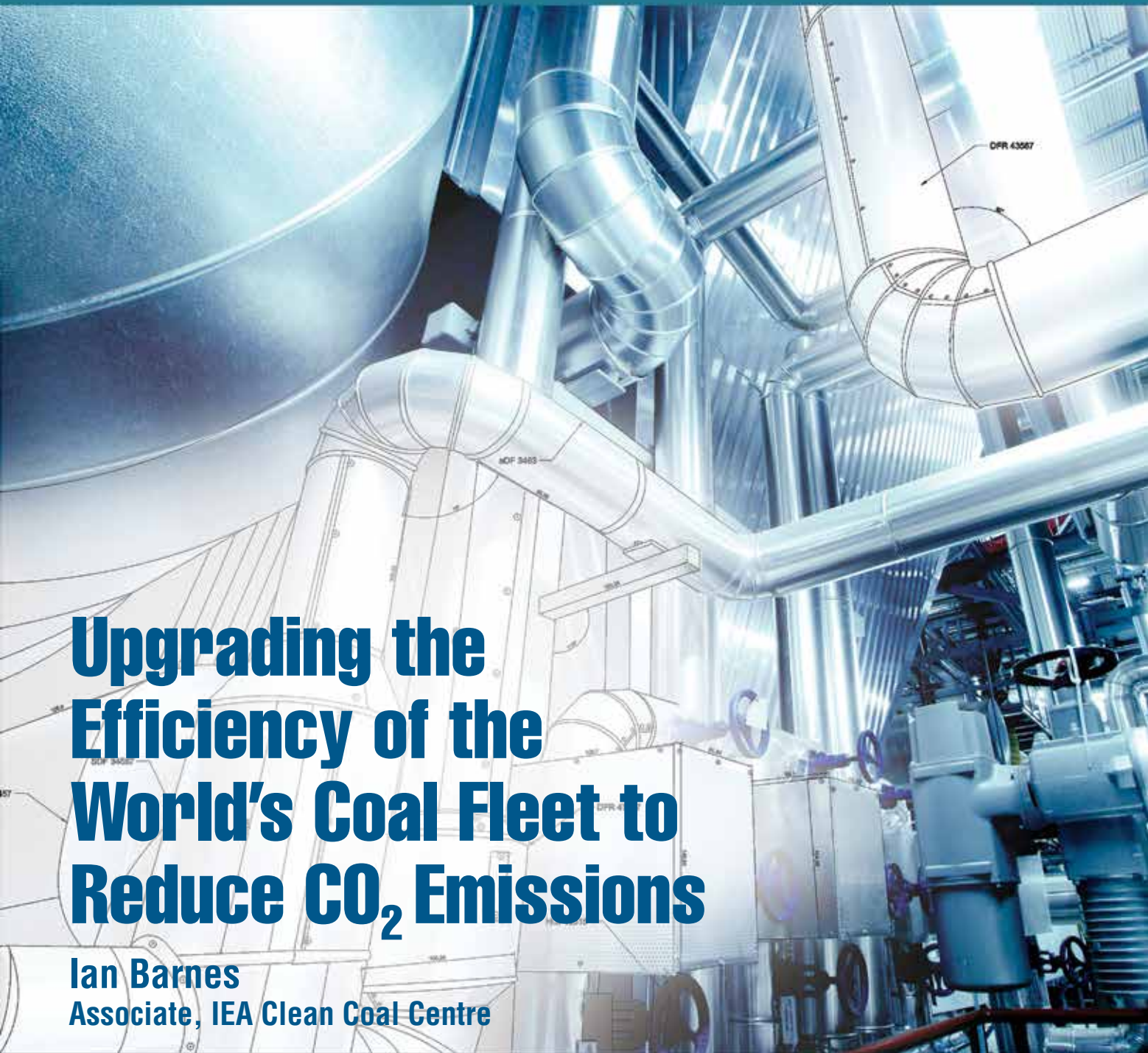


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CORNERSTONE

VOLUME 3 ISSUE 1

THE OFFICIAL JOURNAL OF THE WORLD COAL INDUSTRY



Upgrading the Efficiency of the World's Coal Fleet to Reduce CO₂ Emissions

Ian Barnes
Associate, IEA Clean Coal Centre

**Shenhua's Evolution
From Coal Producer to
Clean Energy Supplier**

**What is on the Cards for
the Coal Industry in 2015?**

**Setting the Benchmark:
The World's Most Efficient
Coal-Fired Power Plants**



“ Our mission is to defend and grow markets for coal based on its contribution to a higher quality of life globally, and to demonstrate and gain acceptance that coal plays a fundamental role in achieving the least cost path to a sustainable low carbon and secure energy future. ”

Benjamin Sporton
Acting Chief Executive
World Coal Association

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Full Steam Ahead to Improved Efficiency



Liu Baowen
Executive Editor, *Cornerstone*

For well over a century the energy in coal and other fuels has been used to create steam for electricity generation. Today, due to a continuously expanding global population, increasing urbanization and industrialization, and energy poverty eradication efforts, energy demand is growing—fueled primarily by coal in rapidly developing countries. According to BP’s Statistical Review of World Energy 2014, coal’s share of global energy consumption climbed between 2000 and 2013, to 30.1%, the highest amount since 1970.

Ancient Chinese philosophers often said that when speaking of material things, one speaks of gains and losses, while in human affairs there are pros and cons—energy production and utilization is a fundamental human affair. There is no denying that coal has supported the development of an industrialized, modern civilization, but there are also challenges, such as CO₂ and other emissions. Numerous clean coal technologies are commercially available and high-efficiency, low-emissions (HELE) coal-fired power plants must play an important role in the transition to a cleaner, lower-carbon energy future.

Replacing or retrofitting a low-efficiency subcritical plant with an ultra-supercritical plant could reduce carbon emissions per unit of electricity by about 20% or more. While deeper reductions may be necessary to meet international climate mitigation goals, global HELE technology deployment represents a step that can have an immediate, substantial impact. According to the International Energy Agency, only about 29% of the existing coal-fired power fleet can be retrofitted for carbon capture, utilization, and storage. Thus, efficiency improvements are the first step on the road to major emissions reductions.

China is making the needed investment by actively increasing the efficiency of its coal-based power fleet. The country has already witnessed considerable improvements by replacing older, inefficient, and smaller power plants with large ones using HELE technologies. For instance, criteria emissions from the Shanghai Waigaoqiao No. 3 ultra-supercritical coal-fired power plant are less than half of China’s limits for natural gas power plants.

There are also unconventional approaches to improving the efficiency of energy utilization that are now being conceptualized and deployed. For example, coal-based polygeneration of electricity, heat, and fuel could address emissions from the transportation and industrial sectors in China—leading to a comprehensive energy transformation. In addition, the demonstration of the world’s first 600-MW_e supercritical circulating fluidized bed has set the stage for the HELE utilization of low-rank coals, wastes, and biomass. In South Africa one independent power producer is looking to HELE underground coal gasification to provide much needed baseload electricity.

This issue of *Cornerstone* is focused on the many ways that coal can be used to fill global energy demand with the highest efficiency and lowest emissions possible. Thus, our hope is the content in this issue will spark deep engagement on the important topic of HELE technologies. On behalf of the editorial team, I hope you enjoy it.

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Upgrading the Efficiency of the World's Coal Fleet to Reduce CO₂ Emissions

Ian Barnes

As the global focus on climate change mitigation grows, it becomes increasingly important for coal-fired power plants to most effectively reduce their CO₂ emissions. As explained by the IEA Clean Coal Centre, improving efficiency can reduce emissions immediately and is a first step toward deep cuts with carbon capture, utilization, and storage.





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Upgrading the Efficiency

By Ian Barnes
Associate, IEA Clean Coal Centre



"A current state-of-the-art coal-fired plant operating with a high-efficiency USC steam cycle will be more efficient, more reliable, and have a longer life expectancy than its older subcritical counterparts."

Coal remains an important source of energy for the world, particularly for power generation. During the last decade the demand for coal has grown rapidly, as has the demand for gas, oil, nuclear, and renewable energy sources. Various projections for future growth in energy demand suggest that this trend will continue, dominated by coal use in the emerging economies, particularly China and India. Continuing pressure to cut CO₂ emissions to mitigate the effects of climate change, specifically to limit the average rise in global temperature to between 2°C and 3°C, will require halving (from current levels) CO₂ emissions by 2050.

To contribute to this goal, emissions from coal-fired power generation will need to be reduced by around 90% over this period: Cuts this deep will require carbon capture and storage (CCS). In the International Energy Agency (IEA) 450 ppm CO₂ climate change scenario, around 3400 large-scale CCS plants must be operating globally by 2050 to abate the required amount of CO₂ emissions.¹ At the same time, the growing need for energy, and its economic production and supply to the end user, must remain central considerations in power plant construction and operation.

of the World's Coal Fleet to Reduce CO₂ Emissions

In 2012, the IEA concluded that, in general, larger, more efficient, and hence younger coal-fired power plants are most suited for economic CCS retrofit. However, the agency also found that only around 29% of the existing installed global coal-fired fleet could be retrofitted with CCS. Furthermore, on average, the efficiency of existing global coal-fired capacity is comparatively low, at about 33% (net HHV basis for all loads, all coals, and all steam conditions)^A, although the recent establishment of large tranches of modern plants, particularly in China, is raising this figure. This article examines the first step in the decarbonization of the coal-fired electricity sector: increasing power plant efficiency.

Recently the IEA CCC published a study evaluating how improving coal-fired power plant efficiency would reduce CO₂ emissions. For all nations evaluated, increasing the efficiency of the fleet of coal-fired power plants offered considerable CO₂ emission reduction benefits, although variability was observed in the time frame in which such benefits could be realized.

REALIZING DECARBONIZATION THROUGH EFFICIENCY GAINS

Operating at lower efficiency means that relatively large amounts of coal must be used to produce each unit of electricity. As coal consumption rises, so do the levels of CO₂ and other emissions. Upgrading existing plants and building new high-efficiency, low-emissions (HELE) coal-fired power plants addresses climate change concerns in two important ways. In the near term, emissions can be reduced by upgrading existing plants or building new HELE plants. Such plants emit almost 20% less CO₂ than a subcritical unit operating at a similar load. Over the longer term, HELE plants can further facilitate emission reductions because coal-fired plants operating at the

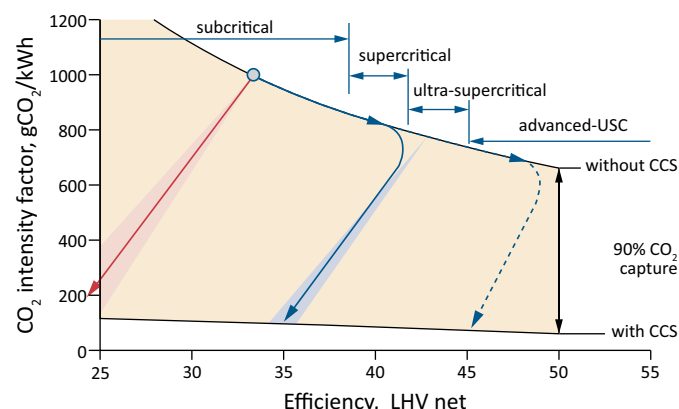


FIGURE 1. Reducing CO₂ emissions from pulverized coal-fired power generation

highest efficiencies are also the most appropriate option for CCS retrofit. For these reasons, there is considerable global interest in HELE technologies. Figure 1 illustrates the impact of employing progressively more effective HELE technologies and CCS on CO₂ abatement (presented in terms of LHV at full load with hard coal).

The terms subcritical, supercritical, ultra-supercritical (USC), and advanced ultra-supercritical (AUSC) describe the steam conditions by which electricity is generated in a thermal power plant. HELE technologies center on improvements to the steam cycle, allowing for higher steam temperatures and pressures and the consequent improvement in the steam cycle efficiency. A switch from subcritical to current USC steam conditions raises efficiency by around four to six percentage points. Historically, the majority of pulverized coal-fired plants were based on subcritical steam-cycle technology, but supercritical technology is now widespread, largely due to improvements in boiler tube materials. Table 1 summarizes the differences in operating pressures and temperatures for various types of

TABLE 1. Approximate pressure and temperature ranges for subcritical, supercritical, and ultra-supercritical coal-fired power plants

<i>Pulverized coal-fired power plant</i>	<i>Main steam pressure, MPa</i>	<i>Main steam temperature, °C</i>	<i>Reheat steam temperature, °C</i>	<i>Efficiency, % net HHV basis (inland, bituminous coal)</i>
Subcritical	<22.1	Up to 565	Up to 565	33–39
Supercritical	22.1–25	540–580	540–580	38–42
Ultra-supercritical	>25	>580	>580	>42

coal-fired plants currently in operation. Although the definitions of supercritical and USC vary from country to country, the ranges cited in the table are used frequently.

Supercritical plants can be found in 18 countries and are now the norm for new plants in industrialized nations; USC steam cycles are now the state of the art. A current coal-fired plant operating with a high-efficiency USC steam cycle not only has improved efficiency, but is also more reliable and has a longer life expectancy.

Whereas the first supercritical units were relatively small (typically less than 400 MW_e), larger units of up to 1100 MW_e are now being built based on USC technology (such as the Neurath USC lignite-fired plant in Germany) and even larger units are planned.

Developments in AUSC steam cycles are expected to continue this trend. AUSC coal-fired plants are designed with an inlet steam temperature to the turbine of 700–760°C. Average metal temperatures of the final superheater and final reheater could be higher, up to about 815°C. Nickel-based alloy materials are needed to meet this demanding requirement. Various research programs are underway to develop AUSC plants. If successful, a commercial AUSC-based plant would be expected to achieve efficiencies in the range of 45–52% (LHV [net], hard coal). A plant operating at 48% efficiency (HHV) would emit up to 28% less CO₂ than a subcritical plant, and up to 10% less than a corresponding USC plant. Commercial AUSC plants could be widely available by 2025, with the first units coming online in the near future.

To illustrate the potential of HELE technologies, Figure 2 summarizes the impact of different steam-cycle conditions on an 800-MW_e power station boiler burning hard coal and operating at an 80% capacity factor. Such a unit would generate 6 TWh of electricity annually and emit the quantities of CO₂ shown in the figure, depending on its steam-cycle conditions

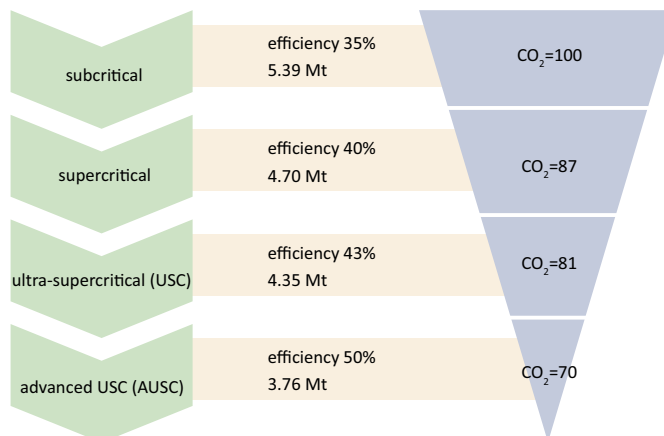


FIGURE 2. The impact of HELE technologies on CO₂ emissions

and corresponding efficiency. Thus, replacing a unit of this type operating with a subcritical steam cycle with a unit based on AUSC technology (under development) would result in savings of CO₂ in the region of 30%.

COAL FLEETS IN DIFFERENT COUNTRIES

Across nations, a legacy of using coal to produce electricity has given rise to coal fleets of differing age and efficiencies. Countries with a long history of using coal to generate power tend to have mature coal fleets that are maintained and upgraded with replacement components and new plants when necessary. Newer coal users tend to have younger coal fleets, in some cases based on the best available technology. These two extremes are well illustrated by comparing the coal fleet profiles of Russia and South Korea (Figures 3 and 4, respectively). Russia's fleet is older, and thus consists of mostly subcritical plants, whereas South Korea's recently built and rapidly growing fleet is made up primarily of supercritical and USC plants.

The IEA CCC recently examined the potential of HELE coal-fired power to reduce CO₂ emissions; the principal coal-consuming

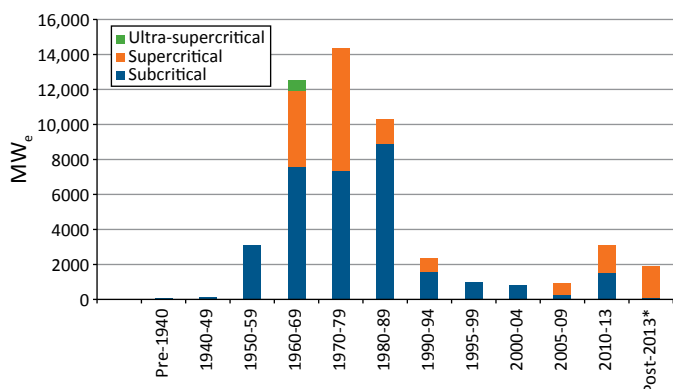


FIGURE 3. Russian coal-fired power fleet by year of construction and steam-cycle conditions

*Planned or under construction

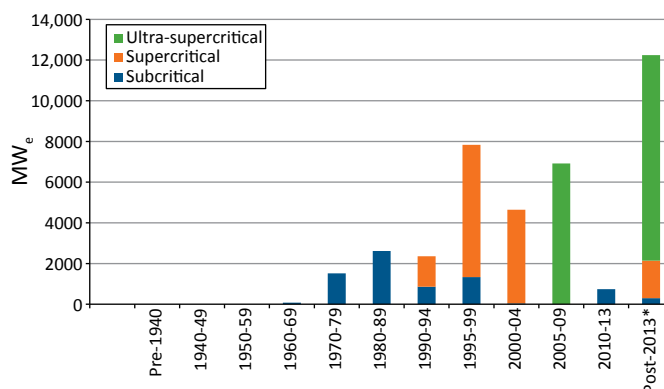


FIGURE 4. South Korean coal-fired power fleet by year of construction and steam-cycle conditions

*Planned or under construction

nations were studied: Australia, China, Germany, India, Japan, Poland, Russia, South Africa, South Korea, and the U.S. Notably, the coal-fired power fleets of these countries vary in age and efficiency, and have different local conditions and policies that affect the possible scope for implementing HELE technologies.

The coal fleet profile of each country to meet future electricity demand was assessed under three scenarios: continuing electricity generation based on the existing fleet and retiring and replacing older plants on the basis of a 50-year or 25-year plant life. The potential impact of HELE upgrades on CO₂ emissions was quantified and costs of implementation were estimated. Industry norms were used for unit efficiency and availability and current assumptions on capture rates from CCS retrofitted to HELE plants were assumed.

HELE UPGRADES IN THE LARGEST EMERGING ECONOMIES

As China and India represent the largest emerging economies and both rely heavily on coal, the key findings for the Chinese and Indian studies are summarized below.

China

The Chinese coal-based fleet is the largest in the world, as are the associated CO₂ emissions. These plants account for approximately 41% of the global coal-fired capacity and are responsible for approximately 37% of global CO₂ emissions from coal through the production of electricity.² China's coal-based fleet—with a median age of less than 20 years—is by far the youngest currently in operation. In addition, a significant number of the newer plants employ supercritical or USC steam conditions.

By the end of 2013, China's total electricity capacity was 1247 GW. With a reported coal-fired power generation capacity of

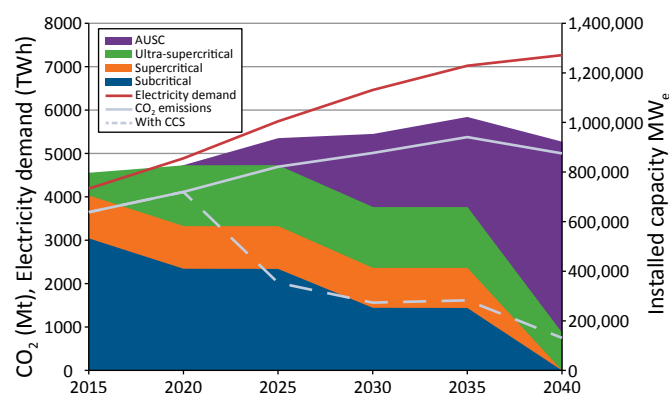


FIGURE 5. China's coal-based power fleet composition and CO₂ emissions under a plan to retire plants after 25 years of operation, from 2015–2040

over 786 GW and an annual total generation of 3947 TWh (2013 data),³ China is the world's largest producer of power from coal. Predictions on the role of coal in China's future energy requirements generally agree that coal will continue to be a very significant contributor to the country's energy needs, although estimates of the relative importance of coal with respect to other primary energy sources differ. China is actively seeking to diversify its electricity supplies. The electricity capacities from other energy sources currently stand at 22% for hydroelectric, ~8% for other renewables (led by wind at ~6% and solar at ~2%), 6% for natural gas, and 1% for nuclear power. Although power from these sources is growing, they still account for a relatively small share of China's energy generation profile, with coal still responsible for about 70% of electricity generation.

The Chinese government has set a target to raise non-fossil fuel energy consumption to 11.4% of the total energy mix by 2015 as part of its 12th Five-Year Plan. The U.S. Energy Information Administration (EIA) projects coal's share of the total energy mix to fall to 59% by 2035 due to anticipated higher energy efficiencies and China's goal to reduce its carbon intensity.⁴ Still, absolute coal consumption is expected to double over this period, reflecting the large growth in total energy consumption.

China is the premier example of a country benefitting from an actively pursued HELE upgrade policy. By utilizing state-of-the-art USC plants for new and replacement capacity, and with the retirement of older, less efficient units, CO₂ emissions are projected to rise less steeply than the increase in demand for coal-based electricity; emissions are projected to reach 6136 Mt in 2040. If China continues to adopt the best technology and retire older units on a roughly 25-year timescale, a largely AUSC-based coal fleet would see projected CO₂ emissions actually fall between 2035 and 2040; in this case the CO₂ emissions are projected to be 5153 Mt in 2040 (a 16% reduction over the base case scenario), despite a continuing increase in demand. If the most effective CO₂ abatement pathway is followed (25-year plant retirement, AUSC upgrades after 2025, CCS installation) emissions could fall to 750 Mt in 2040 (see Figure 5). Although the analysis presented here does not incorporate China's recent announcement to peak coal utilization by 2020, such a policy approach would certainly require continued aggressive deployment of HELE coal-fired power plants.

India

India has the third largest coal-fired power plant fleet installed in a single country. The Indian coal fleet contributes approximately 6% of the global coal-fired capacity with approximately 8% of global CO₂ emissions from coal through the production of electricity.² India has a relatively high share of smaller units

(i.e., <400 MW_e) and many of India's power plants burn high-ash coal (up to 50%). The majority of the Indian coal-fired power plant fleet is based on subcritical technology, although some recently built plants have incorporated supercritical steam cycles. Overall, the fleet is relatively young and a very large portfolio of supercritical plants is reported as planned or under construction, which will make India the second fastest growing user of coal for electricity generation (after China) by 2020.¹

“India is a rapidly developing country with considerable energy poverty and rapidly growing energy demand.”

India's 12th Five-Year Plan (2012–2017) sets a goal that 50–60% of new coal-fired plants must use supercritical technology, although observers suggest that significantly less is likely to be achieved. Early indications of India's longer-term policy direction suggest that the 13th Five-Year Plan (2017–2022) will stipulate that all new coal-fired plants must be at least supercritical, thus no new subcritical plants would be allowed.⁵

India is a rapidly developing country with considerable energy poverty and rapidly growing energy demand. Growth in coal-based energy demand is projected to extend to 2040, with no sign of leveling off. If new capacity is based on the best available HELE technologies and older plants are retired after 25 years and replaced with HELE units, CO₂ emissions will first flatten out and then decline, despite increasing demand: 764 Mt in 2015 to 1063 Mt in 2040; a 39% increase (see Figure 6).

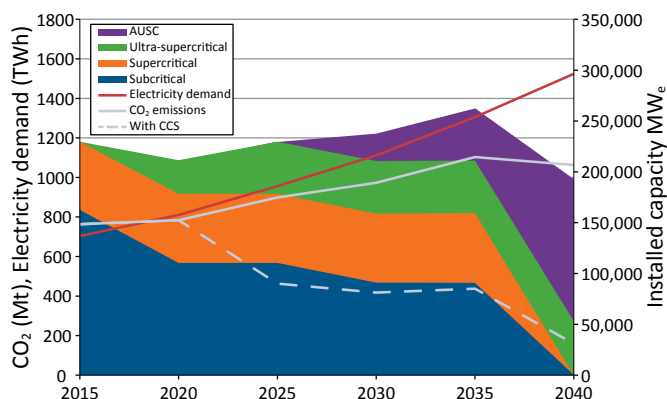


FIGURE 6. India's coal-based power fleet composition and CO₂ emissions if subcritical plants were retired after 25 years of operation, from 2015–2040

With implementation of CCS, emissions could be reduced much more rapidly.

KEY CONCLUSIONS

The results of the IEA CCC study reveal trends for the major coal-consuming countries. Some trends are specific and depend on the profile of the respective coal fleet and the prospects for growth or decline in coal-sourced electricity, while other trends are more generally applicable. A few key conclusions can be garnered from the larger IEA CCC analysis:

- Countries experiencing a prolonged period of growth necessitating additional power capacity and having a relatively new coal fleet are characterized by rising CO₂ emissions, but these are projected to be offset by the use of AUSC over USC plants for new builds (e.g., China and India).
- Countries experiencing a prolonged period of growth necessitating additional capacity and having a more mature coal fleet are characterized by rising CO₂ emissions, but these are projected to be offset by the use of AUSC over USC (e.g., South Africa), particularly when older plants are retired and replaced by AUSC units.
- Countries experiencing a prolonged period of growth necessitating additional capacity and having an old, relatively inefficient coal fleet see falling levels of CO₂ emissions, even with growth in electricity demand (e.g., Poland and Russia).
- Countries experiencing relatively low to moderate levels of growth and having an efficient coal fleet do not see significant reductions in CO₂ emissions until 2040 when some older plants are projected to retire (e.g., South Korea).
- As an existing coal fleet transitions to a HELE composition it becomes smaller with respect to installed capacity. This potentially benefits the siting and replacement of plants, particularly in countries where planning regulations are demanding and time consuming.
- The greatest gains are seen when plant life is limited to 25 years (an evolving practice in China) rather than 40 years or more (common in OECD countries). Policies and incentives to encourage shorter timescale plant renewal would enhance CO₂ savings.
- When CCS readiness is considered, in all cases, the 25-year plant life scenario represents the best option for CCS deployment as all coal fleets transition to a high HELE composition quickly and enjoy maximum CO₂ abatement as any remaining lower efficiency capacity is retired. This is particularly evident in the Indian case where the effects of rapidly increasing electricity demand are attenuated by a combination of HELE and CCS technologies.
- Economics will govern the decision to replace plants unless policies and incentives drive the selection toward HELE technologies.



