirements are providing unprecedented opportunities for young students and workers to enter these fields. Also, U.S. demographics are changing, with growing ranks of minority and women students and people from other countries entering the workforce and seeking degrees and certifications.

These changes underscore the importance of seeking new workers from both traditional and nontraditional backgrounds. Also, current and future workers will need more education than in the past. Enhancing the education pipeline with innovative approaches to expand workforce preparation can enlarge the flow of qualified workers into the U.S. workforce.

Overall, the future is very bright, provided the necessary preparations are made.

## WHERE TO GO FROM HERE?

The workforce study covered a broad range of industries and workforce sectors, each with its own issues, and the study committee that wrote the report found several overarching themes and potential solutions that cut across this diverse landscape. Accordingly, the committee formulated a set of overarching findings and recommendations as a capstone to accompany the conclusions and recommendations specific to the individual workforce sectors. An encapsulation of the report's overarching recommendations follows. The discussion is excerpted from the report, with some editing for brevity, and the recommendations have been edited only slightly where needed for clarity.

### Pathways

Traditional routes to degrees in higher education do not adequately align curriculum to energy and mining industry requirements and are increasingly unaffordable and inaccessible. These routes do not provide enough qualified STEM-educated workers and professionals to meet the U.S. energy and mining workforce needs. The goal in addressing the current education pipeline's shortfalls is to create an education system that can respond to changes in the economy more quickly and produce a more flexible, STEM-competent workforce.

**Recommendation 1:** The Department of Education, in collaboration with the Department of Labor, state departments of education, and national industry organizations, should convene (perhaps in workshops or as a working group) critical industry, government, and educational leaders to create and support new approaches that provide multiple pathways in higher education that take full advantage of the attributes of our higher education system. These workshops and/or meetings should be convened in different parts of the country. These models would benefit greatly from including, for example:

- Community colleges integrating industry-recognized credentials, their learning standards, and content into associate degree programs, providing more "on" and "off" ramps to postsecondary education, resulting in stackable interim credentials with real value in the labor market, and leading to direct employment or continuing postsecondary educational opportunities; and

- Partnerships between four-year colleges and universities and community colleges to create new pathways for STEM curriculum, with the first two years of STEM-related programs of study being offered at the community college and the second two years being offered at the university, thereby expanding the capacity of the critical university degree programs.

### Business–Education–Government Partnership

No one sector—government, industry, or education—can provide the needed energy and mining workforce on its own. University research also can contribute to workforce development by enhancing the education pipeline.

**Recommendation 2:** To address common goals and to provide a mechanism for industry's engagement with the education process and the graduates it produces, federal agencies (e.g., the NSF, Department of Energy, Department of Defense, National Institute for Occupational Safety and Health, and National Institutes of Health) should consider providing increased research funding to universities, with matching funding from industry, with specific requirements to incorporate two outcomes from the research: (1) advancing technology or business processes to drive innovation and enrich graduate and undergraduate education and (2) developing university faculty who work on the cutting edge of research to enhance the quality of higher education. The engagement of both faculty and graduate students in this research will extend the pool of STEM-qualified faculty for all educational levels.

### Energy and Mining Information for the Public

Building the best educational pathways in the world and the most qualified STEM faculty for U.S. educational institutions does not ensure that more students will pursue energy and mining programs of study. The public perception of U.S. extractive industries is often negative (due, for example, to concerns over pollution, noise, environmental degradation, and safety and health issues). This image dissuades some from pursuing careers in these industries. Also, although renewable energy is generally seen as positive, some negative perceptions (e.g., questionable technology viability, long-term existence, and cost-effectiveness) may dissuade people from joining those workforces. Information about all of these industries can educate the public about their importance to the nation and the career opportunities they offer, and it also may motivate students to pursue STEM courses and prepare for energy and mining careers. The government has a natural role to play in providing and disseminating such information as a complement to nongovernment sources.

