Reducing Energy’s Water Footprint:
Driving a Sustainable Energy Future

Michael Hightower
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Sandia National Laboratories

Thirsty Energy:
Integrated Energy-Water Planning for a Sustainable Future

Assessing Water Issues in China’s Coal Industry

Exploring the Possibilities:
The NETL Power Plant Water Program
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

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The WCA provides a voice for coal in international environment and energy forums. This voice has been strengthened by WCA’s recent growth in China, with the Shenhua Group, China National Coal Group and the China National Coal Association joining the WCA.

The Chairman of the Shenhua Group, Dr Zhang Xiwu, became Chair of the WCA in 2012 and will lead the work of the WCA over the next two years. This includes two exciting initiatives – the launch of the new WCA magazine “Cornerstone – official journal of the world coal industry” and the establishment of the World Coal Association Strategic Research Institute in Beijing.

It is an exciting time for the World Coal Association and for the global coal industry. If you have an interest in the future of the coal industry, contact us to see how you can get involved: membership@worldcoal.org

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Water Crisis Calls for Common Action

Liu Baowen
Executive Editor, Cornerstone

Water is a precious, life-giving resource that is essential to the existence of mankind as well as the natural world. Today, this critical resource is becoming more scarce, a trend which is only expected to continue. By 2030 it is forecast that global freshwater demand will grow 30%, while freshwater supply will decrease by 40%.

Industrialization is critical for lifting people out of poverty and for modern life, but many industrial activities, including many energy sectors, are water intensive. Although the largest water consumer globally is the agricultural sector, the link between water and energy is undeniable. Water shortages have already threatened some energy-sector development, including shale gas drilling, oil production, and new coal-fired power plants. The water crisis is a real and pressing worldwide challenge; thus, it deserves the attention and the common action of international NGOs, national and regional governments, industry, and researchers alike.

For the coal industry, participating in water resource management will be necessary to ensure continued development, and there has been some progress in recent years. Water-saving technologies are being developed and some solutions have already been deployed, albeit not yet on the scale needed to make a sufficiently large impact globally. Further development and deployment of technologies such as water recycling, low- or no-water cooling systems for coal-fired power plants, low-water desulfurization technologies, etc., should be a major focus.

In addition to water conservation, technologies exist that can be deployed to find new sources of freshwater. For example, desalination converts seawater to freshwater, which is particularly interesting in coastal areas with little freshwater; the technology is being employed in some areas in China. An additional benefit of desalination is that integrating desalination and coal-fired power plants can lead to water- and coal-saving efficiency improvements.

According to United Nations Children’s Fund (UNICEF), by 2015 about 2.4 billion people will not have access to improved sanitation and 1.1 billion will not have access to improved drinking water. As a result of lack of access to reliable, safe water, millions of people die. Individual mining sites can make a major difference by working with local stakeholders, and the need is immense.

The water cycle is a fragile system, easily affected by many factors; there are many possible improvements that would reduce the energy sector’s impact. First, integrated energy-water planning is important to ensure that water resources are being used sustainably. Second, research, development, demonstration, and deployment of water saving, recycling, and sharing options should be improved. Looking for unconventional sources of water and engaging local stakeholders can reduce the demand on traditional water resources and provide some protection against changes in precipitation patterns. There are many activities that can, and should, be undertaken today to improve tomorrow’s water resources.

Water scarcity is one example of the many challenges facing the international community today. A specific goal of Cornerstone is to dig deeper into such topics and encourage constructive discussions. Therefore, starting with this first issue of Volume 2, we are adding a Letters to the Editors section. We look forward to your participation.
Reducing Energy’s Water Footprint: Driving a Sustainable Energy Future

Michael Hightower

Water is an integral part of energy extraction, production, and generation; water-related risks threaten to become the principal concern to the global energy sector. Steps such as greater deployment of water-saving technologies, improving risk assessment, and integrated energy-water infrastructure planning could help reduce such risks.
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Water-Saving FGD Technologies
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Water is an essential natural resource that impacts all aspects of life: Clean and abundant supplies of water are vital for supporting the production of food, public health, industrial and energy development, and a healthy environment. Water is an integral part of energy extraction, production, and generation. It is used directly in hydroelectric power generation and is used extensively for thermoelectric power plant cooling and emissions control. Water is also used for energy resource extraction such as gas shale fracking and development, biofuels production, coal and uranium mining and processing, as well as for oil and natural gas refining and energy resource transportation.

Historically, energy infrastructures around the world were commonly developed within a context of unconstrained water resource availability. Increasingly, however, unsustainable uses of water resources, population dynamics and migration patterns, and climate change impacts on precipitation and the environment are all altering the baseline supplies of water across the globe. These factors are affecting new energy generation needs, the timing and spatial patterns of energy demand, and the risk factors for energy security, reliability, and price stability.

Therefore, as nations try to balance the demands and availability of water resources to support growing agricultural, human health, energy, industrial, and ecological demands in the coming decades, it is clear that the water footprint, even more so than the carbon footprint, could become the critical factor in defining a secure, resilient, and sustainable energy future for countries around the world.

“The water footprint, even more so than the carbon footprint, could become the critical factor in defining a secure, resilient, and sustainable energy future...”
A COLLISION COURSE BETWEEN WATER SUPPLIES AND ENERGY DEVELOPMENT

The growing concerns about the conflicts between water resource availability and the ability to support sustainable energy growth were first highlighted in a U.S. Department of Energy Report to Congress prepared in 2007 by Sandia and Los Alamos National Laboratories in cooperation with the National Energy Technology Laboratory and the Electric Power Research Institute (EPRI).\(^1\) That report noted a number of trends in water resource availability and growing water demands that could significantly challenge energy growth, reliability, and sustainability.

Since then, concerns over growing water constraints and their impact on future energy development have been recognized by energy, water, and financial and economic development leaders worldwide. The trends observed include the stress in water resource availability in many regions of the globe and how that is being exacerbated by climate change, the growing water needs to support industrial growth and public health that will increase competition for water resources, and the growing trend in implementing higher water-intensive energy technologies. These three trends suggest a collision course between sustainable water resources management and sustainable economic growth, public health, and secure energy supplies in the coming decades. The following sections highlight both the growing water and energy interdependency concerns and the research, development, and technology innovations needed to reduce energy water needs and drive toward a more sustainable water and energy future.

EMERGING ENERGY AND WATER ISSUES AND CHALLENGES

One of the major challenges facing new energy production and generation globally is the current high level of water stress relative to water supply availability around the world (see Figure 1). The projected growth in global energy development

and the estimated increase in water consumption will occur in regions where freshwater availability is already under high stress due to a combination of demands from major water-using sectors and unsustainable surface water and ground-water withdrawal practices.

Unfortunately, precipitation reduction in many of the mid-latitude regions is expected to reduce fresh surface water supplies by 20–40% by mid-century due to changing climate patterns, suggesting even greater water supply stress in many regions in the near future.

A second concern is the growing water demand of new energy technologies. A recent study by the International Energy Agency, presented in their 2012 World Energy Outlook, projects world energy demand will grow by as much as 30% by 2035, but that water consumption for energy generation and production will increase by 85%. This suggests that much of the new energy generation will require greater water use and water-consumptive energy technologies. Table 1 compares the water consumption of some traditional and emerging energy generation and production technologies for electric power, transportation fuels, and natural gas.¹

As can be seen, many of the new energy approaches being suggested to reduce greenhouse gas emissions, such as carbon capture, nuclear energy, concentrating solar-thermal, and biofuels, are all two to four times more water intensive than the traditional energy approaches they are replacing. Some approaches—including irrigated biofuels, which consumes 2000 times more water than traditional oil-based fuel production—are even more water intensive. Some renewable technologies, such as wind and solar photovoltaics, as well as new thermoelectric cooling technologies like dry cooling, require very little water. However, these approaches currently all have reliability and year-round availability concerns for many regional applications. This illustrates that major energy policies need to consider system-level natural resource impacts in order to better support sustainable water, energy, and natural resource conservation efforts in the future.

### TABLE 1. Comparison of water consumption for several energy approaches

<table>
<thead>
<tr>
<th>Energy Generation or Production Technology</th>
<th>Major Water-Consuming Process</th>
<th>Average Water Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric Power Generation and Cooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal/fuel oil/biomass thermoelectric</td>
<td>Open-loop cooling</td>
<td>1000 L/MWhr</td>
</tr>
<tr>
<td></td>
<td>Closed-loop cooling</td>
<td>1600 L/MWhr</td>
</tr>
<tr>
<td>Coal/fuel oil/biomass thermoelectric w/ carbon capture</td>
<td>Open-loop cooling</td>
<td>1800 L/MWhr</td>
</tr>
<tr>
<td></td>
<td>Closed-loop cooling</td>
<td>2900 L/MWhr</td>
</tr>
<tr>
<td>Concentrating solar-thermal</td>
<td>Closed-loop cooling</td>
<td>2900 L/MWhr</td>
</tr>
<tr>
<td>Nuclear steam turbine</td>
<td>Open-loop cooling</td>
<td>1600 L/MWhr</td>
</tr>
<tr>
<td></td>
<td>Closed-loop cooling</td>
<td>2800 L/MWhr</td>
</tr>
<tr>
<td>Natural gas combined-cycle</td>
<td>Closed-loop cooling</td>
<td>700 L/MWhr</td>
</tr>
<tr>
<td>Natural gas combined-cycle w/carbon capture</td>
<td>Closed-loop cooling</td>
<td>1300 L/MWhr</td>
</tr>
<tr>
<td>Wind and solar photovoltaic</td>
<td>Cleaning of blades or solar panels</td>
<td>10 L/MWhr</td>
</tr>
<tr>
<td><strong>Transportation Fuels Production and Refining</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuels: oils, gasoline, diesel fuel, etc.</td>
<td>Traditional oil production and refining</td>
<td>1.5 L/L of fuel</td>
</tr>
<tr>
<td>Grain biofuels</td>
<td>Rainfed production w/refining</td>
<td>4 L/L of fuel</td>
</tr>
<tr>
<td>Cellulosic biofuels</td>
<td>Rainfed production w/refining</td>
<td>4 L/L of fuel</td>
</tr>
<tr>
<td>Biofuels</td>
<td>Irrigated production w/refining</td>
<td>1000–4000 L/L of fuel</td>
</tr>
<tr>
<td>Coal-to-liquids</td>
<td>Processing w/refining</td>
<td>8 L/L of fuel</td>
</tr>
<tr>
<td><strong>Natural Gas and Coal Production and Processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional natural gas</td>
<td>Traditional production/processing</td>
<td>4 L/MMBTU</td>
</tr>
<tr>
<td>Unconventional natural gas</td>
<td>Fracking and processing</td>
<td>6 L/MMBTU</td>
</tr>
<tr>
<td>Coal mining</td>
<td>Mining and washing</td>
<td>20 L/MMBTU</td>
</tr>
</tbody>
</table>
A third concern is the growing water demand by other major water use sectors to support population and economic growth, and the need for additional domestic water supplies to support improved public health and sanitation, especially in developing regions such as Asia, South America, and Africa. In these areas, projected water demand growth is 10–20% for the agricultural sector and 30–40% for the domestic water supply sector by 2035. Table 2 provides an overview of the relative water use by sectors for developed and developing regions of the world.\(^4,5\)

As highlighted in Table 2 and noted in a report by the World Economic Forum in 2009, developing countries could need to increase water allocated for energy development by a factor of three to four to approach the current levels of energy infrastructure in developed countries.\(^6\) This is expected to put the energy sector into increased competition with other sectors for already-limited water supplies in many countries. This was also highlighted by the World Energy Council in their 2010 Water and Energy report, which identifies several regions of the globe where water supply availability is currently insufficient to meet proposed energy development.\(^7\) The competition for water resources to meet the growing water demands in several sectors could pose a serious challenge to many countries, especially many developing countries, to create sustainable energy and water development strategies over the next several decades.

### EXAMPLES OF WATER IMPACTS ON ENERGY GENERATION

In Sandia’s original efforts to support the U.S. Department of Energy’s report to Congress on energy and water interdependencies, we highlighted many cases across the U.S. from 2004 through 2007 where power plants or biofuel refineries had been denied permits because of the lack of water availability in the region. Since that time, we have seen instances of droughts in Texas and the Southwest, the Southeast, and the Northeast U.S. that have caused a large number of coal and nuclear power plants to reduce or stop operations because of low water flows or high water temperatures in the receiving waters that reduced cooling capacity. Since 2005, France has been forced to curtail electric power production of their nuclear and hydropower plants by as much as 20% in three different years, due to low water flows and high water temperatures during heat waves. In India, in February 2013, a thermal power plant with an installed capacity of 1130 MW shut down due to a severe water shortage in the Marathwada region. Many power plants in South Africa have already converted to dry cooling to address the reductions in water supplies over the past few decades. Recurring and prolonged droughts are threatening hydropower capacity in many countries, such as Sri Lanka, China, and Brazil. These stresses will mount as some emerging economies double their energy demands in the next 40 years.

<table>
<thead>
<tr>
<th>Water Use by Sector</th>
<th>Developed Countries</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>64%</td>
<td>84%</td>
</tr>
<tr>
<td>Energy</td>
<td>16%</td>
<td>9%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>11%</td>
<td>9%</td>
</tr>
<tr>
<td>Domestic Supplies</td>
<td>9%</td>
<td>7%</td>
</tr>
</tbody>
</table>

“The competition for water resources to meet the growing water demands in several sectors could pose a serious challenge to many countries, especially many developing countries…”

### DRIVING TOWARD A SUSTAINABLE ENERGY AND WATER FUTURE

To help develop a dialogue on how to address these growing concerns, many agencies have studied ways to reduce these emerging energy and water impacts. For example, Sandia conducted a series of national workshops in the U.S. to identify research areas and innovative approaches to reduce freshwater use by the energy sector and improve water availability.\(^3\) Since then, many other groups in the U.S.—including the National Science Foundation, the General Accountability Office, the National Research Council, the Electric Power Research Institute, the Department of Energy, and non-profits like the Johnson Foundation—have identified innovative approaches to help address identified issues and concerns. Internationally, organizations such as the United Nations, the World Bank, the World Council on Sustainable Development, and the Canada Institute have undertaken efforts to help develop and implement innovative low-water-use technologies or approaches in energy development. Not surprisingly, most ideas fall into one of the four major categories outlined below.

**Reduce freshwater consumption for electric power and transportation fuels.** Many approaches exist that could help reduce freshwater consumption for electric power generation. However, technologies like dry and hybrid cooling and low-water-use renewable energy technologies have cost or intermittency issues that must be improved. Since virtually all new alternative transportation fuels will increase water...
consumption, major scale-up of these fuels must include approaches that use less water for growing, mining, processing, or refining.

**Develop materials and water treatment technologies that more easily enable use of nontraditional water resources.** With freshwater supplies becoming more limited, wastewater reuse and nontraditional water use, including seawater, brackish groundwater, and produced water, will be needed. New water treatment technologies that can meet emerging water quality requirements at much lower energy input will be important. These improvements could reduce energy use for water treatment and pumping, while accelerating the use of nontraditional water resources in the energy sector, such as for cooling or hydraulic fracking.

**Improve water assessment and energy and water systems analysis and decision tools.** Compounding the uncertainty of available water supplies is a lack of data on water consumption. Improved water use and consumption data collection and better water monitoring are needed. Improved decision support tools and system analysis approaches are also needed to help communities and regions better understand and collaborate to sustainably develop solutions that minimize freshwater demand and consumption. Another need is the development of regional climate change models that can better predict regional- or watershed-level impacts of climate variability on items such as precipitation and evapotranspiration. These capabilities will help support a better understanding of water resource availability and support improved water management.

**Improve opportunities to integrate energy and water infrastructure planning.** Currently, water and energy infrastructures are often managed independently. There are potential economies of scale by integrating or co-locating energy and water infrastructure and conducting integrated planning. Waste heat from power plants or refineries and wastewater from water treatment plants could be better utilized to reduce usage of both energy and freshwater resources.

In the private sector, companies and associations have already started to leverage their talent and resources to address these issues. For example, EPRI and their power utility affiliates have initiated studies of new low-water-use cooling approaches and have helped develop a $16M large-scale testing facility at a power plant in the southeastern U.S. to test innovative, low-water-use cooling technologies. The data collected is being shared with European power companies. Coal producers are exploring alternative sources of water, such as desalination, and using mine water to reduce freshwater use. In the oil and gas area, companies in both Canada and the U.S. have started implementing approaches to use brackish water and reuse water in oil sands and hydraulic fracturing to minimize both the use of freshwater and wastewater disposal. These efforts have increased fuel production while significantly reducing freshwater use. These examples highlight the broad focus needed to develop a more balanced use of natural and financial resources by looking at additional environmental metrics, such as the water footprint, to help drive and develop a sustainable energy future.

**REFERENCES**


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With global population projected to reach 9.6 billion by 2050, and about 70% of this number living in cities, energy demand will double during the same period. This presents challenges on many fronts, but few are more pressing than those involving water. Nearly half the world’s people are expected to be living in areas of water stress by 2030, as climate change and mounting water withdrawals, some of which are made to produce energy, deepen existing water scarcity. Water scarcity, in turn, poses risks to energy generation.