Steam turbines at the ultra-supercritical Waigaoqiao No. 3 (Shanghai) (photo courtesy of IEA CCC)

HELE plant upgrades can be considered a “no regret” option for coal-fired power plant owners and operators. A current state-of-the-art coal-fired plant operating with a high-efficiency USC steam cycle will be more efficient, more reliable, and have a longer life expectancy than its older subcritical counterparts. Most significantly, it will emit almost 20% less CO₂ compared to a subcritical unit operating under similar load. In the near future, developments in AUSC steam cycles promise to continue this trend: A plant operating at 48% efficiency would emit up to 28% less CO₂ than a subcritical plant, and up to 10% less than a corresponding USC plant. In addition, when CCS is available it will likely be applied to higher efficiency plants, making HELE a first step toward deep carbon emission reductions.

It is hoped that this study has provided an overview of what might be achieved in the major coal-using countries through an aggressive uptake of HELE technologies and the role they can play in reducing CO₂ emissions. Deeper analysis by the IEA CCC is planned on a country-by-country basis to provide policy makers and planners with a local perspective on how HELE implementation can reduce emissions. 🤖

NOTES

- A. Coal-fired power plant efficiencies are determined by properties such as the steam-cycle conditions, coal grade, load factor,

etc. and are often reported in terms of LHV or HHV. Efficiencies provided in lower heating value (LHV), have subtracted the heat required to vaporize any moisture in the coal and assume that heat is not recovered. The higher heating value (HHV) includes the heat required to vaporize the moisture in the fuel and is usually about 2–3 percentage points higher than LHV.

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Shenhua's Evolution From Coal Producer to Clean Energy Supplier

By Ling Wen

President and Chief Executive Officer, Shenhua Group

China's resource endowment has resulted in an energy mix dominated by coal—a fact unlikely to change for the foreseeable future. However, the continued large-scale extensive production and utilization of coal has resulted in considerable environmental impacts. If China's current approach to coal production and utilization remains unchanged, such problems could worsen. Therefore, the Chinese government has placed an emphasis on environmentally friendly development in the future, actively reforming the methods used in the production and consumption of energy resources, improving the state of the natural environment, and generally working to increase sustainability. As China's largest coal producer, Shenhua Group has an inexorable responsibility in this transformation process.

Shenhua Group's operating strategy hinges on the integration of key business areas, including coal production, electricity

production, railway transportation, ports management, sea-borne shipping, and coal conversion to liquids and chemicals. Therefore, Shenhua has explored the fields of reducing the environmental impact of coal supply, utilization, and conversion; the joint development of coal-based energy and alternative energy; and carbon capture and storage (CCS). Through practice, we believe that environmentally benign, highly efficient development of the coal industrial chain is technically and economically feasible.

"Shenhua's path forward to establish itself as a world-class clean energy supplier will be built on clean coal production, utilization, and conversion."



Shenhua is working to reduce the environmental impact from all its integrated key business areas.



The vegetation coverage at the Shendong mining site has increased dramatically through environmental restoration practices.

CLEAN COAL PRODUCTION

In the process of safely and efficiently producing coal, Shenhua has actively worked in the areas of water resource protection and land reclamation. For example, at its Shendong mining area—an area that contains the only mine in the world operating at a scale of 200 million tonnes of coal per year—building underground water reservoirs in the coal mine allows for mine water that would otherwise be discharged and subject to evaporation (and thus lost) to now be stored, purified, and utilized. This process currently provides over 95% of the water used in the mining area.

In the early stages of mine construction at Shendong, the vegetation coverage rate was only about 10%. Since then, Shenhua has been actively pursuing environmental remediation and land reclamation by strengthening the ability of the surface environment to withstand the impact of coal mining subsidence and adopting innovative environmental protection technologies. Today, vegetation covers 60–70% of the mining area. Given the fragility of the local ecosystem, Shenhua and its subsidiary coal companies set up a special fund for land reclamation: For each tonne of coal produced by the company, a percentage of the revenue is reserved for restorative purposes.

Shenhua produces a variety of coals. High-quality coal accounts for a large percentage; such coal contains a fairly small amount of undesirable components (e.g., sulfur and phosphorus). Nevertheless, Shenhua carries out onsite processing and beneficiation on this high-quality coal, effectively removing

gangue and some sulfur and phosphorus. To mitigate the environmental impact of transportation, dust suppressant is applied after the coal is loaded into railcars.

During both production and transportation, coal is kept from any contact with the ground so that reliable quality can be ensured. Supplying high-quality coal (i.e., ash content $\leq 15\%$ and sulfur content $\leq 0.5\%$) to the Beijing-Tianjin-Hebei area, Yangtze River Delta, Pearl River Delta, and other economically developed regions contributes to reducing emissions from coal utilization and thus limits the impact on air quality.

With respect to the low-rank coal that accounts for about 50% of China's total coal reserves, Shenhua has developed proprietary graded refining technologies and is now able to upgrade low-rank coal so that it contains less sulfur and mercury (see Table 1).

TABLE 1. Properties of low-rank coal before and after upgrading

Coal type	Lower Heating Value, MJ/kg	Total Moisture, Mass%	Sulfur Content, Mass% (air dry)	Mercury Content (Dry Basis), ppm
Raw lignite	17.15	32.0	0.42	0.13
Upgraded coal	24.69	7.7	0.20	0.04



The ultra-low emissions Guohua Zhoushan power plant

ULTRA-LOW EMISSIONS COAL-FIRED POWER

Coal-fired power is the foundation of electricity generation in China because it generates large amounts of power, creates a stable supply, employs mature technologies, and is minimally impacted by weather or other natural conditions. It currently provides 80% of electricity in China, and by all projections will continue to be the country's most important means of power generation for the foreseeable future. However, emissions from coal-fired power plants can be significant. Such emissions are major contributors to the air-quality issues recently observed in China. The development of highly efficient coal utilization technologies, especially high-efficiency, low-emissions coal-fired power, is imperative. Thus, the Chinese government has begun to implement stricter emission standards for coal-fired power plants.

Shenhua is currently the fifth largest coal-fired power provider in China, with a total installed coal-fired power capacity of 68.85 GW at the end of 2014. The company recently carried out extensive revamping and retrofitting of its coal-fired power plants to reduce emissions. Units already in service have been, or are being, upgraded and retrofitted to meet the ultra-low emissions standards, while newly built units are being constructed based on a high-efficiency, low-emissions model.

The domestically designed and constructed 350-MW supercritical coal-fired power unit (No. 4) owned by Shenhua Guohua Zhoushan Power is a prime example of the newer plants being built. On 25 June 2014, the unit's 168-hr trial was completed and it was officially placed into commercial operation. The emissions are far lower than the limits established in the latest "Emission Standard for Air Pollutants of Coal-Fired Power Plants" issued by China's Ministry of Environmental Protection. In fact, the plant's emissions are less than half the limits required for gas-fired power units (see Table 2).

The Guohua Zhoushan plant provides yet another example that ultra-low emissions from coal-fired power plants can be fully realized as long as suitable technical solutions are employed and environmental protection technologies are integrated. The increased investment to accomplish this is no greater than 6%. The increased cost per kilowatt is less than 0.01 yuan, which is a realistic cost to bear.

Currently, the technological transformation to achieve ultra-low emissions has been implemented successively at 48 of the 61 coal-fired units owned and operated by the Guohua Electricity Company, Shenhua's main power company. It is projected that the fleet-wide transformation will be complete in 2017. Meanwhile, all new coal-fired units constructed by the Guohua Electricity Company will adopt ultra-low emissions technologies and all new units will meet or surpass the emissions standards for gas-fired units.

CLEAN COAL CONVERSION

Clean coal conversion offers the opportunity for coal to evolve from being exclusively a fuel to being both a fuel and a raw material. The development of the clean coal conversion industry can reduce China's dependence on petroleum and gas imports and also greatly reduce emissions from coal utilization. Thus, Shenhua has constructed and operates several demonstration projects, including facilities converting coal-to-liquids and coal-to-olefins. These projects have demonstrated stable operation.

Approaches to coal-to-liquids conversion include direct coal liquefaction (DCL) and indirect coal liquefaction (ICL) technologies. Shenhua's DCL demonstration project (1.08 million tonnes of liquids produced per year) and ICL demonstration project (180,000 tonnes of liquids per year) are located in Ordos, Inner Mongolia, China.

Shenhua's DCL project is the only such project in the world operating at the million tonnes per year scale. On 30 December

TABLE 2. Emissions from Shenhua Guohua Zhoushan Power Plant No. 4 compared to national standards

Source	Particulate Matter, mg/Nm ³	SO ₂ , mg/Nm ³	NO _x , mg/Nm ³
<i>Guohua Zhoushan No. 4 Unit</i>	2.46	2.76	19.8
<i>Gas power unit emission standards</i>	5	35	50
<i>Coal-fired emission standards (key areas)</i>	20	50	100



Shenhua Group's original coal-to-olefins plant in Baotou

2008, processes throughout the plant were successfully tested in the first plant-wide trial and qualified products were made. Commercial operation officially commenced in January 2011. In 2014 alone, the facility produced 900,000 tonnes of liquid product, and as of the end of 2014, a cumulative total of 3.94 million tonnes of liquid products had been manufactured at the facility. Products from the DCL plant include diesel, naphtha, and liquefied petroleum gas. The sulfur content of the diesel produced is less than 1 ppm, far lower than the 10-ppm limit specified in the National V standard (the most stringent domestic standard for diesel). The use of diesel produced through DCL can significantly reduce air pollution from vehicle emissions.

Through years of development, Shenhua's DCL demonstration project has not only realized near-zero wastewater discharge, but also a major reduction in freshwater consumption. The water consumed per tonne of product has decreased from the design value of approximately 10 tonnes to the present value of 5.8 tonnes. The water consumption per product value is 17.8 tonnes/10,000 yuan, far less than the national industrial average (68.2 tonnes/10,000 yuan).

Shenhua also owns three coal-to-olefins projects that have been placed into commercial operation. The combined production capacity of these facilities is 1.6 million tonnes per year. This successful demonstration of commercial coal-to-olefins conversion has great practical significance in satisfying China's rapidly growing demand for olefins. Shenhua is also actively exploring new coal-to-olefins technologies to reduce water and coal consumption. As technologies progress, freshwater consumption is continually decreasing. The water consumption per product unit of the coal-to-olefins project in Baotou in the second-phase design has been reduced from the original 30 tonnes of water per tonne of products to 22.

DEVELOPMENT OF ALTERNATIVE AND RENEWABLE ENERGY

Shenhua is dedicated to developing both alternative and renewable energy sources and effectively integrating them with coal-based energy so that they can play a more significant role in changing China's energy mix. Shenhua is also actively exploring energy coupling and optimization technologies to improve the efficiency of energy conversion and utilization. Today Shenhua's installed renewable energy capacity exceeds 5 GW.

In June 2014, the drilling of Shenhua's Baoye Well No. 2 in Baojing County, Hunan Province, marked Shenhua's first shale gas exploratory well. This well officially signified the company's entrance into the field of domestic exploration and development of shale gas.

Shenhua's activities are not only limited to China. In fact, Shenhua is actively implementing an increasingly international strategy. One example is the successful acquisition of a wind power project in Australia with a total installed capacity of 300 MW. This project is the largest overseas wind power project owned by a Chinese energy company. Similarly, Shenhua has also invested in shale gas in the U.S.; such projects have also yielded positive economic returns.

In order to improve the utilization efficiency of renewable energy and to optimize the integration of renewable and coal-based energy systems, Shenhua is developing energy storage technologies, renewable energy-based hydrogen production, and coal-fired power peaking technology improve the utilization efficacy of renewable energy.



Shenhua holds 75% ownership of the Woolnorth wind power plant in Australia.

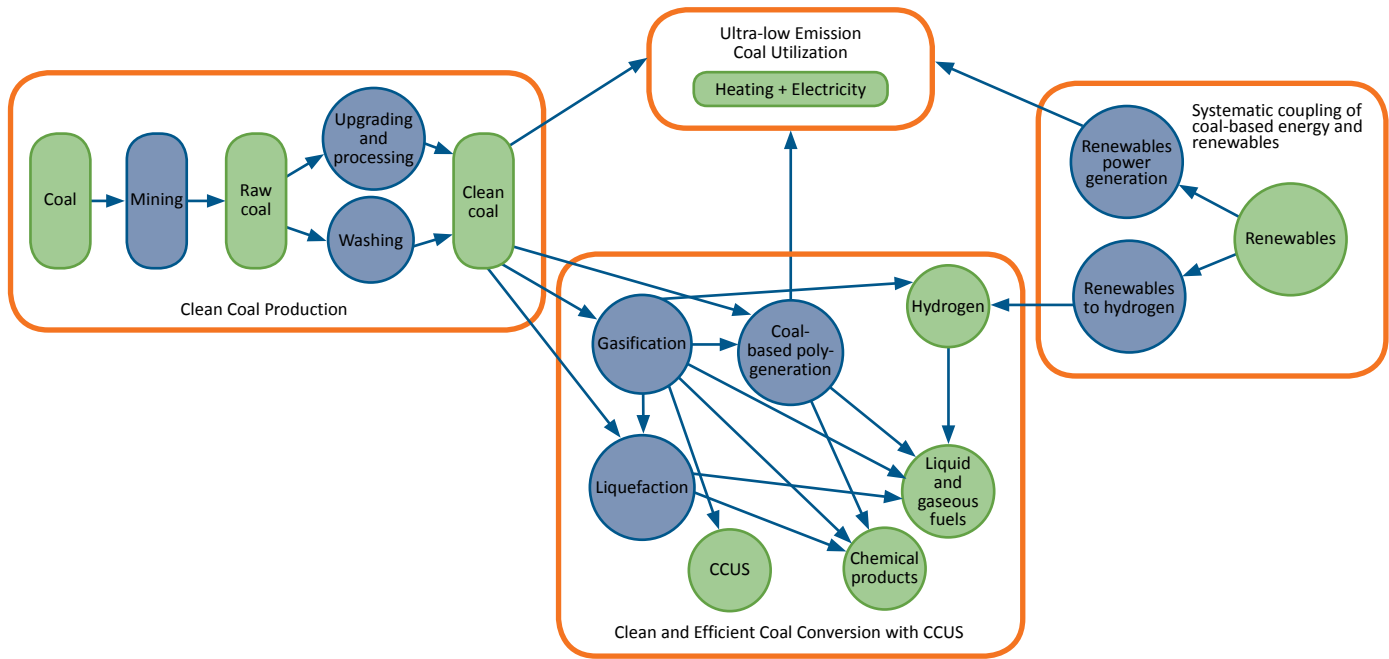


FIGURE 1. The full clean coal industrial chain under Shenhua's clean energy supplier vision

CCS INDUSTRIAL DEMONSTRATION

In November 2014, the U.S.–China Joint Statement on Climate Change was issued. For its part, the Chinese government committed that the country's CO₂ emissions will peak by 2030 with an attempt to do so earlier. Considering that carbon capture and storage could significantly reduce greenhouse gas emissions from the fossil-fuel power sector, Shenhua is working to advance the technology, starting with a pilot-scale CCS demonstration project.

Shenhua constructed the first 100,000 tonnes CO₂/year CCS demonstration project in China. CO₂ from Shenhua's DCL facility is purified, liquefied, injected, and stored as part of the project. In 2011, the entire process was completed and supercritical liquefied CO₂ was successfully injected into an underground saline aquifer. Thus, 100,000 tonnes of CO₂ emissions are mitigated each year—equivalent to a 276.7-hectare forest carbon sink. As of the end of 2014, a cumulative 245,000 tonnes of CO₂ had been injected and stored. This demonstration project is building the foundation for a coal-based low-carbon energy system in China. It is hoped that the

knowledge gained can provide technical support for further development of CCS in China.

OUTLOOK

The transformation of Shenhua from a coal producer to a clean energy supplier reflects not only a change in its business strategy, but also its willingness to actively embrace an energy revolution by promoting clean energy utilization and technological innovation. Shenhua's path forward to establish itself as a world-class clean energy supplier will be built on clean coal production, utilization, and conversion (see Figure 1). The company is constantly working to develop and implement leading technologies, advanced management, value creation, and be innovation driven to further enhance its core competitiveness centering on its model of integration. As the largest coal producer and supplier in China, Shenhua is willing and able to bear the social responsibility of a large energy enterprise looking to provide cleaner energy to the world. 🤖

Global Platform for Accelerating Coal Efficiency

By Benjamin Sporton
Acting Chief Executive, World Coal Association

The World Coal Association (WCA) recently published a concept paper on establishing a global Platform for Accelerating Coal Efficiency (PACE). The vision of PACE would be that, for countries choosing to use coal, the most efficient power plant technology possible is deployed. Its overriding objective would be to raise the global average efficiency of coal-fired power plants and therefore minimize the CO₂ emissions that would otherwise be emitted, while maintaining legitimate economic development and poverty alleviation efforts.

BACKGROUND TO PACE

A number of key points have shaped the development of the PACE concept.

- In the lead-up to COP21 in Paris in December, no evidence has emerged to suggest that mitigation action arising from any climate treaty will come close to achieving emissions reductions necessary to limit the atmospheric concentration of CO₂ to 450 ppm.
- As developing and developed economies grow and urban-

ization increases, demand is growing for affordable, reliable, and secure forms of energy in order to combat energy poverty and ensure competitive economies.

- Thus coal remains the world's fastest growing fossil fuel. Its current contribution to global primary energy consumption (30.1%) is its highest since 1970. In Southeast Asia alone, demand is expected to grow by 4.8% annually through 2035 as the region turns to coal to fuel its growing energy needs.
- There appears to be no concerted international government action to integrate the global priorities of reducing energy poverty and supporting economic competitiveness through affordable energy with global ambitions on climate change.
- Moving the current average global efficiency rate of coal-fired power plants from 33% to 40% by deploying more advanced off-the-shelf technology could cut two gigatonnes of CO₂ emissions each year, while allowing affordable energy for economic development and poverty reduction.^A
- Deploying high-efficiency, low-emissions (HELE) coal-fired power plants is a key first step along a pathway to near-zero emissions from coal with carbon capture, utilization, and storage (CCUS).



The WCA welcomes engagement on the PACE concept.

"Moving the current average global efficiency rate of coal-fired power plants from 33% to 40% by deploying more advanced off-the-shelf technology could cut two gigatonnes of CO₂ emissions each year..."

Given these factors, the WCA has proposed PACE, which would coordinate global action to support developing and emerging economies already choosing to use coal to do so with the lowest possible emissions profile.

BUILDING ON THE WARSAW COMMUNIQUÉ

The WCA and the Government of Poland issued the Warsaw Communiqué alongside the UNFCCC COP19 negotiations in November 2013.¹ Recognizing the critical role coal plays in addressing global energy poverty and the need to address international concerns about CO₂ emissions from coal, the communiqué called for increased international action on the deployment of HELE coal-fired power generation.

This sentiment was echoed at the International Energy Agency's (IEA) November 2013 ministerial meeting where the "Member Countries' Statement on Climate Change" declared that "where coal-fired power is used, encouraging the construction and use of highly efficient coal power plants" should be prioritized.²

BENEFITS FROM EFFICIENCY IMPROVEMENTS

In its *Energy Technology Perspectives 2012* report, the IEA highlighted the significant potential to reduce CO₂ emissions through the deployment of more efficient coal-fired power generation.³

The average efficiency of coal-fired power plants around the world today is 33%, well below the state-of-the-art rate of 45% and even "off-the-shelf" rates of around 40%. Increasing the efficiency of coal-fired power plants by 1% reduces CO₂ emissions by 2–3%. As previously highlighted, improving the current average global efficiency of coal-fired power plants from 33% to 40% through technology deployment could cut two gigatonnes of CO₂ emissions annually. This is a significant contribution, equivalent to

- India's annual CO₂ emissions
- Running the European Union's Emissions Trading Scheme for 53 years at its current rate, or
- Running the Kyoto Protocol three times.

Analysis of the impact various policies or events have had on global CO₂ emissions demonstrates the potential significance of supporting efficiency improvements in the global coal fleet. If a global initiative were in place to increase the average efficiency of the global coal fleet to the level of off-the-shelf technology, its two gigatonnes of savings would place it fourth on this list of 20 activities (see Figure 1).

Policy/Action	Cumulative emissions	Period	Annual emissions*
Montreal protocol	135.0 bn	1989–2013	5.6 bn
Hydropower worldwide	2.8 bn	2010	2.8 bn
Nuclear power worldwide	2.2 bn	2010	2.2 bn
Increase avg. global efficiency of coal-fired power to 40%			2.0 bn
China one-child policy	1.3 bn	2005	1.3 bn
Other renewables worldwide	600 m	2010	600 m
U.S. vehicle emissions & fuel economy standards**	6.0 bn	2012–2025	460 m
Brazil forest preservation	3.2 bn	2005–2013	400 m
India land-use change	177 m	2007	177 m
Clean Development Mechanism	1.5 bn	2004–2014	150 m
U.S. building & appliances codes	3.0 bn	2008–2030	136 m
China SOE efficiency targets	1.9 bn	2005–2020	126 m
Collapse of USSR	709 m	1992–1998	118 m
Global Environmental Facility	2.3 bn	1991–2014	100 m
EU energy efficiency	230 m	2008–2012	58 m
U.S. vehicle emissions & fuel economy standards***	270 m	2014–2018	54 m
EU renewables	117 m	2008–2012	29 m
U.S. building codes (2013)	230 m	2014–2030	10 m
U.S. appliances (2013)	158 m	2014–2030	10 m
Clean technology fund	1.7 bn	project lifetime	N/A
EU vehicle emission standards	140 m	2020	N/A

FIGURE 1. Emissions reductions impact (in terms of billions tonnes CO₂ equivalent)⁴

*Annual emissions are cumulative emissions divided by the relevant period. The estimate for the current emissions avoided under the Montreal protocol is eight billion tonnes CO₂ equivalent. The annual figure for the collapse of the USSR refers to the years 1992–1998.

**Cars and light trucks

***Heavy trucks



Overview model for PACE

In addition to significant benefits from reduced CO₂ emissions, these modern high-efficiency plants have significantly reduced emissions of nitrogen oxides (NO_x), sulfur dioxide (SO₂), and particulate matter (PM). Beyond the climate benefits, reductions in these emissions are important at the local and regional level to address air quality and related health concerns.

PACE

Accelerating the deployment of HELE plants calls for a new approach. In order to give effect to the Warsaw Communiqué and to more effectively integrate global climate and development ambitions, the WCA proposes the PACE concept.

PACE would be an international public/private partnership: In addition to governments and corporations it would also partner with other non-state actors such as non-government organizations, think tanks, and research institutes that can contribute knowledge and support in achieving PACE's vision

and objectives. It would work at both local and international levels.

Internationally, PACE would work to drive a supportive environment for increasing deployment of HELE technologies. Nationally, PACE would facilitate linkages between governments, technology providers, and financiers to smooth the way toward deployment of HELE technologies.

PACE AT THE INTERNATIONAL LEVEL

At the international level, PACE will work to drive a supportive environment for increasing the deployment of HELE technologies and will convene specialist working groups to address challenges.

PACE can help address policy challenges through international action in developing guidance and tools to support policy making at the national level. It may also be able to contribute

to international policy development challenges relating to the deployment of HELE coal. These will also support addressing the financing risks faced by the coal-energy sector as a result of some multilateral development banks and private finance institutions limiting financing for coal projects.

Following establishment, the initial steps of PACE would be to:

1. Define a model for the best available technologies and practices in HELE coal-fired power generation, including identifying potential high-impact research priorities.
2. Identify and begin to address specific policy challenges to the implementation of HELE plants.
3. Drawing on points 1 and 2 above, and in conjunction with the IEA, establish a global target for improving average coal-fired power plant efficiency.
4. Identify potential client countries that are a particular priority to work with, for example those where coal is a major part of the national energy strategy and where involvement from PACE would support HELE deployment.

“The WCA welcomes the opportunity to engage with all stakeholders on the PACE concept.”

ESTABLISHING PACE

The WCA is seeking the support of international partners to progress the PACE concept:

National governments: both sponsoring PACE through financial contributions to support the work program and those anticipated to be client countries (countries could be both sponsors and clients).

Private sector: companies along the coal value chain that can provide financial contributions, be involved in work on technological development, and invest in HELE deployment in developing countries.

International and non-government organizations: particularly those which can advise on policy development and/or environmental and regional issues, and which may make in-kind or financial contributions.

Implementing partners: consultants or other institutions that can provide technical advice and support on high-level issues, but more specifically would be responsible for working with client governments.

ENGAGING WITH PACE

The WCA welcomes the opportunity to engage with all stakeholders on the PACE concept. We are asking for feedback on the concept, how it should be implemented, and how stakeholders can work with us to make it a reality. 🗣️

NOTES

- A. Unless otherwise noted, efficiencies are provided in terms of LHV, net.

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More information on PACE and a copy of the PACE concept paper are available on the WCA website: www.worldcoal.org/coal-the-environment/pace-platform-for-accelerating-coal-efficiency/

Please send your comments to us at PACE@worldcoal.org

Breaking Through the Safety Plateau:

An Exclusive Interview With Bruce Watzman

By Holly Krutka
Executive Editor, *Cornerstone*



Bruce Watzman, Senior Vice President for Regulatory Affairs,
National Mining Association

Bruce Watzman is the U.S. National Mining Association's Senior Vice President for Regulatory Affairs, tasked with managing the association's overall regulatory policy activities to ensure their consistency with the business needs of the association's membership. He has principal responsibility for overseeing the public policies issues in Congress and relevant regulatory agencies that advance the health and safety performance of the U.S. mining industry and manufacturers that provide equipment to the industry.

Mr. Watzman serves on various planning committees for the U.S. Mine Safety and Health Administration (MSHA) and the National Institute of Occupational Safety and Health. In 2007, he was appointed by the U.S. Secretary of Health and Human Services to serve as a member of the MSHA Research Advisory Committee. He is also a member of the Executive Committee of the Holmes Safety Association and serves on the National Executive Committee for the National Mine Rescue Contest.

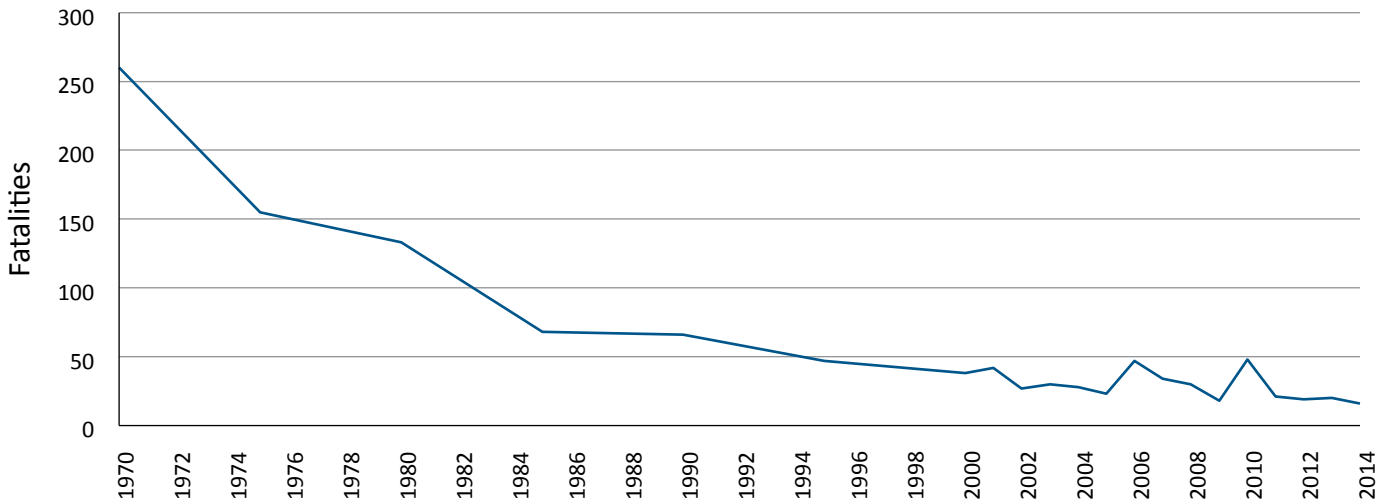
Mr. Watzman is one of the principal authors of NMA's **CORESafety** initiative, a safety and health management system to drive continuous improvement in the industry's safety and health performance. He has testified before Congress on numerous occasions to discuss impediments to performance improvement.