**Recommendation 3:** National industry organizations, in partnership with educational institutions, should embark on a national campaign to create and provide accurate and timely information on the industries and their careers, educational and career navigation resources, and experiential learning opportunities to explore jobs and career paths in energy and mining. These entities should work with the Department of Labor and other government institutions to ensure that timely government information is included.

**Recommendation 4:** In like fashion, national industry organizations and educational institutions should also embark on an informational campaign to educate students, parents, educators, and public policy makers about the importance of the energy and mining industries to the economic and national security of the nation, the relevance of STEM education to jobs and careers in these industries, and the opportunities available in these industries—including timely government information.

## Data Needs

To redesign education programs and business–education partnerships to better provide a qualified workforce, accurate data on occupations, jobs, and skill requirements are needed. Although the federal (and other) databases provide an abundance of information on the energy and mining workforce, such as employment estimates and demographic information, the data currently available for addressing the energy and mining workforce are not sufficiently consistent, comprehensive and up-to-date for these rapidly evolving, technology-infused industries and they do not exist at a sufficient degree of granularity. It is critical to foster the collaboration of government data-gathering agencies with industry.

**Recommendation 5:** The Department of Labor, through its Bureau of Labor Statistics, should determine and pursue a more effective way to partner with industry, through its national industry associations, to more quickly and accurately reflect the fast-paced change of job and occupation titles and characteristics, as well as the levels of education and training required in 21st century jobs.

**Recommendation 6:** The BLS should work with industry and the Departments of Education and Labor to better define the STEM technical workforce needed to support STEM professions in our economy so that appropriate and useful data can be identified, collected, and analyzed.

*"It is critical to foster the collaboration of government data-gathering agencies with industry."*

## The U.S. Federal Workforce

Federal employees have a critical role in, and impact on, the success of the U.S. energy and mining industries. Federal employees are involved in all aspects of the energy and extractive industries and they link industry's ability to produce energy and minerals with society's concerns about these industries. However, the nature of the workforce situation in the federal sector for energy and mining is serious. MSHA projections, for example, indicate that 46% of their coal-sector workforce will be eligible to retire within five years, and they expect to lose 40% of their metal/nonmetal workforce in the same period. Other federal agencies are facing similar conditions. Federal agencies involved in the energy and extractive industries have an acute need to replace departing federal workers, but because of the restrictive personnel processes that federal agencies must follow and the relatively higher compensation offered by industry, it is difficult for federal agencies to hire and retain the employees they need.

**Recommendation 7:** All involved federal agencies should review and revise recruitment, training, and employment arrangements for federal employees directly involved in minerals and energy policy, permitting, and production oversight to ensure the agencies' ability to attract and retain qualified federal workers. Industries involved in energy production and resource extraction should develop collaborative efforts to partner with government at all levels to develop solutions to the problem of recruiting and retaining quality public-sector employees.

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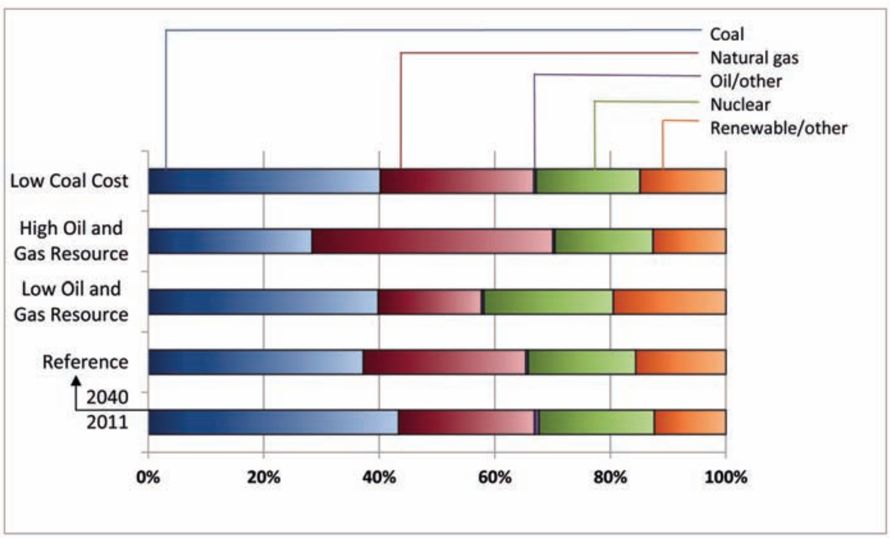
The author can be reached at cy.butner@gmail.com.