These trends coincide with other realities that need to be addressed: 780 million people without access to improved water, 2.5 billion without basic sanitation, and 1.2 billion without access to electricity.

The energy sector—which uses large quantities of water—is a critical actor in this story. Water availability and the quality of water resources are becoming less reliable, adversely affecting energy production around the world. The World Bank Group, in seeking to end extreme poverty by 2030, is helping countries achieve universal access to modern energy and water services. It sees integrated water and energy planning and management as a vital tool to address these challenges.

Water scarcity can threaten the long-term viability of energy projects. Water shortages have temporarily shut down or reduced energy production at power plants in many countries, including the U.S., Sri Lanka, China, and Brazil. In the U.S., several companies that extract natural gas and oil using hydraulic fracturing have faced higher water costs, or were denied water permits during droughts.

Demand for energy is, by far, the largest source of greenhouse gas emissions that cause climate change. Most of this is CO₂ from consumption of fossil fuels, which account for over 80% of global energy consumed. But the energy sector also faces risks, many of them climate-related, of increased water temperatures, sea level rise, more frequent and widespread droughts and floods, and diminished water quality and quantity, among others. These changes, placed in a context of increased demand for energy, will be felt most acutely in developing countries, where governments are struggling to scale up infrastructure and institutional capacity to meet these challenges.

"Nearly half the world’s people are expected to be living in areas of water stress by 2030..."

Worldwide, the energy sector’s demand for water will grow, as will that of other sectors. For example, a 50% increase in agricultural production is expected to cause a 6% rise in already-strained water withdrawals. Hence, we must ensure that energy development and expansion plans consider the water needs of competing sectors such as agriculture, urban areas, industry, and the environment.

Even where water supplies are abundant, efficient use of water is a good idea. Amid scarcity, it is an even better idea. Energy companies and utilities face the challenge of making their water usage practices and processes reflect the cost of supplying water to sites, as well as wastewater treatment. Efficient water use in their operations is an important goal; strategies to achieve it will vary depending on the processes and technologies involved.

Determining energy-water tradeoffs is a complex matter. Energy development requires varying quantities of water, depending on the type of energy resource involved. Also, defining specific water uses by the energy sector is challenging, as not all water uses are the same. Energy-sector water uses are usually broken down into three categories: water withdrawal,
water consumption, and discharge. Withdrawal is defined as the amount of water taken from a water source, such as a river, ocean, or aquifer. Consumption is the volume of water lost from the total water withdrawn. Discharge is the amount of water returned to the water source, usually in a different state.

While upstream energy resource extraction and development might not withdraw large volumes of water at the national level, it can have a dramatic impact on water supply near drilling or mine sites. Water discharges from power plants and upstream energy development can also impact water quality if not regulated properly. The vast differences in water demand in the energy sector impose an important challenge when analyzing and quantifying potential water constraints.

**THIRSTY ENERGY**

Energy companies recognize the scope of the water and energy challenges they face, and the difficulty in balancing these tradeoffs. In 2013, a global survey by the Carbon Disclosure Project’s Global Water Report found that 82% of responding energy companies and 73% of power utility companies saw water as a substantive risk to business operations. Further, 59% of energy companies and 67% of power utility companies reported having experienced water-related business impacts in the previous five years. These findings underline the importance of combining planning and production processes for energy and water. Energy planners in developing countries need to factor in water constraints and risks of extreme weather, while water planners need to account for energy demand, and the water needs of energy generation plants.

The World Bank Group is working with developing countries to integrate water constraints into the energy sector. To address the competing energy-water challenges in a systematic way, the World Bank Group recently launched a *Thirsty Energy* initiative that seeks to prepare countries for an uncertain future by:

- Identifying synergies and quantifying tradeoffs between energy development plans and water use
- Formulating cross-sectoral planning to ensure sustainability of energy and water investments
- Designing assessment tools and management frameworks to help governments coordinate decision-making

Initial work on this in the energy sector has started in South Africa. Dialogue has been initiated in China, Morocco, and Brazil, where demand for integrated approaches to solve these challenges is increasing as climate change impacts mount. The initiative has also established a Private Sector Reference Group (PSRG) to share experience, to provide technical and policy advice, and to scale up outreach efforts. Abengoa, Alstom, Veolia, and EDF have already joined the reference group.

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Source: IEA, 2012 and WWAP, 2012

World Bank ©2014
INTEGRATED PLANNING

With these partners, Thirsty Energy seeks to tackle the water-energy challenge by promoting integrated water and energy planning to assess constraints and synergies between the two resources and avoid inefficiencies. This includes improving operations and regulations to encourage water recycling and reduce water use and impacts in water quality. It also includes technology development and adoption, such as cooling systems that require no water, or use of alternative water sources.

Technical solutions can help address these challenges. But they must be complemented by institutional reform and policy guidance, sound planning, and smart investments. Sectoral planning and resource management are often distinct activities, with each narrowly focused. Successful planning requires government agencies and stakeholders to participate in coordinated decision-making that engages stakeholders and diverse partners.

Integrated resource planning of energy and water issues depends on an open and participatory decision-making process, and coordination of the many institutions that govern water resources. It promotes new institutional roles and processes, while strengthening existing planning and analytical tools. It also encourages consensus building and alternative dispute resolution over conflict and litigation.

Water constraints on the energy sector can be overcome, but all stakeholders, public and private, must work together to develop innovative tools. Water has to be one of the important factors for assessing the viability of projects. A failure to anticipate water constraints in energy project investments can increase their risks and costs. It can also affect competing sectors, with severe social and environmental consequences. Integrated planning that enables innovative policy and technological approaches is an essential tool to address and overcome these challenges.

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Review of BP Energy Outlook 2014

The BP Energy Outlook 2035 (www.bp.com) revealed several trends related to the global energy sector. Between 2012 and 2035 primary energy consumption is expected to rise by 41%. The vast majority of this growth will be fueled by non-OECD countries; China and India alone will be responsible for half. Primary energy consumption is expected to grow through 2035, but the rate of growth is expected to decrease. The primary energy growth rate is expected to be about 2.2% per year until 2015, after which the average growth rate is expected to slow to 1.7% per year from 2015–2025. From 2025–2035 the average growth rate is expected to further decrease to 1.1%. All energy sources are expected to be relied on for this growth: Oil, gas, and coal will each consist of about 27% of the energy mix by 2035, with nuclear, hydro, and renewables making up the remainder.

*Renewable estimates includes biofuels
Nobuo Tanaka is one of the world’s foremost energy experts. Mr. Tanaka obtained a degree in economics and an MBA from the University of Tokyo and Case Western Reserve University, respectively. In 1973 he began his career in the Ministry of Economy, Trade, and Industry (METI) of Japan and joined the Organization for Economic Co-operation and Development (OECD) in 1989 as the Deputy Director for Science, Technology, and Industry. He was Executive Director of the International Energy Agency (IEA) from September 2007 to September 2011. Currently, Mr. Tanaka is a Global Associate for Energy Security and Sustainability at the Institute for Energy Economics Japan (IEEJ) and a professor at the University of Tokyo.

Japan faces challenges in maintaining its energy security due to a high percentage of imports. However, these challenges have put Japan in a unique position. Concerns about energy security have led to a diverse energy mix and a robust energy research sector, including a world-class program focused on high-efficiency clean coal technologies. Such technologies serve not only the purposes of Japan, but also the world, and could play an important role in addressing environmental and energy poverty concerns on the global stage. Cornerstone sat down for an exclusive interview with Mr. Tanaka to discuss Japan’s energy challenges, their role in encouraging clean coal technology, and his thoughts on global energy challenges.

Q: You have had many high-level positions and accomplishments to date in the global energy sector. What are your goals for yourself and for the organization in your current role with the Institute for Energy Economics Japan?

A: My current role in Japan is providing global context to the domestic energy policy discussion. As a former Executive Director of the IEA, I am emphasizing energy security through a well-diversified energy mix, including nuclear power, in the public debate. The IEEJ must play an important role of supplying evidence-based analysis for Japan’s energy policy discussion.

Q: Japan’s energy sector faces many challenges, such as extreme resource limitations (<5% self-sufficiency), a growing economy under “Abenomics” activities, and a public wary of nuclear energy since the Fukushima disaster. What is the best course of action for Japan to ensure a sustainable, secure energy sector under these challenges? What is coal’s role?
A: Energy security exists only in the diversity of supply. Fossil fuels, renewables, nuclear power, and energy conservation are all important. Abenomics needs the fourth arrow; that is, restarting of nuclear power to reduce fuel costs. Japan needs to reduce dependency on Middle Eastern oil by increasing natural gas imports from North America, Australia, East Africa, and Russia. In addition to the LNG, a gas pipeline with Russia will be an important component of diversification. Coal will also play an important role in diversification with its cheaper prices and abundance. Japan’s clean coal technology helps to achieve sustainability.

Q: Japan has a strong clean coal R&D program and can be considered a world leader on improving power plant efficiency. Can you elaborate on the most important recent advances from this program? Do you foresee any changes in the future focus of clean coal research in Japan?

A: Yes, as you know, the technology applied at Japanese coal-fired power plants is the most advanced in the world. In the hopes of utilizing coal imports more efficiently, Japan has tackled the development of high-efficiency coal-fired power generation technology. Japan’s electricity companies introduced USC (ultra-supercritical) technology in the 1990s. The energy efficiency of the coal-fired Hirono power plant and the Hitachinaka power plant of the Tokyo Electricity Company (which commenced commercial operation in December 2013) is 45.2% (gross thermal efficiency, LHV).

With regard to de-SO₂ and de-NOₓ technologies, Japan is a world leader as well.

Japan’s coal-focused energy strategy is to ensure a stable coal supply and clean coal technology (CCT) development as well as expansion of CCT in the world, focusing primarily on Asia. For this reason, Japan has been working to introduce and spread the use of supercritical and ultra-supercritical coal-fired power plants.

Regarding specific high-efficiency technologies, Japan has been developing integrated gasification combined cycle (IGCC) (including both air blown and oxygen blown), advanced ultra-supercritical (A-USC), oxygen combustion, etc. IGCC (250 MW, air blown) has already been demonstrated and has been ready to move to commercial operation since April of 2013. Regarding A-USC development, material suitable to higher temperature (i.e., >700°C) has also been under development.

Q: What do you think will be the net impact of unconventional hydrocarbon production on the sustainability and security of Japan’s energy mix? What will be the impact to the rest of Asia?

A: Unconventional gas and oil will help ease the demand-supply balance by adding significant supply. Reserves are globally distributed and increase the diversity of supply, and thus energy security, for importers like Japan and Asia. To ensure sustainability we need to complete further analysis of the life-cycle impacts of the shale revolution in terms of water recycling, contamination, and/or gas flaring.

Q: The Chinese government has proposed changes to its national energy industry in the 12th Five-Year Plan: Total
energy consumption should be limited and the energy mix should be optimized. In addition, environmental protection was highlighted with increased prominence. As you know, coal accounts for about 70% of China’s primary energy consumption; what are your suggestions for the Chinese coal industry so it can comply with energy reform and the new energy policies of the Chinese government?

A: China will continue using coal because it is abundant and cheap. But the air pollution issue is becoming serious and the Chinese government needs to fuel switch to gas by developing shale gas and coal bed methane. Nuclear and renewables are other options, but the cost of power grid development is increasing. Cleaner coal technologies such as ultra-supercritical power or IGCC technologies with the possible use of CCS will be encouraged together with closing down old subcritical power plants.

Q: Changes to the coal industry are not only being discussed in China, but also on the global stage. In November 2013 at the International Coal and Climate Summit in Warsaw, Poland, Christiana Figueres, Executive Secretary of the United Nations Framework Convention on Climate Change, called for changes in the coal industry, including the closure of all subcritical coal-fired power plants. What would be the implications of such a step to global energy security and improving energy access to the 1.3 billion people who do not have it?

A: The IEA publicized the report called “Redrawing the Energy Climate Map” in June 2013. Four measures are prescribed to reduce CO₂ emissions by 3.1 Gt by 2020, achieving 80% of the required reductions toward containing the global temperature increase to 2°C. One of the four measures is the closure of subcritical coal-fired power plants. Coal is abundant and cheap, therefore it has a key role for energy security and economic growth if cleaner coal technologies are applied together. Efficient thermal technologies and CCS will be important for coal to be deployed to its full potential.

Q: Were the costs associated with closing all subcritical plants calculated by the IEA? How could these closures be best reconciled with energy security concerns as well as efforts to reduce energy poverty?

A: The IEA report was not based on the closure of all subcritical coal power plants, rather a ban on the construction of new plants and some constraints on the operation of existing plants so long as it does not impact on the reliability of power supply (and therefore energy poverty). The IEA proposes: (i) a ban on the construction of new subcritical coal power plants and (ii) a reduction in operating hours for existing inefficient coal power plants. However, operating hours of inefficient plants were only reduced when they can either be compensated by increased output from more efficient plants or complemented by a reduction of power demand due to the implementation of energy efficiency measures. Therefore, in their analysis the reduction of operating hours of inefficient coal plants differs regionally, taking into account each individual power system’s ability to adopt such a policy package without jeopardizing reliability of supply.

Q: Does “closing” all subcritical plants allow for room to retrofit those plants so they are high-efficiency, low-emissions plants (including CCS)?

A: If the plants could be retrofitted to improve their environmental performance, there would be no need for them to be closed in the IEA analysis. Although it is worth noting that it typically would not be practical to add a CCS unit to a subcritical power plant as you would end up with extremely low efficiency.
Advancing China’s Coal Industry

By Wang Xianzheng
President, China National Coal Association

China is responsible for more coal production than any other country. Since the beginning of the 11th Five-Year Plan in 2006, many efforts have been made to reform the Chinese coal industry. Transforming a large industry during a time of rapid growth is not an easy task. However, using science and technology to fuel much of this transformation has led to carefully implemented changes throughout the industry. Looking forward, we will have many more opportunities and challenges related to the industry’s continued development and reform. To address future challenges, the China National Coal Association (CNCA) recommends that China’s coal industry place greater importance on technological progress, implement innovation-driven development strategies, strengthen structural changes, promote quality and efficiency, and strive for a general advancement.

PROGRESS SINCE THE 11TH FIVE-YEAR PLAN

Industry-Wide Restructuring

Since the start of the 11th Five-Year Plan, the coal industry has undergone an industry-wide restructuring, rapidly changing to focus on large, modern mines. The total number of coal mines in China has decreased from 24,800 in 2005 to about 14,000 in 2012. The average annual production for an individual mine has increased from 90,000 to 260,000 tonnes per year. In 2012, large-scale modern coal production accounted for about 65% of China’s total output and the contribution of small-scale production had been reduced to 17%. Today about 600 million tonnes of coal per year are produced from 47 large-scale mines, each of which is producing more than 10 million tonnes per year.

“Since the beginning of the 11th Five-Year Plan in 2006, many efforts have been made to reform the Chinese coal industry.”

China’s coal production has also become more concentrated geographically. The total annual production from the 14 large-scale coal bases is 3.3 billion tonnes of coal, accounting for 90.4% of total coal output.

There has also been a shift in focus to fewer and larger coal producers. Today, there are 52 companies producing from China Coal Group’s Pingshuo mine is an example of a large, high-efficiency, modern mine; there has been a push by China’s coal industry to construct many such facilities.
more than 10 million up to 461 million tonnes of coal per year; their combined annual output is 2.76 billion tonnes. Seven companies produce over 100 million tonnes of coal per year; their combined output is 1.227 billion tonnes. The top four coal-producing enterprises account for 22.2% of the total annual coal production.

The focus on increasing mine size came at a time when coal production was expanding: 2.35 billion tonnes were produced in 2005 compared to 3.65 billion tonnes in 2012. Increased integration has been necessary to utilize coal more effectively. For example, today there is increased integration between coal producers and power generators. Currently, the combined installed capacity of coal enterprises is more than 130 GW. In addition, coal producers are becoming more involved in downstream industries such as coal-coking and coal-to-chemicals. Many of today’s coal companies not only mine coal, but also engage in trading, logistics, finance, and other diversified businesses.

**Innovation Based on Science and Technology**

The move toward larger, more modern mines in China would not be possible without the adoption of greater mechanization, technology, and innovation throughout the industry. Closer collaboration with research institutions has also been important. From research to commercial deployment, the integration of technology is critical for China’s coal industry. Specific areas where research, development, and demonstrations have resulted in significant improvements include improved safety and increased efficiency. For example, improved technology for mine gas extraction has been deployed as a result of breakthroughs in the construction of kilometer-deep shafts. There has also been an increase in development and utilization of domestically developed large-scale (i.e., output of more than 10 million tonnes) mining technologies, which has led to an increase in the vertical integration of the industry.

When considering coal-related innovation, one would be hard-pressed to find a better example than the expansion of the coal-to-chemicals industry in China. In a relatively short time frame the technology has been commercialized, and today China is the world leader in this field. Examples of technologies developed in China include direct coal liquefaction at the megatonne scale, 600,000 tonnes of coal-to-olefin conversion, and the construction of coal-to-gas demonstration projects.