He received an undergraduate degree from the George Washington University and a postgraduate degree from the University of Maryland.

In our Summer 2014 issue, *Cornerstone* published an article by Mr. Watzman that focused on the **CORESafety** initiative.¹ Nine months later, we're following up to learn how implementation is progressing.

Q: *Coal mining is the largest constituent of U.S. mining and, as you explained in your previous *Cornerstone* article, is thus responsible for demonstrating leadership on health and safety. The NMA is spearheading CORESafety as part of an overall movement to improve health and safety. What is the current status of that initiative?*

A: We continue to see progress in terms of the implementation of **CORESafety** at NMA's participating member operations and at operations of companies not affiliated with NMA. These signs are encouraging and we would expect more companies to consider implementing **CORESafety** or a functionally



U.S. coal mining fatalities per year, 1970–2014

equivalent system as they come to understand the value of managing safety and health using a systems approach, just as they use this approach to manage other vital functions across their organizations. We believe the adoption of **CORESafety** will continue to grow across the U.S. mining industry.

I also think in the past year we have seen the **CORESafety** brand become an identifiable symbol of enlightened management. As the word spreads about the purposes and use of the initiative, more companies want to be affiliated with mine safety innovations and, therefore, with initiatives like **CORESafety**. So I would say there is a growing reputational value to this initiative. The word is spreading.

Q: What aspects of CORESafety have been most successful? Are there any aspects of the framework or its implementation that are currently being actively modified or improved?

A: **CORESafety** is built on a risk management philosophy where attendant risks of activities are proactively analyzed. In this way, risks can be eliminated, to the maximum extent practical, before an activity is undertaken. This central feature is what distinguishes it from the reactive, command-and-control approach that is at the heart of the regulatory structure used by the U.S. MSHA to guide mine safety and health. Additionally, as risk analysis is implemented, safety culture is enhanced. Quite simply, by instilling a risk assessment culture across an organization, we are putting thinking before acting. It gives employees an understanding that management's attention to the safety and health of its workforce is a core value, not an afterthought.

As with any new initiative, we recognize that **CORESafety** will likely have to be tweaked as companies gain experience implementing the system into their operations. It's still too early to

define what this might entail. But I think the governing philosophy here remains sound and that any modifications will be focused on streamlining its structure rather than redesigning it wholesale.

A final feature that we have found to be very advantageous is that our initiative is created to be adaptable to varied mining conditions. We didn't want to mimic the top-down, one-size-fits-all model typical in federal regulation. We wanted the safety modules that comprise **CORESafety** to form an organic program, one that is flexible and practical. This feature enhances its broad acceptance and the more its safety principles are adapted, the safer our mines will become.

Q: We now know that, in terms of fatalities, 2014 was the safest year that the U.S. has ever seen. What are the factors that you believe have allowed the coal-mining sector to break through the previously observed plateau? What is the next milestone on the horizon?

A: I think there are several factors that contributed to 2014 being the safest year on record with the fewest fatalities in the history of U.S. coal mines. Certainly one contributing factor is **CORESafety**. We all take pride in the fact that the 16 coal mine fatalities recorded was a record. But the flip side is that 16 deaths is a stark reminder that more needs to be done to achieve the goal we all seek of zero fatalities across the entirety of the mining industry. Some point to the enhanced enforcement activity of the MSHA as being the central factor to drive the improvement. Of course enforcement plays a role. But let's remember that we've been operating under the Mine Act for 45 years, so while the coal industry's safety record has improved throughout this period, clearly enforcement alone is not going to get us to where we need to be. If that were the case, we wouldn't be having this conversation. Industry would

have achieved its long-sought goal of zero fatalities because enforcement today is as strict as it has ever been.

In developing and embracing **CORESafety**, NMA's leadership recognized the limitations of the reactive enforcement model at the heart of the Mine Act. We understood that MSHA's implementation of this model would not, in and of itself, get the industry to zero fatalities—the goal we're still working towards.

I would say the next milestone is to achieve a critical mass of industry acceptance. We're on our way, but we're not there yet.

Q: How will the NMA work to make further progress toward the ultimate goal of an industry with zero fatalities? What do you see as the most significant obstacle to reaching this goal?

A: As noted previously, we continue to work with companies to provide tools and resources to implement **CORESafety**, but it doesn't stop there. **CORESafety** is unlike any other safety and health management system in U.S. industry in that the NMA leadership made a conscious decision to make all of the tools and resources available to all in the mining community free of charge.

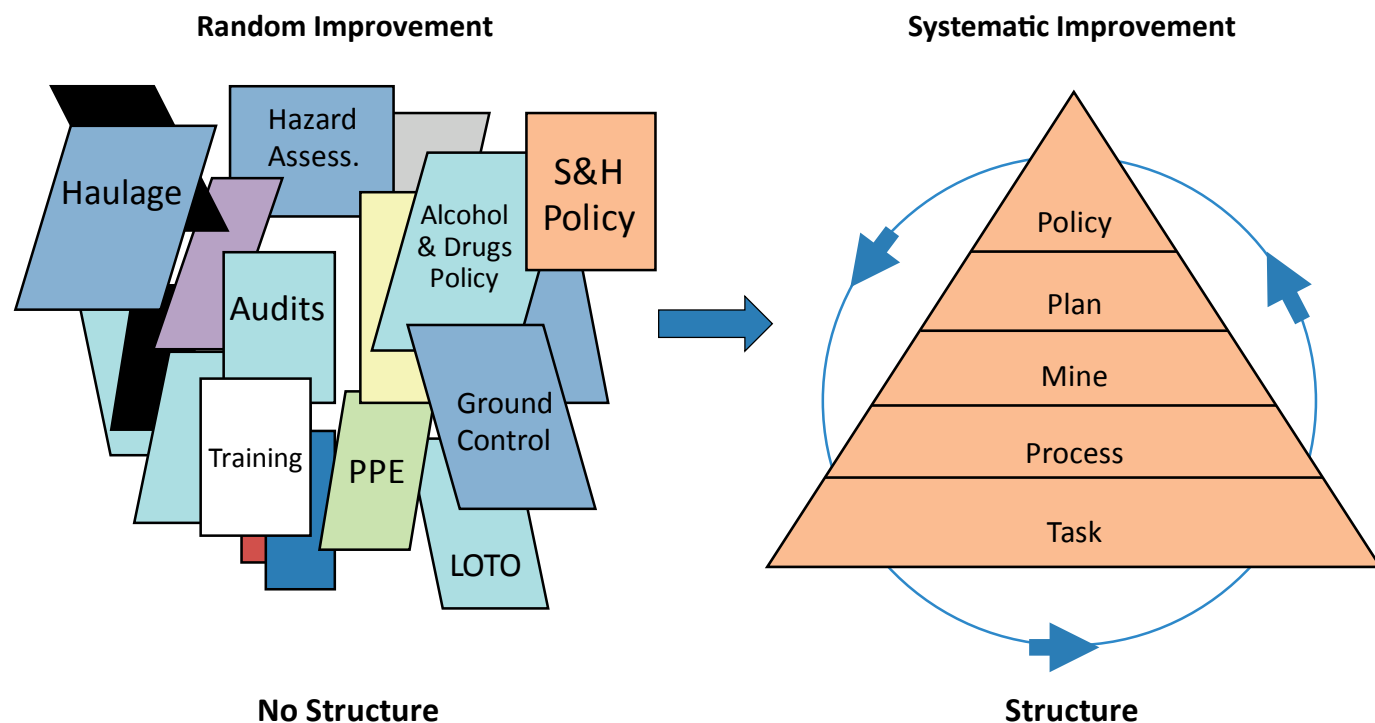
Quite simply, the goal was to drive improvement across the mining sector. And we are encouraged that companies outside



CORESafety hinges on identifying hazards proactively

of NMA, both domestic and international, are availing themselves of these resources to drive continuous performance improvement across their operations too.

Implementing **CORESafety** depends on changing or expanding one's understanding of how we have managed safety and health historically, and then changing the command-and-control reactive model for a proactive, risk management approach. This is one of the first hurdles that must be overcome and will remain an obstacle as companies come to learn more and invest in this new, voluntary approach.



CORESafety is based on structured systematic improvements, rather than one-by-one improvements.



Sharing knowledge and lessons learned is an important component of driving continuous improvements in coal mining health and safety.

The other obstacle is co-managing MSHA's compliance approach along with the **CORESafety** model. Unfortunately, these twin objectives are not entirely complementary. In some quarters, it remains a challenge to overcome the mindset that compliance with MSHA's regulatory requirements is all one must do to provide a safe workplace. That is obviously necessary, but it is not sufficient.

Q: Can you provide examples of how you are working with other industries and the coal producers abroad to share experiences and lessons learned?

A: One of the first things we did when our leadership directed us to develop a new model to drive continuous performance improvement was talk to those who were already moving beyond simple regulatory compliance. So we visited with companies, and associations representing companies, that had already embarked upon this safety journey to learn from their experience. In this way, we benefited from the lessons

that had already been learned by others.

We continue to dialogue with representatives from the chemical, nuclear, and oil and gas industries who share our goal—continuous safety performance improvement. These discussions have reinforced the belief that there are many positive initiatives underway across industry both in the U.S. and internationally and that communicating and sharing these accrues benefit to all. Working with international groups like World Coal Association and the International Council on Mining and Metals, we have been able to bring the proactive tools to U.S. mining companies that are already spreading worker safety and health improvement across the globe. 🌐

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What is on the Cards for the Coal Industry in 2015?

By Aleksandra Tomczak
Policy Manager,^A World Coal Association

Last year the coal industry saw a number of important changes to policies and regulations, both nationally and internationally, that directly affect coal demand and the business of mining coal. Among the most important were the repeal of the carbon tax in Australia, the EPA's CO₂ emission limits on new and existing power plants in the U.S., the EU's initial agreement on the 2030 energy and climate package, and the election of a new prime minister in India.

Following a year that saw over 40% of the world's population voting in national elections and major new policy developments in the key coal demand and production regions, what is on the cards for the coal industry in 2015? Undoubtedly, the major event that could structure policy and regulatory developments of interest to the coal industry in 2015 is COP21 in Paris. COP21 is expected to bring about the world's first comprehensive climate deal. In fact, some of the most important jurisdictions—including the EU, China, the U.S., Australia, South Africa, Australia, and Japan—will see national climate policies debated as part of the preparations for the international climate negotiations. This makes 2015 a year of strategic importance to the coal industry as it continues to make its case for the sustainable use of coal and cleaner coal technologies as part of the global mitigation strategy.



The United Nations climate change talks started the year off by advancing the draft text leading to COP21 in December.

COP21 PUTS CLIMATE AND ENERGY POLICIES AT THE TOP OF THE AGENDA

The international community set itself a deadline at COP21 in Paris this year to agree on a comprehensive climate deal which will, for the first time in the world's history, cover both developed and developing countries under a single agreement. In session from 30 November until 11 December, COP21 is the concluding point of the four-year-long negotiations under the Durban Platform, established during COP17 in South Africa.

“With COP21 on the horizon and the long-expected comprehensive climate deal, many jurisdictions of importance to the coal industry will be weighing the future of various energy fuels in their long-term energy mixes.”

The deal can be expected to follow a bottom-up approach whereby countries make pledges that reflect their national circumstances. This differs significantly from the top-down approach adopted in the Kyoto Protocol, which had a global mitigation target and country targets allocated based on a developed/developing country division.

COP21 will structure climate and energy policy developments worldwide as governments debate and consult domestic stakeholders to define national mitigation pledges under the United Nations Framework Convention on Climate Change (UNFCCC). Although it is far from certain that COP21 will result in ambitious mitigation targets for all countries, it is certain that the national-level preparatory work will be carefully scrutinized throughout the year by stakeholders.

UNITED NATIONS TO ADOPT SUSTAINABLE DEVELOPMENT GOALS

In September 2014, the UN General Assembly released a set of draft Sustainable Development Goals set to be agreed upon at a special UN summit in September 2015. These goals form part

of the post-2015 development framework and will replace the UN's Millennium Development Goals. According to Benjamin Sporton, Acting Chief Executive of the World Coal Association, "It is important that the goals refer to energy access and recognize the role of cleaner fossil fuel technologies."

FOSSIL FUEL DIVESTMENT CAMPAIGNS GAIN RENEWED VIGOR

In December 2014 the independent-expert group set up to advise the Norwegian government on investment in fossil fuel assets supported continued investment in coal and petroleum companies—counter to the global campaign to divest from fossil fuels, particularly coal. Despite that, the global divestment campaign is expected to continue, with renewed vigor, leading to the COP21 climate negotiations in Paris.

There is a proposal that the climate agreement in Paris should include a call to achieve zero net CO₂ emissions by 2050. Although the proposal is unlikely to be adopted, activists are describing it as a proposal to end all fossil fuels by 2050 and using it in their campaign for divestment based on the carbon bubble hypothesis. "It is likely that the divestment campaign will strengthen through 2015 as higher profile participants, including Pope Francis, sign on to the campaign. These campaigns will require a strengthened response from the industry at a global level," says Benjamin Sporton.

CHINA TO PUT FLESH ON THE 13TH FIVE-YEAR PLAN

China recently announced its intention to peak CO₂ emissions around 2030, and to strive to peak earlier. China's policy-makers will be finalizing the details of the 13th Five-Year Plan (2016–2020) this year, adopting the final text in March 2016. The 13th Five-Year Plan will provide insight into China's energy and climate policy objectives as to the role of coal in its energy mix and the role of cleaner coal technologies in mitigating greenhouse gas emissions.

China's five-year plans typically include a set of environmental and energy targets and guidelines. According to the Yale Center for Environmental Law & Policy,¹ a consultative draft of the 13th Five-Year Plan should be developed between February and October 2015 and discussed during the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China (CPC) taking place in mid-October. Media speculation about the new plan includes a possible introduction of a cap on carbon emissions, the expansion of existing pilot emissions trading schemes, or the introduction of carbon taxes. The new plan is also likely to include a new target for the expansion of renewable energy technologies.



China's 13th Five-Year Plan will be developed in 2015 and due for passage in March 2016 by the National People's Congress.

Several recently announced policy shifts or actions are already underway that will affect the coal industry in 2015. For instance, China recently announced that coal consumption will be capped by 2020.² Existing coal utilization will be increasingly cleaner under the Action Plan for Upgrading of Coal Power Energy Conservation and Emission Reductions, released in September 2014.³ Finally, China changed how its coal resource tax is applied. Coal produced in China will now be taxed on price, instead of quantity—a move that had been called for by a coal industry struggling against lower commodity prices.⁴

New regulations will also come into force in 2015. As of 1 January, a new regulation restricting coal qualities went into effect. This regulation, called "Interim Measures on the Management of Commercial Coal Quality", specifies the following quality standards for coal produced, sold, and used in the Chinese market:

- Lignite quality requirements: ash (<20%), sulfur (<1%)
- Other types of coal quality requirements: ash (<30%), sulfur (<2%)

- “San Coal” (coal used for small boilers, domestic heating, and in some hotel/restaurants) used in the Yangtze River Delta near Shanghai and the Pearl River Delta near Hong Kong: ash (<16%), sulfur (<1%).

According to the International Energy Agency (IEA), this regulation will impact both domestic and international markets.

U.S. EPA TO FOCUS ON FINALIZING CARBON REGULATIONS FOR POWER PLANTS

A priority for the U.S. Environment Protection Agency (EPA) for 2015 is the completion of carbon emissions regulations, including the rules regulating CO₂ emissions from existing and new power plants, explains Bruce Watzman, Senior Vice President, Regulatory Affairs at the U.S. National Mining Association. The two rules are expected to help meet the target pledged by President Obama prior to COP20 in Peru: reduce U.S. GHG emissions by 26–28% by 2025, compared with 2005 levels.

The rule limiting CO₂ emissions from existing power plants is anticipated to be finalized in the summer of 2015. Under that rule, the EPA would require individual states to meet CO₂ emission targets on a state-wide basis, starting in 2020. States will have four “building blocks” to meet those goals: heat rate improvements, energy efficiency, plant retirements, and renewable energy. The EPA projects that the proposed rule will result in power-sector emission reductions of 26–30% from 2005 levels by 2030. According to Watzman, the exact impact of that rule on existing coal-fired power generation remains uncertain, although analysts agree that it is most likely to further reduce coal-based power generation.

Carbon emissions from new power plants are covered under the “Carbon Pollution Standard for New Power Plants”, first



In 2015, the U.S. EPA plans to finalize carbon emission standards for new and existing power plants.

proposed by the EPA in 2013. The rule introduces an emission performance/control technology standard for fossil fuel plants at a level that makes it impossible to build new coal-fired units, but still allows unabated gas-fired power plants. The EPA is currently reviewing public comments on the proposed standards and plans to issue final rules for both existing and new power plants in summer 2015.

Coal ash is another issue to watch in 2015. The U.S. Office of Surface Mining (OSM) is expected to issue a proposal on the handling of coal ash at mine sites in April. The EPA also finalized a rule in December 2014 on the handling of coal ash at the utility level. The EPA’s final rule concluded that coal ash was not hazardous. However, “there is a possibility that OSM’s rule might be far harsher than the EPA rule. OSM could prohibit the use of coal ash for reclamation purposes. If this happens, mine operators will have to obtain other materials and this will drive up the costs,” Watzman explains.

2015 COULD FIX THE EU COAL POLICY LANDSCAPE UNTIL 2030

In the EU, the 2030 climate and energy package is still at the top of the policy agenda for the coal industry in 2015. At the end of last year, EU member states agreed with the European Commission proposal to reduce the EU’s greenhouse gas emissions by at least 40% by 2030 (compared to 1990), to increase energy efficiency, and to set a new EU-wide target for renewables in final energy consumption of at least 27% by 2030. EU leaders also decided to establish several funds, including a successor to NER300, which will be used to finance carbon capture and storage (CCS) and renewable projects. As the package will now go through the European Parliament, Brian Ricketts, the Secretary General of EURACOAL, expects that parliamentarians will propose many amendments. However, he expects that the most ambitious climate and energy policy amendments will struggle to win support under the political make-up of the European Parliament following last year’s elections.

The EU will also continue its work on the proposal to reform the EU Emissions Trading Scheme. The proposal from the Commission last year would establish a Market Stability Reserve (MSR) whereby allowances can be moved in and out of a reserve, but not canceled permanently. In this form, the MSR is unlikely to affect the competitive position of coal in the EU, according to Brian Ricketts. This would change, however, if emission allowances were to be withdrawn permanently—an option that remains possible until a final decision is taken, probably in 2015.

The new European Commission (EC), officially appointed and approved in November 2014, has already established an image



Jean-Claude Juncker, President of the European Commission

of being pro-business and pro-industry. One of the objectives of the new Commission President, Jean-Claude Juncker, is to reduce the number of work items in order to improve the quality of decision making. As part of this exercise, the new Commission withdrew several existing legislative proposals, including the National Emissions Ceiling Directive intended to introduce more stringent limits on emissions of certain pollutants at the national level. The directive is now expected to be modified as part of the legislative follow-up to the 2030 Energy and Climate Package.

The new EC will continue the work started by the previous team on limiting emissions from medium-size combustion plants, such as heating plants. This proposal would affect coal consumption in a number of Central and Eastern European countries that rely on coal-fired medium-size plants for district heat production.

The EU will also continue its work on the European Energy Security Strategy, creating an opportunity for the coal industry to promote the security benefits of using coal. However, according to Brian Ricketts, the document released on this

subject by the EC in May 2014 proposes “more of the same medicine”, which means more renewables, more energy efficiency, and more gas pipelines, with virtually no mention of the security benefits offered by coal.

SOUTH AFRICA GEARS UP FOR A CARBON TAX

South Africa will finalize its carbon tax legislation in 2015, expecting to introduce a tax early in 2016. The 2015 debate will focus on the issue of carbon budgets and the alignment of this mechanism with the carbon tax, which is linked to the Intended Nationally Determined Contributions that will be submitted to the UNFCCC prior to COP21. According to Nikki Fisher, Coal Stewardship Manager at Anglo American, the South African Department of Environmental Affairs will be consulting stakeholders in the first quarter of 2015. As in other jurisdictions that have already introduced a price on carbon, this new policy can be expected to shape the circumstances for investments in coal-based power.

Changes are also expected in the rules governing the power generation sector. Historically, coal-fired plants in South Africa have been run exclusively by the public utility Eskom. However, 2015 may see the first investments in independently constructed coal-fired power plants. Debate in South Africa about investment in nuclear energy and more investment in renewables will also continue.

In 2014 Eskom’s flagship coal projects, Medupi and Kusile (each to supply 4800 MW of coal-fired generation), once again suffered delays in construction. Currently, Medupi is projected to be in commercial operation in the second half of 2015. Kusile’s commissioning program will follow at least one year after. As a result of these delays and maintenance issues with Eskom’s existing coal fleet, South Africa experienced electricity blackouts in December 2014 for the first time since 2008, perhaps intensifying calls for more independent power producers.

The Mineral and Petroleum Resources Development Act (see author’s previous *Cornerstone* article for a description)⁵ was ratified by South Africa’s Parliament in 2014 and now awaits presidential signature. Although a number of the more onerous provisions of the original bill were amended, uncertainties persist regarding the modalities of implementation and its impact on coal investment—especially in relation to the minister having powers to designate coal as a “strategic mineral” and a “designated mineral”. The latter would result in a portion of existing production being slated for domestic sales.



As a result of reviewing its energy strategy, Japan may reopen nuclear reactors and add new coal capacity.

JAPAN TO CLARIFY COAL AS PART OF ITS ENERGY FUTURE

In 2014, the government of Japan launched its first review of energy strategy since the Fukushima nuclear accident resulting from the earthquake of 2011. In this new strategy, which sets basic policies for the next 20 years, the cabinet positioned coal and nuclear power as key “baseload power sources”. In fact, according to Shintaro Yokokawa, Deputy General Manager at Japan’s Federation of Electric Power Companies, most of Japan’s planned 10 GW of new capacity through 2030 will be coal-fired.

Mr. Yokokawa also explains that two nuclear power plants are scheduled to re-open in 2015. Those two plants (four reactors) have already passed the security screening by the Nuclear Regulatory Authority and are now under the final approval process by the local government; 17 reactors at 12 other power plants are also waiting to be screened.

STEP-BY-STEP REFORM OF INDIA’S COAL SECTOR

Narendra Modi, India’s prime minister and the leader of the Bharatiya Janata Party (BJP), is expected by many to unlock the economic potential of India, by reducing red tape, making India more business-friendly, and investing in new transport and energy infrastructure.

At the end of last year, Modi’s government issued an executive order that includes a provision to allow the government to end the state monopoly on mining and selling of coal. While analysts consider the move crucial to boosting coal output, unions fear it could lead to job losses. This year began with one of the largest strikes by coal miners India has ever seen, resulting in half of the production and shipments of Coal India Ltd being shut down. Although many are tempted to draw parallels with the miners’ strikes in the UK, local experts argue that the Modi government is much more likely to take a step-by-step approach to reform of India’s coal sector to ensure that energy security is not compromised.

MORE COAL-FRIENDLY POLICIES EXPECTED IN AUSTRALIA

In 2014 Australia saw two major policy developments: the repeal of the tax on carbon and on mining. According to Brendan Pearson, the Chief Executive of the Minerals Council of Australia, the industry and the Australian economy are saving much money as a result of these changes. From 2012 to 2014 the overall cost of the carbon tax to coal miners in Australia was AU\$1.6 billion. “This is a big weight off the coal industry, as [coal] prices are 50% lower than what they were in 2011/12.”

Another issue carrying over from 2014 was the finalization of trade agreements with the largest coal-importing countries:



Newcastle, Australia, is the world's leading coal export port.

China, Japan, and Korea. As a result of the new agreement with China, the Australian coal industry will be exempt from the 3% tariff recently imposed on coking coal imports and the 6% tariff on thermal coal imports.

In 2015 the coal industry will closely watch two existing legislative projects: a reform of the environmental approvals for mining projects and the Australian government's new climate policy—consisting mainly of an Emissions Reduction Fund.

“At the moment, going from exploration to the commissioning of a mine in Australia can take up to seven years. In the 1990s the same process would only take 18 months,” explains Brendan Pearson. The Australian government is in the process of developing a one-stop shop for assessment and approval processes that covers both federal and state levels to address the problematic delays in environmental approvals. “If we can reduce this process by a year in the mining sector, the economy will gain AU\$160 billion over 2014–2025.” The MCA Chief Executive believes the legislation blocked last year should be adopted in the first quarter of 2015.

The MCA is also keeping a watchful eye on the so-called Safeguard Mechanism under the Emissions Reduction Fund. The proposed mechanism is expected to introduce a soft cap on emissions in sectors not participating in the auctions. “This could be problematic for methane emissions from coal mines because they are linked to a specific geology, not poor design of the coal mines,” says Pierson.

Another important development to watch in 2015 is the draft decision by the World Heritage Centre, expected in March or April, on whether to list the Great Barrier Reef as endangered. “We could see much more unnecessary restrictive regulation on port developments if the decision is positive,” argues Pearson, who highlights the objective of the coal industry is to ensure a strong coexistence between an essential export industry and the world heritage values of the reef.

INDONESIA EXPECTS A YEAR FOCUSED ON ECONOMIC GROWTH

The Indonesian Parliamentary and Presidential elections in 2014 resulted in a new president, Joko Widodo (Jokowi), as well as a new cabinet. According to a local expert, the appointment of a new Mines and Energy Minister, Sudirman Said, was broadly welcomed by the coal industry as he brings solid credentials from both the public and private sectors. In fact, one of his previous positions was at a senior corporate level in an Indonesia coal group.

The nationalistic ideals that shaped the 2014 elections are now largely muted and no changes in the laws and regulations regarding foreign investment in the coal sector are now expected. The new administration has so far focused on economic and infrastructure development. On the energy front, one of the key aspects is a plan for considerable growth in coal-fired power production. It is believed that domestic demand for coal will continue to grow, particularly in two to three years when more new plants come online.

The new government has also already relaxed the caps on coal production levels. The increase of mining royalties, proposed but not implemented in 2014, remains under consideration. However, the government recognizes that such increases at present may lead to increased mine closures with resultant unemployment, and less value flowing to mining communities.