# The Future of the Energy Mix in the U.S.

The U.S. Energy Information Agency (EIA) recently released its Annual Energy Outlook for 2013 (AEO2013), which includes projections of the U.S. energy infrastructure in the near term and also through 2040. In the near term, the report suggests that rising natural gas prices will lead to coal recapturing some of the energy market that has been lost in recent years. The report included several scenarios for the energy mix in 2040, including a reference case, high cost of coal, low cost of coal, high oil and gas resource, and low oil and gas resource.




*Source*: Reproduced from the EIA AEO2013 (www.eia.gov/forecasts/aeo)

In all scenarios coal was projected to play a major role in the energy mix. Coal-fired power plants as a percentage of total installed capacity were projected to decrease (both in terms of GW and as a percentage) from 2011. For the most favorable cases for coal demand in 2040 (the low coal cost and the low oil and gas resource) coal was projected to account for approximately 23.5% and 22.9% (290 GW and 283 GW), respectively, of installed capacity. However, the study tells a very different story when actual generation is examined. In the reference case, coal-based electricity was projected to grow by ~0.2% per year—meaning that even while the total installed capacity of coal-fired power plants was decreasing, the remaining plants will be increasing the total coal-based electricity output. In the reference case the average capacity factor for coal-fired power plants in 2040 was projected to be 78% (compared to approximately 57% in 2012). In the range of scenarios presented, the lowest average coal-power plant capacity factor was 69% in 2040 with a contribution of over 1300 billion kWh (just over 30% of the total energy generated).

# Caterpillar's Approach to the U.S. STEM Workforce Gap

**By Gwenne Henricks**
Chief Technology Officer, Caterpillar Inc.

What does it mean to be a global leader? Caterpillar is the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives. For us, being a global leader means that we must be constantly vigilant. You don't need a global footprint like ours to recognize the landscape today is more competitive than ever. Our competitors are growing exponentially around the world. There are plenty of companies vying to be the next Caterpillar.

So how do we remain competitive in this ever-changing and growing global marketplace? We must innovate to differentiate our products and meet our customers' needs. And our customers are looking for advances like hybrid technology, electric drive technology, autonomous solutions, and alternative fuels. To drive those innovations, we rely on talent from the fields of science, technology, engineering, and math (STEM).


**Fully autonomous, semi-autonomous, and remote control systems help provide a safer work environment and improve the efficiency of mining operations.**

*"The increase in demand for STEM talent, coupled with an aging workforce, has created a 'perfect storm' of sorts for the industry."*

Today, we have a STEM community of more than 10,000—and many of these employees are on the ground at mines across the globe. As a major employer of mining talent, our U.S. workforce mirrors the trends highlighted in the National Research Council's report, "Emerging Workforce Trends in the U.S. Energy and Mining Industries".[1] We are experiencing these challenges firsthand as many of our openings for highly skilled STEM positions continue to go unfilled. This is a major concern for Caterpillar, and we are working hard to be part of the solution.

## INNOVATING THROUGH PRODUCT TECHNOLOGY

We're addressing these challenges from a few different angles, one of which is our technology. Caterpillar offers fully autonomous, semi-autonomous, and remote control systems for machines in various applications. These systems help bridge the workforce gap primarily in two ways: 1) by providing a safer and more comfortable work environment for mine personnel, making it easier to attract and retain skilled workers and 2) by improving the efficiency and productivity of mining operations.