**Environmental Stewardship Adopted**

China’s coal industry continues to explore ways to make mining more environmentally friendly. Approaches include water conservation, resource utilization, increased oversight of mining activities, and more land reclamation and environmental rebuilding efforts. For example, to avoid wasting coal gangue (the material left behind during mining that is often considered to be of little value), it is used to fuel power plants with a combined capacity of 29.5 GW, utilizing gangue equivalent to 46 million tonnes of standard coal equivalent. In addition, reclamation of mining areas is increasing; today, about 62% of mines are reclaimed after closure.

**Market Reforms**

Today’s coal industry is primarily led by market forces. Gone are the days of fully government-directed ordering systems and fixed prices. The formation of a national coal market trading system has been of critical importance. Currently 31 regional coal-trading centers have been established. Coking coal and thermal coal futures contracts are traded in the Dalian Commodity Exchange and Zhengzhou Commodity Exchange. The decades-old coal production and licensing system has been abolished, key coal contracts have been canceled, and coal pricing is often based on actual market value. Although the industry is generally moving toward being market-based, the transition is not yet complete.

**Improvement in Long-Term Production Safety**

Improving safety is a key concern for China’s government as well as the coal industry. To ensure that adequate attention is given to improving safety, nation-wide directives now specify what fraction of production costs must be spent on safety-related measures. The General Office of the State Council issued “Opinions on Further Strengthening Coal Mine Production Safety”, which proposed coal mine safety initiatives designed to tackle the root issues that have led to less-than-satisfactory safety practices in the past. The coal industry has been able to improve safety through a focus on increased technology deployment, risk management, and improved equipment maintenance. These actions have resulted in a decrease in national coal mining deaths from 3306 in 2005 to 1384 in 2012. The fatality rate per million tonnes of coal fell from 2.81 in 2005 to 0.293 in 2013—a substantial improvement in seven years.

**Accelerated Globalization**

As a result of the rapid growth in coal demand, China has become a net coal importer. China’s coal industry has taken advantage of favorable international coal markets and has increased its openness to globalization. For example, several Chinese coal companies—Yankuang Group, Shandong Energy Group, Kailuan Group, the China National Administration of Coal Geology, XuZhou Coal Mining Group, Jiangxi Coal Group, Beijing Haohua Energy Resource, among others—have invested internationally to develop coal resources abroad.
Not only coal producers are finding opportunities abroad; this is also true for several of China’s large-scale mining equipment manufacturers.

**Socially Responsible Mining**

The coal industry is a major contributor to China’s economy, and we believe it is the responsibility of the industry to play a leading role in improving the quality of life in China, not only through providing energy, but also by providing assistance to the local community. Since the start of the 11th Five-Year Plan, coal mining enterprises have increased their investment in shanty town improvement projects, enhanced construction in the mining site’s community, engaged stakeholders, improved environmental stewardship, and increased the pay of miners. Miners may have benefited the most from such reforms.

**“Enhanced efforts are needed to maintain the industry’s momentum achieved to date.”**

**MID- AND LONG-TERM DEVELOPMENT STRATEGY**

There have been significant improvements in China’s coal industry. However, it is important to acknowledge there is more work to be done. For example, productivity must be improved, environmental standards and regulations will continue to be strengthened, and the coal industry must be ready. Resources must be utilized more effectively; the coal industry must address the fact that the excess capacity under construction today will result in overall coal reserves that have been mined to the point that they will be insufficient to keep up with increases in demand in the long term. The coal industry still faces daunting, but not insurmountable, challenges.

Heading into the 13th Five-Year Plan and beyond, China’s coal industry should implement further reforms in several key areas. The focus on development recommended by the CNCA has been described as “one enhancement, five advancements, and six shifts” to strengthen research, innovation, and conduct reforms within the industry.

**One Enhancement**

Enhanced efforts are needed to maintain the industry’s momentum achieved to date, and to invigorate energy and creativity while removing institutional obstacles. We should strengthen and improve the modern coal market system, giving full play to the market’s decisive role in the allocation of resources. The coal industry should strongly support implementation of innovation-driven development strategies. Innovation can lead to breakthroughs in key technologies where the industry-wide improvements are currently limited. The CNCA recommends that the industry should promote science and technology research and development that could lead to new competitive advantages.

**Five Advancements: Progressing Innovation**

First, encourage reforms related to coal production and utilization. Coal production and utilization reforms can help alleviate the pressure on coal resource development and environmental concerns. The coal industry should actively promote reforms in coal production and coal use, advocate safe and efficient mining, and clean and efficient use of coal, so as to maximize the yield of resources with minimal environmental impact, while providing energy security for China.

Second, continue to restructure and modernize the coal industry. To date, this has been an arduous task for an industry traditionally focused completely on resource development. China’s coal industry should continue to focus on building large-scale coal production bases (because large modern mines are safer and more efficient), increase the rate at which inefficient production capacity is eliminated, promote projects integrating coal production and electricity generation, boost processing and conversion of coal, and generally optimize the industry’s structure. The industry should carry out its own development plans based on China’s national development goals to “control the output in the eastern region, stabilize the output in the central region, and develop the output in the western region”. The coal industry should also stand by its market-oriented focus, promote corporate mergers and reorganizations, and better coordinate the development of upstream and downstream coal industries.
Third, promote construction of environmentally friendly and socially responsible mines. The delicate balance between the need to develop coal resources and the need to protect the environment must be handled with care. In addition, we believe the coal industry should ensure that resource development contributes to regional and local economies, which requires a focus on overall planning and coordination with the local government. Finally, we support the construction of environmentally friendly and socially responsible mining by taking into consideration regional economies, social stability, and sustainable development during resource exploration.

Fourth, promote innovation and development of coal-related technologies. Science and technology constitute the foundation of improving productivity. China’s coal industry should employ technologies that can affect everything from economic restructuring to integration to achieving sustainability. The industry should promote a new collaborative innovation system that combines production and research, market-oriented and corporate based operation, so as to enhance the innovation of coal technologies.

Fifth, tap into the unique culture of the coal industry. CNCA recommends that China’s coal industry recognize the unique value of its mining workforce, which is generally characterized by high morale and loyalty. These traits are the foundation of the culture of the industry and we believe they should be more fully encouraged.

Six Shifts: Changing the Industry’s Economic Development Model

First, shift from a partial market orientation to being fully market oriented. Also, there should be a continued emphasis on the activities yet to be undertaken to complete the transformation from being government supported to being market oriented. China’s coal industry should actively promote market-oriented reforms, including boosting resource allocation according to market rules, market prices, and market competition, so as to maximize returns and achieve maximum efficiency.

Second, shift from a labor-intensive to an integrated talent- and technology-intensive model. The industry should take full advantage of advanced technology and equipment to enhance modernization, collect data for management purposes, accelerate the construction of smart mines, and increase the education and talent level of its mine workers.

Third, shift from viewing coal as a fuel to considering it a raw material to produce a wide array of products. Based on the initial results of coal conversion demonstration projects in China, such as coal-to-liquids, coal-to-olefins, and coal-to-gas, China’s coal industry should accelerate the construction of large-scale, clean, and efficient coal-conversion projects, which could effectively replace some oil and gas.

Fourth, shift from production and sale of raw coal to sale of upgraded, cleaner coal. The industry should gradually move toward reduced shipping and burning of raw (i.e., untreated) coal. Instead, the industry should make progress toward providing primarily high-quality coal. The price of coal should be based on the calorific value of coal when it is sold. Therefore, China’s coal industry should increase the proportion of coal that is washed or blended. Adding more coal upgrading will extend the coal product value chain, add product value, and raise overall industrial efficiency.

Fifth, shift from focusing on production volume and speed to focusing on quality and efficiency. From its historical developmental model, which has traditionally been based on increasing output and scale expansion, the coal industry should move toward reliance on scientific and technological progress, structural adjustment, modern management, and quality to increase returns. This will also lead to a workforce that is less labor-intensive and more talent- and technology-intensive.

Sixth, shift from focusing on reducing mining accidents to holistic health. We believe China’s coal industry should work toward providing good health services for its miners. Along with a steady improvement in China’s coal mine safety, the industry should increase investment related to improving working and living conditions for coal miners, strengthen occupational disease prevention, improve occupational health protection levels, and make an earnest effort to protect miners’ mental and physical health.

CONCLUSION

Coal is China’s main energy source and an important industrial feedstock; the coal industry is the backbone of the energy industry. In retrospect, the coal industry has made remarkable advancements, but there are still difficult tasks ahead. China’s coal industry needs to accurately envisage its overall development, seize development opportunities, and actively address challenges. The development of the industry should be based on science and technology, implementing improvements based on innovation. There must be a push to make structural adjustments, strengthen efforts to boost coal production and utilization reforms, improve China’s coal upgrading industry, and strive to build a new coal industry system that is strong in resource utilization, is safe and secure, and has good economic returns, low environmental pollution, and a sustainable and healthy development.
What to Watch in 2014: Policy Developments That Will Shape the Coal Industry

By Aleksandra Tomczak
Policy Manager, World Coal Association

With around 40 national elections, representing 42% of the world’s population and more than half of its GDP, 2014 could be one of the most significant policy years on record. New governments, policies, and regulations expected over the year will influence the policy environment for the energy and mining sectors. Bearing the highest potential for change are this year’s general elections in India, which many experts believe could finally unlock the country’s economic potential and further increase coal-based energy demand.

2014 will also be an important year for clean coal technologies, with Boundary Dam, the world’s first pulverized coal-fired power plant operating with commercial-scale CCS technology, scheduled to start operating officially in the early spring.

Largely based on interviews with industry experts, this article looks at the most important developments of 2014 for the coal industry, including the carbon tax repeal in Australia; coal demand prospects in China, India, and Southeast Asia; new emissions performance standards for coal plants in the U.S.; the negotiations for a 2030 energy and climate policy framework in the EU and South Africa; and potential production restrictions in several coal-producing countries.

“2014 could be one of the most significant policy years on record.”

CARBON TAX REPEAL IN AUSTRALIA

Policy expectations for 2014 in Australia center on the promises made by the Liberal National Coalition during last year’s general elections. The new government’s plan, and one of the main points of last year’s election manifesto, is to repeal several flagship Labor policies, including the carbon tax and the mineral resource rent tax. The repeal is expected to take place as soon as the new Senate takes office in July 2014. Although the results of the Senate vote on carbon tax cannot be guaranteed, the Chief Executive of the Minerals Council of Australia (MCA), Brendan Pearson, believes it is most likely that the Tony Abbott government will succeed in gathering the necessary support from the independents.

A clear priority for the new government has been to replace the carbon tax by an Emissions Reduction Fund, which will be based on tenders for projects designed to reduce carbon emissions. “This new approach to reducing GHG emissions is a step in the right direction, introducing an incentive based approach, as opposed to a punitive approach introduced by the carbon tax legislation,” says Pearson.

The Abbott government is also currently reviewing Australia’s energy policy. The Department of Industry is expected to...
publish an Energy White Paper in September. As part of the energy review, the Australian government is likely to propose a mechanism for streamlining environmental approvals at the federal and state level. The MCA is hopeful that this proposal will address the problem of delays in obtaining environmental approvals—a problem which increases the costs for coal in Australia.

Also under review is the renewable energy target that binds Australia to a 20% share for renewables by 2020. The Australian government is considering postponing the target to 2025, with a decision on this issue most likely to occur in the first half of 2014.

**IN CHINA COAL CONTINUES AS THE KEY SOURCE OF ENERGY**

New regulations and policy initiatives in China in 2014 can be expected to reflect the priorities set in China’s 12th Five-Year Plan, including “higher quality growth”, which includes a stronger focus on environmental protection, climate, and energy efficiency. However, despite stricter environmental standards, China’s coal demand is expected to increase by almost 20% over the next five years.\(^2\)

By the end of 2014, China is expected to finalize all of the seven pilot emission trading schemes it announced in 2011. Once finalized, China’s emissions trading schemes will cover about 7% of the country’s total greenhouse gas emissions, in Shenzhen, Beijing, Shanghai, Tianjin, and Chongqing, as well as in the Guangdong and Hubei provinces. At the moment, allowances are allocated for free and cover 10 different industries, including coal-consuming plants. Under the trading program, companies that produce more than their allocated share of free emission allowances have to buy additional allowances from the market. As of January 2014, carbon prices in China ranged from 51 RMB (US$8.3) in Beijing, to 26 RMB (US$4.2) in Tianjin, to 31 RMB (US$5.0) in Shanghai.

2014 will also see new clean air targets. Early this year Zhou Shengxian, Minister of Environmental Protection, announced that the 2014 reduction target for nitrogen oxides will be set at 5%, a level much more aggressive than in previous years, according to media reports. Minister Zhou Shengxian also announced a separate national emission reduction target of 2% for the other major pollutants, such as sulfur dioxide.\(^3\)

Despite new regulatory initiatives, China’s annual thermal coal consumption is projected to grow from 2277 Mtce in 2012 to 2669 Mtce in 2018, a 17% increase. The IEA also points to potential coal demand growth coming from coal conversion projects—a “sleeping giant” of Chinese coal demand. In fact, with about 325 Mtce of planned coal-to-gas, coal-to-liquids, and coal-to-chemicals projects, coal conversion could be a source of huge coal demand growth in the future.

**THE YEAR THAT COULD UNLOCK INDIA’S ECONOMIC POTENTIAL**

The policy agenda in India will be dominated by general elections that take place before the end of May. According to regional experts, regardless of the outcome of the elections, public opinion will place tremendous pressure on the new government to deliver economic growth and create jobs. If the Indian National Congress Party, currently in power, is ousted by the Bharatiya Janata Party (BJP), we are most likely to see a more pro-business environment in India. The BJP’s presidential candidate, Narendra Modi, earned himself a name for engineering the economic miracle of the State of Gujarat where he served as the Chief Minister.

IEA analysis shows that higher economic growth in India will go in tandem with higher energy demand and higher coal imports. India is also set to pass China as the world’s largest importer of coal soon after 2020. With power generation
based on coal and a population of over one billion people, including over 300 million with no access to electricity, higher economic growth in India would have a huge impact on the international coal industry.

Experts say that India needs a comprehensive plan to unlock its economic potential because the current infrastructure is simply insufficient to address India’s developmental needs. This will mean better railway and port capacity and necessary reforms to the energy sector. For the coal mining industry in India, change would have to bring private-sector investment and make environmental planning more effective to speed up investments, while also respecting the rights of local communities.

ENERGY AFFORDABILITY AND SECURITY TOP PRIORITIES IN SOUTHEAST ASIA AND JAPAN

Affordability and security of energy supply top the energy policy priorities for Southeast Asian governments, according to a special report on the region published by the IEA last year. This means that policy and investment decisions to be taken in Southeast Asia over the coming years will result in a spectacular growth in coal-fired power plant generation capacity—from 25 GW today to 160 GW in 2035. These capacity additions will increase regional demand for coal by 300%, according to the IEA report. Most of the new coal-fired power plants are expected to be built in Indonesia, Vietnam, Thailand, Malaysia, and the Philippines; in these countries thermal coal demand will grow by 113 Mtce until 2018, with 7.3% average growth per year.

Energy security is also a key concern for Japan. This year Japan will review its basic plan for energy which will define the role of various energy fuels and technologies in the country’s long-term energy mix. As of January 2014, all 48 nuclear reactors in Japan were still shut down, among which 16 were being examined for potential reopening. “The current generation capacity available is insufficient to meet the expected maximum demand of electricity during peak season,” says Shintaro Yokowawa, Deputy General Manager at the Federation of Electric Power Companies of Japan. He has argued that coal and clean coal technologies will have to play an important role in the new document, delivering an affordable and secure energy mix in Japan.

INDONESIA CONSIDERING HIGHER ROYALTIES AND PRODUCTION RESTRICTIONS

The policy and regulatory environment for coal mining operations and coal use in Indonesia will be strongly influenced by this year’s parliamentary elections in April and the presidential elections which will follow in July, with a possible runoff in September. A new president will be appointed in October, the current president having reached his term limit, and a new cabinet will be formed in the latter part of the year. It is expected this will include a new Minister of Mines and Energy.

“Affordability and security of energy supply top the energy policy priorities for Southeast Asian governments…”

According to regional experts, the electoral campaigns will be influenced by brewing nationalism and pressures from civil society to make better use of Indonesia’s natural resources for the benefit of Indonesians. These aspects are likely to affect the environment in which coal companies operate.

Restrictions on coal production and coal exports, and increased royalty rates, have already been discussed at the national government level and could emerge as key points in the electoral campaign. In fact, regardless of the outcome of the elections, coal miners in Indonesia already expect some sort of restrictions to be introduced in 2014—most probably production based. On the table is also an increase in the royalties paid to provincial and federal governments by companies that produce from coal mining leases, known as IUPs. Current royalties for IUP producers range from 5% to 10%, depending on coal quality, and rates possibly could increase to as much as 10–13.5%.