The new Indonesian government, led by Joko Widodo, has already relaxed caps on coal production. [www.flickr.com/photos/ukik/ (Ahmad Syauki)]

TABLE 1. Critical dates to watch in 2015

<i>Date</i>	<i>Event</i>	<i>Relevant jurisdiction</i>
1 January	“Interim Measures on the Management of Commercial Coal Quality” come into force	China
1st Quarter	Carbon tax consultation	South Africa
1st Quarter	One-stop shop for environmental approvals expected to be passed through Australian Parliament	Australia
March/April	World Heritage Centre expected to issue a draft decision on the Great Barrier Reef	International
April	U.S. Office of Surface Mining expected to issue a proposal on handling of coal ash at mine sites	U.S.
Summer	EPA plans to issue final rules on CO ₂ emissions reduction for both existing and new power plants	U.S.
25–27 September	Special Summit on Sustainable Development, New York	International
October	Consultative draft of the 13 th Five-Year Plan to be discussed at the Fifth Plenary Session of the 18 th Central Committee of the Communist Party of China	China
30 November–11 December	COP21 in Paris	International

Although some caution exists because the new administration has yet to detail their coal-sector requirements, most Indonesian coal industry experts believe that 2015 will see limited, if any, increase in regulation. There could be streamlining in some areas, a small production increase, or continuing emphasis on coal supply to the domestic market with a resultant flattening, or decline, in export levels.

2015: A YEAR OF STRATEGIC IMPORTANCE

With COP21 on the horizon and the long-expected comprehensive climate deal, many jurisdictions of importance to the coal industry will be weighing the future of various energy fuels in their long-term energy mixes (see Table 1 for a summary). This makes 2015 a key year for the international coal industry and a year that should see renewed efforts to make a strong case for coal as a sustainable energy fuel and for cleaner coal technologies as an irreplaceable element of any effective global climate mitigation strategy. 🌱

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NOTES

- A. This article was prepared in January 2015 when Aleks Tomczak was Policy Manager at the World Coal Association. Aleks has since left the WCA.

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Navigating India's Coal Maze

By A.M. Shah
Contributing Author, *Cornerstone*

The year 2014 saw momentous changes in leadership in India as Narendra Modi took the office of Prime Minister, filled his top ministerial positions, and began to lay out his administration's ambitions to the world. As was highlighted in a previous article for *Cornerstone*,¹ while arguably challenging, the plans put forth for India's energy sector reflected the broader hope expressed during the campaign that the country would break free of the roadblocks that had plagued the past. In the six months since that article was published, the groundwork for progress has been laid. However, major hurdles remain, especially in India's critically important coal sector. Every link in India's coal supply chain requires upgrading for coal to fulfill its required role in meeting perhaps one of Modi's most important campaign promises: to provide affordable, reliable electricity to every person in India. In a country that has over 300 million people living without access to any electricity, this would be a momentous feat.

In addition to providing basic energy access, much hope remains that Modi can make India more favorable for businesses and continue to grow the economy. Despite some lower projections, India's GDP growth increased from less than 5% to around 5.6% by the end of FY15 (ending March 2015) and Citigroup's projections in December estimated around 6.5% in FY16 (ending March 2016).² To take this momentum further,

a bare minimum requirement will be to generate more electricity and have more reliable coal-based power generation.

"Every link in India's coal supply chain requires upgrading for coal to fulfill its required role ... to provide affordable, reliable electricity to every person in India."

Prime Minister Modi has entrusted India's Coal and Power Minister, Piyush Goyal, to lead the overall reform effort for India's coal sector. Goyal regularly conveys his strong desire to rectify the country's energy situation, especially as it relates to coal. While India's underperforming coal sector may hope to meet such aspirations, navigating the maze of India's coal sector is not straightforward.

RELIABLE PRODUCTION

Improving the coal sector unquestionably begins in the area of coal production. India is coal rich, but continues to import coal from abroad. Goyal is working to achieve Modi's target



India's Parliament progressed much-needed energy-sector reform in 2014.



Modernization of India's coal industry will be necessary to achieve production goals. (AP photo/Ajit Solanki)

to increase Coal India's (CIL) annual production to one billion tonnes by 2019, far more than any other coal producer generates today. The reasoning is that such a move could push India toward energy security and independence, especially as it relates to its thermal coal requirements.

Aspirations Meet Reality

Although the country is now moving toward opening its coal sector to foreign firms and also looking to modernize some of its mining practices, it remains questionable whether India can ramp up production to meet the stated goals.

The one-billion-tonnes-per-year target set by the Modi government would require a compound annual growth rate of 18%. Such a growth pace has not been achieved in the last decade. India substantially missed its target to ramp up coal output to 680 million tonnes (MT) by the end of the 11th Five-Year Plan (2007–2012), as production touched only 540 MT in FY12, and 565 MT in FY14. For perspective, China produces roughly 3.5 billion tonnes a year.³ While it remains to be seen how Modi's coal production goal will be met, there are various approaches underway that could make some progress.

A Time for New Players

For decades, Indian laws ensured CIL a coal mining monopoly, but soon this will come to an end. India reformed its coal mining laws during the most recent Parliament winter session.

An executive ordinance was legislated and the Parliament is in the process of enacting a law allowing the entry of private (including international) players to engage in commercial mining.⁴ Today, the Indian government is vigorously assuring corporate enterprises that the law will be enacted, despite political opposition and recent strikes from CIL miners.

The new coal mines law allows the government to e-auction mines and was necessitated by the 24 September decision of the Supreme Court to declare the allocation of 204 mines between 1993 and 2008 as illegal and cancel the mining licenses.⁵ In October 2014, the Indian government released the ordinance framing the new law amending the Mines and Minerals Act and allowed the participation of private players. Subsequently the government announced the first phase of allocation: The target is to e-auction 104 mines by 31 March 2015.⁶ There has yet to be a decision on how to compensate the existing operators that have made genuine investments.

It is expected that together these mines could produce an additional 100 MT of coal annually. Out of those with canceled licenses, 30 mines were already producing a total of 40 MT, 17 were nearing production, and 13 could have begun producing within one year. As a conservative estimate, it will require at least a year to disburse all 204 mines under the new law.

While this enabling legislature may be enacted by the end of March, it will take time before the world's large coal miners will seriously consider mining in India. They may also wait to see how a proposed industry watchdog will handle oversight.⁷

Can India's Coal Giant Stand Again?

Even as other options to fix India's coal industry and ramp up production are being pursued, the main challenge and reform focus will likely remain on improving the functionality of CIL—the world's largest coal producer with roughly 338,000 employees.⁸ The company currently holds 81% of Indian market share. Modi has pushed through changes at the top, putting individuals into leadership positions with a history of advancing projects that had previously stalled.

Although there were some calls to break up CIL, it quickly became clear this was unpalatable for Goyal. Perhaps this was based on the conclusion that keeping CIL intact may be necessary for it to compete with international mining companies at a time when India is opening up for commercial mining. Instead of splintering CIL, on 28 January the Modi government successfully offloaded 10% of its ownership of CIL to domestic and international investors.

Although CIL will not be broken up, it must find a way to improve efficiency despite its size. In 2011, CIL's production averaged 4.92 tonnes of coal per man-shift hour, whereas other players in India are producing at roughly 6.9 tonnes of coal per man-shift hour. Both figures are much less than the global average, which is more than 15 tonnes per man-shift hour.¹⁰ The first step in improving efficiency is CIL's deployment of modern equipment and evacuation vehicles.

The ability to reliably meet demand and actively increase production has not been demonstrated by CIL to date. Throughout most of 2014 more than half of India's thermal power plants, which source most of their coal from CIL, could not operate for a full week relying only on their coal stockpiles. In FY14, India imported 168 MT of coal from countries such as Indonesia, South Africa, and Australia. The dipping price of coal on the international market and the lower output of CIL led India to import 210.6 MT of coal during the 2014 calendar year, an increase of roughly 19%.¹¹ Similarly, India imported more than 110 MT from April to September, compared to 92.98 MT during the same time period in FY14.¹² It remains too early to make judgments on the impact of national-level policies on CIL, but to date imports have slipped in the wrong direction.

Meanwhile, the government is busy resolving problems that continue to derail production and could scare off potential new producers. For example, a new national coal dispatch monitoring center has become operational. India has never seen such a control room, where real-time surveillance at all major sensitive zones is possible.¹³ The movement of trucks can be monitored through a global positioning system (GPS). The intent behind this is to curb coal theft at major mines.¹⁴

Potentially the most important challenge facing Goyal, and critically important to improving production, is determining how best to work with CIL's historically strong union, an endeavor in which the previous UPA government was generally unsuccessful. On 9 December, Goyal flew to Kolkata before proposing the coal mines bill in Parliament, seemingly to discuss this action with the union a priori.

The union knows its own power; if CIL workers strike and refrain from coal production for one day, 30,000 MW of electricity generation capacity could be immediately affected. On 5 January, CIL workers went on a five-day strike that captured global headlines to protest changes, including the opening up of the coal sector beyond CIL. In response, Goyal quickly flew again to Kolkata; after hours of discussions the union members returned to work. During the negotiations, Goyal maintained the government's ability to sell 10% equity in CIL and commitment to bringing in private players.¹⁵ To date, it appears that the Modi government, despite proposed reforms to the coal sector, is faring better with the union than its predecessors.

One potentially positive development for improving Indian coal production is the recent election in Jharkhand where the BJP party won the state assembly with a clear majority. As successfully reforming India's coal industry will rely on political victories, the success of the BJP party in Jharkhand is a critical development—the state sits on 27% of India's coal reserves and is home to 11–12% of CIL's production. CIL intends to increase coal production by 20% in the state over FY14–19. The new BJP government is likely to assist the Modi government in the execution of key mining and rail projects that have been on hold for years.



Completing construction of key rail lines and rationalization of linkages could unlock millions of tonnes of coal annually.



The story of India's work to bring electricity to all its people continues to unfold.

THE TROUBLE WITH TRANSPORTATION

Transportation of coal in India presents its own set of problems. The railways are one of the biggest carriers of natural resources in India. The Modi establishment is working to unlock more than 300 MT of coal annually by 2017 through collaboration between the Transportation and Coal Ministries. As per Coal Ministry estimates, three railway lines connecting Tori-Shivpur-Kathautia (in North Karanpura, Jharkhand), Jharsuguda-Barpalli-Sardega (in Ib Valley, Odisha), and Bhupdeopur-Raigarh-Mand (in Chhattisgarh) could help transport an additional 150–200 MT annually by 2021. The work on some of these lines started nearly a decade ago, but delays with land acquisition, environmental clearances, and complex relations between the regional and the central governments have hampered progress. Although the construction of these railways is a priority in Delhi, the states of Jharkhand, Odisha, and Chhattisgarh have yet to start the process of handing over land, despite obtaining necessary clearances.¹⁷ Jharkhand was the major remaining stumbling block; with the BJP now in control, these important rail projects may begin to move forward.

In anticipation of the successful completion of the new rail lines, Goyal asked CIL to buy 250 additional coal trains—doubling the existing capacity—to make full use of these tracks when they become operational.

In addition to building more rail capacity, there is also a grand plan to rationalize coal linkages so that power plants are linked to the nearest mines or ports. This reform would likely require alteration in existing railway routes and schedules; at least one example exists of successfully changing (i.e., rationalizing) the

source of coal for a power plant. Such changes may lead to savings on transportation costs for some power plants, but given the lack in uniformity of coal quality, it could also lead to challenges.

GENERATING ELECTRICITY

India is a power-starved nation and coal-based power will undoubtedly continue to be its principal electricity source. The main challenge facing the electricity sector is that there simply is not enough electricity or coal. The situation becomes more critical as India looks to provide complete energy access by 2019.

Out of a total installed power capacity of 255 GW, 153.5 GW of India's capacity are fueled by coal.¹⁶ On any given day, this 60% of the installed capacity generates more than 75% of electricity consumed in the country. The impact of insufficient coal for these plants is evident. No coal means no power for many Indian people.

Although coal will remain the predominant energy source, India, like many countries, is looking to diversify its power sector. For example, the country has announced plans to shift a sizable portion (40 GW) of baseload power generation to nuclear power plants, but the domestic laws defining liability in case of any accident keeps investors away. India's plans to boost solar- and wind-based power generation are perhaps more likely to be implemented. Currently, India has 23.7 GW of capacity based on these two energy sources, most of which are fed by wind. The plan is to increase solar-based generation capacity from the existing 2.6 GW to 100 GW by 2022.

However, it is still India's coal plants that will continue to feed the majority of the power demand in the country.

GREEN PRESSURE

Increasing, or even maintaining, coal utilization rates faces both domestic and international environmentally based opposition. Recently, the Indian national government took a stand on greenhouse gas emissions, saying that India will not sacrifice the country's development imperatives for climate-related reasons. Still, pressure to limit emissions remains strong. The recent agreement between the U.S. and China, whereby the U.S. has agreed to emit 26–28% less carbon in 2025 than it did in 2005 and China has agreed to stop increasing its coal use by 2020, has led some to ask if and when India will curb emissions.¹⁸ While India's emissions are growing, it produces annually only two tonnes of CO₂ per capita—a fraction of the 20 tonnes in the U.S. or even the eight tonnes in China. The current priority for India is development, although there are some steps that could decrease the carbon intensity of electricity.

One important step supported by Goyal is to modernize India's aging power plants. In addition to reducing carbon intensity, this will reduce criteria emissions, which is an important near-term objective. He has identified 32 GW of capacity and hopes to replace these with ultra-mega supercritical plants.¹⁹ Goyal's main challenge in advancing this objective is to motivate banks to lend more toward the construction of new plants. Another major environmental hurdle for India remains coal quality. Most of what is used is low in quality and high in ash (4500 kcal/kg). The modern plants must be capable of handling lower coal grades.

On the production side, 90% of India's coal is from open cast mines on lands that are often not reclaimed. Eventually India must improve its mining practices and bring them to the international standards. After the G20 summit in Brisbane, India and Australia agreed to share knowledge around coal mining, especially underground.

STAY TUNED

India's coal industry may have a tortuous path to modernization and a production rate of one billion tonnes per year seems elusive. However, there are actions in progress that will ensure that India's energy sector will continue to be a developing story. 🔄

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Conceptualizing a Revolution in China's Coal Utilization:

An Exclusive Interview With Cen Kefa

By Li Xing
Editor, *Cornerstone*



Cen Kefa, President, Institute for Thermal Power Engineering at Zhejiang University and an Academician of the Chinese Academy of Engineering

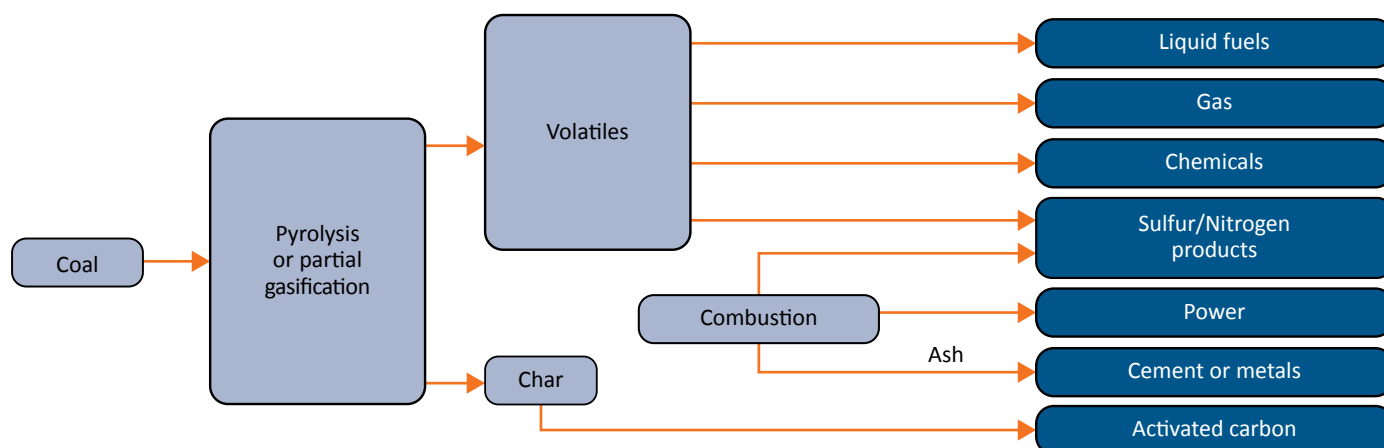
Dr. Cen Kefa is one of the world's foremost experts in the field of thermophysics engineering. Born in January 1935, Dr. Cen graduated from the Department of Power Engineering, Huazhong Engineering College (now the Huazhong University of Science and Technology) in 1956 and later received his doctorate from the Department of Power Engineering of Bauman Moscow State Technical University in 1962. He then accepted a professorship in the Department of Mechanical and Energy Engineering at Zhejiang University. He was appointed as an Academician of the Chinese Academy of Engineering in 1995. Currently Dr. Cen is President of the Institute for Thermal Power Engineering at Zhejiang University.

Academician Cen has overseen groundbreaking achievements in a range of fields, including high-efficiency, clean energy technologies; resource utilization, including utilization of fossil fuels and waste-to-energy; development and utilization of renewable energy; utilization of biomass energy, hydrogen production, clean coal combustion and gasification technologies; coal-water slurry combustion; fluidized bed combustion for power generation; technologies for simultaneous multi-pollutant removal during the course of energy utilization; engineering gas-solid multiphase flow technologies; power plant boiler computer-aided testing technologies; and advanced laser diagnostic technologies.

Cornerstone sat down with Dr. Cen to discuss his perspective on how the environmental impact of coal utilization in China can be most effectively reduced.

Q: *Coal is the principal energy source in China and has thus supported rapid economic growth over the past few decades. However, coal is considered one of the important contributors to air quality issues. In the report of the 18th National Congress of the Communist Party of China, it was proposed that an "energy production and consumption revolution" must be carried out. How do you think a coal utilization revolution can and should be realized?*

A: In 2014, coal consumption in China was approximately 3.5 billion tonnes. Coal-fired power is the largest coal-consuming industry, accounting for 58% of China's coal consumption. Presently, the main high-efficiency, low-emissions coal-based power generation technologies include ultra-supercritical steam cycles, ultra-low emission technologies, and integrated



Flow chart for low-emissions coal utilization using staged coal conversion

gasification combined-cycle (IGCC) technologies. Due to the severe shortage of oil and gas in China, there has been a focus on the production of clean coal-based fuels or chemicals using high-efficiency, low-emissions conversion technologies, the core of which is the complete gasification of coal. Such technologies include production of coal-derived oil and synthetic natural gas, coal-to-olefins, coal-to-ethylene glycol, coal-to-aromatics, and methanol-to-gasoline. To revolutionize coal utilization, the dual nature of coal, as an energy source and as a raw material, should be considered—leading to a change in the current industrial model in China and realizing energy conversion and emission reductions simultaneously.

Staged coal conversion, a clean power generation technology, is one of the revolutionary approaches to coal utilization that has been proposed based on China's specific conditions. This technology is based on the nature and conversion properties of various components found in coal. This approach utilizes coal as a raw material and an energy source simultaneously by organically combining coal pyrolysis, combustion, and other processes—thus realizing staged conversion and the stepwise utilization of coal.

In this process, coal is first pyrolyzed in a pyrolysis furnace, and the gases evolved are extracted to generate a gas mixture (i.e., fuel gas or syngas) and tar. The leftover char is then sent to a boiler for combustion. Steam, a gas mixture, and flue gas are generated during the process. Emission controls, including the removal of carbon, can be employed to achieve ultra-low emissions. The gas mixture generated can be used to produce natural gas and other fuels. The steam can be used for electricity generation and to supply heat. Based on the chemical speciation, value-added components in the ash can be extracted. Ash can also be used to produce cement and other construction materials.

The staged conversion of coal is closely linked to China's demands for industrial restructuring, a circular economy,

energy conservation, and emission reductions. These needs are spawning new industrial models and driving the conversion and upgrading of the coal-based power industry. The basis of the technology is the innovative concept of simultaneously controlling emissions of centralized and distributed energy sources. To explain, coal can be converted and ultimately used by distributed consumers. The first step of staged coal conversion is to process the coal at centralized facilities that generate low-emissions electricity, natural gas, and steam. These products are cogenerated without the need for high-pressure, pure (or enriched) oxygen so that the conversion costs are greatly reduced and valuable water resources are conserved compared to standalone coal conversion facilities. At the same time ultra-low emissions are realized in the production of power. The cogenerated electricity, natural gas, and/or steam provide surrounding or dispersed industrial kilns and private boilers with sources of energy to realize the low-emissions operation of these facilities as well.

Q: Starting this year, China proposed stricter emission control requirements for newly built coal-fired power plants. In your opinion, how big a role will achieving ultra-low emissions from coal-fired power plants play in reducing energy-related environmental impacts? Also, how should one evaluate the economic and environmental benefits of ultra-low emission controls?

A: In 2012, China's total SO₂ emissions were 21.176 million tonnes. Out of this total, the SO₂ emissions from the electricity industry were 8.83 million tonnes, accounting for 41.7% of the country's SO₂ emissions. Similarly, the total national NO_x emissions were 23.378 million tonnes, of which the NO_x emissions from the electricity industry were approximately 9.48 million tonnes, accounting for 40.6% of NO_x emissions nation-wide. The total emissions of particulate matter from the electricity industry were approximately 1.51 million tonnes. According to estimates, if ultra-low emission technologies are applied to all of

China's coal-fired units, the emissions from the coal-based fleet will be effectively reduced to 530, 760, and 80 thousand tonnes for SO_x, NO_x, and particulate matter, respectively. Such reductions in criteria emissions from the coal-fired power industry would result in a 90% decrease in total emissions from the electricity sector (compared with 2012 levels). Undoubtedly this will have a significant impact on improving air quality in China.

For newly constructed and retrofitted coal-fired units with different levels of various emissions as well as different plant sizes, the required investment costs and operating costs differ for new construction versus retrofitting. The increase in the cost for power generation with ultra-low emission retrofitting is 0.01–0.02 yuan/kWh, while the increased power generation cost of new construction of ultra-low emission units is even lower, at 0.005–0.01 yuan/kWh.

For some time, there have been active calls for power generation in China to switch from relying primarily on coal to gas. However, if current coal-fired power plants are converted to gas-fired power plants, power generation costs will increase significantly. Take natural gas combined-cycle power generation as an example. If the natural gas price increases from 2.0 yuan/Nm³ to 5.0 yuan/Nm³, the power generation cost would increase from 0.59 yuan/kWh to 1.23 yuan/kWh, while the power generation cost of coal-fired power plants is approximately 0.4 yuan/kWh. Therefore, although there has yet to be comprehensive investment in achieving ultra-low emissions coal-fired power plants, the environmental and economic benefits are worthwhile.

Q: The use of coal for power generation only accounts for a little over 50% of the coal consumption in China. A significant amount of coal is still used in industries such as the production of cement, steel and plate glass, and in numerous, dispersed, and small coal-fired boilers. How can the issue of environmental impact be resolved for the smaller, dispersed, coal consumers?

A: Presently, due to the large amounts of coal consumed, the percentage of nation-wide emissions from coal-fired power remains the highest among key coal-consuming industries. However, the regulation and subsequent emissions reductions at large coal-fired power plants are relatively easy. Industrial boilers are smaller, more numerous, and widely dispersed, making regulating, supervising, and the overall control of emissions more difficult. The emissions from burning one tonne of coal in an industrial boiler could result in emissions that are dozens of times larger than the amount released from burning the same amount of coal at a large coal-fired power plant.

In 2013, the electricity industry accounted for approximately 58% of coal consumption in China, which is far lower than

the 92% in the U.S. or 80% in Germany in 2010. Compared with these other major coal-consuming countries, the coal-consuming industries in China are too widespread, making it challenging to manage emissions.

Instead of directly controlling emissions, small boilers, especially coal-fired industrial kilns that use 10 tonnes or less per hour of steam, can substitute fuels such as coal-derived natural gas from staged coal conversion to limit emissions. Thus, the staged coal conversion approach can transform power plants and ensure low-emissions power generation while simultaneously generating syngas or coal-derived natural gas for these smaller, dispersed industrial kilns. With regard to industrial parks and other areas with numerous medium and small boilers, centralized heat supply could also be adopted. In doing so, ultra-low emission technologies would be in place at the boilers responsible for centralized heat supply so that the net emissions could meet emission requirements for natural gas units. For example, flue gas emission controls are being implemented at five 220 tonnes/hr combined heat and power boilers at Jiaxing Xinjia Aisi Thermoelectricity Co., Ltd. The efficiency of existing particulate removal, desulfurization, and denitration systems is being improved; high-efficiency simultaneous emission removal technologies are being adopted so the major criteria emissions (i.e., particulate matter, SO₂, and NO_x) in the flue gas of coal-fired units can meet the national standards for natural gas-fired power plant emissions.

Q: Zhejiang University began research relatively early in the field of staged utilization of coal in China. What progress has been made to date? What are the prospects for commercialization?

A: Zhejiang University has been researching staged coal utilization for over 20 years. Our researchers proposed the concept of polygeneration processes for heat, electricity, and fuel gas as early as 1987. Supported by the original National Board of Education Doctoral Fund, National 8th Five-Year Science and



The ultra-low emissions coal-fired Zheneng Power Jianxing supercritical unit

Technology Research Plan, National High-tech R&D Program of China (863 Program), and National Program on Key Basic Research Project of China (973 Program), experimental 1-MW syngas and steam cogeneration apparatuses were built—much experimentation and theoretical research have been since conducted on the key technologies of the proposed approach. The research indicates that staged coal utilization offers extensive fuel applicability, high rates of fuel utilization, and low emissions. A series of national invention patent applications have been submitted. In June 2007, Zhejiang University and Huainan Mining Industry (Group) Co., Ltd. collaborated to transform a 75-tonne/hr coal-fired power unit into a 12-MW staged conversion power generation unit. Thermal commissioning and operation showed that without using high-pressure or purified oxygen, the calorific value of the gas mixture from coal pyrolysis was over 20 MJ/Nm³. The major components of the fuel gas were CH₄ and H₂, with a tar yield over 10%. The system operation was stable and could be modified relatively easily. Generally, operation was safe and reliable. The production of tar and fuel gas was stable. The production of multiple high-value products in an organically integrated system with coal as the raw material was accomplished.

Based on this, Zhejiang University and China Guodian Corporation's Xiaolongtan Power Plant collaborated to convert a 300-MW_e lignite-burning circulating fluidized bed boiler into a 300-MW_e circulating fluidized bed heat, electricity, and fuel gas polygeneration facility (still using lignite). The project was constructed in two phases. To date, the conversion project's first stage of construction has been completed, with the experimental apparatus designed to use 40 tonnes/hr of lignite. The 72-hr evaluation operation and performance parameter testing were completed in June 2011.



Zhejiang University's 1-MW syngas and steam cogeneration pilot

Building on existing research and development, Zhejiang University and Dongfang Boiler Co., Ltd. are collaborating to carry out the design of 350-MW_e and 600-MW_e supercritical circulating fluidized bed pyrolysis and combustion staged conversion facilities, which are intended to lay a foundation for future large-scale industrial application. Such technology could be used in the new construction of power plants as well as retrofitting older power plants. The technology's economic and environmental benefits are considerable and the application prospects are broad.