First and foremost, these systems enhance the safety of mine sites. Like most employers of mining talent, safety is a top priority for Caterpillar. Autonomous solutions can reduce or even eliminate the number of people working around large equipment, lowering the risk of personal injury. Redundant safety systems also reduce risks attributable to fatigue, boredom, or distraction, especially when the machine is performing repetitive tasks.

While a safer environment is great, a controlled environment is even better. Our remote control and semi-autonomous systems

**NASA's Lunabotics Mining Competition is one of many student pipeline programs sponsored by Caterpillar to engage students in STEM fields.**

allow operators to work from remote stations. These stations can be located a few hundred feet or several hundred miles away from their machines. Remote operation is also easier to learn compared to traditional machine operation—novice operators can become experts in a shorter amount of time.

Improvements to the work environment aren't the only benefit. Autonomous solutions let mines achieve more with less by enabling the same number of workers to operate more machines. These systems also enhance overall productivity and mine output by guiding machines consistently each time a particular operation is required. Continuous utilization is another advantage. Autonomous machines have the ability to work almost continuously, without stopping for breaks or shift changes.

## BUILDING THE U.S. TALENT PIPELINE

While these technologies aid in addressing the workforce gap, the report anticipates these advances alone are not enough to offset the shortage of STEM talent. Even a highly automated mine site still demands a substantial human presence. Equipment needs to be serviced on site, and it's imperative to have trained eyes, ears, and senses on the ground in management, planning, and supervisory roles.

Despite the great demand for these skilled, degreed workers, the U.S. isn't producing nearly enough graduates in STEM fields. Caterpillar is addressing this issue by 1) proactively working to attract and engage young and diverse workers in STEM careers and 2) providing meaningful education and training opportunities for these individuals.

The first part of this effort is our proactive pipeline programs to help spark and maintain student engagement in STEM fields. We know that by the time students reach high school, it's often too late to pique their interest in STEM careers. That's why we work with For Inspiration and Recognition of Science and Technology (FIRST, www.usfirst.org), an organization that provides global, mentor-based programs to build STEM skills. We sponsor FIRST programs for students of all ages—from grade school through high school—and for locations throughout the world.

This momentum is carried on with a variety of programs for college students. One such program is NASA's Lunabotics Mining Competition, where students are challenged to construct an excavator capable of mining simulated lunar soil. Caterpillar also hosts regional collegiate design competitions for the Society of Automotive Engineers. Each of these initiatives simulates real-world engineering challenges and prepares young students for work in STEM fields.

***"While a safer environment is great, a controlled environment is even better."***

So how do we position these individuals for success once they are interested in STEM fields? Caterpillar provides a number of learning opportunities. We administer a corporate internship program to provide students with work experience, sometimes without even leaving campus. We have a presence at strategic partner universities, where employees work side-by-side with students. These facilities include our Pittsburgh Automation Center at Carnegie Mellon University, Black Hills Engineering Design Center at the South Dakota School of Mines, and Champaign Simulation Center at the University of Illinois.

We also support several industry organizations that encourage diverse workers to engage in STEM careers. Hundreds of Caterpillar employees are involved in STEM outreach through groups like the Society of Women Engineers (SWE), National Society of Black Engineers (NSBE), Society of Hispanic Professional Engineers (SHPE), and the National GEM Consortium. In fact, one of our employees will serve as SWE President in 2014. These partnerships are a critical piece of Caterpillar's efforts to build a sustainable

**Caterpillar CTO, Gwenne Henricks, is shown testifying before the U.S. Senate on immigration reform. Caterpillar often relies on foreign nationals to fill skilled positions, but obtaining a green card can be a long and tedious process.**

STEM pipeline, as we need diverse teams with diverse ideas to drive innovation.

## IMPLEMENTING INTERIM SOLUTIONS

Although Caterpillar enthusiastically supports building a sustainable pipeline of STEM talent in the U.S., we must acknowledge these efforts are still not enough to close the workforce gap. We are moving in the right direction, but the pipeline cannot be filled overnight. We also can't afford to fall behind in terms of innovation. What are we doing now to ensure we have enough STEM talent to keep the company moving forward?