Domestic electrification efforts and the desire to extend the lifetime of Indonesia’s coal resources are among the key motives behind the idea to restrict coal production or exports. As more coal-fired power plants are being built to address energy poverty, still affecting 66 million people living in Indonesia, the proportion of coal destined for the export market could drop from the current 80%. Currently the government is working through its Customs Department to better register and control exports, particularly those of the small-scale miners who often ship from local ports. It is expected that this program will result in further monitoring of, and a possible restriction on, coal exports.

RISKS OF RESOURCE NATIONALISM IN SOUTH AFRICA, ENERGY POVERTY STILL A CHALLENGE

With the release of an updated 2030 roadmap for the electricity sector and the possible passing of amendments to the Mineral and Petroleum Resources Development Act, 2014 is
certainly an important year for the coal industry in South Africa.

The Integrated Resource Plan for Electricity for 2010–2030, most likely to be announced in the first half of the year, will define the contribution of various energy technologies and fuels toward incremental energy supply in South Africa. The current draft of the plan prescribes additional coal-fired generation capacity of 2450 MW, in comparison to 11,230 MW from gas and 13,070 MW from solar energy, indicating a desire to diversify an electricity mix in which coal currently supplies 90% of the country’s electricity.

A higher share of more expensive gas-fired and renewables-based power generation could be problematic for the South African economy and consumers, says Ian Hall, General Manager at Anglo American Thermal Coal. “South Africa is already experiencing unprecedented hikes in electricity prices—a 200% increase since 2008.” This, together with low annual GDP growth rates of around 2% and aggressive demand reduction initiatives, has contributed to electricity consumption remaining flat for the past three years, despite up to 25% of the population not having access to electricity.

The issue of affordable and reliable energy could also be an important theme of the forthcoming general elections as companies and households face restrictions on their energy demand and many have had to drastically reduce their energy use due to rising costs.

The South African government is also expected to adopt a number of important amendments to the Mineral and Petroleum Resources Development Act. The proposed amendments introduce a new category of “strategic minerals”, which could be made subject to export and price controls. According to Hall, the proposed amendments could discourage future investments in coal mining in South Africa until the full effects of the changes are known, as investors would run the risk of having their assets declared strategic, which may mean potential price or export restrictions on coal produced.

“The issue of affordable and reliable energy could also be an important theme of the forthcoming general elections...”

EU DEBATES 2030 CLIMATE TARGETS, PROPOSES NEW ENVIRONMENTAL STANDARDS

Companies operating in the energy sector in the European Union (EU) are likely to see the next 12 months dominated by discussions around the new Energy and Climate Policy Framework for 2030, as well as new environmental standards proposed as part of the Clean Energy Package. For the coal industry, it is not climate targets, but environmental regulations, that are likely to be most challenging.

New environmental standards for coal-fired power plants and smaller coal-fueled boilers could prove challenging for the position of coal in the EU. The three key initiatives to watch are:

• More ambitious definitions of best available technologies (BAT) for controlling the emissions of various pollutants from large coal plants
• New environmental standards for medium combustion plants, such as heat-generating boilers
• Tighter limits on pollutant emissions allowed for each of the EU member states

According to Bernd Bogalla, Head of European Affairs at the German Hard Coal Association, the revision of BAT standards for large combustion plants could result in more ambitious technology requirements on all new coal-fired power plants in the EU. A new standard for mercury emissions, which were not covered by previous EU rules, has also been discussed, but this falls outside the scope of current legislation.

Also problematic could be two other pieces of legislation targeting smaller combustion plants and defining emission limits per member state. Until now medium combustion
plants in Europe have only been subject to national regulations. According to EURACOAL, small heat producers using coal might find it difficult to comply with any new EU rules, while the newly proposed national emissions ceilings might trigger new regulatory action against large point-source emitters, such as power stations, given the political reluctance to tackle emissions from transport.

Also on the European Commission (EC) agenda is a proposal for a 2030 Climate and Energy Policy in January this year. The proposal includes a binding target for greenhouse gas emissions reduction of 40% by 2030, and a non-binding target for a 27% share of renewable in the EU energy mix by 2030. The package also includes a proposal to reform the EU’s Emissions Trading Scheme.

The EC would like to see all elements of the package finalized in 2014. However, with the growing controversy around the costs of the EU’s climate policies and the forthcoming European Parliament elections, reaching any final decisions within that timeframe will be challenging.

More than any other issue, the economic competitiveness of the EU’s industrial sectors could set the tone for the negotiations. Until now, companies in EU member states have been granted some relief from the costs of decarbonization. According to Brian Ricketts, Secretary General of EURACOAL, the Commission proposes to continue this relief for the energy-intensive sectors, but an EC probe into Germany’s energy subsidies could see other sectors in the country facing higher costs with the growing burden of renewable energy subsidies, which runs to billions of euros each year.

EU elections scheduled for May 2014 could have an impact on both energy and climate policies. The elections will result not only in new members of the European Parliament from all EU member states but also new commissioners (ministers) and a new president of the European Commission.

“More than any other issue, the economic competitiveness of the EU’s industrial sectors could set the tone for the negotiations.”

U.S. EPA LEADING THE CHARGE ON COAL

In the U.S., the policy environment for power generation and mining activities is going to be shaped by U.S. Environmental Protection Agency (EPA) regulatory action.

Among the most debated EPA regulations is the rule which will limit CO₂ emissions from new power plants. Proposed in 2012 and expected to be finalized this year, the rule is currently being challenged at the state level and in Congress.

The EPA is now also expected to propose guidelines for states to develop CO₂ limits for existing plants. Although the proposal is anticipated before July this year, it is difficult to gauge in which direction the EPA will go with regulations governing existing plants, says Alex Bond, Director of Air Quality at the U.S. National Mining Association.

With upcoming mid-term elections scheduled in November, the Democrats are likely to see their power decline in the U.S. Congress. While it is possible that under a Republican majority the House of Representatives and the Senate could decide to go against the EPA’s rule on CO₂ emissions from new power plants, according to Alex Bond such moves are unlikely to succeed given the veto power held by the White House.

Climate policies are not the only source of concern for the coal industry in the U.S. 2014 will see the finalization of a number of other pending EPA regulations such as the federal effluent limitation guidelines and a proposal for a rule governing the handling of coal ash. Compliance costs associated with these rules for coal-fired power plants could be significant.

New water quality regulations could also directly impact
mining operations in the U.S. “We are seeing escalating legal and regulatory activity under the federal Clean Water Act that is making it more difficult and costly to mine coal in the U.S.,” says Amanda Aspatore of the U.S. National Mining Association.

FIRST TEST CASE FOR THE WORLD BANK’S NEW ENERGY STRATEGY

2014 will see the first test case for the World Bank’s new energy strategy, which includes a decision to limit financing for coal-fired power plants to “rare circumstances”. In fact, at the end of 2014 the World Bank is expected to take a final decision on whether to finance a coal-fired power plant in Kosovo—it will be the Bank’s first decision relative to a coal project since the adoption of its new energy strategy.

The project would see the replacement of a 45-year-old plant, considered to be one the biggest emitters in Europe, with a more modern and reliable plant, and retrofitting a 25-year-old plant to bring it into compliance with the EU environmental standards. According to earlier World Bank analysis, the proposed new plant “is the least expensive thermal option, even when the relatively higher environmental costs are priced in”.

Milton Catelin, WCA Chief Executive, says it is critical that development banks support developing countries in accessing state-of-the-art coal technologies. “Coal has been vital to global development—almost half of this century’s incremental energy has come from coal alone and virtually all of the world’s poverty reduction between 1981 and 2008 took place in coal-fueled China.”

INTERNATIONAL COMMUNITY GEARS UP FOR 2015 AGREEMENTS

No firm decisions should be expected in the framework of international climate change negotiations this year, although the two major international meetings scheduled for 2014 should give a better understanding of possible future policy directions. In September, UN Secretary-General Ban Ki-moon will hold a Climate Summit bringing together heads of states. The Summit could be a useful indicator of the readiness and ambition of the international community for a global climate deal. It will be followed by international climate change negotiations in Peru in December (COP20) where countries will discuss issues such as the type and the level of mitigation commitments that should be made as part of the global climate deal.

2014 will also see the first substantive proposal for the post-2015 Sustainable Development Goals (SDGs). The proposal will be finalized in the first half of 2014 and will then be debated by the UN General Assembly. The SDGs will include a target on energy access, but how this is achieved remains to be seen. A formal negotiating process will commence in September to agree on the goals in mid-2015.

Contributing to the discussion on the post-2015 Sustainable Development Goals, the World Coal Association has called for clear action to improve energy access and address the challenge of energy poverty affecting 1.3 billion people worldwide. “Including energy access targets post 2015 will be critical to mobilizing global action and supporting investment in modern energy technologies in the developing world. A robust energy access target is one essential component, but what derives from that target must also be recognition that different countries will achieve it in different ways. For some, renewable energy might be the best approach, but for many other countries, coal is going to play a huge role in delivering energy access,” said Milton Catelin.

CONCLUSION: COAL REMAINS THE BACKBONE OF ELECTRICITY GENERATION

Despite the challenges facing the coal industry in 2014, the global outlook for coal remains positive, driven by global demand for affordable and reliable energy and encouraged by the deployment of more efficient and sustainable coal combustion technologies.

Over the next five years, global coal demand is expected to increase by 15%, as shown in recent IEA analysis. Based on these consumption trends, the IEA also forecasts that coal is likely to pass oil within a decade as the world’s top energy source and by 2035 world coal consumption is set to increase by almost 50%. Given the aspirations for social and economic development of countries in Asia and India, it seems unlikely that any new policy or regulatory initiatives will substantially reverse this global trend,
especially when these countries have access to domestic coal reserves and their population is still affected by energy poverty.

Even in developed countries the cost of energy generation and climate action are becoming the leading issues in any debates on policies guiding future energy supply. This new policy environment is more likely to favor more practical steps toward sustainable energy supply and sustainable development, such as through the deployment of clean coal technologies and more efficient use of coal.

See Table 1 for a checklist of critical dates to watch in 2014.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>March and June</td>
<td>EU Council will discuss climate and energy issues</td>
<td>EU</td>
</tr>
<tr>
<td>25–29 March</td>
<td>Publication of the IPCC WGII contribution to the Fifth Assessment Report “Impacts, Adaptation and Vulnerability”</td>
<td>N/A</td>
</tr>
<tr>
<td>9 April</td>
<td>Parliamentary elections</td>
<td>Indonesia</td>
</tr>
<tr>
<td>7–11 April</td>
<td>Publication of the IPCC WGIII contribution to the Fifth Assessment Report “Mitigation of Climate Change”</td>
<td>N/A</td>
</tr>
<tr>
<td>22–25 May</td>
<td>Elections to the European Parliament across 28 Member States</td>
<td>EU</td>
</tr>
<tr>
<td>Pre-31 May</td>
<td>General elections</td>
<td>India</td>
</tr>
<tr>
<td>May</td>
<td>Publication of the IEA Technology Perspectives</td>
<td>N/A</td>
</tr>
<tr>
<td>April–July</td>
<td>General elections</td>
<td>South Africa</td>
</tr>
<tr>
<td>1 June</td>
<td>EPA proposals for carbon pollution standards, regulations, or guidelines for modified, reconstructed, and existing power plants</td>
<td>U.S.</td>
</tr>
<tr>
<td>June/July</td>
<td>Final BREFs (Best Available Techniques Reference Documents) published</td>
<td>EU</td>
</tr>
<tr>
<td>9 July</td>
<td>Presidential elections</td>
<td>Indonesia</td>
</tr>
<tr>
<td>July</td>
<td>New Senate takes office</td>
<td>Australia</td>
</tr>
<tr>
<td>July</td>
<td>Emission Reduction Fund to start operating</td>
<td>Australia</td>
</tr>
<tr>
<td>Post-June</td>
<td>Italian presidency of the European Council may seek to reach agreement with European ministers on Air Quality Package</td>
<td>EU</td>
</tr>
<tr>
<td>September</td>
<td>Scheduled publication of the Energy White Paper</td>
<td>Australia</td>
</tr>
<tr>
<td>September</td>
<td>UN Secretary-General 2014 Climate Summit</td>
<td>New York, U.S.</td>
</tr>
<tr>
<td>4 November</td>
<td>Mid-term elections</td>
<td>U.S.</td>
</tr>
<tr>
<td>November</td>
<td>Publication of the IEA World Energy Outlook 2014</td>
<td>N/A</td>
</tr>
<tr>
<td>December</td>
<td>International climate change negotiations (COP20)</td>
<td>Lima, Peru</td>
</tr>
</tbody>
</table>

REFERENCES


The author can be reached at ATomczak@worldcoal.org
Water is essential for energy production—when water risks arise, energy producers around the world feel the impacts. A massive flood in Australia in 2011 reduced its coal export volume, pushing global coal prices higher. Drought in the U.S. Midwest ravaged corn fields in 2012, contributing to higher gasoline prices.

The trend is clear: Regional water concerns are creating significant financial risks, thanks in large part to advanced global commodity trading and energy industries’ high dependence on water. And it’s a trend that is poised to worsen. BP projects a 36% increase in global energy consumption by 2030, while the Water Resources Group predicts that in the same amount of time freshwater supplies will fall 40% short of total demand globally.

The water–energy nexus is becoming one of the great challenges of our generation—one that also holds significant implications for political leaders and investors alike. This article explores how water risks are already impacting the world’s coal industry, and how risks will change over time.

GLOBAL ENERGY AND COAL INDUSTRY OVERVIEW

Coal continues to be a dominant force in the global energy market (see Figure 1). The fossil fuel accounts for one-third of total energy consumption, second only to oil. Global coal consumption grew by 2.5% in 2012, continuing coal’s years-long streak as the fastest-growing fossil fuel. Many of the world’s top coal producers are also the biggest consumers (listed in Tables 1 and 2, respectively), with China, India, and the U.S. near the top of both lists.

“The water–energy nexus is becoming one of the great challenges of our generation…”

According to an analysis by the World Resources Institute (WRI), as of July 2012, 1199 new coal-fired power plants with a total installed capacity of more than 1400 GW have been proposed for construction in 59 countries worldwide (see Figure 2). More than three-quarters of this capacity is slated for development in China and India.

GLOBAL WATER TRENDS AND RISK HOTSPOTS

As with most energy sources, coal-related industries—including mining, coal-to-chemicals, and power generation—are extremely water-intensive. Coal mines depend on water to extract, wash, and process coal, while coal-burning power plants need water to create steam and for cooling. Use varies widely at different plants depending on their generating and cooling technologies. In the U.S., for example, dry cooling, when employed, requires small amounts of water for system maintenance and cleaning. Once-through cooling systems withdraw the most water—between 20,000 gal/MWh (75.7 m³/MWh) and 50,000 gal/MWh (189.3 m³/MWh). They consume far less—between 100 gal/MWh (0.4 m³/MWh), and 317 gal/MWh (1.2 m³/MWh). (The difference in water withdrawal and consumption is explained in the box at the bottom of the
Without effective regulatory enforcement and long-term water-resource management, water-energy choke points create uncertain financial risks to companies and investors.

Like much of the world’s energy supply, the coal industry’s thirst is especially concerning when you consider global water trends and risk hotspots. According to WRI’s Aqueduct Water Risk Atlas, water stress—taking into account agricultural, industrial, and domestic users (see Figure 3)—is growing worldwide. Baseline water stress has been more prevalent and more severe in every continent in 2010 than it was in 2000, particularly in China, South and Central Asia, and the U.S. west coast. This increased stress can be attributed to a growing demand for freshwater and supply shortages caused by shifting global precipitation patterns from climate change, among other factors.7

As well, more than 50% of the world’s largest coal-producing/consuming countries face high to extremely high levels of

### TABLE 1. Top 10 coal-producing countries as of 2012

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Coal Production (Mtoe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>1825.0</td>
</tr>
<tr>
<td>2</td>
<td>U.S.</td>
<td>515.9</td>
</tr>
<tr>
<td>3</td>
<td>Australia</td>
<td>241.1</td>
</tr>
<tr>
<td>4</td>
<td>Indonesia</td>
<td>237.4</td>
</tr>
<tr>
<td>5</td>
<td>India</td>
<td>228.8</td>
</tr>
<tr>
<td>6</td>
<td>Russian Federation</td>
<td>168.1</td>
</tr>
<tr>
<td>7</td>
<td>South Africa</td>
<td>146.6</td>
</tr>
<tr>
<td>8</td>
<td>Kazakhstan</td>
<td>58.8</td>
</tr>
<tr>
<td>9</td>
<td>Poland</td>
<td>58.8</td>
</tr>
<tr>
<td>10</td>
<td>Colombia</td>
<td>58.0</td>
</tr>
</tbody>
</table>

### TABLE 2. Top 10 coal-consuming countries as of 2012

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Coal Consumption (Mtoe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>1873.3</td>
</tr>
<tr>
<td>2</td>
<td>U.S.</td>
<td>437.8</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>298.3</td>
</tr>
<tr>
<td>4</td>
<td>Japan</td>
<td>124.4</td>
</tr>
<tr>
<td>5</td>
<td>Russian Federation</td>
<td>93.9</td>
</tr>
<tr>
<td>6</td>
<td>South Africa</td>
<td>89.8</td>
</tr>
<tr>
<td>7</td>
<td>South Korea</td>
<td>81.8</td>
</tr>
<tr>
<td>8</td>
<td>Germany</td>
<td>79.2</td>
</tr>
<tr>
<td>9</td>
<td>Poland</td>
<td>54.0</td>
</tr>
<tr>
<td>10</td>
<td>Australia</td>
<td>49.3</td>
</tr>
</tbody>
</table>
water stress, which can be attributed to the many competing demands on water resources. WRI developed a country-level water stress measurement that identifies where agricultural, domestic, and industrial users are withdrawing water. This is important, since water supply and demand varies significantly within a country, from dry prairies to lush rainforest and from industrial megacities to rural townships. High to extremely high stress indicates that farms, municipalities, and industries nationwide already account for at least 40% of the water naturally available to them, based on a weighted average. That fact can pose significant hurdles for energy producers and other water-intensive businesses.