Q: In November 2014, China and the U.S. issued the U.S.–China Joint Statement on Climate Change, announcing the actions of each country for dealing with climate change after 2020. China plans to peak CO₂ emissions around 2030 and will attempt to reach this peak early. China also plans to increase non-fossil energy's share of primary energy consumption to 20% by 2030. In light of these goals, how should low-carbon coal utilization be realized in China?

A: The main paths to low-carbon utilization of coal include high-efficiency, low-emissions utilization and the development of CO₂ capture, utilization, and storage (CCUS) technologies. Achieving high-efficiency clean utilization of coal mainly relies on the integrated innovation of technologies. Ultra-supercritical power generation units, IGCC technology, and staged coal conversion are the principal approaches for high-efficiency, low-emissions coal utilization.

Another path to low-carbon coal utilization is to develop CCUS. CCUS technologies are necessary to realize the large-scale control of coal-derived CO₂ emissions. In 2007, China surpassed the U.S. and became the world's largest carbon emitter. For a very long time, fossil fuels, especially coal, will continue to dominate the energy mix in China. Since 2006, China has funded a series of research and development projects to support the development of CCUS technologies, including the 863 Program, 973 Program, and National Key Technologies R&D Program. These projects include key technologies in areas such as CO₂ capture, bioconversion, geological storage, and enhanced oil recovery. With the support of the government and corporations, many demonstration projects have been completed in recent years.

Although significant progress has been made in the research and development of CCUS technologies in China in recent years, there are challenges that have yet to be fully overcome. Such issues include high cost and energy consumption as well as proving the technology is safe and reliable over the long term. Therefore, the large-scale implementation of CCUS will continue to require the combined efforts of the government, research institutions, and corporations. 🤖

Setting the Benchmark: The World's Most Efficient Coal-Fired Power Plants

By Dawn Santoianni

Managing Director, Tau Technical Communications LLC

International efforts to mitigate climate impacts have intensely scrutinized carbon emissions from the electricity sector. Coal, in particular, has been targeted as a source of emissions that could be reduced. The International Energy Agency recognizes that “coal is an important source of energy for world...we must find ways to use coal more efficiently and to reduce its environmental footprint.”¹ With global coal demand projected to increase 15% through 2040, reducing carbon emissions from coal-fired electricity has become a policy focus in many countries as part of an overall strategy to reduce emissions.² Although roughly half of new coal-fired power plants constructed during 2011 used high-efficiency low-emissions (HELE) technologies, approximately 75% of operating coal-fired units worldwide are based on less efficient, non-HELE technology.¹

Globally, the average efficiency of coal-fired generation is 33% HHV (higher heating value) basis or 35% LHV (lower heating value) basis.^{3,A} In a survey of countries worldwide, the average three-year (2009–2011) efficiency of coal-fired electric generating fleets ranged from a low of 26% in India to a high of 41% in France, normalized to LHV.⁸ Those countries that were among the first to widely deploy HELE technology now have the most efficient coal-fired fleets.

Achieving higher steam temperatures and pressures (see Figure 1), HELE generating units employ advanced steam

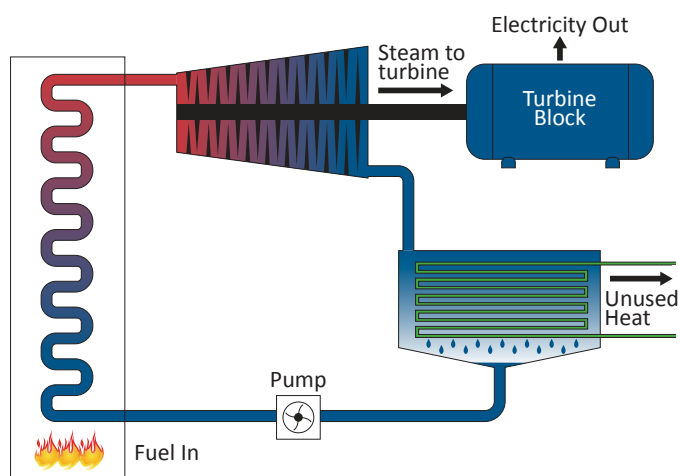


FIGURE 1. The steam cycle is at the heart of coal-fired power plant efficiency.

path design with multiple steam turbine pressure modules to extract the maximum amount of power from the steam produced. As the steam passes through each turbine module, the pressure decreases. These modules are referred to as the high-pressure (HP), intermediate-pressure (IP), and low-pressure (LP) turbine sections. Some turbine designs feature multiple IP or LP modules, while others may have a combined HP/IP cylinder. Steam exiting the HP section is returned to heaters that increase the steam temperature (reheat) to about the primary steam temperature before undergoing further expansion through the IP section. In double-reheat turbines, the steam exiting the IP module is again reheated before passing through the LP turbine module. Reheating is used to keep the steam humidity low, preventing the formation of water droplets that could damage turbine blades. Turbine blades are designed for each module to limit turbulence and efficiently convert steam kinetic energy into torque.

“Roughly half of new coal-fired power plants constructed during 2011 used high-efficiency low-emissions technologies...”

The upfront cost of ultra-supercritical (USC) HELE technology is 20–30% more expensive than a subcritical unit, but the greater efficiency reduces emissions and fuel costs. Therefore, USC units are being constructed where new coal-fired capacity is integral to maintaining security of energy supply while reducing emissions and also where older, less efficient fossil units are being retired. Although there are numerous examples of highly efficient coal-fired power plants around the world, four generating stations are highlighted in this article because they are particularly notable based on economic, technical, and policy perspectives.

CLAIMING THE WORLD RECORD: NORDJYLLAND POWER STATION UNIT 3, DENMARK

Nordjylland Power Station (Nordjyllandsværket) is touted by its owner Vattenfall as holding the world record for most efficient coal utilization since Unit 3 was commissioned in 1998.⁴ Nordjyllandsværket is a combined heat and power (CHP)

plant located in northern Jutland, Denmark. The decision to build Nordjylland Unit 3 was made in 1992, at a time when European energy markets were being liberalized to create an EU-wide integrated energy market. This market restructuring and competition demanded increased efficiency, improved environmental performance, and cost-effectiveness of heat and power supply. These priorities were used to determine the plant design criteria. In addition to electricity supplied to the Nordic Power Exchange, Unit 3 provides district heating to the city of Aalborg using low-pressure steam extraction.

The 400-MW_e USC Unit 3 employs a 70-m-high once-through steam generator and double-reheat steam cycle. To accommodate steam pressures of 29 MPa (4200 psi) and primary and two reheat temperatures of 582°C/580°C/580°C, high-performance superalloys were used for boiler and turbine components. An impulse turbine (in which fast-moving fluid is fired through a narrow nozzle) expands the steam from 29 MPa to 0.7 MPa. The HP and IP steam paths are combined in a common HP/IP module. Steam is passed back to the boiler for reheating before it continues through the IP and LP turbine modules. With the double-reheat cycle and cold seawater for cooling, Unit 3 boasts a net electrical efficiency of 47% (LHV basis). The asymmetric double-flow IP steam path (steam is received in the center of the cylinder and discharges at the ends) is configured to suit district heating requirements. Extracted steam is passed through two heat exchangers where water from the Aalborg city grid is heated to 80–90°C. This dual use allows Unit 3 to utilize up to 91% of the energy content in the bituminous coals it burns.

BRIDGING THE ENERGY GAP: TRIANEL KOHLEKRAFTWERK LÜNEN, GERMANY

In a country where the transition to renewable energy is being spurred by government investment, building a new coal-fired power plant might seem incongruous. However, the shut-down of Germany's nuclear plants is presenting challenges to maintaining a reliable and dispatchable power supply. Many of Germany's existing fossil-fueled power plants are over 25 years old—replacing aging plants with more efficient generation also supports the country's decarbonization efforts. Construction of the €1.4 billion Lünen plant in North-Rhine Westphalia began in 2008; the plant has been delivering power to the electric grid since December 2013. Lünen is owned by Trianel Kohlekraftwerk Lünen GmbH & Co. KG, a consortium of 31 municipal utilities and energy providers. The plant was built to allow the municipal utilities to be independent and ensure a safe and affordable energy supply for 1.6 million households.⁵

The 750-MW Lünen plant has a USC tower-type once-through boiler that burns low-sulfur hard coal delivered via canal. Main steam is produced at 28 MPa (4060 psi) and 600°C. The Siemens SST5-6000 steam turbine has one HP, one IP, and two LP cylinders. The plant uses Siemens' advanced 3DV technology (three-dimensional design with variable reaction levels) for the HP and IP blades, which optimizes stage reaction and loading to achieve the highest efficiencies. Using USC technology, the Lünen plant has saved over one million tons of CO₂ per year compared to the average German coal-fired power plant.⁶ In addition to supplying electricity, steam is extracted to heat water for district heating purposes. The plant has an



Nordjyllandsværket Power Station boasts the world's most efficient coal use.



Trianel Kohlekraftwerk Lünen power plant (photo courtesy of Trianel)

electrical efficiency of nearly 46% (LHV basis) while meeting stringent German environmental requirements, making it the cleanest hard coal-fired power plant in Europe.

While Lünen is one of the most efficient coal-fired power plants in Europe, what makes it particularly notable is the ability of Unit 3 to ramp quickly, making it ideally suited to balance intermittent wind and solar loads.⁷ To remove the ramping constraint posed by heat transfer into thick-walled HP turbine components, an internal bypass cooling system allows a small amount of cooling steam to pass through radial bores between the HP casings. This system protects the casing surfaces so the wall thickness could be less than without the cooling steam. This design also effectively allows more rapid heat-up (and thus startup) of the turbine.

FIRST USC IN THE U.S.: JOHN W. TURK JR. POWER PLANT

The 600-MW John W. Turk Jr. power plant in Arkansas holds many distinctions. Completed in December 2012, it was the first USC plant built in the U.S. It also reigns as the country's most efficient coal-fired power plant with an electrical efficiency of 40% HHV basis (~42% LHV basis).⁸ After the project was announced in 2006, American Electric Power's (AEP) Southwestern Electric Power Co. (SWEPCO) spent several years trying to secure the necessary permits while fighting legal battles launched as part of national anti-coal campaigns. Under the legal settlement, SWEPCO agreed to retire an older 582-MW coal-fired unit in Texas, secure 400 MW of renewable power, and set aside US\$10 million for land conservation and energy efficiency projects. At a final cost of US\$1.8 billion to build the plant, the Turk plant also became the most expensive project ever built in Arkansas.

The Turk plant burns low-sulfur subbituminous coal in a spiral-wound universal pressure-type boiler, producing steam at 26.2 MPa (3789 psi) and 600°C. The plant has an Alstom STF60 single-reheat four-casing turbine with a single-flow HP section, double-flow IP section, and two double-flow LP sections.⁹ Using separate cylinders for the HP and IP turbines allowed the number of stages to be increased by about 25% compared to a subcritical steam turbine. The Turk steam turbine was manufactured such that different superalloys were selected for each section of the rotor to match the exact steam conditions with a specific stage on the rotor, allowing faster startups. The Turk plant is equipped with state-of-the-art emissions control technologies, including a selective catalytic reduction (SCR) system, flue gas desulfurization (FGD), fabric filter baghouse, and activated carbon injection.

With inexpensive natural gas and proposed carbon standards for new power plants that would require carbon capture for coal-fired units, permitting another HELE plant in the U.S. could be extremely difficult for economic reasons.¹⁰ Thus, despite its efficiency and excellent environmental performance, the Turk plant may be the last HELE plant built in the U.S. for the foreseeable future.

SETTING THE STANDARD FOR CLEAN COAL: ISOGO NEW UNITS 1 & 2, JAPAN

The Isogo Thermal Power Station is located only six kilometers from Yokohama, the second largest city in Japan. The power station originally consisted of two 1960s-vintage 265-MW subcritical units. During the late 1990s, Yokohama's environmental improvement plans aimed to enhance the stability of electric power supply while retiring older facilities. Electric Power Development Co., Ltd. (J-POWER), which owns and operates Isogo, entered into a pollution prevention agreement with the city. The new USC Unit 1 (600 MW) was built while the original facility remained in operation, becoming operational itself in 2002. The two older units were then shut down and demolished. The new USC Unit 2 (also 600 MW) was constructed on the site of the old plant and started commercial operation in 2009. Isogo Unit 2 operates at 25 MPa (3626 psi) and 600°C/620°C reheat achieving 45% efficiency, while Unit 1 operates at a slightly lower 600°C/610°C. Completion of both units more than doubled the power generated at the small peninsula site while lowering emissions levels to that of a natural gas-fired combined-cycle plant.

Combined, the two larger new units emit 50% less SO_x, 80% less NO_x, 70% less particulate, and 17% less CO₂ than the older subcritical units that were replaced.¹¹ The reduction in criteria emissions has been accomplished using a multipollutant regenerative activated coke dry-type control technology (ReACT™) that captures SO_x, mercury, and NO_x while only using 1% of the water required by conventional wet FGD systems.¹² ReACT™



Turbine blading design plays a role in achieving high-efficiency operation.

technology consists of a moving bed adsorber with activated coke pellets downstream of the electrostatic precipitator. Mercury, SO_x , and NO_x are adsorbed onto the carbon pellets with ammonia injected to promote the nitrogen and sulfur reactions. In addition, the ReACT™ system offers a secondary method of particulate control as the flue gas impinges on the coke pellets. Activated coke from the adsorber is regenerated to reduce NO_x to N_2 and drive off SO_x . In the process, the concentrated sulfur-rich gas stream created is used to produce sulfuric acid as a byproduct for commercial sale. Isogo's Unit 2 has permit levels of 10 ppm and 13 ppm for SO_2 and NO_x , respectively, and usually achieves single-digit ppm concentration emissions. The system provides such exceptional pollution control that Isogo is ranked the cleanest coal-fired power plant in the world in terms of emissions intensity.

THE FUTURE OF HELE TECHNOLOGY

With USC well established, R&D is underway to increase steam temperatures to 700°C and beyond, which could achieve coal-fired efficiencies as high as 50%. Known as advanced ultra-supercritical technology (AUSC), such high pressures and temperatures will require more advanced (nickel or nickel-iron) superalloys that are expensive and currently present fabrication and welding challenges. In early 2014, Alstom and Southern Company (U.S.) announced a milestone in the development of AUSC, with steam loop temperatures maintained at 760°C for 17,000 hours during a trial at Plant Barry Unit 4 in Alabama. The loop contained an array of different superalloys and surface coatings that enabled it to withstand the exceedingly high temperatures within the boiler.¹³ Further advances in HELE technology, material science, and emissions control will enable coal-fired power to retain a primary role in future power systems. 🤖

NOTES

- A. Although HHV is the efficiency convention most widely used in the U.S. for coal-based systems, in parts of Europe and elsewhere LHV is commonly used to report efficiencies.
- B. Efficiencies normalized based on lower heating value (LHV), which refers to the quantity of heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as vapor and the heat not recovered.

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China Brings Online the World's First 600-MW Supercritical CFB Boiler

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Circulating fluidized bed (CFB) combustion technology has proven to be the most economical and flexible technology to utilize low-rank coal, waste from coal washing, biomass, and other forms of waste for large-scale power generation. Over the last 30 years, CFB combustion technology has developed rapidly in China as coal is the principal energy resource and most coal in China is of low quality. However, conventional CFB combustion has not achieved high efficiency (i.e., supercritical or ultra-supercritical operation), so there

has been a strong push in China to improve CFB power generation efficiency, and thus unit capacity, by increasing the steam parameters (i.e., temperature pressure). The most recent major achievement for CFB power development in China is the demonstration of a 600-MW supercritical CFB (SC CFB) power plant at the Baima power plant. This facility boasts the world's largest capacity CFB boiler with SC steam parameters.

“CFB offers superior flexibility in feedstock options—fuel flexibility is important in China where there is a need to combust not only low-rank coal, but also wastes.”



The fully constructed 600-MW SC CFB Baima power plant

THE NEED FOR FLEXIBLE, HIGHLY EFFICIENT POWER

As the dominant energy resource in China, coal is responsible for the majority of China's power generation. By the end of 2014, the total capacity of coal-fired power was 825 GW.¹ The major combustion technology used in those power plants is pulverized coal (PC) combustion. Over the last decade, the need for improved efficiency has driven many companies to adopt SC and ultra-supercritical (USC) steam parameter design and operation for new PC boilers. This allows power generation efficiency to be improved from 38% LHV (lower heating value) (subcritical steam: pressure, 16 MPa; temperature, 540°C) to 41% (SC steam: pressure, 24 MPa; temperature, 566°C) and even up to 45% (USC steam: pressure, 28 MPa; temperature, 600°C).

Although PC boilers can be designed and operated to combust low-rank coals, CFB offers superior flexibility in feedstock options—fuel flexibility is important in China where there is a need to combust not only low-rank coal, but also wastes. For instance, in Chinese coal mines, waste from coal washing (which includes gangue, slurry, and washing middlings) makes up about 10–20% of total coal production.² This waste is characterized by high ash content, high moisture (for the coal washing slurry), high sulfur content—and is not readily combustible in the vast majority of PC boilers. Therefore, the development of CFB technology for power production has strategic value for China.

“By 2010, the capacity of CFB-based power was around 15% of China's total coal-fired power capacity.”

Development of CFB for power generation has been ongoing for several decades. At the end of the 1970s, the German company Lurgi first introduced CFB technology, originally developed for heterogeneous reactors, to the field of coal combustion. CFB operation is characterized by rapid gas–solids mixing, reactions, and heat transfer, all of which create an environment in which low-grade solid fuels can be stably burned at 800–900°C. At these relatively lower temperatures, NO_x formation and emissions are much lower than what is observed for PC combustion. In addition, limestone additives can be combined in the boiler to capture the SO_x in situ. Therefore, CFB offers the least expensive means to control NO_x and SO_x emissions from coal combustion. Other environmental benefits, such as waste reduction and a smaller carbon



The 600-MW SC CFB boiler

footprint, can also be achieved through cofiring coal with biomass or waste. As CFBs are inherently fuel flexible, they can readily accept lower rank fuels that can be varied over time pending availability and other factors.

Therefore, CFB combustion technology has been rapidly developing in China since about 1980. By 2010, the capacity of CFB-based power was around 15% of China's total coal-fired power capacity.³ At that time, the largest capacity of a single CFB boiler was 300 MW_e—this plant was accomplished only with subcritical steam parameters.

As early as 2000, Chinese researchers began considering developing an SC CFB boiler. The idea was encouraged and supported by China's Ministry of Science & Technology (MOST) as well as the National Development and Reform Commission (NDRC). By 2005, MOST had approved a research program to advance SC CFB technology development and deployment.

RESEARCHING SC CFB

Prior to tackling the development of SC CFB combustion, Chinese researchers and engineers had already accumulated enormous experience after two decades of research focused on revising and using a new design theory for CFB combustion. This theory covered all major aspects of CFB boiler design, such as two-phase flow, combustion, and heat transfer.⁴ A particularly notable engineering achievement was the ability to distinguish the fluidization status in a CFB boiler through two parameters. Based on that work a fluidization state map was published that now serves as guidance for CFB boiler design in China.⁵ Thus, researchers successfully practiced theory to develop an advanced CFB boiler. This technology and approach now dominates the Chinese CFB market, with the plants increasing in scale until the first 300-MW_e subcritical power plant was achieved.

TABLE 1. Design parameters of the 600-MW_e SC CFB boiler

Design Parameter	Units	Value
Steam Output	tonnes/hr	1900
Main Steam Pressure	MPa	25.4
Main Steam Temperature	°C	571
Reheat Steam Flow Rate	tonnes/hr	1553
Inlet/Outlet Pressure of Reheated Steam	MPa (absolute)	4.58/4.43
Inlet/Outlet Temp. of Reheated Steam	°C	317/569
Feeding Water Temp.	°C	284
SO _x emission	mg/Nm ³	<380
NO _x emission	mg/Nm ³	<200

As Chinese researchers and engineers began research and development focused on SC CFBs, there were no available demonstrations from which to learn. The information available in public literature was also limited: Most articles only mentioned the possibility of SC CFB without any substantial engineering-focused information.⁶⁻⁹

With the goal set to demonstrate scale-up of SC CFB boilers to 600 MW, two principal challenges were identified:

1. Increase the scale and operation of the boiler by developing the corresponding knowledge regarding two-phase flow, combustion, and heat transfer in this larger furnace.
2. Mitigate the risk of combining forced water circulation with an unknown heat flux distribution on the combustion side of the CFB.

Based on these key uncertainties, the most important topics for the development of a large-scale SC CFB boiler were identified and thoroughly investigated.¹⁰

As an example, one area in which additional knowledge was needed relates to the gas–solids two-phase flow characteristics in an SC CFB. The estimated height of an SC CFB is around 55 m, but no data on two-phase flow in such a tall furnace was available. Thus, a 54-m-high CFB cold-flow test facility was built to measure the solids concentration profile along the height of the furnace as well as the impact of bed inventory on this solids concentration.¹¹

Another example of an important investigation related to the 2D distribution of heat flux and the heat transfer coefficient in a large-scale CFB furnace. A series of field tests were conducted on a 300-MW_e CFB boiler that had a furnace width identical to the initial design of the 600-MW_e CFB. The test data offered

the basis for the heating surface design and furnace water membrane safety evaluation for the larger SC CFB boiler.¹²⁻¹⁴

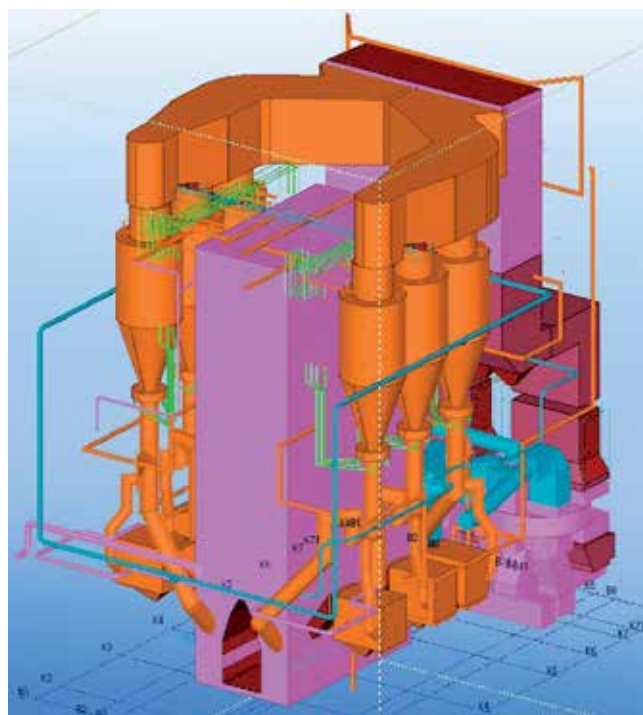
A third example of research conducted to support the design and operation of the 600-MW_e SC CFB is the investigation of the safety of the water membranes under forced-water circulation, which was part of the design for the furnace water wall of the SC. A comprehensive computational model was built to predict the metal temperature of water membranes.^{15,16} The model combines the hydrodynamics of the tube-side water as well as heat flux distribution on the combustion side of the tubes.

DEMONSTRATING THE 600-MW SC CFB

Based on this extensive research, the conceptual design of a 600-MW_e SC CFB boiler was completed by Harbin Boiler Co., Ltd., Shanghai Boiler Co., Ltd., and Dongfang Boiler Co., Ltd. by the end of 2005. In 2007, the demonstration of the 600-MW_e SC CFB at the Baima power plant in Sichuan was approved by NDRC. The investment in the demonstration project was around 3.3 billion RMB (2015US\$530 million). In 2009 Dongfang Boiler Co., Ltd. was selected to be the boiler supplier.

The major design parameters for the Baima SC CFB boiler are listed in Table 1.

The twin boiler furnace has twin air distributors (see Figure 1 for a 3D schematic). The cross-section dimensions are 15 × 28 m,

**FIGURE 1. Schematic of the Baima 600-MW_e SC CFB boiler**

with a height of 55 m.¹⁷ Six steam-cooled cyclones with inner diameters of 9 m are located on both sides of the furnace (three on each side), followed by six external heat exchangers (EHE). There are 12 superheater (final) wing walls in the upper regions of the furnaces. The primary superheater and primary reheater are located in the second pass. The final reheater and the secondary superheater are located in EHSs (see Figure 2). The water mass flow rate in the water wall was selected to be less than 800 kg/(m²·s); this value was based on calculations and laboratory tests conducted by Tsinghua University researchers. Six water-jacketed rotary ash coolers are utilized instead of fluidized bed ash coolers due to prior experience with poor ash drainage and cooling when operating with Chinese coal.¹⁸

OPERATING PERFORMANCE

In 2011, the engineering for the demonstration project was authorized by NDRC. The erection and commission of the 600-MW_e SC CFB was finalized by the end of 2012. On 14 April 2013, the unit passed a 168-hr full load test.

The boiler was transitioned to commercial operation upon successful completion of the full-load test. After a year of commercial operation, a boiler performance test was conducted in May 2014. The test results are provided in Table 2.

The test results demonstrate that the performance of the world's largest SC CFB boiler continues to meet the design criteria after a year of operation. In fact, the measured emissions data actually exceeds expectations for burning such low-quality coal. This power plant is an effective model to convey the advantages of SC CFBs for emissions control in large-scale utilization of low-rank coal.

There is room still for further improvement. During the operation of the SC CFB power plant, it was noticed that the temperature difference experienced by the water membrane tubes was less than 17°C—a value substantially lower than that of SC PC boilers. This has encouraged Chinese engineers to consider the next CFB development target: USC CFB. The steam parameters for USC CFB are 28 MPa/600°C/600°C. With such high steam parameters, the power generation efficiency could be as high as 45% (LHV).