In light of the current U.S. shortage of STEM talent, Caterpillar relies on foreign nationals to fill openings for highly skilled positions. But it's not easy. The process is long and tedious. For example, the employment-based green card process requires Caterpillar to conduct labor market tests to ensure we have not displaced any qualified and available U.S. workers. Further, we must establish that we pay foreign nationals wages consistent with what we pay similarly situated U.S. workers. Then our employees have to wait. Some employees from China and India have waited more than eight years for a green card. And others are not even allowed to stay at all. These are valued employees, and we lose them.

We need to find a way to welcome these productive professionals to the U.S. This is the main reason Caterpillar decided to take action on the immigration issue. We actively support comprehensive immigration reform and have been very engaged in the effort to date. We've worked closely with the National Association of Manufacturers (NAM) and U.S. Chamber of Commerce to provide input on proposed legislation and participated in numerous forums and panel discussions. Our CEO visited the White House to voice his support, while I recently testified in front of the Senate Commerce Committee.

So what do we want to come of this? We would like to see significant reforms to the high-skilled visa system. H-1B visas are an important tool for hiring foreign nationals with advanced STEM degrees. Currently, the number of H-1B visas is capped each year without regard to current market demand. This year the cap was reached on the first day, which prevents U.S. companies from hiring new H-1B employees for another 18 months. But the H-1B issue is just the tip of the iceberg. We need realistic immigration solutions that hold workers accountable for meeting immigration requirements, going through the proper channels, and making a real contribution to the country they want to call home.

*"Even a highly automated mine site still demands a substantial human presence."*

## OUR COMMITMENT

The state of the U.S. mining industry and its workforce is at critical juncture. The increase in demand for STEM talent, coupled with an aging workforce, has created a "perfect storm" of sorts for the industry. Caterpillar will weather this storm by making mining operations safer and more efficient through technology, making a concerted effort to build a sustainable pipeline of STEM talent in the U.S., and supporting comprehensive immigration reform as an interim solution. We agree that the future of mining is bright as long as we remember that people will always be the foundation of a successful mining industry.

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## International Events & Politics

### *WORLD BANK LIMITS FUNDING FOR COAL-FIRED POWER STATIONS*

The World Bank has announced that it will no longer fund coal-fired power stations except in a few rare cases, in a move pioneered by the bank's President, Jim Yong Kim, and now backed by the board. In the past five years the Bank has financially supported over US$5 billion in funding for new coal-fired power plants.

### *U.S., CHINA HOLD DIALOGUE ON COAL*

At the annual U.S.-China Strategic and Economic Dialogue the two countries, which account for nearly 60% of global coal use, disclosed new initiatives focused on reducing greenhouse gas emissions, including joint support of large-scale CCUS projects.

## Recent Select Publications

***Medium-Term Renewable Energy Market Report – IEA*** – The most recent release of the MTRMR estimated that energy from renewable sources will overtake natural gas as soon as 2016.

***Technology Roadmap: Carbon Capture and Storage 2013 Edition – IEA*** – This updated Technology Roadmap discusses how CCS will be necessary to meet climate goals by providing one-sixth of the necessary emissions reductions.

## Movers & Shakers

**Kenneth Fairfax, a career diplomat** in the U.S. State Department, will replace Richard Jones as the IEA Deputy Executive Director.

**Orica announced** that its Executive Director Finance, Noel Meehan, will leave the company at the end of October 2013 when he is replaced by Craig Elkington, the current Executive Global Head Mining Services.

Orica Limited announced that Alberto Calderon and Gene Tilbrook have been appointed as non-executive Directors.

**Anglo American announced** a restructuring of its 10 business units into six units, effective as of January 2014. Tony O'Neill has been named as the new Group Director. Anglo American is the leader in the 2013 Dow Jones Sustainability Index.