Additionally, nearly half of the seven most water-stressed countries also face high to extremely high seasonal variability (see Table 3); in each of these countries, the water supply varies dramatically between wet and dry seasons within a year. That volatility can disrupt operations and increase production costs. For example, a drought in Texas in 2011 placed exceptional stress on the power grid, and the state only avoided blackouts by placing restrictions on farmers and ranchers with senior water rights, showing the tension on the water resources from the competing demands of primarily agriculture and energy.8

Water stress is not limited to geographically dry countries. Indonesia, South Korea, and Japan—all coal producers/users—are classified as highly water-stressed because they use more than the annually available surface freshwater supply for city, agricultural, and industrial development. Because naturally occurring, renewable freshwater cannot meet these countries’ needs, their cities are heavily dependent on costly alternative water sources, such as groundwater, seawater desalination, and inter-basin transfers. The more dependent an area is on alternative freshwater sources, the higher the water-related risks to its financial assets.

These risks can be wide-ranging, as Société Générale outlined in an October 2013 report.9 The report found that limited

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CONSUMPTION VS. WITHDRAWAL

“Water withdrawal” and “water consumption” describe two different processes. Water that is withdrawn is used and then returned to the source. Therefore, most of the water used by once-through cooling systems is withdrawn. Water that is consumed is used and not returned to the source. Consumption happens when water evaporates or is incorporated into other products—especially agriculture. Almost 50% of the water used in agriculture is lost to the atmosphere or transpired through plant leaves.


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FIGURE 3. 2010 water withdrawal by sector of major coal-producing/consuming countries

Water withdrawal is not limited to geographically dry countries. Indonesia, South Korea, and Japan—all coal producers/users—are classified as highly water-stressed because they use more than the annually available surface freshwater supply for city, agricultural, and industrial development. Because naturally occurring, renewable freshwater cannot meet these countries’ needs, their cities are heavily dependent on costly alternative water sources, such as groundwater, seawater desalination, and inter-basin transfers. The more dependent an area is on alternative freshwater sources, the higher the water-related risks to its financial assets.

These risks can be wide-ranging, as Société Générale outlined in an October 2013 report.9 The report found that limited
access to water-supply sources can disrupt operations. Cutting water-allocation permits due to insufficient water in an area can delay project development. Securing new water sources is often an expensive process, increasing project costs. Possible up-front investments—which can reduce those long-term costs—include efficiency, recycling, and wastewater treatment to meet regulatory requirements meant to protect stressed resources. Companies could avoid all those issues with sufficient naturally occurring supplies. However, as demand exceeds renewable supplies, alternative sources and all their associated issues come to the forefront.

EXPLORING CHINA’S COAL–WATER NEXUS

Given that China is the world’s largest coal producer and consumer—accounting for more than half of the planet’s coal consumption—it is worth exploring that country’s specific water-energy risks in greater depth. China’s total installed coal-fired power generation capacity at the end of 2012 was 758 GW, more than 66% of the nation’s total power generation capacity.10

However, China is also quite dry. Its average water resources are only 1730 m³/yr-capita, barely above the United Nations’ water scarcity marker.11 Eight provinces have fewer than 500 m³/yr-capita of total available surface water, which is on par with Middle Eastern countries such as Jordan or Syria.

More importantly, there’s a geographical mismatch between the country’s water resources and its coal reserves. While water is generally much more abundant in southern China, two-thirds of China’s coal mines are located in the water-stressed north.12 According to a recent Wood Mackenzie report, 58% of China’s existing coal-fired power generation capacity is located in high to extremely high water-stress areas, where local water demands are high and water resources face strong competition among users in the industrial, agricultural, and domestic sectors.13

WRI’s study found that, as of July 2012, the Chinese government had planned another 363 coal-fired power plants for construction across China. Those plants’ combined generating capacity would exceed 557 GW. This amounts to an almost 75% increase in the nation’s total power-generating capacity, 50% of which is located in areas with high to extremely high water stress. More than 60% of the proposed generating capacity is slated for six northern provinces, which account for only 5% of China’s total water resources.

If China builds all the plants now in the planning stages, China’s coal industry—including mining, chemical production, and power generation (not including the water withdrawal for once-through cooling systems)—could withdraw as much as 10 billion m³ of water annually by 2015. That’s more than one-quarter of the water available for withdrawal every year from the Yellow River.14 We believe water withdrawal is as important as water consumption because, while water that is withdrawn does return to the ecosystem, it is still not always available for all other users. These water withdrawal and consumption estimates assume no policy changes or technology improvements, so actual usage rates could be lower.

The power plant sites were selected because they are located next to coal mines, a proximity which would reduce coal transportation costs. The proposed sites would, however, exacerbate the industry’s environmental impacts on already stressed water resources.

The Chinese government recognizes the need to balance its water and energy consumption. The Ministry of Water Resources recently announced a new policy document called the “Water Allocation Plan for the Development of Coal Bases”, aimed at protecting water resources in large coal bases.15 The plan specifies water use efficiency and discharge requirements for existing coal bases and requires all new coal mines to submit a water resources planning study.

These new rules proved a step in the right direction, since proposed power plants in major coal bases facing water scarcity must apply air cooling technology. Air cooling uses far less water than other cooling systems, so it dramatically reduces coal-fired power plants’ overall water usage.16 The Water Allocation Plan is important, considering most of the bases

### TABLE 3. Water stress and seasonal variability levels of major coal-producing/consuming countries

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Water Stress Level</th>
<th>Seasonal Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kazakhstan</td>
<td>Extremely High</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>High</td>
<td>Extremely High</td>
</tr>
<tr>
<td>3</td>
<td>South Korea</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Australia</td>
<td>High</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>5</td>
<td>Indonesia</td>
<td>High</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>6</td>
<td>Japan</td>
<td>High</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>7</td>
<td>South Africa</td>
<td>High</td>
<td>Medium to High</td>
</tr>
<tr>
<td>8</td>
<td>China</td>
<td>Medium to High</td>
<td>Medium to High</td>
</tr>
<tr>
<td>9</td>
<td>U.S.</td>
<td>Medium to High</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>10</td>
<td>Germany</td>
<td>Low to Medium</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>Poland</td>
<td>Low to Medium</td>
<td>Low</td>
</tr>
<tr>
<td>12</td>
<td>Russia</td>
<td>Low to Medium</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>13</td>
<td>Colombia</td>
<td>Low</td>
<td>Low to Medium</td>
</tr>
</tbody>
</table>
are already under high water stress. Still, without expanding water recycling and wastewater treatment, additional water withdrawal activities would only make things worse.

A broader policy vision acknowledges and responds to this reality. China’s State Council created three national goals for water, called the “Three Red Lines”. The plan aims to cap annual maximum water use nationwide at 700 billion m$^3$, improve industrial water use efficiency to an internationally advanced level, and protect water quality to maximize sustainable development.

In the face of highly stressed water resources, coal mining and power generation industries in China could see increased production costs in the short term as it could be more expensive to access alternative water supplies, address ongoing regulatory changes, and guard against potential disruptions. To mitigate these risks, China should pair water risk management at its power plants with consistent, carefully crafted legislation like the Water Allocation Plan. Such measures may require up-front investment, but any such expenditure will support sustainable water management and long-term business continuity.

**FINANCIAL RISKS ASSOCIATED WITH THE WATER–COAL NEXUS IN INDIA**

Already one of the world’s top coal consumers, India’s dependence on coal-fired power generation is expected to grow. The country proposed nearly 520 GW of new coal-fired capacity nationwide as of July 2012 to meet high growth in electricity demand.

India is already highly water stressed, however, largely based on water use in the agricultural sector. Total water withdrawals in 2010 topped 760 billion m$^3$. That is more than China and Russia’s total withdrawals combined, while India’s total renewable water resources account for only a quarter of China and Russia’s combined total.

More than 70% of India’s power plants are located in water-stressed or water-scarce areas. Stressed water resources are already impacting power projects in India, causing delays and operational losses. For example, inadequate water supplies in the state of Chhattisgarh shut down the National Thermal Power Corporation’s Sipat plant in 2008. Project execution delays and lost power output can also turn water-related risks into financial losses.

**“Infrastructure investments, including backup supply reservoirs and desalination plants, will better secure long-term business growth...”**

While shareholders are usually not financially exposed to water-related risks, as they are shielded by protective regulations enabled by India’s state-owned power sector, water risks may become more material under certain circumstances. Unregulated plants, for instance, might not be able to pass costs on to end-users, reduced power outputs could violate the terms of the purchase agreements, or the regulatory framework could change. Any changes would fall against the backdrop of the Government of India’s National Water Mission. The national policy framework calls for a 20% improvement in water efficiency nationally through regulatory mechanisms. It also encourages conservation and water waste minimization. Every water user, industrial power generators included, will need to optimize their conservation, recycling, and reuse practices to meet this goal.

Several measures can help utilities in stressed regions better manage and mitigate water-related cost, output, and regulatory risks. Infrastructure investments, including backup supply reservoirs and desalination plants, will better secure long-term business growth, even though such capital spending requires up-front investment. The Energy and Resources Institute in India also recommends third-party, regular water audits, as well as standards for water consumption in the power sector. More consistent legislation overall will give companies a framework for long-term energy production and financial planning while protecting at-risk water supplies.
**MANAGING GLOBAL WATER RISKS IN THE COAL BUSINESS**

The case studies from China and India illustrate that unmanaged water risks have financial consequences for national and international companies. Recent guidelines from China’s Ministry of Water Resources will limit coal expansion based on regional water capacity, and may slow down coal-project approvals. The guidelines will also push companies to pay for wastewater recycling and wastewater treatment systems. That large capital investment, combined with higher annual operating costs, means that companies must take a long-term view. They should pursue advanced water risk management at power plants while understanding the value in consistent, carefully crafted legislation. The combination will ensure that energy production can grow within natural resource limits.¹⁹

Considering the potential for increased regulatory uncertainty and likelihood of supply constraints, water poses a variety of business risks for the global coal industry. The World Resources Institute recommends that the industry assess water risks more deliberately and broadly, hold itself accountable, and take actions to respond to the challenges. A range of actions is available, including innovative technology and public policy engagement to collectively reduce shared water risks, all on the path to advanced water stewardship.

Furthermore, governments around the world should protect water resources and encourage energy projects that face fewer risks from water stress and limits on greenhouse gas emissions. Those precautionary measures will better align policy-making with water and energy planning, and balance resource constraints with economic growth.

**NOTES**

A. Baseline water stress is a measure of demand and supply for water in a given area, and is calculated as a ratio of local water withdrawal over water supply. In extremely high water-stressed areas, 80% of the available supply is withdrawn every year. A high percentage means more water users are competing for limited supplies.

**REFERENCES**


To start assessing your business's global water risks, please contact one of the authors (tluo@wri.org, botto@wri.org, tshiao@wri.org, amaddocks@wri.org) or visit aqueduct.wri.org
China has been experiencing rapid industrialization and urbanization since the 1980s, with an annual gross domestic product (GDP) growth rate of approximately 10.7% from 2003 to 2011. Although the rate of growth has slowed, the general trend of an increasing GDP is projected to continue into the foreseeable future. To support this economic development, a corresponding increase in primary energy consumption is also expected. Coal makes up nearly 70% of China’s total primary energy consumption. Coal production, the vast majority of which is consumed in China, increased rapidly from 1.38 billion tonnes in 2001 to 3.68 billion tonnes in 2013. Although the rate of increase has slowed in recent years, coal will continue to be the principal energy source for China in the long term. However, some sectors in the coal industry are highly water intensive, and water shortages could become a major barrier for further development. Moreover, water and coal resources are unevenly and inversely distributed in China. Coal reserves are mainly located in north China, while water resources are abundant in the south but scarce in the north. Considering these issues, water scarcity could become a constraining factor for the future development of the coal industry in China’s coal-rich regions.

This article provides a comprehensive analysis of water use in China’s coal supply chain, including coal mining, preparation, transport, conversion, and final disposal. We also illustrate the interaction between the water system and the coal industry and analyze several scenarios for water usage in China’s coal supply chain in 2020 and 2030, based on which several technical and policy suggestions are proposed for water savings.

WATER ISSUES IN THE COAL SUPPLY CHAIN

The main stages of the coal supply chain are shown in Figure 1. The supply chain comprises mining, preparation, transport, conversion, and disposal of pollutants, emissions, and waste. In each stage, water is either withdrawn directly from natural water bodies (i.e., surface or underground water) or recycled from other stages and reused. Concerns over water issues in the coal supply chain mainly involve impacts to water use for production and living, water recycling, wastewater treatment, and the local environment.

In 2011, 610.7 billion m³ of water was consumed in China, 23.9% of which was used for industrial purposes. The coal industry, including coal mining and preparation, coal-fired power generation, and the coal-to-chemicals industry, is one of the most water-intensive industries.
Mining

It is estimated that China has approximately 14,000 coal mines, which produced 3.63 billion tonnes of coal in 2012. Approximately 70% of these mines are located in water-scarce areas and about 40% experience severe water shortage problems. During coal mining, 0.5 tonnes of water are consumed to produce 1–2 tonnes of coal, while on average four tonnes of pit water are drained. Cumulatively, coal mining produces approximately 3–6 billion tonnes of wastewater per year. Mining activities can also cause damage to water systems, especially underground water. For instance, 1.07 tonnes of underground water reserves are used to produce one tonne of coal in Shanxi Province in China.³

Coal Preparation

In the coal preparation sector, water is mainly consumed for coal-washing purposes, although coal preparation consumes far less water than other areas in the coal industry. In China, 94% of cleaned coal is prepared via wet methods (i.e., coal washing). On average, for one tonne of prepared coal 2.5 tonnes of water is used: 0.15 tonne is removed with the by-products, 0.05 tonne is consumed in the process and for maintenance purposes,³ and the remainder is recycled in a closed loop. According to data from the China National Coal Association, by 2012 about 56% of coal was washed and about 35% of steam coal was washed. Coal preparation reduces the ash and sulfur content in coal, increasing its quality. In coal-fired power generation, coal consumption is reduced by 2–5 gce/kWh for every 1% decrease in ash content.⁵

Although wet preparation methods are mature and highly effective, water-related issues are one of the key technical barriers to increasing the coal-washing rate in China. The actual water loss during the preparation process is unacceptable in extremely arid regions, such as northwest China. In addition, China’s abundant young coal readily degrades in water, and is thus not suitable for wet processing. Also, the product of the wet washing process has an external water content of over 12%, which can result in freezing when transported under severely cold conditions.⁶

Conversion

Coal-fired power generation remains the dominating sector for coal conversion. Most water used in the coal industry is used for coal conversion, specifically for coal-fired power plants, many of which are located in arid regions. According to the China Electricity Council, in 2010 the average water consumption of thermal power plants in China was 2.45 kg/kWh, most of which were coal-fired plants, while the average water consumption of thermal power in the U.S. in 2005 was 1.78 kg/kWh.⁷ This disparity is mainly due to the difference in
the countries’ respective power generation fleets (i.e., higher ratio of coal- to gas-fired power plants in China compared to the U.S.). For each coal-fired power plant, most of the water requirements are due to cooling. Dry air cooling, instead of wet cooling systems, can reduce power plant efficiency, but also offers substantial water savings if employed. China has made major progress employing dry air cooling. In 2013, there was a total of 150 GW (based on data from the China Electricity Coal Council) of installed thermal power units with dry air cooling, which was 17% of the total thermal power installed capacity. Increased deployment of supercritical power plants, ultra-supercritical power plants, and various water-saving technologies will reduce the average water consumption, which will be more important in areas with water scarcity.

In the coal-to-chemicals industry, approximately 2.5 tonnes of fresh water are consumed to produce one tonne of coke. However, in the coal-to-liquids industry, an indirect coal-to-liquids plant with a capacity of 1.5 million tonnes per year consumes 6–10 tonnes of water to produce one tonne of product, making it an extremely water-intensive industry.

Clearly the efficiency of water utilization by China’s coal industry leaves substantial room for improvement. Potential water savings can be further increased through integrated planning, where the water issues can be considered from a supply-chain-wide viewpoint rather than stage by stage separately.