CONCLUSIONS

Coal is the major resource for power generation in China. CFB technology is playing an important role in allowing the utilization of low-rank coal and coal washing waste with economical emissions control. Chinese engineers have embarked on a major effort to investigate CFB combustion theory and develop a unique CFB combustion technology to dominate the Chinese CFB market. To date, the major achievement is

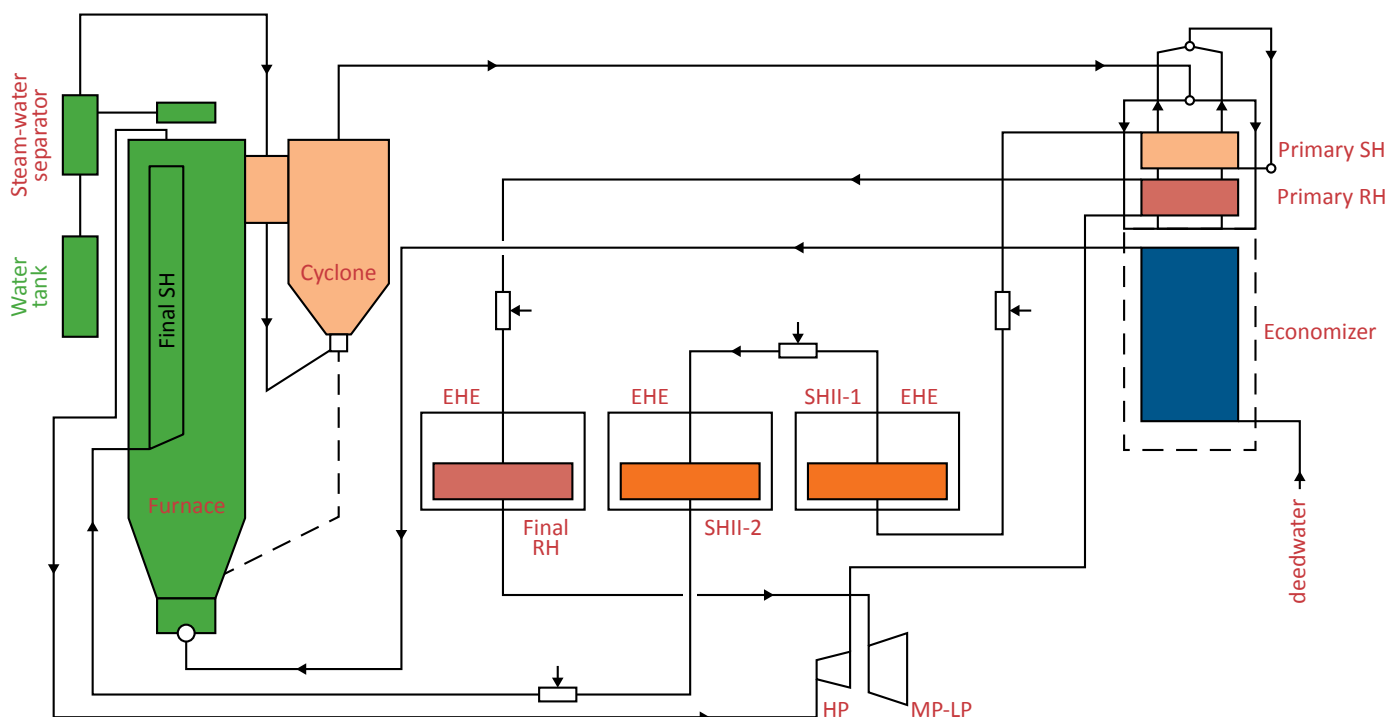


FIGURE 2. Water-steam flow diagram of the Baima 600-MW_e SC CFB boiler

Table 2. CFB boiler performance test result: Performance test

Parameter	Units	Design	Test Measurement
Power Load	MW	600	601
Steam Pressure	MPa	25.39	24.81
Steam Temperature	°C	571 ⁺³ ₋₅	570
Steam Flow Rate	tonnes/hr	1819.1	1747.96
Reheat Steam Pressure	MPa	4.149	4.04
Reheat Steam Temperature	°C	569 ⁺³ ₋₅	566.96
Attemperator Injection Water Flow Rate	tonnes/hr	142	109.2
Furnace Temperature	°C	890	~890
Boiler Efficiency	%	>91.01	91.52
SO _x Emissions	mg/Nm ³	<380	192.04
Calcium/Sulfur Molar Ratio	mol/mol	2.1	2.07
De-SO _x Efficiency	%	96.7	97.12
NO _x Emissions	mg/Nm ³	<160	111.94
Particulate Emissions	mg/Nm ³	30	9.34

the successful demonstration of the 600-MW_e SC CFB at the Baima power plant. The reliable operation and the excellent emissions control performance now points toward the next step: the desire to design, build, and operate the world's first USC CFB power plant in the near future. 🏗️

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Challenging Efficiency Limitations for Coal-Fired Power Plants

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In today's international community the strategic importance of energy efficiency and moving toward a low-carbon economy continues to gain prominence. In China, it is predicted that coal-fired power will remain the principal contributor to the power industry for the long term; therefore, today there is a strong focus on improving the efficiency of China's coal-fired power plants.

To improve the overall efficiency of the thermal power industry, the Chinese government has, since 2004, shut down about 10,000 MW of low-efficiency plants, often those smaller than 200 MW. Simultaneously, construction of new supercritical and ultra-supercritical units, with capacities ranging from 600 MW to 1000 MW, has increased; these plants utilize imported technologies that are domestically manufactured.

One of China's first such projects, the Shanghai Waigaoqiao No. 3 power plant, includes two 1000-MW ultra-supercritical power generation units. This landmark project was initiated in July 2005 with the two units being placed into commercial operation in March and June 2008. Throughout the project,

emphasis was placed on optimization and technological innovation as related to design, equipment selection, construction, commissioning, startup, and operation. As a result, the units' overall performance has been greatly improved with a net efficiency of 45.03% (LHV basis throughout this article), as demonstrated during the performance test (circulating water temperature of 19°C) prior to commercial operation. This efficiency far surpassed the design value and that of the other similar units. During the first year of commercial operation, the actual net efficiency was 42.73% at an average operational load of 74%.

"There is a strong focus on improving the efficiency of China's coal-fired power plants."

Since the units were placed into commercial operation, the pace of technological innovation has continued through a series of new energy-saving and emission reduction R&D projects, such as utilization of waste heat upstream of flue gas desulfurization (FGD) and selective catalytic reduction (SCR) to reduce NO_x with any load rate. Any modifications associated



The ultra-supercritical Shanghai Waigaoqiao No. 3 is one of China's flagship high-efficiency, low-emissions coal-fired power plants.

with these projects have been implemented during planned annual maintenance. Through such modifications, the net efficiency and environmental performance have improved considerably each year.¹ For example, in 2009 and 2010 the plant average net efficiency increased to 43.53% and 43.97%, respectively, again with a 74–75% average load rate. In 2011, the average net efficiency further improved to 44.5% (including FGD and SCR). This means the unit net efficiency including FGD and SCR has reached above 46.5% at rated conditions (i.e., full load).

EFFICIENCY CONTRIBUTIONS FROM MAJOR COMPONENTS

Boiler

Shanghai Electric imported Alstom's boiler technology for the basis of the plant. The boiler is an ultra-supercritical tower-type design with single reheat, built-in separator, spiral water wall, sliding operation, single furnace, corner tangential firing, open arrangement, balancing ventilation, solid slag disposal, and pulverized coal firing. The main boiler parameters are provided in Table 1.

Turbine

Shanghai Electric imported Siemens technology for the 1000-MW, single-shaft turbine with four cylinders and four exhausts, and double backpressures. The main parameters for the turbine are provided in Table 2.

TABLE 1. Shanghai Waigaoqiao No. 3 boiler parameters

<i>Maximum continuous evaporation</i>	2955 tonnes/h
<i>Main steam pressure/temperature</i>	28 MPa/605°C
<i>Reheat steam pressure/temperature</i>	6.4 MPa/603°C
<i>Feedwater temperature</i>	298°C
<i>Designed startup mode</i>	Startup with circulating pumps
<i>Design coal, heat value</i>	China Shenfu Dongsheng bituminous coal, 21–23 MJ/kg
<i>Design efficiency</i>	93.75%
<i>Pulverizers</i>	Medium-speed pulverizers, five in operation, one in standby

TABLE 2. Shanghai Waigaoqiao No. 3 turbine parameters

<i>Rated output</i>	1000 MW
<i>Rated steam flow</i>	2738.6 tonnes/hour
<i>Maximum output</i>	1059.97 MW
<i>Frequency control</i>	Control valve/overload valve
<i>Main steam temperature</i>	600°C
<i>Rated main steam pressure</i>	25.86 MPa
<i>Reheat steam temperature</i>	600°C
<i>Number of extraction stages</i>	Eight
<i>Cooling water temperature and design backpressure</i>	19°C; double backpressure 4.19/5.26 kPa
<i>Design heat rate</i>	7320 kJ/kWh
<i>Boiler feedwater pump</i>	1×100% turbine-driven pump, no motor-driven pump
<i>Condensate pump</i>	2×100%
<i>Feedwater preheater</i>	3×100% one-string, tube sheet preheater
<i>High-pressure bypass/ Low-pressure bypass</i>	100%/65%

LIMITATIONS TO IMPROVING EFFICIENCY

A number of conventional approaches are used to improve the efficiency of modern thermal power plants:

Improving the steam parameters (temperature and pressure): The maximum parameters are limited by materials technology. Currently, the most advanced steam temperature and pressure are 600/620°C (main/reheat) and 28–30 MPa. Research and development are progressing globally toward advanced ultra-supercritical plants (with steam temperatures of 700°C and beyond), but widespread commercial prospects are unlikely within the next 10 years.

Reducing the turbine exhaust parameters: For example, the Nordjylland power plant Unit 3 takes advantage of naturally cold water available for cooling (average temperature of 10°C). Thus, the 411-MW double reheat, ultra-supercritical unit can operate with a backpressure of only 2.3 kPa. However, it is restricted by the turbine exhaust area, exhaust steam humidity, length of the last blading, natural conditions, etc.

Adopting double reheat: Currently the most popular cycle for power plants is single reheat. Double reheat, which can

improve the unit efficiency, is seldom adopted due to system complexity, the large investment required, and concerns related to balancing the performance and costs.

Promoting boiler efficiency: This is accomplished primarily by reducing the amount of excess air and increasing the use of the flue gas heat. The designed efficiency for bituminous coal-fired boilers has reached ~95%. This can be limited by the burn-off rate and coal type, and especially by the sulfur content.

ROUTE TO HIGH EFFICIENCY AND LOW EMISSIONS AT WAIGAOQIAO NO. 3

Efficiency improvements are also possible for existing power plants. To find such opportunities, losses in efficiency due to equipment and operation must be identified and the economic feasibility of modifications must be examined. There are several areas on which to focus.

Reducing Flue Gas Heat Losses

Heat loss from flue gas is a critical area because 80% of all boiler losses can be attributed to flue gas. In addition, the enthalpy and temperature (maximum 10°C) of the flue gas can be increased due to the induced fans and FGD booster fans. With flue gas temperatures normally around 130°C or lower, the energy available for recovery is limited. Compounding this is the important issue of erosion of the recovery heat exchanger surface caused by SO₂ and even SO₃ and NH₄HSO₄ after installing SCR denitration, which results in reduced heat recovery from the flue gas. In addition, fly ash can adhere to the surface of the exchanger. The combination of the alkaline ash and the sulfur acid dew can form a concrete-like substance that is difficult to remove and hinders heat exchanger operation.

This problem has been addressed through several different approaches at Waigaoqiao No. 3. Sulfur dew deposition on the heat exchanger surface is prevented, assisted by the use of anti-acidic materials in the lower temperature sections. In addition, the heat exchanger is placed in the low-ash zone between the booster fan and FGD tower, which prevents abrasion and reduces ash accumulation. Also in this arrangement, the heat generated by the induced fan and booster fan is recovered. As well, a fin-type heat exchanger has been adopted for improving heat exchange. The recovered heat is transferred to the condensate and, thus, low-pressure extraction steam can be returned to the turbine to reduce the turbine heat rate.

The FGD flue gas heat recovery systems for the two units were placed into operation in June and October 2009. To date, they have performed well with minimal erosion detected. The performance test revealed that the unit efficiency was improved

by 0.4 percentage points with the operation of this device, and the water used for the FGD was reduced by 45 tonnes/hr.

Improving the Air Preheater Seal

Air leakage is an important efficiency consideration because it can lead to increased power consumption by all fans due to the increased air and gas flow. In addition, the heat exchanger efficiency can decrease with leakage, leading to a decrease in boiler efficiency.

Similar to most large modern boilers, the two units at the Waigaoqiao No. 3 power plant use rotating air preheaters (diameter 17 m, height 2.5 m). Although such air preheaters have many advantages generally, a nonlinear “mushroom” deformation of the rotor can occur during operation. The clearances between the rotating and stationary parts are not easily controlled, leading to an increase in air leakage. At Waigaoqiao No. 3, the designed air leakage was less than 5%. After the first year of operation the actual air leakage was less than 6%.

“Losses in efficiency due to equipment and operation must be identified and the economic feasibility of modifications must be examined.”

To reduce the air leakage, a round, flexible sealing technology was researched and developed without changing the structure of the air preheater. The sealing device is contacting, flexible, and wear controlled. The flexibility of this new seal compensates for the nonuniform changes in the clearance between the rotating and stationary parts of the air preheater. This technology has led to a significant reduction in air leakage. The service power consumption, including FGD and SCR, was below 3.5 percentage points. The boiler efficiency was increased by 0.29% with the increased air temperature for the boiler as a result of reducing air leakage.

Optimization of Turbine Steam Parameters and Operation

Supercritical and ultra-supercritical turbines supplied by Siemens adopt no control stage design; the basic mode of

operation is that of a sliding pressure run. To address the need for turbine load variation, Siemens introduced ultra-supercritical turbines in China with an overload valve suitable for grid frequency regulation and overload control. There is an additional port for steam injection in the high-pressure turbine immediately after the fifth stage of blading. The overload valve is placed between the additional port and downstream of the main steam stop valves. During normal operation, the main steam control valve and the overload valve work together to control load. Changes in load can be met by opening the overload valve or closing the control valves. Turbine efficiency deteriorates as the overload valve opens. In cases where the overload valve is frequently opened and closed or is maintained slightly open, erosion and leakage are likely.

To avoid this, the design parameters and the control mode were optimized. First, the main steam pressure was selected and the opening point of the overload valve was set to the rated load point which corresponds to the maximum cooling water temperature (during the summer season). Thus, opening of the overload valve can be avoided throughout the year as the load demand will always be equal to or lower than the rated output.

Second, focusing on the turbine load control mode, an energy-saving turbine load adjustment technology based on adjusting the extraction steam was developed. In this way, the main control valves are fully open while the overload valve is always closed. Therefore, the throttling loss across the valves can be eliminated. This method of operation changes the turbine load basis by adjusting the condensate flow to indirectly change

the amount of extraction steam, supported by controlling the extraction steam for the feedwater preheaters. Through this approach, transient turbine output can be obtained and the load requirements set by demand will be satisfied by adjusting the boiler combustion system.

By applying this approach, a fast response to changes in load demand can be achieved and a relatively large range of loads can be handled. This new, successful frequency regulation mode was demonstrated in practice at the two units at Waigaoqiao No. 3 power plant. Currently, the load change rate for frequency control reaches or surpasses 15 MW/min.

These methods have improved the unit operational efficiency by 0.22 percentage points. However, these benefits cannot be detected during performance tests.

Boiler Feedwater Pump Turbine

Based on success at other projects abroad, a 1×100% turbine-driven feedwater pump was adopted at Waigaoqiao No. 3 power plant—a first in China. The plant thus eliminated the motor-driven pump. This boiler feed pump turbine (BFPT), with its own condenser, is able to start up independently using steam from the neighboring boiler.

In addition to successfully developing and implementing the new technology so that the boiler feedwater pump can operate at a wide range of speeds, this technology saves a tremendous amount of energy during startup. It also simplifies the system control strategy and eliminates the risk of minimum flow valve



Operators monitor plant operation at Waigaoqiao No. 3.



FIGURE 1. Oxide deposits on boiler tubes (left) and solid particle erosion on turbine blades (center) and bypass valve plug (right)

leakage and enhances equipment safety. Compared with competing options, this specific boiler feedwater pump increases the unit efficiency by 0.117 percentage points.

Flexible Heat Regenerative Technology

Most power plants today utilize heat regenerative technology wherein steam is extracted from the turbines to heat the boiler feedwater. However, regenerative technology as applied at Waigaoqiao No. 3 has been reformed from standard practice by expanding the regenerative media from only water to water, air, and coal. Based on this new approach, a series of new heat regenerative technologies has been developed. As a result, unit efficiency has improved.

One of these technologies is flexible regenerative technology, which adapts an adjustable high-pressure extraction steam to the additional feedwater heater; the feedwater temperature (into the boiler) can be sustained and the flue gas temperature decreases downstream of the boiler economizer can be minimized during low-load operation. Thus, the SCR can be used at low load without difficulty. Another benefit is the ability to increase the potential rate of load change to respond to changes in demand. Also, by increasing the fraction of bleeding steam at low-load operation, unit efficiency is also improved. Finally, an increase in the combustion air temperature, and the water temperature at the inlet of the water wall during low load, improves combustion stability and efficiency, and the fluid dynamics. At 75% of full load, applying flexible regenerative technology can improve unit efficiency by 0.2 percentage points.

MAINTAINING HIGH EFFICIENCY

Supercritical and ultra-supercritical power plants offer the benefits associated with higher efficiency and lower emissions; to maintain these benefits, however, stable operation and high

efficiency must be maintained. Some challenges, such as steam-side oxidization of the boiler tubes and subsequent solid particle erosion (SPE) of the turbine blades, substantially threaten safe and economic operation. These issues often occur during startup. The oxidized scales in the boiler tubes (steam side) can peel off due to heat shock (see Figure 1). This mass can then be deposited in the tubes or form larger particles that move with the steam.⁷ A major problem can occur when steam tubes burst due to a major deposition. Erosion of the turbine blades can be caused by the particles carried by the steam, and the power plant efficiency will be irreversibly decreased. Furthermore, the particles can also erode the sealing surface of the bypass valve plug during startup, causing leakage and allowing for steam to bypass the turbine, further decreasing efficiency. Recently, several such problems have occurred at many supercritical and ultra-supercritical units in China—in some cases the efficiency has decreased by 4% after only two years of operation.

Therefore, to maintain high-efficiency operation it is important to prevent or slow the oxidization on the steam side of the boiler heat exchanger. This requires comprehensive prevention, incorporating this concern during design, equipment selection, installation and commissioning, and normal operation. After 10 years of research, a comprehensive approach to preserving the high efficiency of the power unit of Waigaoqiao No. 3 has been developed and implemented. Some of the most important components of this effort include:

- Apply dry steam blowouts with highly superheated steam in the outlet area of the water wall, effectively increasing the force and resulting cleaning during blowouts.
- Deploy a large-capacity bypass system designed to bypass the turbine during unit startup and also implement a high-momentum flushing procedure to send oxides directly to the condenser during startup.
- Develop a new configuration design and control strategy to avoid eroding the bypass valve plugs.



FIGURE 2. Pipe from the second reheater tube after 30 months of operation

- Use steam to heat the feedwater that is used to heat the boiler during startup and also during low-load operation.

After 30 months of operation with these strategies in place, the tubes in the third superheater and the second reheater of a boiler at Waigaoqiao No. 3 were inspected. There were no indications of oxidation or deposits. Samples of the second reheater tubes are shown in Figure 2; the results of the inspection of the third superheater were similar.

At the same time, the first blading of the intermediate-pressure turbine was checked. As illustrated in Figure 3, the blading was also undamaged. Notably, a performance test indicated that the turbine interior efficiency has not deteriorated since the initial power plant startup.

CONCLUSIONS

In order to rapidly decrease the carbon emissions from the electricity industry, the potential to save energy and increase efficiency through all means possible must constantly be evaluated. This effort includes researching and developing new technologies, challenging efficiency limitations, and developing the most efficient thermal power based on available technologies.

Operational experience with the Waigaoqiao No. 3 power plant demonstrates that much room remains to save energy through equipment selection, design, commissioning, operation, emission control strategies, etc. Through optimization, improvement, and innovation, tapping the energy-saving potential is the best solution to achieve lower cost, lower risk, and near-term results for efficiency improvements. For



FIGURE 3. First blading of an IP turbine after 30 months of operation

new plants, the strategies implemented at Waigaoqiao No. 3 can incrementally improve net power plant efficiency by over three percentage points, which is equivalent to increasing the steam temperature of an ultra-supercritical plant from 600°C to 700°C. Although these technologies are principally used for newly constructed units, they can also be employed for existing units, resulting in an efficiency improvement of more than two percentage points. 🤖

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Improving the Efficiency of Power Plants Firing High-Moisture Coal

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Low-rank, high-moisture coals constitute about 50% of U.S. and world coal reserves. Given the abundance of these low-cost coals, the use of high-moisture coal for power generation is already common and is growing. In the U.S. alone, plants burning high-moisture coals produce nearly a third of the coal-fired electric generation, according to the Department of Energy.¹

Unfortunately, plants that utilize high-moisture coal pay a substantial price in efficiency. When such coals are burned in utility boilers, about 7% of the fuel heat input is used to evaporate and superheat the moisture in the fuel. Most of this lost heat can be attributed to the energy needed to evaporate the moisture in the fuel. Furthermore, high-moisture, low-heating value coals result in higher fuel and flue gas flow rates, auxiliary power requirements, net unit heat rate, and increased mill, coal pipe, and burner maintenance compared to bituminous (hard) coals. Conversely, a reduction in coal moisture through thermal drying improves boiler and unit efficiency, plant operation, and economics while reducing CO₂ and criteria emissions.



Coal Creek Station has improved performance through coal drying with the DryFining process at both units, in commercial operation since 2009.

COAL DRYING IMPROVES PERFORMANCE

The opportunities for thermal integration to dry coal are site-specific and depend on the available heat sources, space constraints, and general layout of the plant. The benefits of coal drying, such as heat rate improvement, increase as the moisture in the coal is reduced. The achievable reduction in coal moisture content may be limited by thermal performance of the boiler convection pass, the amount of available heat, or by the equilibrium moisture content of coal.^A

“A reduction in coal moisture through thermal drying improves boiler and unit efficiency, plant operation, and economics while reducing CO₂ and criteria emissions.”

To take advantage of the benefits of using waste heat to dry coal at power plants, a novel low-temperature coal-drying and -cleaning process was developed. This process employs a moving bed fluidized bed dryer (FBD) that harnesses waste heat from the power plant to decrease the moisture content of low-rank coals. This technology, commercially available as the DryFining Fuel Enhancement Process (DryFining™), was developed and commercialized by Great River Energy (GRE) at its Coal Creek Station (2×600 MW).

For existing units, depending on site specifics, coal drying with DryFining has been demonstrated to reduce total coal moisture (TM) by 10 to 20 percentage points (see Table 1). The higher end of the range corresponds to supercritical

TABLE 1. Net unit heat rate improvement through drying of high-moisture coals¹⁻⁷

Coal	TM (%) Raw → Dried	ΔHR _{net} (%)	
		Min	Max
Washed Illinois	20 → 10	0.6–1.4	1.7
PRB	30 → 15	1.9–3	3.6
Lignite	38.5 → 23.5	3–5	5.9

power plants. The maximum improvement in net unit heat rate (ΔHR_{net}), shown in Table 1, represents off-site coal drying and the delivery of dry coal to the site. The minimum corresponds to basic DryFining thermal integration options. The results are conservative because the analysis did not account for system draft and fan power reductions. A new plant with integrated DryFining will have a lower capital cost, compared to a plant burning raw coal, including the front-end coal drying system, and will not be limited by the boiler convection pass performance.

Implementation of onsite thermal drying in newly built power plants operating with high steam parameters (i.e., supercritical and ultra-supercritical steam cycles) is especially beneficial for units burning low-rank coals that contain higher moisture content (see Figure 1). This is because the efficiency of such plants is more negatively affected by the high coal moisture content. A reduction of coal moisture is necessary to achieve the very high efficiencies made possible through supercritical, ultra-supercritical, and eventually advanced ultra-supercritical technologies.

THE DRYFINING FUEL ENHANCEMENT PROCESS

GRE's moving bed FBD is the heart of the DryFining system, which serves two important functions. It cleans the coal by removing a significant portion (~30%) of the sulfur and mercury from the raw coal in the first FBD stage and then dries the coal in the second stage. The cleaning function, accomplished by gravitational segregation in a fluidized bed, distinguishes this technology from others commercially available and provides the critical co-benefit of emissions reduction. At those power plants that do not have modern environmental controls applied, a process that removes pollutants from coal and increases power plant efficiency could have even greater value than a process that only dries the coal.

A moving bed FBD was selected for the DryFining process because such a process offers rapid heat and mass transfer, resulting in a more compact dryer design. The coal is fluidized by air instead of the commonly used steam.^B Potential devolatilization of coal during the drying process is avoided by drying with low-grade waste heat from the power plant.

Crushed coal is fed to the first stage of the fluidized bed dryer, where non-fluidizable material such as rocks and other higher-density fractions are segregated at the bottom of the dryer, while less dense and smaller particles float. Therefore, the segregated stream discharged from the dryer has higher mineral matter content (including pyrite) in comparison to the dried coal (product stream). As most of the inorganically associated sulfur is contained in pyrite forms, in the case of North Dakota (ND) lignite, about 30% of the sulfur and mercury (Hg) from coal are segregated out in the first stage of the FBD.^{4,5,8}

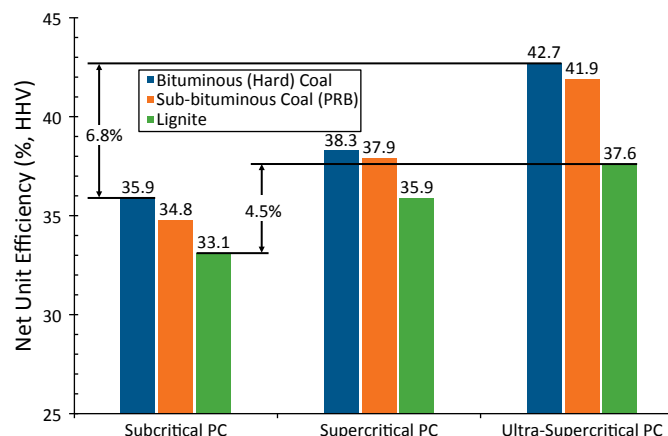


FIGURE 1. Effect of coal rank and steam parameters on net unit efficiency

The tests conducted with other lignites and sub-bituminous coals confirm that about 20 to 30% of sulfur and mercury in the coal can be segregated out. The amount of segregated sulfur and mercury depends on many factors, such as the percentage of inorganically associated sulfur in the coal, the presence or absence of clays, and other factors related to coal morphology.

After segregation, the fluidizable material next enters the dryer's second stage, where the surface and a portion of the inherent coal moisture are evaporated by the heat supplied by the fluidizing air and the in-bed heat exchanger. The in-bed heat exchanger increases the temperature of the fluidizing (drying) air and fluidized coal bed, improving drying kinetics (the rate of coal drying). The drying process affects the micro-structure of coal particles that disintegrate during drying. The drier and finer coal is discharged from the FBD as the product stream. The bed residence time and temperature primarily control the residual moisture content.

FIVE YEARS OF OPERATING EXPERIENCE

Three series of controlled tests were conducted on Coal Creek Unit 1 at full gross load (i.e., 600 MW), steady-state operating conditions before and after the implementation of coal cleaning and drying with the DryFining process. The coal cleaning and drying equipment was sized to treat up to 1100 tons/hr of raw North Dakota lignite with moisture content in the range of 38% to 40%. The process has been in continuous commercial operation at Coal Creek Station since December 2009.

Measurements were made at the power plant with the raw (wet) coal and no treatment in September 2009 to establish baseline unit performance and emissions. Then tests with the DryFining process in service were performed in March–April 2010 and October 2011. Those test results are summarized in Table 2. The complete test report is available elsewhere.⁴

TABLE 2. Coal Creek Unit 1 operating conditions with and without coal drying applied

Test	P_G (MW)	$O_{2,APH,in}$ (%)	APH Leakage (%)	FGD Inlet Temp. (°F)	Stack Temp. (°F)	Opacity
Raw Coal	600	2.54	8.2	345	188	6.6
Dried Coal	606	2.76	4.1	309	156	5.8

Note: APH,in = air preheater inlet.

Operating Conditions

When the coal was dried, air preheater (APH) air leakage decreased due to the lower drafts. In addition, the temperature of flue gas at the APH exit decreased, resulting in lower volumetric flow of flue gas entering the flue gas desulfurization (FGD) system. As Coal Creek employs a FGD gas bypass to avoid condensation at the power plant stack, less flue gas means that less can be bypassed, which allows a larger proportion of the flue gas to be scrubbed and reduces overall plant emissions even further.