**Tony O'Neill**
**Group Director at Anglo American**

**BHP Billiton opened** the new Daunia mine in central Queensland, which is the company's ninth operating metallugical mine in the region.

**Shenhua Group announced** that the 4000-ktpa indirect coal-to-liquids project has been approved by the National Development and Reform Commission. This will be the world's largest ICTL project and has an expected completion date in 2016. The total investment will be 55 billion RMB (US$9 billion), which is the largest investment for a single chemical industry project in the world.

**Glenn Kellow**
**COO at Peabody Energy**

**Peabody announced** that Heather Wilson, President of the South Dakota School of Mines and former member of the U.S. Congress, has been appointed to the company's Board of Directors.

Peabody also announced that Glenn Kellow, a veteran mining executive, has been named Chief Operating Officer and will report to CEO Gregory Boyce.

## Key Meetings & Conferences

Globally there are numerous conferences and meetings geared toward the coal and energy industries. The table below highlights a few such events. If you would like your event listed in *Cornerstone*, please contact the Executive Editor at cornerstone@wiley.com.

| *Conference Name* | *Dates* | *Location* | *Website* |
|---|---|---|---|
| *Longwall Conference 2013* | Oct. 14–15 | Hunter Valley, NSW, Australia | www.informa.com.au/conferences/mining-conference/operational-mining-conference/longwall-conference |
| *33rd Coaltrans World Coal Conference* | Oct. 20–22 | Berlin, Germany | www.coaltrans.com (Other Coaltrans conferences are listed on the website) |
| *Power-Gen International* | Nov. 12–14 | Orlando, FL, U.S. | www.power-gen.com |
| *Power-Gen Africa* | Nov. 12–14 | Cape Town, South Africa | www.powergenafrica.com |
| *International Coal & Climate Summit* | Nov. 18–19 | Warsaw, Poland | scc.com.pl/konferencje/en/cct/ |

## Meeting Spotlight

# The 30th Annual International Pittsburgh Coal Conference


**Dr. Zhang Yuzhuo presented the opening keynote address at the annual IPCC.**
*Source: Wen Min*

The 30th Annual International Pittsburgh Coal Conference (IPCC) was held at the Beijing International Convention Center from Sept. 16–18. The conference was hosted by the Division of Energy and Mining Engineering of the Chinese Academy of Engineering and the National Institute of Clean and Low-Carbon Energy (NICE). Dr. Zhang Yuzhuo, President and CEO of Shenhua Group, was the Conference Chair and provided the opening keynote presentation. Xie Kechang, Vice President and member of the Chinese Academy of Engineering, also presented in a keynote session.

The focus topic of the conference was “Energy, Environment, and Sustainable Development”. This year’s conference provided an effective forum for the approximately 300 international participants from industry, government, and academia to hold in-depth discussions regarding the direction of the global coal industry.

**The Australian coal mining industry is projected to lose more than 11,000 jobs.**

## AUSTRALIA

The Australian government has announced that it will end the tax on carbon emissions on 30 June 2014, and has proposed that the carbon tax be replaced by an emissions trading scheme linked to the European Union ETS. The change is projected to save the average Australian household approximately US$350 annually.

The number of jobs lost in the last year in the Australian coal mining industry is projected at more than 11,000.

## BANGLADESH

The government in Bangladesh has announced that coal-fired power generation will receive a tax break for the next 15 years. Currently, coal makes up only 2% of Bangladesh's energy mix, but the government has set a goal of increasing that amount to 24%.

**24%**

**of Bangladesh's energy could come from coal in the future**

## CHINA

China's government has planned to invest US$375 billion in projects that save energy and reduce emissions during the period of the 12th Five Year Plan.

China's State Council approved a new 3% tariff on imports of lignite.

**10%**

**of particulate matter pollution in China will be reduced by 2017**

China's government recently announced an action plan to reduce particulate matter pollution. Particles of 10 microns or less will be reduced by more than 10% by 2017 from 2012 levels; in Beijing, Tianjin, and Hebei the reduction objective is 25%. To meet these targets the action plan proposes to reduce coal's role in the primary energy mix to below 65%, among other measures.