**SCENARIO ANALYSIS: WATER USE IN THE COAL SUPPLY CHAIN IN 2020 AND 2030**

In November 2010, the State Council of China released a response to the Comprehensive Plan for National Water Resources (hereafter referred to simply as the “Water Plan”), which set water use targets for industrial use in China of 127 billion m$^3$ and 120 billion m$^3$ in 2020 and 2030, respectively. According to the Water Plan, any water-intensive industry should not increase its percentage of total industrial water use; this is especially true for applications such as coal-fired power plants that have significant potential for water savings.

**Scenario Design**

In its World Energy Outlook (WEO) 2010, the International Energy Agency (IEA) provided three scenarios to analyze global and regional energy trends in 2020 and 2030. For our research the coal demand data in the WEO Current Policies Scenario was taken as a base case; the data in the New Policies Scenario was used to estimate the impacts of policy on future trends. In addition, based on the present status of technology development, the effects of technology on water use were applied in the scenarios. Building on these factors, we proposed the following four scenarios:

- Scenario 1 (S1) serves as a baseline, without any consideration given to policies changes and/or technology improvements.
- Scenario 2 (S2) considers the impacts of technology improvements under current policies.
- Scenario 3 (S3) considers the impacts of policy changes without technology improvements.
- Scenario 4 (S4) combines the policy changes and technical progress to account for the synergistic impacts.

Note that the 2010 State Council response to the Water Plan used 2008 as the base case year; for this reason, 2008 was also used as the base case year for these analyses. In this study water use does not include water withdrawal for once-through cooling systems in the coal-fired power industry. While the water withdrawal can be large in such systems, very little is consumed and the vast majority is returned to the original water source.

**Results and Discussion**

The results of the scenario analysis are presented in Figure 2, which illustrates water use in the coal supply chain from 2008 to 2030, as well as the estimated total industrial water use targets according to the Water Plan. In Scenario 1 and Scenario 3, where technological improvements are not considered, water use in the coal supply chain continues to increase. In Scenarios 2 and 4, water use in the coal supply chain decreases slightly before 2020 and declines appreciably after that.

The results from Scenario 1 indicate that if no water-saving policies or technological improvements are adopted water use in the coal supply chain will continue to increase dramatically; by 2030, water use is projected to be more than twice as much as in 2008.
reasons discussed above. However, it is clear that both stricter use is likely to exceed the water-saving target for the same industrial water use target. In this case, actual industrial water use in the coal supply chain would be 10.7 billion m$^3$, 9% of the industrial water use target. However, around 2030, water use in the coal supply chain to about 11% of the total 2030 industrial water use target. In 2020, this ratio is only slightly higher than in 2008, but between now and 2020 there is also expected be growth in other water-intensive industries (e.g., paper making, metalurgy, and textile industries). Therefore, we predict that actual industrial water use will exceed the targets around 2020 if only technology improvements are applied. New effective policies are necessary to ensure the water use target is achieved.

In the Scenario 3 analysis the impact of policy changes were taken into account. Water use in this scenario does not increase noticeably from 2020 to 2030, but water use levels are higher than those in 2008. The results indicate that the potential capability of policy changes alone to reduce water use in the coal supply chain is rather limited. To achieve necessary water savings, the government should implement stricter policies and develop relevant water-saving technologies.

Comparing the results of Scenario 2 and Scenario 3, technological improvements have more substantial effect than policy changes. We suggest more rapid progress in technological improvement is critical to ensuring that the 2020 and 2030 industrial water use targets can be achieved.

The results of Scenario 4 demonstrate the integrated influence of policies and technical progress on water use reduction. In 2030, water use in the coal supply chain would be 13.3 billion m$^3$, 8% of the industrial water use target. However, around 2020, we identified the same problem with that described in Scenario 2. Under Scenario 4, water use in the coal supply chain in 2020 was projected to be 14.9 billion m$^3$, ~12% of the industrial water use target. In this case, actual industrial water use is likely to exceed the water-saving target for the same reasons discussed above. However, it is clear that both stricter policies and faster technological improvements must contribute to further reductions in water use.

Figure 3 illustrates water use by sector in the coal supply chain in China, 2030. Water use in coal-fired power generation makes up the largest share, and therefore offers the greatest potential for water savings. In 2008, water use in coal-fired power generation was 7.86 billion m$^3$, with electricity generation of 2759 TWh. In Scenario 2, coal-fired power generation is 6605 TWh in 2030, an increase of 140% compared to 2008, while total coal industry water use is reduced by 20%. In Scenario 4, coal-fired power generation is 5060 TWh in 2030, an increase of 83%, while total coal industry water use is reduced by 36% relative to 2008 actual levels. In general, since major water use reduction is most likely to occur in coal-fired power generation, we conclude that promoting strict policies and technical progress in the coal-fired power industry would be the most effective way to reduce water use in the coal industry in China.

Although the absolute water savings in coal mining, coal preparation, and coal-to-chemicals industry are relatively small compared with that for coal-fired power generation, there are significant differences between the four scenarios when examining the water use reduction rate in each sector. For coal mining, water use is 11.1 billion m$^3$ in Scenario 1. In Scenario 2 the coal mining water use is reduced by 57% compared to Scenario 1. In Scenario 3 water use is reduced by 17%. In Scenario 4 projected coal mining water use is reduced by 64%.

For the coal-to-chemicals industry, the results are similar. These outcomes indicate that, with technology improvements and the implementation of new policies, significant reductions in water use could be achieved, providing economic benefits (e.g., reduced water cost) as well as environmental benefits (e.g., less wastewater drainage).

**PRACTICAL PATHWAYS FOR WATER SAVINGS**

As discussed above, the water issues in the coal supply chain in China could severely constrain the further development of China’s coal industry. Therefore, we suggest the following pathways for water savings in each stage of a coal supply chain.

In coal mining, large quantities of the wastewater are discharged currently. Thus, the largest potential of water savings in the coal mining stage is to recycle the mining wastewater for other purposes according to the water quality.

As coal preparation contributes to higher efficiency in coal-fired power generation, great water-saving benefits can be obtained by increasing the ratio of washed steam coal in China.

The scenario analysis results indicate that coal-fired power generation accounts for the largest share of water use in the...
coal supply chain in China, and has the greatest potential for water savings. For a circulating cooling system, the optimum concentration ratio (i.e., the ratio of solids in the water being added to the system versus the solids in the water being removed from the system, which is important to limit build-up of solids in the cooling tower) is 4–5, whereas in China 80% of the coal-fired units are operating with a concentration ratio lower than 3. It is effective to increase the concentration ratio to reduce water consumption. Another practical method is to control water loss in cooling towers by reducing the quantity of circulating water. In addition, recycling wastewater as well as utilizing air-cooling units in arid areas and seawater cooling in coastal areas will also reduce total water consumption.

In the coal-to-chemicals industry, water use is likely to increase quickly as many new plants are either under construction or planned. As projects are developed, building in higher plant efficiency and wastewater treatment could contribute to water savings.

CONCLUSIONS

Water issues are of great importance to China’s coal supply chain. The results of our analysis have indicated that, by 2030, coal-fired power generation will continue to account for the greatest fraction of water use in the coal supply chain. Both technology improvements and stricter policies are necessary to control the overall water use, but technology improvement is likely to be more effective than policies in the near-term future for reductions in water use. In terms of water savings, various options are available for each coal industry sector. Recycling wastewater, increasing the fraction of washed coal, optimizing the circulating cooling system and ash handling systems for coal-fired power plants, and improving plant efficiencies are considered practical and comparatively effective to improve water savings. With these measures, the targets for water consumption set by the State Council may be achieved to allow the sustainable development of China’s coal industry.

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Coal-Based Electricity Generation in India

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THE LINK BETWEEN ELECTRICITY AND DEVELOPMENT

Electricity is a critical input needed for the development of any country. As a country develops, the share of electricity in its primary energy mix increases. Since electricity is convenient and clean (from the perspective of local environmental impact), it is preferred as a substitute for other forms of energy. The development of a country is often measured by a quality of life index. The commonly accepted quality of life index is the Human Development Index (HDI), which is a combination of life expectancy at birth, education, and disposable income per capita. National averages of the HDI values are compiled by the United Nations Development Program as “Human Development Reports.”

Figure 1 is a plot of the HDI versus electricity use per capita for different countries in 2010. In 2010, India had a HDI of 0.56 and an average electricity use of 700 kWh/capita·yr (shown using a red data point). Globally, average electricity use in 2010 was 2100 kWh/capita·yr and the average HDI was 0.7.

The total primary energy used in India was about 29 EJ (exajoules is 10^18 joules) in 2010, which is approximately 5% of the global primary energy consumption. Notably, India accounts for about one-sixth of the world’s population, but only 5% of the primary energy use.

Based on official statistics, more than 25% of India’s population does not have access to electricity and modern convenient cooking fuels. The goal of India’s development plan is to provide electricity access to all. Meeting this goal will require an increase in the electricity supply and the installed capacity of power generation. Estimates indicate that a target of 4000–5000 kWh/capita·yr is the threshold value for achieving a high HDI and quality of life. For India, a moderate growth scenario with a lower target of 2600 kWh/capita·yr has been proposed for 2035 as a part of an ongoing national exercise: Energy Technology Vision 2035. This scenario assumes a moderate GDP growth (5.5%/yr) with constant electricity intensity of GDP.

“Based on official statistics, more than 25% of India’s population does not have access to electricity and modern convenient cooking fuels.”

GROWING INDIA’S ELECTRICITY SECTOR

The Indian power sector has witnessed significant growth since India’s independence in 1947. In 2012, the total installed power sector capacity was 236 GW, which includes non-utilities–captive power plants, and the annual generation in 2011–2012 was 1.051 billion MWh. A comparison of the installed capacity and generation of India with a few select countries is provided in Table 1.

The compound annual growth rate of installed power generation capacity in India over the last 40 years has been 6.6%/year, while the compound annual growth during the last decade has been 5.8%/year. Despite the best efforts of India’s planners, the growth in installed capacity has not kept pace with the increasing electricity demand, resulting in peak electricity shortages. In most parts of India utilities are forced to exercise load shedding (switching off electricity feeders at peak times to curtail demand) for a few hours during a day. In 2012–2013 the peak shortage was estimated to be 12,000 MW during a total peak demand of 123,000 MW (nearly 10%).

During the past few decades, the power sector has accounted for about 16% of the total plan outlay of the central government. During the 13th plan period (2013–2017) the projected additional installed electricity capacity is 118,000 MW, which
will require a total investment of about INR600 billion (US$12 billion). This includes an additional capacity of 69,000 MW of coal-fired power plants. The annual coal requirement for the power sector in 2017 is projected to be 730 million tonnes (including 180 million tonnes of imports).5

**WHAT IS COAL’S ROLE TODAY?**

The Indian power sector used about 400 million tonnes of coal in 2011–2012 (almost 75% of the total demand of 535 million tonnes). The other important sectors that utilize coal are steel and cement production.

### Coal Production

Domestic coal production has been steadily growing at a rate of 6–7% annually for the last 30 years. However, the rapid growth in coal production has not been sufficient to meet the demand for coal, which has resulted in shortages. Annual shortages of coal during the monsoon months are common.

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A young Indian child studies by candlelight during the 2012 massive power outages.
The shortages are being addressed through imports. Coal imports have increased steadily, primarily for electricity generation; in 2011, approximately 95 million tonnes of coal were imported, accounting for about 15% of the country’s coal demand. Several power plants near the coast line prefer to import high-quality coal from Australia and Indonesia to ensure better power plant operation. Indian coal is characterized by high ash and low sulfur and hence has a lower calorific value than most international coals. Some plants blend imported coal with domestic coal to improve the fuel calorific value.

Coal Conversion

At present India’s energy mix is predominantly dependent on coal, which accounts for 41% of the total primary energy used in India. Much of this reliance is due to electricity production, which is principally based on thermal power plants fueled by coal. Figure 2 shows the share of electricity generation in India by different fuel sources in 2011, and Figure 3 provides the total installed capacity for different fuel sources in 2013. Coal accounted for nearly 69% of the total electricity generation in 2011 and 59% of the installed capacity in 2013.

In India, power generation from coal is usually based on the conventional steam cycle with subcritical steam parameters (range: 535–575°C, 175–230 bar) with pulverized coal combustion. As of 2008 the coal-fired unit size varied from 30–500 MW (mean of 175 MW, mode of 210 MW). There is a wide variety in heat rates and auxiliary consumption for these units. The average auxiliary power consumption is 9.5%, which offers ample room for improvement. For example, measures like variable speed drives in the forced draft fan and the boiler feed pump can help reduce auxiliary consumption and improve overall power plant efficiency. Today’s Indian power sector is opting for supercritical plants (steam conditions: 568–593°C, 241 bar).

A number of ultra megawatt power plants have been approved, including four 4000-MW projects, each made up of several smaller units, based on supercritical technology, through open bidding. The supercritical projects that have been approved to date are owned by Tata Power (one project) and Reliance Power (three projects). The first of these supercritical units came online in 2012 and 2013. However, some of these projects are facing issues related to fuel supply because the projects based preliminary cost estimates on imported coal and recently they have seen increases in coal prices (due to policies of the source country), but the tariffs in the power purchase agreements do not permit pass-through of fuel cost increases.

There are significant local environmental impacts of coal use in India—from coal mining to coal-fired power generation. Coal dust and land reclamation are often cited as significant issues associated with coal mining in India. There are very few regulations for coal-fired power plants, or the power industry in general. In addition, enforcement of what regulations are in place is difficult because emissions monitoring is not a standard practice. Table 2 provides an overview of the operating parameters for a typical 210-MW coal-based unit operating in India today. The enforcement of more stringent environmental regulations and investments in coal washing, proper reclamation planning, and investments in power plant pollution control equipment are essential to ensure that adverse impacts of coal-based power are limited. Fly ash utilization
The share of imports in the Indian energy supply mix has been increasing over the last two decades. In 2012 energy imports accounted for about 26% of the total primary energy supply, mainly due to oil imports. India imported about 124 million tonnes of crude oil and about 23 million tonnes of petroleum products with exports of about 41 million tonnes of petroleum products in 2010. India’s oil production has been nearly stagnant at about 33–38 million tonnes annually. The increasing demand for oil and petroleum products is being met by increasing imports. Foreign exchange rate fluctuation (devaluation of the rupee) results in a major impact on the economy with an increase in oil prices and resultant inflationary pressure (in 2013 the $-rupee exchange rate increased from 50INR/US$ to 64INR/US$). Like any country, India would like to ensure it’s own energy security; from the perspective of improving energy security, I suggest that India should rely primarily on domestic coal. However, the recent trends have shown increasing coal imports. Investments in efficient coal-based power technology and improved efficiency during coal mining and extraction could help increase the contribution of domestic coal.

Table 3 shows the production, consumption, and estimates of India’s conventional fossil fuel reserves. The physical units have been converted into energy units by using an assumed average calorific value. It can be seen that coal is India’s principal coal reserve. Even if only the proven fossil fuel reserves are considered, the static reserve-to-consumption ratio is over 100 years.

Table 4 shows a comparison of coal-based electricity generation with the major large-scale centralized generation options for India. Coal is clearly the most cost-effective option—both in terms of the capital cost and the final cost of generation. Coal-based plants have the highest CO₂ emission factors and are also responsible for local air pollution (SOₓ, NOₓ, particulates). However, the cost of pollution control equipment does not add significantly to the cost of electricity generation if the least cost emission control strategies are adopted, and could dramatically reduce emissions. In addition, opting for supercritical power plants, thereby reducing auxiliary consumption, will also reduce emissions. In the next 25–30 years,
high-efficiency coal-fired power plants can provide one of the most cost-effective options for India that will enable rapid growth of the power sector.

Figure 4 shows the share of thermal-based power, renewable (including large hydro), and nuclear in India’s electricity generation mix. The power sector in India had a large share of hydro in the early 1970s. Over the last 40 years the share of thermal generation has increased and currently the share of thermal generation is now more than 70%. An ongoing exercise for Energy Technology Vision estimated possible supply mixes for the Indian electricity sector in 2035. Given the difficulty of constructing large hydro projects, its share is unlikely to increase in the future. The nuclear installed capacity is projected to increase to about 69 GW (under the most optimistic scenario) from the existing base of about 5 GW. The share of coal in the electricity generation mix is likely to range from 50–60% in 2035. A scenario whereby India reduces the coal mix to 40% is considered as the highest possible reduction in coal usage. This would imply a 22% share of renewable energy in the electricity generation mix. Even with this high renewable share, the coal installed capacity must grow to 270 GW by 2035. The more likely estimate of installed coal-based power capacity is 340 GW (50% share) in 2035, which represents significant growth from the existing installed capacity of 132 GW in 2013 (i.e., growth rate of 4.4% per year).

The growth of the power sector has been constrained by the availability of capital. As mentioned previously, to date the outlay for the power sector has been about 16% of the total central government outlay. The outlay for new generating capacity is about 12% of the total allotted central government outlay.