As a consequence of the reduced FGD bypass flow, the stack temperature decreased, but remained well above saturation temperature. Also, with lower flue gas temperature, flue gas velocity through the electrostatic precipitator decreased, resulting in improved particulate collection efficiency and lower opacity.

Unit Performance and Emissions

The effect of drying the coal with the DryFining process was measured through changes in the net unit heat rate and boiler efficiency, fuel and stack flow, and mill and induced draft (ID) fan power (see Table 3). During the October 2011 tests, the coal moisture content was reduced by five percentage points (i.e., 13%), resulting in a 10.6% increase in coal heating value. Further reduction of fuel moisture at Coal Creek was limited by steam temperatures, which began to decrease due to the

lower flow rate of flue gas through the convective pass of the boiler. There are plans to increase the boiler heat transfer surface area to allow further coal drying in the future.

The decrease in coal utilization rate resulted from the increased higher heating value (HHV) of the coal. The reduced-moisture coal also had improved grindability, thus mill power decreased by almost 10%. This allowed the unit to be operated with six mills in service, instead of the customary seven or eight. Freeing one of the mills to be used as a spare improved plant availability, as mills can be rotated in and out of service for routine maintenance or repair without reducing the fuel-processing capacity. In addition, mill maintenance is no longer carried out during plant outages when labor is more costly.

The volumetric flow rate of flue gas downstream of the APH decreased with the lower coal flow rate and flue gas temperature, resulting in lower draft losses and lower ID fan horsepower.

With drier coal, the net unit heat rate (HR_{net}) decreased by 3.5%, while boiler efficiency increased by 3.4%. The improvement in net unit heat rate is higher than the improvement in boiler efficiency because, with drier coal, the station auxiliary power requirement is reduced compared to the raw, wet coal.

The reduction in CO₂ emissions determined by using the performance test data shown in Table 3 was 3.5%. However, this reduction was somewhat limited by site-specific conditions; other power plants could potentially achieve greater efficiency improvements. At Coal Creek, adding additional heat transfer surface area to the boiler will allow further reductions in the coal moisture content, with a projected heat rate improvement of 4.5% and a more than 4.6% reduction of CO₂ emissions. The CO₂ intensity was reduced by 3.0%.

The implementation of coal drying with the DryFining process also had a significant positive effect on NO_x, SO₂, total mercury (Hg^T), and CO₂ emissions (see Table 4). A reduction in NO_x emissions is attributed to the lower coal input and lower ratio of primary air (PA) to secondary air (SA), compared to operation with raw coal. Parametric testing before separated over-fired

TABLE 3. The effect of DryFining on the performance of Coal Creek Unit 1

Test	TM (%)	HHV (Btu/lb)	Coal Used (klb/hr)	Flue Gas (kscfm)	Mill Power (kW)	ID Fan Power (kW)	HR_{net} (Btu/kWh)	Boiler Efficiency (%)
Wet Coal	37.1	6251	946	1557	3989	8767	10,246	80.34
Dried Coal	32.1	6914	856	1467	3596	7251	9890	83.06
Difference, %	-13.5	10.6	-9.5	-5.8	-9.9	-17.3	-3.5	3.4

TABLE 4. Effect of DryFining on emissions at Coal Creek Unit 1

Test	NO _x (lb/MBtu)	SO _x (lb/MBtu)	Hg ^T (mg/dNm ³ @3% O ₂)	CO ₂ Intensity (lb/MWh)
Wet Coal	0.284	0.578	14	2209
Dried Coal	0.200	0.346	8.5–9	2144
Reduction, %	30	>40	35 to 40	3.0

air installation in the late 1990s revealed hot primary air drying to the mills to be the top NO_x driver. The resulting 30% NO_x reduction allowed Coal Creek to meet its new NO_x emission limits by boiler tuning, avoiding a costly installation of a selective non-catalytic or catalytic reduction (SNSR or SCR) reactors.

SO₂ emissions reductions were attributable to three factors. First, the lower flow rate of dry coal to the boiler reduced the amount of sulfur entering the boiler. Second, a significant portion of the inorganically bound sulfur (approximately 30%) was segregated out by the moving FBD. Finally, the lower volumetric flow of flue gas allowed a larger proportion of flue gas to be scrubbed (with less being bypassed), further reducing SO₂ emissions (see Figure 2).

The 35–40% reduction in Hg^T emissions is due to reduced coal combustion (as a result of higher efficiency), removal of approximately 30% of the pyrite-bound mercury from the coal during coal cleaning, change in mercury speciation, and increased flow rate of flue gas through the FGD where oxidized mercury (Hg²⁺) is removed. The reduction in Hg^T emissions allowed Coal Creek to meet new emissions limits with

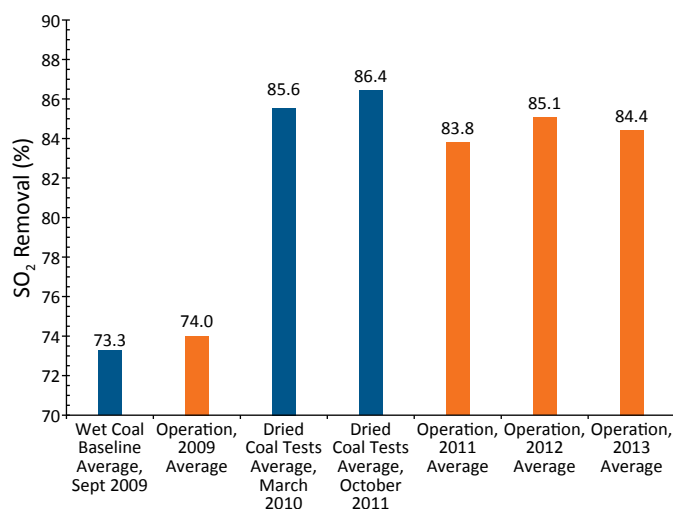


FIGURE 2. SO₂ removal in the FGD before and after implementation of DryFining

FGD additives to reduce Hg²⁺ re-emission, thereby avoiding activated carbon injection.

Overall, by implementing DryFining at Coal Creek, Great River Energy avoided an estimated \$366 million in capital expenditures, which would otherwise be needed to comply with emissions regulations.

LONG-TERM OPERATING EXPERIENCE

DryFining has been in continuous commercial operation at Coal Creek Station for over five years, achieving availability higher than 95% without causing a single unit outage.

The performance, in terms of reducing the heat rate, of both Coal Creek units has continued to improve since commercial operation of the DryFining process began in December 2009. Figure 3 offers a comparison of monthly average net unit heat rate values. The average annual improvement in net unit heat rate for Unit 1 is 3.4%—virtually the same as measured during the baseline tests. The heat rate improvement for Unit 2 of 5.8% is higher because it also includes the effect of a steam turbine upgrade. The station net generation has increased since implementing DryFining since the auxiliary power use of each unit has decreased 5 MW.

Annual averages of NO_x and SO_x emissions for Units 1 and 2 at Coal Creek are presented in Figure 4 for the 2005–2013 time period. Following implementation of DryFining, SO_x emissions were reduced by 44–46%, while the NO_x emissions were reduced by 24–25%, compared to the 2005–2009 average. The long-term reduction in NO_x was smaller compared to the test results presented in Table 4, because changes in unit load

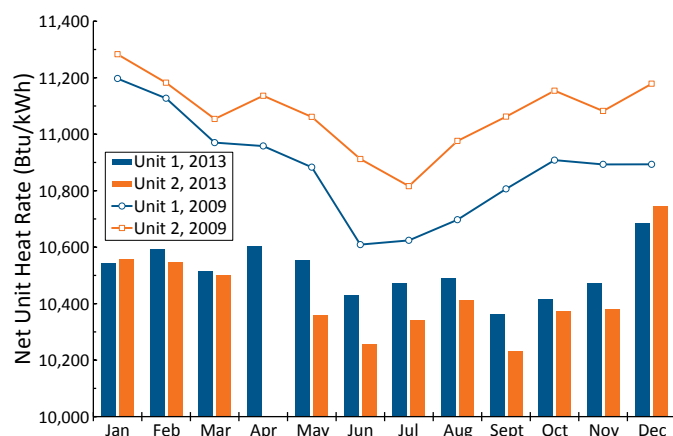


FIGURE 3. Monthly average net unit heat rate for refined (2013) and raw (2009) coals

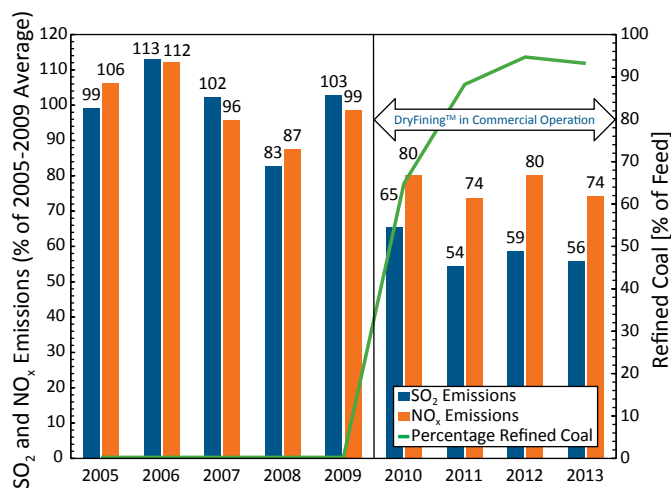


FIGURE 4. NO_x and SO₂ emission levels at Coal Creek Units 1 and 2 before and after implementation of DryFining

and combustion settings, experienced in regular operation, increase NO_x.

CONCLUSIONS

With a tremendous amount of low-rank, high-moisture coal reserves globally available and being increasingly utilized, it is important to integrate thermal drying to increase the efficiency of power plants relying on such fuels. A novel low-temperature coal drying and cleaning process, DryFining, employing a moving bed fluidized bed dryer and using waste heat to decrease moisture content of the North Dakota lignite and other high-moisture coals was developed in the U.S. by a team led by Great River Energy.

Considerable efficiency improvements and emissions reductions have been demonstrated with near-continuous operation since 2009. This process has allowed the plant to meet strict emissions standards without the addition of new equipment, saving an estimated \$366 million in capital expenditures for emissions control equipment.

The potential application of coal cleaning and drying with DryFining can be expanded. It may also be very effectively used to improve the quality of washed coals,⁸ as well as to improve the efficiency of the plants that have switched from bituminous fuel to PRB to reduce SO₂ emissions. Additionally, DryFining may be employed to improve the efficiency of coal gasification plants (e.g., IGCC and CTL) and lignite-fired oxy-fuel power plants using dry-feed gasifier designs.^{8,9}

NOTES

- A. Oxy-fuel and oxygen-blown gasification plants are not subject to the equilibrium moisture content limit. The studies conducted with DryFining integrated with the lignite-fired oxy-fuel and CTL plants employing dry-feed gasifiers have demonstrated coal moisture reduction in the 40–55% range to the target moisture level of 8–12%.
- B. Inert fluids, other than steam, may be used for fluidization to achieve deep reductions in coal moisture content.

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Helping to Seed a CCS Industry: The White Rose CCS Project

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The White Rose Carbon Capture and Storage Project (White Rose) is a proposal to build a new ultra-supercritical coal-fired oxy-fuel power plant up to 448 MW_e (gross) with full carbon capture and storage (CCS) deployed from the outset. The plant will be located at the Drax Power Station site, near Selby in North Yorkshire in the UK, and will generate enough low-carbon electricity to supply the equivalent needs of over 630,000 homes. White Rose would be one of the first large-scale demonstration plants of its type in the world and the first oxy-fuel coal-fired CCS plant to be built at commercial scale, representing a core step toward the advancement of CCS technology globally.

The project is currently in the FEED (front-end engineering and design) stage, having been awarded a contract in December 2013 by the UK government, under the UK CCS Commercialisation Programme. This program is one component of the UK's Department of Energy and Climate Change (DECC) CCS Roadmap that sets out the necessary steps required to support the development of a CCS industry in order to meet the target of an 80% reduction in greenhouse gas emissions by 2050 (from a 1990 baseline).¹

White Rose additionally secured an award decision in July 2014 for European Union (EU) funding through “NER300” (New Entrant Reserve 300)—one of the world's largest funding programs for innovative low-carbon energy projects to be demonstrated at a commercial scale within the EU.²

“White Rose will demonstrate that CCS oxy-fuel technology can be used to generate reliable, flexible, low-carbon electricity competitively...”

DELIVERY OF WHITE ROSE THROUGH CAPTURE POWER LIMITED

Many aspects of coal-fired oxy-fuel combustion have been demonstrated; however, White Rose would be the first comprehensive project at commercial scale. To ensure an experienced team is in place to lead the first-of-a-kind project, a strong consortium, Capture Power Limited, has been formed by three companies: Alstom, Drax, and BOC. Each team member brings unique capabilities to the project.



Artist's rendition of Drax cooling towers (left) facing the White Rose oxy-fuel power plant (right) (image from Arup Associates, UK)

Alstom is a recognized global leader in power generation; a quarter of the world's power station fleet relies on Alstom technologies. The company is a pioneer in large-scale and efficient CCS technologies and is considered one of the foremost experts in coal-fired CCS development.

Drax owns and operates Drax Power Station, the largest power station in the UK. The output capacity from the station's six units is a combined 3870 MW. Currently average output levels meet approximately 7–8% of the UK's electricity needs. Two of the power station's six generating units have been fully converted to burn sustainable biomass in place of coal and a third unit is planned to be converted in 2015/16.

BOC, part of the Linde Group, is the UK's largest industrial, medical, and special gases provider. Its strategy is centered on innovation with clean energy technologies, including CCS, which is currently a major focus of the company's research and investment.

CCS BENEFITS AND ENERGY SECURITY

Many independent studies have indicated that CCS on power stations is critical in enabling the lowest cost pathway to decarbonization, with the International Energy Agency proposing power plants with CCS contribute 14% of emissions reduction to 2050, or the equivalent of 950 GW globally.³ CCS demonstration and deployment must advance more rapidly for it to play the projected required role in carbon emission mitigation. Therefore CCS projects at commercial scale are of paramount importance. As one such project, White Rose will demonstrate that CCS oxy-fuel technology can be used to generate reliable, flexible, low-carbon electricity competitively, while helping to reduce global greenhouse gas emissions.

Limited options exist to achieve flexible, low-carbon power at a large scale. Power stations with CCS must displace conventional (i.e., unabated) load-following thermal plants in order to meet fluctuating consumer demand and ensure a secure power supply as greater intermittent renewables are incorporated into the energy mix. CCS on thermal power plants is the only low-carbon technology available to most countries that is of sufficient size, stage of commercial development, and cost competitiveness to provide this important role in enabling continuous, flexible, low-carbon power supply.

FUEL FLEXIBILITY AND CARBON ABATEMENT

White Rose would be capable of capturing two million tonnes of CO₂ per year, which is about 90% of all the CO₂ emissions produced by the plant. In addition, White Rose will be capable of firing a range of fuels and has the potential to co-fire biomass alongside coal, a step that would enable the plant to

release zero or even increasingly negative net CO₂ emissions depending upon the level of biomass co-firing. This technology would enable a co-fired coal and biomass oxy-fuel power plant with CCS to form a carbon sink, offsetting carbon emissions from other sources. Such flexibility in fuels adds significantly to the value of an oxy-fuel power plant through the potential to assist total decarbonization over and above the power sector's contribution.

“Many independent studies have indicated that CCS on power stations is critical in enabling the lowest cost pathway to decarbonization...”

AFFORDABILITY

CCS technology can enable the most cost-effective path to decarbonization at a large scale, according to reports by the Energy Technologies Institute, International Energy Agency, and UK Trade Union Congress, the latter estimating that the cost of decarbonization would be 20–25% higher in the UK without CCS.⁴ Similarly, the Intergovernmental Panel on Climate Change has projected that, without CCS, the cost of global carbon mitigation efforts will increase by approximately 140%.⁵

White Rose is expected to confirm cost effectiveness aligned with the findings of the UK's CCS Cost Reduction Task Force (CRTF) that has identified pathways for reducing the costs of CCS as the industry develops. Specifically, the CRTF concluded: “UK gas and coal power stations equipped with carbon capture, transport and storage have clear potential to be cost competitive with other forms of low-carbon power generation, delivering electricity at a levelised cost approaching £100/MWh by the early 2020s, and at a cost significantly below £100/MWh soon thereafter.”⁶

SEEDING A CCS INDUSTRY

The CO₂ captured at White Rose will be transported by pipeline to a permanent geological storage site beneath the North Sea by National Grid through their Yorkshire and Humber CCS pipeline, which will be developed alongside this project (see Figure 1). The CCS pipeline would have the capacity to transport up to 17 million tonnes of CO₂ every year, significantly in excess of the two million tonnes of CO₂ captured annually at White Rose,



FIGURE 1. Approximate path of the Yorkshire and Humber CCS pipeline that White Rose could help establish

which is intended to act as the anchor project and potential catalyst for development of the regional CCS pipeline network.

The Yorkshire and Humber region in the UK is an ideal location for CCS project proposals due to the number of power stations and large industrial plants in relatively close proximity, which together represent approximately 19% of the UK's CO₂ emissions. A report published by the research organization CO2Sense, "The National, Regional and Local Economic Benefits of the Yorkshire and Humber Carbon Capture and Storage Cluster", found that the Yorkshire and Humber region is the "best strategic location in Europe" to establish a CCS cluster due to the high concentration of emitters, as well as the proximity to potential North Sea storage sites and the presence of an advanced supply chain.⁷

The CCS network connecting such facilities aligns with the recommendations of the Energy Technologies Institute report on the "Potential for CCS in the UK", which states: "The most effective way to implement CCS is through a national infrastructure comprising a handful of shared transport and storage networks because this captures economies of scale and drives asset utilisation."⁸

OXY-FUEL BASICS

Although White Rose will be a first-of-a-kind demonstration, the specific components of coal-fired oxy-fuel combustion are commercially proven. The oxy-fuel process is based on a conventional power-plant steam cycle, but uses oxygen mixed with recycled CO₂ instead of air in the combustion process (see

Figure 2). The oxygen is provided by an air separation unit (ASU), using standard technology. The oxy-fuel combustion gas eliminates nitrogen from the system, producing a flue gas consisting mainly of CO₂ and water. Additional components including particulates, SO_x, and NO_x are handled in conventional treatment steps. A CO₂ processing and compression unit, similarly using established processes, is installed to treat and compress the CO₂-rich flue gas before being transported to storage.

The oxy-fuel process proposed at White Rose has a number of distinct benefits, including:

- Oxy-fuel is similar to conventional air-fired operation, developed from well-known systems and processes and all the main components of an oxy-fuel power plant already exist, providing a reliable and proven technology basis.
- The oxy-fuel process does not require large quantities of new chemicals compared to post-combustion technologies.
- Oxy-fuel operation is highly flexible, beyond even the level of conventional coal-fired power plants, due to the integration of the ASU. This flexibility allows oxy-fuel plants to make and store liquid oxygen using low-cost power during periods with low demand, which can then be used to boost power production during peak power periods, through reducing the ASU load (as the oxygen being produced is supplemented by stored oxygen), enabling a higher net output.

In addition to these advantages for White Rose, oxy-fuel technology has been estimated to represent the lowest cost solution for CCS on coal-fired power stations, according to the UK's CRTF report, where the levelized cost of electricity in

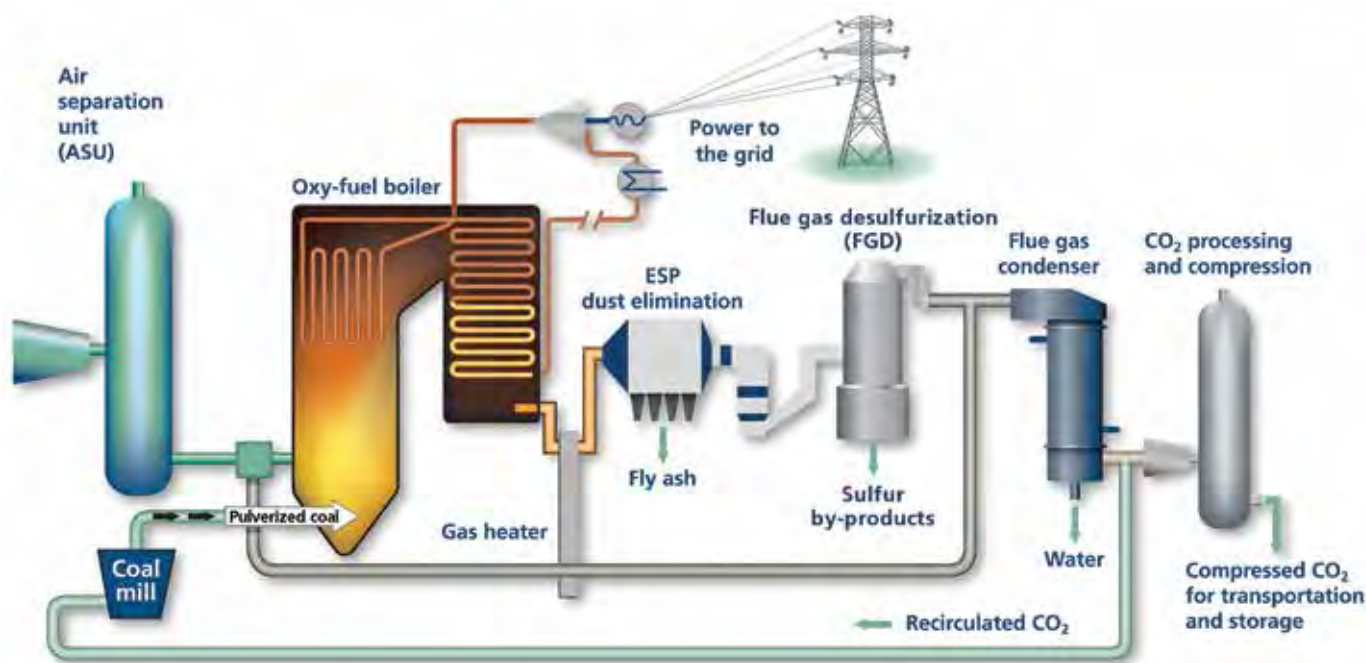


FIGURE 2. Alstom's oxy-fuel process

Source: Alstom

2013, 2020, and 2028 was estimated to be lower than other options.⁶

CHALLENGES AND OPPORTUNITIES

The UK government's CCS Commercialisation Programme,⁹ providing funding support to the White Rose CCS project FEED Programme, is the first step toward advancing commercial-scale CCS in the UK. Subsequent policy mechanisms must be implemented in the UK and elsewhere to benefit from the lowest cost route to decarbonized power, capitalize on the much-needed flexible operation they offer, and make a competitive CCS industry a reality.

In the meantime, White Rose represents a unique opportunity to demonstrate that abated fossil-fuel power stations will be able to generate flexible, reliable, and affordable power as load-following plants, providing security of supply and grid stability complementing baseload nuclear generation and intermittent renewables. 🌱

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Update on the 50-MW_e Theunissen Underground Coal Gasification Project

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South Africa is facing an energy crisis. Its net maximum generating capacity of ~42 GW (85% coal-based) is characterized by an aging fleet. About 75% of Eskom's 20 GW of capacity is over 40 years old and set to be decommissioned starting in 2018. The current combined availability of the aging fleet is below 80%, leaving the country with zero operating margin. In addition, South Africa's steady economic growth, together with its mass electrification program in rural areas, has contributed to an increase in power demand. Growth in demand, combined with the shortage of electricity supply and coal quality deterioration, has resulted in a critical energy crisis.

The scale of infrastructure investments required to fill the need is quite significant and too large for Eskom, the principal national electricity provider, to carry alone. This has led South

Africa to open up the market to allow independent power producers (IPPs) to generate electricity and sell it to local electricity providers. A national program initiated by the South African government in 2010 has seen a steady increase in the amount of power allotted to IPPs since 2011, mostly contributing to the planned 3725 MW of renewable generation.¹

"To overcome the current crisis, South Africa needs new forms of reliable baseload electricity. One emerging option is underground coal gasification."

To provide new baseload electricity capacity, three new-build power stations were planned: Medupi, Kusile, and Ingula. Of the three, Ingula has been canceled and the commissioning of Medupi's and Kusile's first 800-MW units has been delayed by more than two years (the originally announced date was December 2014). The cost of new-build power stations has sky-rocketed, and this—coupled with labor unrest, delays, and quality control issues—has caused severe stress on the electricity price that must be charged to pay for these investments. The average annual selling price of Eskom electricity has risen from R12.98 c/kWh (US\$1.12 c/kWh) in 2001 to R79.73 c/kWh (US\$6.83 c/kWh) in 2014 (see Figure 1) and is set to increase further in the coming years.²

To overcome the current crisis, South Africa needs new forms of reliable baseload electricity. One emerging option is underground coal gasification (UCG). Current electricity prices have made power generation from UCG competitive in South Africa.

Africary is now actively pursuing a fully commercial 50-MW_e UCG project based on its Theunissen coal resource and completed a bankable feasibility study (i.e., comprehensive technical and economic study) for the project in June 2014. This project will be submitted in the first quarter of 2015 as part of the Request for Proposals (RFP) in the Department of Energy baseload electricity production scheme as a private

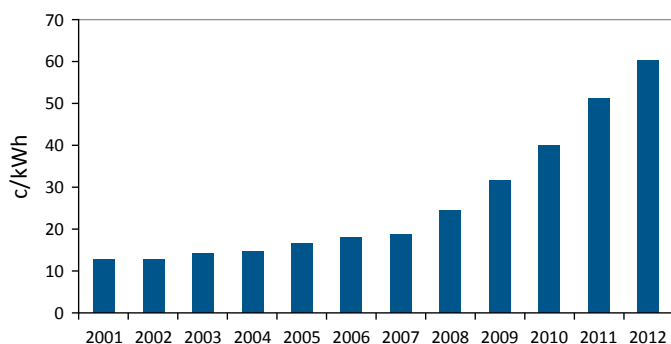


FIGURE 1. Average electricity price (in South-African Rand)

sector IPP. The end goal is that the flagship 50-MW_e project will further develop, maintain, and grow the Palmietkuil mine into a stable, low-cost producer of syngas for electricity generation, eventually expanding to include the production of syngas for polygeneration of chemicals and liquid fuels.

UCG BASICS

UCG is not a new technology. In fact, UCG references can be found in the late 1800s and the earliest U.S. patented posting of UCG as an alternative mining method was filed in 1901.

In all forms of gasification, solid or liquid fuels are converted into synthesis gas (or syngas) consisting mostly of carbon monoxide (CO), hydrogen (H₂), methane (CH₄), and carbon dioxide (CO₂). The concentrations of these components in the final syngas product depend on the type and chemical composition of the fuel (coal for UCG), the reactant(s) (air, oxygen, CO₂, and/or steam) and their ratio, and the operating conditions.

The main difference between UCG and more conventional surface gasification projects is that gasification occurs in a manufactured reactor in the latter, whereas the reactor for a UCG system is the natural geological formation (consisting mainly of sandstone) containing unmined coal. In UCG, coal is gasified in situ and converted into syngas, which is then transported to the surface via a specially designed and manufactured production borehole. The conversion of the coal to syngas is achieved through a partial combustion process controlled by the injection of oxygen (O₂) into the coal seam through the injection well.