## UNITED KINGDOM

The UK government is backing off a policy to subsidize the use of biomass to generate electricity and will phase out the subsidy by 2027. This policy change is based largely on public pressure after it was revealed that millions of tons of wood were being shipped from the U.S. to meet the demand for biomass.

## UNITED STATES

President Obama announced a Climate Action Plan, in which he issued an order for the U.S. Environmental Protection Agency to develop a greenhouse gas standard for existing power plants.

**Corrigendum: Issue 2, page 59, corrections are noted with red text: Subsidy requirements would be less at higher crude oil prices. For example, at $115/bbl: (a) the first CTL-OT-CCS plant would require a $1.5 billion subsidy, (b) only the first three plants would require subsidies (at an average rate of $0.68 billion per plant), (c) net new government revenues would average $2.1 billion per plant for these first three plants, and (d) net new government revenues would be positive ($1.4 billion) for the very first plant.**

## From the WCA

The WCA is organizing an International Coal & Climate Summit in Warsaw during the November climate change negotiations. The speakers confirmed as of early September are listed below:

- Janusz Piechociński, Deputy Prime Minister, Minister of Economy of Poland
- Dr. Zhang Xiwu, Chairman of the World Coal Association and Chairman of the Shenhua Group
- Prof. Jerzy Buzek, Member of the European Parliament
- Changhua Wu, China Director, Climate Group
- Milton Catelin, Chief Executive, World Coal Association
- Paweł Smoleń, EURACOAL President and COO of PGE SA
- Christoph Frei, Secretary General, World Energy Council
- Paul Dougas, Chairman, Global CCS Institute
- Ashok Bhargava, Director, Energy, Asian Development Bank
- Brian Ricketts, Secretary General, EURACOAL
- Boguslaw Sonik, Member of the European Parliament
- Bogdan Marcinkiewicz, Member of the European Parliament
- Mike Monea, President, Carbon Capture and Storage Initiatives, SaskPower
- Giles Dickson, VP Environmental Policies & Global Advocacy, Alstom
- Ilya Solovyev, Solutions Sales Executive, Gasification, GE Power & Water Europe & CIS
- Simon Schulte Beerbühl, Karlsruher Institut für Technologie, EGTEI
- John Topper, Managing Director, IEA Clean Coal Centre
- Annika Seiler, Finance Specialist, Energy Division, East Asia Department, Asian Development Bank
- Grzegorz Zieliński, Senior Banker, Power & Energy Utilities, European Bank for Reconstruction & Development
- John Marion, Director, Technology & R&D, Alstom
- Arto Hotta, Director, Research & Development, Foster Wheeler, Finland
- Andrew Minchener, General Manager, IEA Clean Coal Centre
- Marion Wilde, Policy Officer, European Commission – EC international cooperation projects on coal
- Roman Łój, President, Katowicki Holding Węglowy S.A.
- Dr. Marek Ściążko, Director, Institute for Chemical Processing of Coal in Zabrze, Poland
- Julie Lauder, CEO, Underground Coal Gasification Association, UCGA
- Serge Perineau, President, World CTX
- Dr. Lesley Sloss, Principal Environmental Consultant, IEA Clean Coal Centre

**Picturesque Warsaw will be the host city for the International Coal & Climate Summit.**

- Hans Joachim Meier, Environmental Technology, Chemistry, Safety and Health, VGB
- Bryony Worthington, Founder, Sandbag

Visit the Summit website to see the updated, complete list of speakers at: scc.com.pl/konferencje/en/cct/. Also, see the Summit ad adjacent to the inside back cover for additional event details.

## THE WCA, BRAZILIAN COAL ASSOCIATION ANNOUNCE RESEARCH PARTNERSHIP

The WCA and the Brazilian Coal Association have announced a new partnership to pursue collaborative work to advance technical, environmental, and strategic research on clean coal technologies.

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