**TABLE 4. Comparison of centralized electricity generation options for India**

<table>
<thead>
<tr>
<th>Source</th>
<th>Capital Cost* (million/MW)</th>
<th>Gestation Period (years)</th>
<th>Availability (maximum capacity factor)</th>
<th>Cost of Generation (INR/kWh)</th>
<th>Land Area (m²/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal</strong></td>
<td>INR50/MW US$1/MW</td>
<td>5</td>
<td>92%</td>
<td>INR3/kWh 6 US₵/kWh</td>
<td>2000</td>
</tr>
<tr>
<td><strong>Gas</strong></td>
<td>INR40/MW US$0.8/MW</td>
<td>3</td>
<td>95%</td>
<td>INR3.5–4/kWh 7–8₵/kWh</td>
<td>N/A**</td>
</tr>
<tr>
<td><strong>Nuclear</strong></td>
<td>INR70/MW US$1.4/MW</td>
<td>7</td>
<td>80%</td>
<td>INR4/kWh 8 US₵/kWh</td>
<td>1200–4700</td>
</tr>
<tr>
<td><strong>Hydro</strong></td>
<td>INR60/MW US$1.2/MW</td>
<td>6</td>
<td>50–60%</td>
<td>INR2.5–3.50/kWh 5–7 US₵/kWh</td>
<td>222,000</td>
</tr>
<tr>
<td><strong>Solar PV</strong></td>
<td>INR120/MW US$2.4/MW</td>
<td>1</td>
<td>25%</td>
<td>INR10/kWh 20 US₵/kWh</td>
<td>12,000</td>
</tr>
<tr>
<td><strong>Solar Thermal</strong></td>
<td>INR150/MW US$3.0/MW</td>
<td>2</td>
<td>26%</td>
<td>INR15/kWh 30 US₵/kWh</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>INR60/MW US$1.2/MW</td>
<td>1–2</td>
<td>30%</td>
<td>INR4–6/kWh 8–12 US₵/kWh</td>
<td>100</td>
</tr>
</tbody>
</table>

*Computed at 2012 exchange rate of INR50-US$. **Data not readily available for India, but estimated by author to be 1000 m²/MW.
Consider an alternative scenario where an equivalent amount of generation is to be built using solar photovoltaic. At current costs this would involve an initial investment of 8–8.5 times the investment required by coal or more than 90% of the existing total central government outlay. Hence in the next 25–30 years coal is likely to remain the main source of electricity supply for India, even though its percentage share in the mix may decrease.

RECOMMENDATIONS FOR COAL-BASED POWER IN INDIA

As coal will be a principal source of energy for India for the foreseeable future, I believe improvements in coal resource assessment, production, and utilization are necessary. For example, there is a need to move to the UN classification scheme for reserves (which has been agreed to by India). A more accurate estimation of coal reserves and a mapping of the uncertainties and the quality of the reserves would be useful for energy planning. Development of supply curves for coal, including possibilities for underground coal gasification, coal-based methane, and coal mine methane, would give a clearer idea of the costs of the coal options for the future.

There is also a need to improve the efficiency of coal mining, coal conversion, and utilization. Setting targets for energy efficiency and water consumption in the processing steps would result in a more cost-effective coal sector and also help conserve coal. Issues related to land reclamation, land use for coal mining, coal-fired power plants, ash disposal, and water usage must be addressed for the coal sector to continue growing.

Mining safety is another important issue. The fatality rate per thousand workers has decreased from 0.82 in 1951 to 0.21 in 2007. This should be further reduced by improved safety procedures and technology. Investments in efficient equipment and processes, environmental control equipment, and a well-managed coal and power sector are essential for the continuing growth of a cost-effective coal-based electricity sector.

Supercritical power plants, coal-to-methane conversion, and coal mine methane have already been demonstrated in India. Support should be provided to these important options so they can be slated for accelerated deployment. Underground coal gasification and integrated gasification combined cycle power plants should be demonstrated and assessed for potential commercial viability. Investments in R&D in these fields in India have been subpar. Investment in technology development, R&D, and demonstration projects for clean coal as well as carbon capture and storage is urgently needed. The Ministry of Coal spends a very small fraction of its turnover on R&D. In addition to supporting renewables through projects such as the Jawaharlal Nehru Solar Mission, there is a need to launch focused missions for R&D and technology development for efficient coal-based combustion and gasification. Presently it is not clear if carbon capture and storage will be a viable and cost-effective option vis-à-vis renewables in India. Therefore, it is necessary for India to explore carbon capture and storage options with some well-designed prototypes and a long-term targeted research program.

In order to meet the national goals for development, access to electricity, and energy security, India will need to continue to rely on coal for its electricity sector during the next 25 years. It is important that supporting investments in technology development and R&D are made in coal extraction, coal conversion, and coal-based power technologies in order to improve the efficiency and performance of coal based electricity generation.

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Considering Emissions From Amine-Based CO₂ Capture Before Deployment

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In recent years, there has been movement at both the national and international levels to regulate atmospheric emissions of CO₂. Several potential technologies for carbon capture and storage (CCS) could dramatically reduce global CO₂ emissions from fossil-fueled power plants and other large energy-intensive industries. The successful widespread deployment of post-combustion CO₂ capture (PCC) presents an opportunity for fossil fuel-based economies to significantly reduce their CO₂ emissions while continuing to use their abundant natural resources. In addition, PCC will likely reduce the emissions of criteria pollutants such as SO₂ and NOₓ. Although the potential of PCC to reduce global CO₂ emissions is undeniable, and PCC is moving forward, some hurdles still exist that must be considered before widespread deployment can occur. For example, it is critical to understand, characterize, and regulate any potential emissions that could be caused by the application of PCC technologies.

“Although the potential of PCC to reduce global CO₂ emissions is undeniable, and PCC is moving forward, some hurdles still exist that must be considered before widespread deployment can occur.”

PCC: CAPTURE OF CO₂ FROM FLUE GAS

Amine-based PCC from power plant flue gas is widely recognized as the most advanced PCC technology and will likely be one of the best approaches to dramatically reduce emissions from the existing fleet of power plants (see Figure 1 for a general process schematic). In PCC the flue gas is usually pre-treated to reduce the temperature (typically to 30–50°C) and also remove components which might interfere with the CO₂ capture process. The flue gas is then brought into contact with the aqueous amine-based liquid absorbent in the absorber column. This absorbent reacts with the CO₂ and is subsequently pumped to the desorber (i.e., regenerator) column. In the desorber column the CO₂ is released from the liquid absorbent as a result of the higher temperature (typically 100–120°C). The absorbent is then pumped back to the absorber column for the next cycle.

Aqueous amine absorbents have been used to capture CO₂ and other acid gases for many years in the oil and gas industry. Significant PCC R&D progress has been made over the last decade, resulting in a 25% reduction in the energy consumption of the capture process. The technology is available from...

FIGURE 1. A generic process diagram of a CO₂ capture system.
at least 10 vendors, although it is yet to be tested at full scale. This technology is now ready to be applied to capture CO₂ from flue gas streams of fossil-fueled power plants in demonstration projects such as the 110-MW Boundary Dam project, which is expected to come online in the spring of 2014.

There is a potential for amine losses and solvent degradation during PCC operation at gas- and coal-fired power plants. This article is focused on the concerns associated specifically with coal-fired power plants. A typical 400-MW pulverized coal-fired power plant produces about one million m³ of flue gas per hour. This gas is made up of primarily N₂, CO₂, H₂O, O₂, NOₓ, SO₂, fly ash, and other flue gas constituents. Many of these impurities can be removed using commercially available air pollution control technologies. However, the remaining constituents not captured upstream of the CO₂ capture could affect PCC operation. For example, during the amine absorption process, the solvent can degrade due to interaction with some flue gas constituents. Oxygen, acid gases, and particulates can react with the solvent to produce by-products that will reduce the CO₂ capture efficiency. Some of these by-products are volatile and have the potential to be emitted into the atmosphere. The large quantity of flue gas that must be treated during PCC capture presents a technical and scientific challenge, particularly when impurities already present and new impurities formed need to be taken into consideration.

Non-volatile compounds, which do not evaporate, such as heat stable salts (HSSs), large polymeric compounds, and suspended particles can also accumulate in the PCC system. The non-volatile compounds cannot absorb CO₂ and must be removed from the solution because they affect the physical properties of the solvent and can lead to corrosion and foaming. To reduce the impact of by-product formation in the solvent, a slipstream of the contaminated solvent is drawn to a reclaimer. The contaminated amine solution can contain a complex mixture of chemical compounds that must be identified and quantified prior to disposal.

Amine-based PCC pilot plant studies as well as several laboratory-scale studies have reported the presence of different by-products formed by complex chemical reactions occurring between the flue gas constituents and amines at different sections of the plant. Some of these by-products have the potential to be directly released from the plant as gaseous compounds; others could be entrained in droplets to reach the atmosphere. Once in the atmosphere, amines and their degradation products can undergo further chemical reactions to produce new products, some of which may be toxic.

For amine-based PCC plants, therefore, identification and quantification of major degradation products of health and environmental concern are required. Any potential risks associated with these releases should be identified and mitigated before PCC systems are widely deployed.

Fortunately, the assessment of the potential health and environmental impacts of amines and amine degradation products being released to the atmosphere from PCC plants is becoming the focus of research around the world. This research is needed to reduce gaps in the current knowledge and to provide a better understanding of the various issues related to the atmospheric fate of amine release to the atmosphere.

AMINE SOLVENT LOSSES

Understanding and controlling amine losses is an important aspect to successfully operate and safely deploy a PCC plant. Amine losses will affect the economics of operating the plant due to chemical costs associated with replacing the solvent. In addition, increases in amine losses will increase the subsequent environmental concerns. The amine losses stem from:

- Degradation of solvent to produce different by-products
- Entrainment of solvent defined by the physical carry-over as a mist or spray depending on the droplet size
- Evaporation
- Fugitive losses from the plant due to mechanical issues such as leaks

Generally, amine loss through degradation is the greatest concern; most other mechanisms for amine loss generally can be minimized through correct design.

AMINE DEGRADATION: CASE STUDY OF MEA

Solvent degradation is a challenging issue that can affect the rate of CO₂ capture and can increase corrosion rates, reducing equipment life and increasing the cost of the PCC, and also lead to unwanted emissions of by-products. For monoethanolamine (MEA), a common and widely studied amine solvent, the two recognized degradation pathways are (1) oxidative degradation driven by O₂ and other constituents in the flue gas and (2) thermal degradation.

It has long been recognized that CO₂, O₂, SO₂, NOₓ, and other compounds in flue gas from coal-fired power plants can undergo complex chemical reactions with MEA to produce different degradation products. In addition, the presence of selected trace metals such as Fe and Cu was found to catalyze the amine degradation. Several compounds, such as ammonia, aldehydes, amides, and hydroxymethylamine, have been identified as the primary products resulting from amine degradation. Reactions between aldehydes and O₂ produce carboxylic acids that may dissociate in the solution to form
HSS. In addition, ammonia formed by solvent degradation reacts with MEA in the presence of O₂ to form amides and alkylamines.

Nitrosamines and nitramines, which are carcinogenic compounds, have also been reported as possible degradation products. Although this is cause for concern, the actual risks are unclear because it is not well understood how much of these substances will be formed and emitted during the capture process or formed in the atmosphere after emission. It is known that nitrosamines readily break down in the atmosphere under the influence of sunlight, while nitramines have longer lifetimes. Clearly, much more research is needed on the identification and quantification of nitrosamines and nitramines.

Additionally, more research is needed to understand the effects of fly ash transition metals on the degradation of amines, although the majority of such metals should be captured upstream of PCC.

AMINES IN THE ATMOSPHERE

If amines, which are reactive organic compounds, are emitted from the PCC plant, they and their degradation products can undergo chemical and physical transformation in the atmosphere. As a result, secondary compounds will be formed that can be transported. The nonlinear chemistry of the process of the secondary-pollutant formation makes it difficult to predict these anticipated species and their concentrations. It has been reported that ammonia (NH₃), aldehydes, amides, and secondary aerosols can be produced.

Despite substantial efforts over the last few years to elucidate the atmospheric chemistry of amines, the oxidation mechanisms of these compounds—in particular, the basic formation of selected secondary compounds and growth mechanisms of secondary aerosols—are still poorly understood. Numerous oxidized species have been identified in the gas and aerosol phases, but the formation mechanisms for many species still remain speculative and the full carbon balance is yet to be completed.

INCREASING KNOWLEDGE THROUGH RESEARCH

To better understand amine degradation by-products and how they might behave once emitted from a power plant, CSIRO employed a combination of experiments and simulations. The CSIRO smog chamber, shown in Figure 2, was used to carry out experiments under a controlled environment to study reactive organic amines. Experiments were generally conducted at concentrations and humidity representative of atmospheric conditions. The results were then used to model the degradation of reactive compounds and formation of secondary compounds.

Using data collected in the smog chamber, a simulation was run using the CSIRO coupled, three-dimensional meteorological, emission, and chemical-transport modeling system. A coal-fired power plant in New South Wales was selected as the base case plant. Select emissions with and without PCC are provided in Table 1.

As expected, the emissions of NO and NO₂ (NOₓ) decreased and emissions of MEA and NH₃ increased, although predicted emissions remained low.

RECOMMENDATIONS TO POLICYMAKERS

The deployment of CCS technologies could drastically decrease CO₂ emissions from fossil fuel-fired power plants and would allow for coal and other fossil fuels to continue to be used to meet future energy demand in a carbon-constrained world. Amine-based post-combustion capture of CO₂ technology is a readily

<table>
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<th>Parameter</th>
<th>Base Case Power Plant</th>
<th>With PCC (Hypothetical)</th>
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</thead>
<tbody>
<tr>
<td>Flue Gas Volumetric Flow Rate (m³/s)</td>
<td>1900</td>
<td>1500</td>
</tr>
<tr>
<td>NO (g/s)</td>
<td>482</td>
<td>482</td>
</tr>
<tr>
<td>NO₂ (g/s)</td>
<td>24</td>
<td>0.0</td>
</tr>
<tr>
<td>MEA (g/s)</td>
<td>0.0</td>
<td>0.21</td>
</tr>
<tr>
<td>Ammonia (NH₃) (g/s)</td>
<td>0.02</td>
<td>0.18</td>
</tr>
</tbody>
</table>
available technology, but it is important that emissions from the deployment of PCC meet implemented air quality regulations.

The deployment of PCC will reduce SO_2, NO_x, and particulate emissions of coal-fired power plants. However, some other emissions could be generated in the process and may be emitted to the air if appropriate control technologies are not adopted.

The economic, social, and environmental impacts of PCC must be fully understood before the technology can be widely deployed. To date, an extensive amount of research has been focused on improving the techno-economic aspects of the PCC. Over the last few years, the importance of social and environmental acceptance has begun to attract increasing interest, including studies related to the identification and quantification of the potential health and environmental risks. Operating in a financially sound way—while demonstrating the social and environmental benefits of the technology—will benefit stakeholders, society, and regulators, so this research must receive increasing support.

We recommend that analysis of the potential health and environmental risks associated with the emissions from a PCC plant be considered as the basis for qualifying future operation of a PCC plant. Operation and technical mitigation measures, as necessary, are recommended to reduce the anticipated impacts.

We also suggest that regulatory agencies should specify maximum acceptable levels of PCC-related emissions for specific regions. Emissions of carbon monoxide (CO), NO_x, SO_2, hydrogen fluoride (HF), hydrogen chloride (HCl), and particulate matter (PM) from the flue gas are already authorized under existing air permits issued by regulators, and a similar model could be followed for PCC-related emissions. Once more information related to their emissions is conclusive and available, current air quality guidelines may need to be updated to include limits for NH_3, nitrosamines, and nitramines. More generally, PCC-related emissions need to be better understood before PCC is widely deployed.

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Exploring the Possibilities: The NETL Power Plant Water Program

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Water is essential for thermoelectric power production. In fact, thermoelectric generation is one of the largest usages of water in the U.S. and around the world. However, most of this water is returned to the water body of origin (slightly warmer). Irrigation for agriculture results in the largest consumption of water, most of the water used in agriculture is not returned to the place of extraction. Converting heat (fossil fuel, biomass combustion, or nuclear reactions) to electricity is accomplished with the Rankine cycle (i.e., steam cycle). To provide an example of a steam cycle in thermoelectric power production, a typical pulverized coal-fired power plant and the associated water path is shown in Figure 1. Water is pressurized and boiled to produce high-temperature, high-pressure steam which is expanded over a turbine to spin a generator to produce electricity. The steam is condensed from a gas to a liquid at the turbine exit. This creates a vacuum that pulls the steam over the turbine. The water is constantly recirculated within this Rankine cycle and is repeatedly converted from gas to liquid and back again. The overall power plant efficiency is restricted by the temperature difference between the steam and condensate; the upper temperature limit is determined by steel properties and the lower temperature determined by the cooling water temperature. Much electricity-related water usage occurs in the steam condenser; ideally, the condensate will be a low temperature, the steam will be a high temperature, and the power plant efficiency can be maximized. If the condensate is not at a low temperature there will be a backpressure on the turbine, which decreases the efficiency of the power plant. If insufficient cooling is available, the plant will not be able to operate. Since water is most often responsible for cooling,

FIGURE 1. Water balance for a 500-MW subcritical bituminous coal-fired power plant. Not shown leaving the flue gas stack is approximately 928 gpm of water vapor (19%).