UCG Advantages

UCG offers some considerable environmental benefits. The syngas is generated deep underground inside the coal mine, while most ash remains in the seam. About 80% of the energy in the coal reaches the surface in the form of syngas, making UCG an efficient utilization process. At the same time, no person has to be underground for UCG to occur, which offers safety benefits. As a technology process to produce electricity, UCG uses about 10% of the water used by an equivalent-sized boiler system. UCG is not just more environmentally friendly and efficient, but also offers the following advantages:

- UCG power generation produces 25% less CO₂ per MWh and in large-scale combined-cycle mode can reach energy efficiencies of up to 58% compared to current ~35% efficiency (LHV) often obtained using boilers.
- UCG produces no particulate emissions, thus the process requires no ash handling, and little or no leaching of trace elements from ash when operated correctly.

- Less sulfur and fewer heavy metals are released or emitted by the UCG process.
- UCG can monetize economically unmineable coal that otherwise would be lost to the country's economy. Less than 26% of South African coal reserves are economically and technically recoverable with conventional mining.³
- UCG deployment can create new high-value jobs in the drilling, gas processing, and gas engine maintenance industries.
- UCG projects can be located in economically depressed areas of South Africa, often far from current mining areas.
- No chemicals are used in the UCG process as only air and water are required for gasification.
- Fracking is not required and no drilling chemicals are injected to create the boreholes.

UCG Challenges and Progress

UCG as a technology has been studied in depth globally over the last few decades. Major progress has been made to address the technology's main challenges, including improving efficiency and understanding the geology better so as to have a solid foundation to select the optimal coal seams and address environmental concerns. Each UCG project faces a number of challenges, which often require in-depth scientific evaluation or must be carefully managed, including:

- Coal selection and characterizing the geology
- Ignition of the coal
- Hydrogeology
- Groundwater monitoring
- Managing public perception
- Environmental and legislation permit applications

Global UCG Activities

Recent UCG developments (see Figure 2) have been concentrated in China, Australia, and South Africa, which all have or previously had operating power or chemical plants fed by UCG syngas. Other pilot UCG projects were also successfully operated in New Zealand and Canada.

Gasification is not new to South Africa: Sasol has been gasifying Free State and Highveld coal (above ground) since the early 1950s. More recently, Eskom embarked on a small-scale pilot UCG project to enhance production efficiency and lower costs at Majuba in 2007 when it ignited and first produced UCG-derived syngas. Eskom has since increased production and plans to build a 2100-MW_e power station at Majuba set to be operational in 2020.⁴

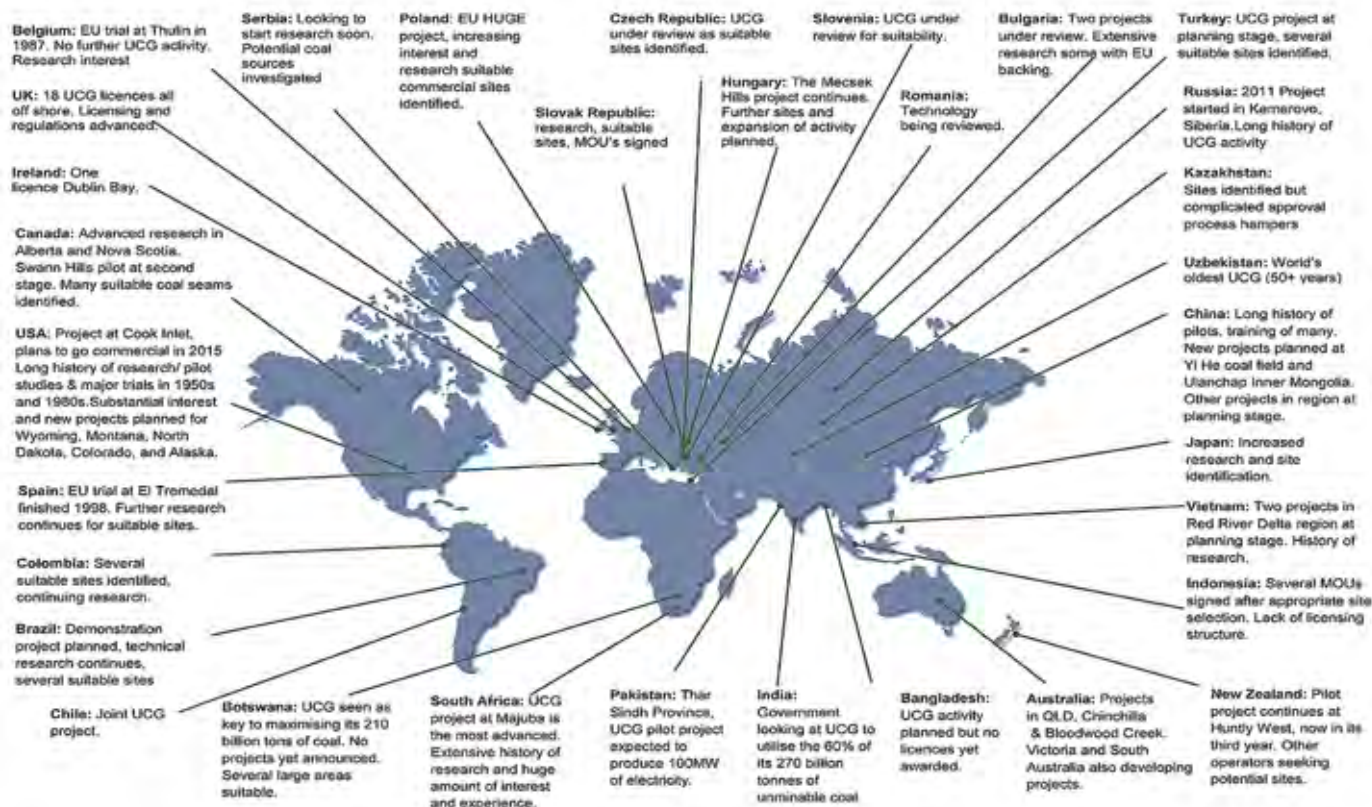


FIGURE 2. International UCG activities

AFRICARY'S APPROACH TO UCG

Premier Project

African Carbon Energy (Pty) Ltd and its subsidiaries, collectively known as "Africary", formed a project development company focused on developing power generation and chemical feedstocks from coal, while realizing the environmental benefits associated with UCG. For the 50-MW_e project in the Free State province of South Africa, near the town of Theunissen (termed the TUCG Project), key project aspects have been finalized, such as the surface rights, geology and exploration requirements, mine works program, engineering designs, semi-definitive cost estimates, environmental impact assessments (EIA), permit applications, and financial modeling.

To develop and implement the TUCG Project (see Figure 3), Africary purchased the Theunissen coal rights (including all the relevant prospecting permits, surface rights, land, geological information and studies) from BHP Billiton SA. The company also acquired coal prospecting rights over an area of more than 300 km². This coal resource is considered ideal for UCG. It is of excellent quality, and it offers superlative geo-mechanical qualities for in situ gasification as the coal seam is between 300 and 500 m in depth. For the initial project,

the syngas generated will be used to produce much-needed power, but the gas could also be used to generate heat or as a feedstock for liquid/organic fuels and chemicals.

The current TUCG Project will involve gasification of about five million tons of coal over 20 years under an area of about 150 hectares, which will be sufficient to provide 50-MW_e baseload electricity to the grid. Once the technology has been proven at this scale, modular UCG expansion will be undertaken to design larger-scale polygeneration facilities at the same site. Any new expansion will undergo the necessary approval process.



FIGURE 3. TUCG location in South Africa

Africary UCG Technology

Africary's UCG design involves an arrangement of directional injection and production wells drilled into the coal seam. A borehole is drilled through the 350-m overburden down to the coal seam, which is then ignited by means of specialized techniques. Oxygen or oxygen-enriched air is injected to feed the process and drive the gasification reactions that produce a syngas mixture, which is collected by the production borehole to be harnessed at the surface.

Coal ignition is initiated near the face of the coal seam. Continuous gas flow through the injection well allows for gasification of the coal to be sustained. The temperature of the gasification process is maintained by varying the oxygen concentration to the underground reactor. In UCG systems, the coal face can reach temperatures in excess of 1100°C.

The basic design of Africary's planned UCG facility is a combination of two injection wells working in tandem to feed a single production well. This layout has several advantages, but the major benefit is to double the amount of gasification zones that can feed into a production well.

Various chemical reactions, temperatures, pressures, and gas compositions exist at different locations within a UCG gasifier. The gasification channel is normally divided into zones similar to those observed in a fixed bed gasifier: combustion, gasification, pyrolysis and drying, with an ash bed throughout the cavity.

However, with a UCG reactor, the reaction zones are not uni-directional, but instead are in a multi-directional zone environment or 3D cavity growth where gasification occurs. An illustration of where the reactions are taking place in a generic UCG cavity is given in Figure 4.

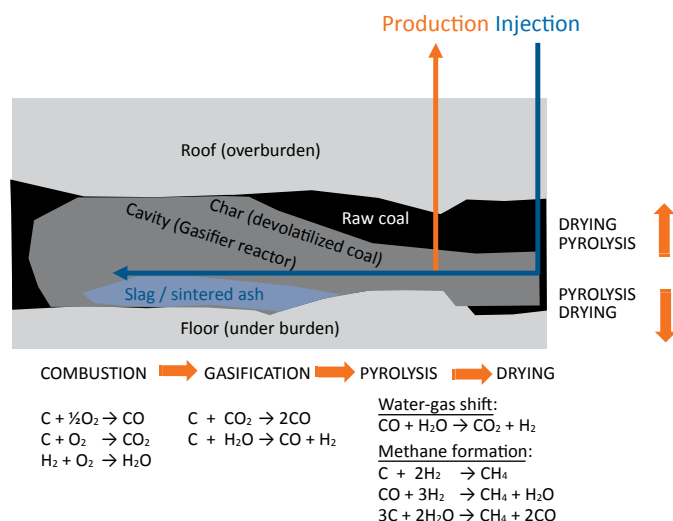


FIGURE 4. Generic UCG process

TABLE 1. Proximate analyses (mass percentage on an air dry basis)

Component, Unit	Average	Range
Moisture, wt%	3.3	3.2–3.7
Ash, wt%	33	23.9–33.3
Fixed Carbon, wt%	44	42–52
Volatile Matter, wt%	19.7	18.6–21.2
Calorific Value, MJ/kg	20.1 (as received)	19.7–23.2

Resource Estimates and Coal Characteristics

The Africary prospecting rights for the prospective mine carry a SAMREC-inferred status of one billion tons of coal (sufficient coal to provide 10,000 MWh annually for 20 years). Africary has completed an exploration program and obtained 3,700,000 tons of SAMREC-measured resource (i.e., proved and measured portion within the one-billion-ton reserve) on the Palmietkuil farm.

A detailed coal exploration study was conducted on the Palmietkuil coal area as extensive knowledge of the coal characteristics is essential to predict coal conversion (combustion or gasification) behavior and complete the overall design.⁵ The average coal properties of the TUCG coal are given in Table 1.

Syngas Production and Utilization at the TUCG Site

The TUCG operational design is based on a conventional high-pressure operating envelope using oxygen-enriched air as feed. This allows for more robust control of the gasification process and has the advantage that the caloric value of the syngas is higher, resulting in lower syngas volumes for the same amount of power production. The designed gasification infrastructure is expected to access the coal effectively, while feeding and controlling the UCG process so as to extract all the syngas to the surface at the highest pressure possible and provide all the monitoring to support this aim.

Detailed thermodynamic modeling based on the coal characteristics shown in Table 1 was completed to simulate the expected and optimum operation for this project. The simulated gas composition is shown in Table 2. The gasification and CO₂ reactivity characteristics of the coal were then tested and verified via independent thermodynamic testing at North-West University. These experiments were carried out on actual samples from the coalfield using oxygen-enriched air gasification conditions.

TABLE 2. Simulated average raw synthesis gas composition for the TUCG site

Component	Mol%
H ₂	8–12
CO	16–24
CO ₂	18–25
CH ₄	8–12
C ₂ H ₄₋₆	<1
N ₂	30–40
H ₂ S, COS	0, 2

Exploiting a deep coal resource by implementing a novel technology like UCG can only be effectively achieved when there is a suitable market for the commodity. The one drawback to producing syngas as a sole product is that it is not generally a saleable commodity. Syngas must be converted into natural gas, electricity, or some other chemical or fuel that can be easily transported and for which a commodity market already exists.

“With two-thirds of the planet’s coal unable to be mined through conventional techniques, UCG’s global potential may increase over time.”

For Africary’s principal Theunissen project, the best fit was to generate 50-MW_e electricity using syngas combustion engines. Due to a high number of parallel units the gas engines provide a significantly higher output on a yearly average basis. Any single engine can be taken out of commission for maintenance while the rest of the facility remains in operation, with minimal impact on the total output of the facility. Should gas loads from the UCG process decrease for any reason, single engines can be taken out of commission progressively to match the syngas production rate. Therefore, it is not necessary to operate the engines at turned-down rates and hence a high electrical efficiency per engine is maintained. When syngas production increases, an engine can be recommissioned in less than five minutes.

The electricity produced by the engines will be connected to the local electricity supply grid via a new 132-kV power line routed to the nearest Eskom transmission substation.

HARNESSING THE ENERGY UNDER OUR FEET

UCG utilizes previously stranded coal reserves in situ. Generally, UCG can be an economically and environmentally viable option for mining deep coal reserves (200 m or deeper). In some locations, such as South Africa, UCG is already economically competitive. With two-thirds of the planet’s coal unable to be mined through conventional techniques, UCG’s global potential may increase over time.

Although UCG may be a break with South Africa’s traditional coal-mining industries of opencast or shaft mining, it could play a complementary role in the country. Recognizing the potential of UCG, Exxaro, Eskom, Sasol, and Africary have founded the South African UCG Association to champion the technology and create industry standards and training schemes. It is our objective that this project and this association will propel the energy-strapped country to the forefront of a global industry based on an unconventional technology. 🧐

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Movers & Shakers

Alpha Natural Resources, Inc. Chief Financial Officer Frank Wood retired effective 28 February 2015, after which Executive Vice President and Chief Strategy Officer Philip J. Cavatoni assumed the additional duties of the CFO for Alpha.

The International Energy Agency announced the appointment of Dr. Fatih Birol as the next Executive Director of the Agency. His term in the position will begin as of September 2015.

Peabody Energy Corp. announced that its current Chief Operating Officer, Glenn Kellow, will succeed CEO Greg Boyce on 4 May. Boyce had held that job since 2006 and will stay on as the company's executive chairman of the board. Kellow joined Peabody in 2013 from mining company BHP Billiton, where he spent 28 years and served as president of its aluminum and nickel businesses.

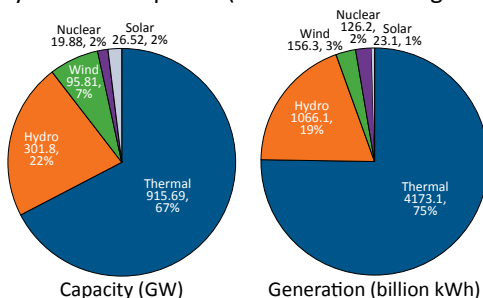
Shenhua Group's first overseas investment project, the Watermark coal mine in Australia, was approved by the Planning and Assessment Committee of the New South Wales government. The Watermark mine is located near Gunnedah, in northwest New South Wales, about 282 km from Newcastle Port. This planned open-pit mine has an estimated 298 million tonnes of coal resources to be mined during the first phase of operation.

International Outlook

China

In 2014, coal production in China fell for the first time in this century, down 2.1% compared to 2013. The Vice President of the China National Coal Association, Jiang Zhimin, said that the Association projects production to decline by 2.5% in 2015.

The China Electricity Council recently released the 2014 statistics on China's power industry. In 2014, total power generation was 5545.9 billion kWh, a 3.6% increase over the previous year. The total capacity and generation from different power sources are shown below. Although natural gas and coal are combined into the category of thermal power, this constitutes primarily coal-fueled power (90% in the case of generation).



Germany

The German Association of Energy and Water Industries (BDEW) recently released preliminary figures for the German electricity generation mix for 2014. For the first time ever, renewables were responsible for the largest share at 25.8% of gross electricity production, followed by lignite (25.6%), hard coal 18%, nuclear (15.9%), and gas (9.6%). Total gross electricity production was down to 610.4 TWh, from 633.2 TWh in 2013, with generation quantities from lignite and hard coal being lower in 2014 than in 2013.

India

The Indian government sold off 10% of its holdings in Coal India Ltd. This sell-off and plans to move forward by opening coal production to private and international players sparked a strike from unionized workers.

U.S.

The U.S. coal mining industry reached a safety milestone in 2014, recording the fewest ever annual number of coal-mining fatalities.

The progress of carbon capture and storage in the U.S. remained mixed as the U.S. Department of Energy's Illinois Basin-Decatur Project crossed the benchmark of having injected one million tonnes of CO₂ into a saline aquifer. In addition, the Obama administration called for \$2 billion in tax credits for carbon capture projects in its budget. However, the U.S. government also announced that it was pulling its \$1 billion in funding from the FutureGen project.

Vietnam

Vietnam announced that its coal output in 2014 increased 1.0% over the previous year, to 41.2 million tonnes. Out of this, 7.2 million tonnes was exported. It has been projected that the country will have an overall output of 40.2 million tonnes of coal this year, of which 37.3 million tonnes are likely to come from the state mining group, Vinacomin.

International

At a February meeting in Geneva, nearly 200 countries approved the draft text to serve as the basis for negotiations on the international climate change deal due to be agreed upon later this year at COP21. The negotiating text is available here: unfccc.int/2860.php

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 (2015)	Location	Website
World CTX 2015: Focus on Falling Oil Price Impact on Coal to X Development	14–17 April	Beijing and Yinchuan (Ningxia Autonomous Region), China	www.worldctx.com
IHS Energy CERAWEEK	20–24 April	Houston, TX, U.S.	ceraweek.com/2015/
World of Coal Ash Conference	4–7 May	Nashville, TN, U.S.	www.worldofcoalash.org/
Seventh International Conference on Clean Coal Technologies	17–21 May	Kraków, Poland	www.cct2015.org/ibis/CCT2015/home
Clearwater Clean Coal Conference	31 May–4 June	Clearwater, FL, U.S.	www.coaltechnologies.com/
Carbon Capture, Utilization & Storage: Defining the Frontiers	31 May–5 June	Easton, MA, U.S.	www.grc.org/programs.aspx?id=16854
China (Taiyuan) International Coal Industry Expo	22–24 Sep	Taiyuan, Shanxi, China	www.cicne.com.cn/
China (Shanxi) International Coal Chemical Industry Exhibition	22–24 Sep	Taiyuan, Shanxi, China	www.cisete.com/

There are several Coaltrans conferences globally each year. To learn more, visit www.coaltrans.com/calendar.aspx

From the WCA

The World Coal Association has welcomed Banpu Public Company as its newest Corporate Member. Banpu is a significant addition to the WCA membership. A Pan-Asian coal-focused energy group with coal mining and power generation assets, Banpu is based in Thailand and operates in six main geographical areas: Indonesia, Australia, China, Mongolia, Thailand, and Laos.

The WCA has announced that Chief Executive Milton Catelin is stepping down from the role after nearly 10 years. The WCA has commenced a recruitment process to select a new Chief Executive. In the interim, Deputy Chief Executive Benjamin Sporton is Acting Chief Executive.

WCA Calls for Greater Investment in Cleaner Coal Technologies

Coal plays a vital role in society by providing over 40% of global electricity and as an indispensable ingredient in mod-

ern infrastructure. International Energy Agency forecasts show that coal use is set to grow by around 17% in the next 20 years. With 1.3 billion people globally without access to electricity, it is clear all sources of energy will be needed to meet this demand, including coal. Greater investment is needed in cleaner coal technologies to meet global energy demand, alleviate energy poverty and minimize CO₂ emissions.

Technologies such as high-efficiency, low-emissions (HELE) coal plants and carbon capture, utilization, and storage (CCUS), can make a significant contribution to reducing global CO₂ emissions as part of the energy mix.

Benjamin Sporton, WCA's Acting Chief Executive, stated: "The WCA recognises the vital role that all low emission technologies can play and has created a global Platform for Accelerating Coal Efficiency (PACE) to promote adoption of these technologies. PACE's vision is for the most efficient power plant technology possible to be deployed when coal plants are built. PACE's objective is to raise the global average efficiency of coal-fired power plants and so minimise

CO₂ emissions, whilst maintaining legitimate economic development and poverty alleviation efforts.”

Increasing the average efficiency of the global coal fleet from the current level of 33% to 40% can be done with off-the-shelf technology that is currently available. This would make a significant contribution to global efforts, saving around two gigatonnes of CO₂ annually—roughly equivalent to India’s total annual emissions. For more information on PACE see the article on page 15 of this issue.

Furthermore, CCUS technology is also a reality, as demonstrated by the Boundary Dam coal-fired power station in Canada. This pioneering project will reduce greenhouse gas emissions by one million tonnes of CO₂ annually, the equivalent to taking more than 250,000 cars off the road each year.



Mr. Sporton, stated: “Calls for divestment ignore the global role played by coal and the potential offered by HELE and CCUS technologies. It is essential that responsible investors actively engage with the coal industry. All low emission technologies are needed to meet climate targets. We cannot meet our energy needs, tackle energy poverty and reduce global emissions without utilising all options available to us, including low emissions coal.”

Recent Select Publications



Fossil Forward: Revitalizing CCS: Bringing Scale and Speed to CCS Deployment — U.S. National Coal Council — The study was prepared in response to a request from the U.S. Secretary of Energy Moniz that the federal advisory committee “conduct a study that assesses the value of the Department of Energy’s Carbon Sequestration Program. The capture of carbon dioxide (CO₂) emissions from the combustion of fossil fuels used in electrical power generation is critical to the future of fossil fuels, particularly coal, used in this country.”

The study concluded that while the U.S. Department of Energy (DOE) is indisputably a world leader in the development of CCS technology, the DOE CCS/CCUS program has not yet achieved critical mass. Although there have been some successes, there is a need for a substantial increase in the number of large-scale demonstration projects for both capture and storage technologies before either approaches commercialization. For example, the current number of demonstration projects that are in operation or under construction globally is just over 20, while it is projected that 3400 will be needed by 2050. In addition, the current global CO₂ storage rate is 40 million tons/year, whereas the projected need is 10 billion tons/year. There are too few demonstration projects to meet future requirements. Thus, the Council recommended greater international collaboration and advancement of CCS by the DOE. The full study is available at www.nationalcoalcoalcouncil.org/studies/2015/Fossil-Forward-Revitalizing-CCS-NCC-Approved-Study.pdf

Commercial Recovery of Metals from Coal Ash – Global Review

— Lucid Insight — This report presents an up-to-date global landscape for the recovery of metals from coal ash by-products from power stations, based on over 300 sources of scientific, patent, and business literature as well as interviews with experts. Select key conclusions from the report include:



- Analysis of 11 coal power station ash samples from the British Geological Survey found metals worth between \$4400 and \$46,500 per tonne of ash at current market prices, with significant values seen particularly for scandium, dysprosium, yttrium, and aluminum, suggesting that there is high value in at least some ashes.
- Processes are being developed to extract metals and simultaneously recover the bulk materials for use in construction, chemicals industry, and other applications, to enable near-complete utilization of the coal ash material.
- There is political interest in the future management of the large volumes of ash, resource recovery, and reduced primary raw material production, as well as ensuring critical raw material supplies.

The full report is available for purchase at www.lucid-insight.com/briefings

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THE ENERGY FRONTIER OF COMBINING COAL AND RENEWABLE ENERGY SYSTEMS

I do agree with the author that coal will continue to be used widely and in considerable quantities, and remains vitally important for many economies. Realizing this I would like to add that more than 70% of the natural coal/lignite resources across the globe are non-extractable and coal/lignite is not necessarily a green fuel; its combustion produces CO₂ and other emissions. However, in situ coal biomethanation (ICB) is centered on the concept of extraction of energy from the non-extractable coal/lignite and utilization of CO₂ for value addition so that industrial-scale energy extraction becomes almost carbon-neutral or, in some cases, even carbon-negative.

ICB or underground coal biogasification (UCBG) is an emerging energy extraction technology. Biomethanation is a natural, ongoing phenomenon in some coal seams, while actively bio-converting coal into methane includes acceleration of the process for commercial exploitation.

My research reveals that ICB is techno-commercially feasible in most coals and capable of commercially extracting more than 66% of the energy contained therein with more than

75% carbon-neutrality at present. With continued efforts, the process would likely be techno-commercially feasible in any and all types of coal for extraction of energy on a sustainable basis with 100% carbon-neutrality or even carbon-negativity.

Therefore, my comment is that while considering “The Energy Frontier of Combining Coal and Renewable Energy Systems”, international agencies like IEA Clean Coal Centre and others should also examine and explore the possibility of conversion of all coals into a renewable source of energy.

Umesh Singh

Former Chief Manager
Coal India Ltd

THE FLEXIBILITY OF GERMAN COAL-FIRED POWER PLANTS AMID INCREASED RENEWABLES

This is a well-written article that provides a clear explanation of the issues facing reliable electricity supply as renewable generation provides more and more of the capacity, yet still must rely on coal as a backup. As shown in the article, the consumer is paying dearly for this renewable energy portfolio.

David Stopek

Director
LTI - Global

**TO SUBMIT A LETTER TO THE EDITOR,
EMAIL CORNERSTONE@WILEY.COM OR CORNERSTONE@SHENHUA.CC (CHINESE).**

We're in the process of planning the editorial schedule for 2015.

We'd appreciate hearing from you regarding what topics you would like us to cover.

We're looking for any and all feedback from our readers.

Cornerstone aims to be inclusive to all things related to coal and energy, especially those pieces that are focused on scientifically derived solutions for the challenges associated with ever increasing energy demand. Our goal is to include diverse material, such as interviews, letters, op-ed editorials, technical articles, global news, conference listings, etc. If you are interested in contributing or have suggestions about what we should cover, please don't hesitate to contact the editorial team.

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Platform for Accelerating Coal Efficiency

The World Coal Association has published a concept paper on establishing a global Platform for Accelerating Coal Efficiency (PACE).

The vision of PACE is that when coal plants are built, the most efficient power plant technology possible is deployed. The overriding objective would be to raise the global average efficiency of coal-fired power plants and so minimise CO₂ emissions which will otherwise be emitted, while maintaining legitimate economic development and poverty alleviation efforts.

Moving the current average global efficiency rate of coal-fired power plants from 33% to 40% by deploying more advanced, off-the-shelf technology could cut 2 gigatonnes of CO₂ emissions now, equivalent to India's annual CO₂ emissions.

The concept paper is available for download on the WCA website

www.worldcoal.org

or email

PACE@worldcoal.org

to request a copy

The WCA has released the concept paper for stakeholder input and engagement. If you would like to provide feedback or discuss PACE in more detail, contact us at

PACE@worldcoal.org



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HELE plant upgrades can be considered a “no regret” option for coal-fired power plant owners and operators.

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