Note: 1000 gpm = 227 m³/hr
it is clear that the relationship between water and electricity is a critical one. However, as water resources become more scarce, researchers and technology developers are employing different options to reduce water requirements.

WATER USE FOR DIFFERENT SOURCES OF ELECTRICITY

Figure 2 shows the average water requirements for several sources of electricity generation, all of which utilize the Rankine cycle described in Figure 1. Several options for coal-based power generation are included. Coal-fired power plant water requirements are generally higher than those for natural gas, but lower than the water usage required for nuclear-based power. Among the different types of coal-fired power plants there is still room for improvement; there are many water-saving technologies that can be employed to reduce overall water consumption. From Figure 2, it is clear that for all the different types of thermoelectric plants, the vast majority of the water requirements are related to cooling. This is a tremendously important focus area when developing water-saving technologies.

SOLUTIONS IN THE WATER/COAL ENERGY NEXUS

As noted, the relationship between water and electricity is a critical one. For coal-fired power plants, many potential improvements can be made to reduce water consumption; in the U.S. some of these improvements have been driven by regulation. With revisions to the U.S. Environmental Protection Agency (EPA) Clean Water Act 316(b), regulations on cooling water intake structures made withdrawing water for cooling more costly and advocated for the replacement of once-through cooling with cooling towers. As the regulations were revised, water permits for coal-fired power plants became more difficult to obtain. In addition, increased regulations on air emissions also resulted in increased water use for power plants; the control of air emissions often involved the use of technologies that transferred the emissions from the gas phase into water. To characterize the water usage by coal-fired power plants and explore potential solutions to water usage concerns, the National Energy Technology Laboratory (NETL) Strategic Center for Coal initiated a power plant water research program in 2001. The following sections in this article discuss general options for specific water-saving strategies explored under this research program.

Cooling and Emissions Control

As is shown in Figure 2, cooling is the largest user and consumer of water for coal-fired power plants. Emissions control, especially wet flue gas desulfurization (FGD), is also another significant consumer of water. Together, emissions control and cooling make up the majority of water usage for coal-fired power plants, although both can be accomplished with alternative technologies.

Once-through cooling is considered the traditional method of cooling coal-fired power plants. However, to meet EPA regulation requirements and to avoid discharging large quantities of water and potentially affecting the original water body, many power plants have opted for recirculation and cooling towers.

FIGURE 2. Water consumption by various thermoelectric power production options

Note: 1000 gal = 3.79 m³

FIGURE 3. Fort Martin power plant in West Virginia. The water exiting the stack (foreground) and the cooling towers (diffuse cloud in the background) can easily be seen as the cold air condenses the water.
The recirculating water must be cooled, which is accomplished by evaporating water in the cooling tower; the latent heat of evaporation cools the water. Cooling towers result in less water being withdrawn, but more water being consumed (i.e., water is continually lost to evaporation). Figure 3 is a photograph of the Fort Martin power plant in West Virginia, U.S. The large plume of condensing water from the cooling towers, which is sometimes mistaken for pollution, is clearly visible and indicative of the amount of water being evaporated. Figure 4 illustrates the water balance at a subcritical plant that employs recirculating cooling: The plant loses 542 gal/MWh from the cooling tower and 88 gal/MWh for FGD makeup. Clearly cooling is responsible for the majority of this plant’s water consumption.

Dry cooling is another option that can be employed: Air, not water, is the cooling media. The power plant condensate is usually cooled inside a heat exchanger as ambient air is forced via large fans to flow around finned tubes, all of which is often referred to as an air-cooled condenser (ACC). Although no water is consumed for dry cooling, there are drawbacks. The power plant water temperature can only be lowered to a certain point (i.e., the ambient dry bulb temperature), which in the summer creates a large energy penalty, on the order of 10% of the power plant’s electricity output. This energy penalty results from backpressure on the power plant turbine. Dry cooling is also more capital intensive, as it requires a larger structure. However, dry cooling can be an important option for power plants in severely water-restricted areas.

Various novel improvements in cooling technology are also being studied; because the most significant opportunity for water savings is to employ dry cooling, therefore, alternative options for dry cooling are being investigated. For example, a liquid desiccant has been tested at the pilot scale as a heat-transfer medium between the condenser and the atmosphere. Water is used to condense the steam, and the warm water is cooled in a water-to-desiccant heat exchanger. The desiccant is then cooled with a direct-contact desiccant-to-air heat exchanger. The water in the desiccant does not evaporate; in fact, the desiccant absorbs additional water during the night, and this excess moisture evaporates during the day. This provides an additional cooling effect and allows the desiccant temperature to go below the dry bulb temperature, and therefore reduces the energy penalty of dry cooling. Preliminary cost estimates collected under the NETL power plant water program were 40% less than a traditional ACC and the parasitic power requirements were 35% lower. The annual costs for desiccant dry cooling were within ±10% of the comparable wet system.

Currently, wet FGD is the largest emission-control-related water requirement at coal-fired power plants. As is shown in

Figure 4, the FGD make-up can require about 88 gal/MWh. There are also dry FGD technologies, although they can require injection of large amounts of dry sorbent. Whether wet or dry FGD is employed is a plant-by-plant decision.

Although CO₂ capture and storage (CCS) is not yet commercially deployed, the water consumption of the process has been considered by NETL. The addition of carbon capture to an existing coal-fired power plant was analyzed using the most commercially viable option, an amine absorption process. Fluor’s Econamine technology was used as the basis for the analysis. This process requires a large amount of additional water, primarily due to the loss in efficiency from separating CO₂ from the flue gas as well as the compression of the CO₂. Figure 5 includes a water balance for a subcritical coal-fired power plant with recirculating cooling, FGD, and CCS. Notably, the cooling water makeup has increased from 524 gal/MWh (no CCS) to 1049 gal/MWh for a similar plant with CCS.

**Using Waste Heat**

NETL supports external research through competitive solicitations and, through this mechanism, has supported novel research to improve and reduce water use in coal-fired power plants. Utilization of power plant waste heat—for example, using hot air to dry coal—is one approach to reduce the amount of water needed for cooling. Drying coal prior to combustion increases the efficiency of the power plant. Based on lab-scale coal drying research, a fluidized bed dryer was designed; the fluidized bed dries the coal using air warmed...
Finding Alternative Sources of Water

Alternative sources of freshwater, rather than from the surface, have also been studied and several options exist. For example, mine pool water, which is water that has collected in underground voids left by mining, is used for cooling in the anthracite region of Pennsylvania and could also be used from the area under the mined Pittsburgh coal seam. Another example of an alternative water source is water produced during oil and natural gas production, although applications would be limited by transportation and treatment costs. While it has been shown that CCS technologies could result in increased water usage, there is also a chance to recover water during the process. If CO₂ is stored in saline aquifers, it is possible that the CO₂ storage could be enhanced by removing the aquifer water; then the water could be used for power plant cooling. Today, the most used alternative cooling water supply is treated municipal wastewater. This water source is fairly good quality and located next to nearly all U.S. power plants.

Water can be recovered from within the power plant, from water vapor leaving the cooling towers and/or the flue gas stack. For example, NETL funded research that led to the commercialization of the SPX ClearSky Plume Abatement Cooling Tower, which employs an air-to-air heat exchanger that uses ambient air to condense some of the water vapor in the evaporative cooling tower exhaust. The first prototype was tested at San Juan Generating Station (New Mexico, U.S.); a follow-up NETL project redesigned the heat exchanger to make it smaller. The tower condenses about 20% of the water leaving the cooling tower. It is estimated that the current model will pay for itself in water savings in about seven years. With further development and a larger heat exchanger, it is thought that this tower could condense 40–50% of the water from the cooling tower. Modularization of the heat exchangers could decrease the size and lower the cost.

Water could also be recovered from the flue gas. NETL has supported testing this opportunity in three ways: heat exchangers, desiccant absorption, and a ceramic membrane. All were found to be economically viable. Lehigh University tested the condensing heat exchangers in a flue gas slipstream at three coal-fired power plants. Cost–benefit studies of condensing heat exchangers for full scale suggest that placing them downstream of wet FGDs could be cost effective. Estimated annual benefits are $1.3 million versus costs of $0.8 million. In addition to the recovered water, latent heat from the condensing water is put back into the steam cycle for increased efficiency.

Along the same lines of capturing water from flue gas, a calcium chloride desiccant solution was successfully used to absorb water from pilot-scale flue gas using both natural gas and coal at the North Dakota Energy and Environmental Research

FIGURE 5. Water balance on a subcritical, pulverized coal, 500-MW power plant with recirculating cooling, FGD, and amine absorption-based CCS

by passing over the condenser and also using some heat from the flue gas. This concept was demonstrated with Clean Coal Power Initiative funding at Great River Energy’s Coal Creek Station. This project resulted in an estimated 2–4% efficiency improvement (or heat rate reduction). Part of the efficiency increase is due to improved performance of the coal pulverizers and induced draft fans. Notably, it was also estimated that the process would save 5–7% of the cooling water normally required.

Another possible use of waste heat is to reject the heat from the steam cycle to another Rankine cycle, such as ammonia or an organic chemical that boils at a lower temperature. This “bottoming cycle” would generate additional power from the waste heat. Although this concept has not been tested at a power plant to date, it is believed that it has merit. While a bottoming cycle may be capital intensive, an absorption chiller could be integrated into many processes. Another project funded by DOE investigated the use of ice produced in off-peak times to cool the inlet air of a gas turbine. This was calculated to have a net power gain up to 40% and a heat rate reduction as much as 7%. Water can also be recovered from the inlet air as it cools, thus being a water source. An absorption chiller run on waste heat could provide cold air to the turbine. Also, cold air could be used to offset energy penalties of dry cooling on a hot day or to reduce the overall size of an ACC.
Center (EERC). The Gas Technology Institute (GTI) tested their Transport Membrane Condenser (TMC) in a five-week slipstream of coal-fired boiler flue gas. The TMC is a ceramic membrane with nano-sized pores that condense water. High-purity water was recovered and some of the latent heat was put back into the steam cycle. This membrane was originally used in natural gas applications and there are ongoing discussions to further test it in coal-fired applications. GTI is also testing a smaller version in home furnaces to recover water from home heating systems and use it to humidify indoor air.10

Southern Company is testing waste heat integration into a solvent (amine)-based 25-MW CO2 capture project at Plant Barry.9 A waste heat recovery (High Efficiency System, HES) technology is a heat exchanger that extracts waste heat from flue gas exiting the power plant’s air preheater (flue gas cooler) and makes that heat available elsewhere in the power plant. In addition to other benefits, the flue gas cooler will reduce the amount of water used in FGD by about 30%. This flue gas cooler is already used in Japan to reheat scrubbed flue gas to eliminate visible plumes. Corrosion can be a problem, but tests in Japan have shown that if the ash/sulfur ratio is in the proper range, sulfur can be removed on the ash in an electrostatic precipitator.

Cooling towers require discharging salty or hard (mineral rich) water (blowdown) to keep the condenser tubes free of corrosion and buildup. In some cases it could be worthwhile to treat this blowdown stream so that it can be reused. NETL has supported experimentation on methods to remove contaminants in the cooling water: removing hard water ions by precipitation with an electrical pulse spark and mechanical filtration; precipitation with electrodeionization; and using various sorbents to filter out impurities. These methods could also be employed to utilize lower quality water instead of freshwater in cooling towers.

Some work was also done on managing the wastewater from coal-fired power plants.11 Several novel adsorbents were tested to remove various contaminants. Also wetlands were used to collect additional water and treat and clean wastewater. Management of water in wetlands was tested at the Hines Energy Complex in Florida and significant improvements in cycle efficiency were found by using wetlands in a cooling pond to reduce cooling water temperature.

CONTINUED EFFORTS

The projected growth in global population will continue to increase the pressure on water and energy resources. As the U.S. Department of Energy further investigates the close link between water and electricity, it is hoped that further research will lead to development and deployment of the options to reduce the water requirements associated with thermoelectric power production.

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Electric power generation requires reliable access to large volumes of water. This need persists at a time of declining supply, when regions of the world are experiencing water constraints due to population growth, precipitation fluctuations, and changing demand patterns. Water constraints could affect future electricity generation technology selection, plant siting, and plant operation.

Although water needs are plant specific, for most pulverized coal-fired power plants over 90% of water demand is drawn for cooling. As a result, the Electric Power Research Institute (EPRI) and other research organizations worldwide are seeking to optimize power plant water utilization by developing technologies to reduce the largest single use—cooling. Thermal power plants cannot operate without adequate cooling; steam from the electricity generation turbine must be cooled to minimize back pressure on the turbine. Improved cooling allows for power plants to operate at an overall higher efficiency.

Most existing power plant cooling systems in the U.S. are based on wet cooling technologies. Alternative dry cooling technologies that reduce water consumption are available and becoming more prevalent. However, these technologies often come with economic tradeoffs (higher capital expenses, increased operational/maintenance costs) and steam-condensing performance penalties.

“For most pulverized coal-fired power plants over 90% of water demand is drawn for cooling.”

Advanced cooling technology development, therefore, is focused on research to improve the efficiency of existing cooling technologies and to discover techniques, designs, and applications that reduce the economic disadvantages and improve the efficiency associated with alternative technologies. Other important considerations for improvements include reducing the size or footprint of cooling systems, utilizing alternative coolants instead of potable water, and enhancing condensation, evaporation, and sensible heat transfer mechanisms.

**COOLING SYSTEMS**

Power plant cooling technologies generally include four different types: once-through cooling, recirculated wet cooling, dry cooling, and hybrid cooling.

**Once-Through Cooling**

Once-through cooling (OTC) systems withdraw water from a natural water body (such as a lake, river, ocean, or manmade reservoir). The water is pumped through the tubes of a steam condenser (see Figure 1 for a schematic) where it is warmed about 10–30°F (8–17°C) depending on system design, after which it is returned to the original source. The amount withdrawn varies from 25,000–50,000 gallons/MWh (95–190 m³/ MWh). Although none of the water is consumed within the plant, some consumptive loss results due to evaporation.
Recirculated wet cooling is similar to OTC in that cold water flows through the tubes of a steam condenser and steam condenses on the outside of the tubes. However, instead of being returned to the source, the heated water leaving the condenser is pumped to a cooling device such as a tower, pond, or canal, where it is cooled by evaporation of a small portion of the water. The cooled water is then recirculated back to the condenser tube inlets (see Figure 2). Cooling towers involve 95% less water withdrawal than OTC systems, but typically are less efficient due to the higher parasitic load of the fans (mechanical draft towers) and the higher condensing temperatures compared to OTC.

Cooling towers do not increase the temperature of the water source, but they do consume more water than OTC. Water is lost through evaporation (necessary to reduce the temperature of the water so it can be recirculated), blowdown (i.e., removal of a fraction of the recirculating water to manage the mineral content), and drift (i.e., less than 0.0005% of the water is lost as droplets are entrained and carried out of the tower).

Although water withdrawal is reduced, recirculated wet cooling systems have several cost- and energy efficiency-related disadvantages compared to OTC: 1) capital costs are typically twice as much as OTC, 2) they typically have higher parasitic load for the fans, and 3) they have a potential for power generation capacity reductions on hot days.

Recirculating cooling systems can reduce impingement and entrainment by as much as 90% or more, but their cost can make the option problematic for some power plants. Less costly protection technology alternatives (e.g., fish-friendly traveling water screens including fine mesh, barrier nets, velocity caps, behavioral deterrence, wedge wire screens) can attain similar performance depending on site-specific hydraulic, biological, and plant operating characteristics.

Dry Cooling

Dry cooling systems can be either direct or indirect. Direct dry cooling systems condense turbine exhaust steam in an air-cooled condenser (ACC) (see Figure 3). Indirect dry cooling systems utilize a cooling water loop to condense turbine steam in a conventional surface condenser or a contact condenser (i.e., Heller system). The cooling water, which has been heated by the condensing steam, is then recirculated to an air-cooled heat exchanger before being returned to the condenser.

Although dry cooling achieves significant water savings, the capital costs are up to five times more expensive than recirculating wet cooling. Also, the condensing temperature, in the case of direct dry cooling, or the cold water temperature, in the case of indirect dry cooling, is limited by the ambient temperature and humidity. As a result, dry cooling systems can produce up to 10–15% less power during the hottest days of the year, when the steam condensing temperature (and hence the turbine exhaust pressure) is substantially higher than it would be with wet cooling.
Hybrid Cooling

Hybrid cooling refers to cooling systems with both dry and wet cooling elements, which are used individually or together to achieve the best features of each: that is, the wet cooling performance on the hottest days of the year and the water conservation capability of dry cooling during the remainder of the year. Hybrid systems have the potential for more than 50% water savings compared to wet cooling towers (see Figure 4).

The drawback to hybrid cooling is that it can be more expensive compared to recirculated wet cooling towers alone, and significant amounts of water may still be needed, particularly during the summer. A hybrid system will also be subject to all of the operation and maintenance issues of both cooling systems (e.g., fan power, blowdown, cooling water treatment, freeze protection). Therefore, it is most suitable for sites where conservation is required, but some water is still available for partial evaporative cooling to shave hot-day efficiency penalties.

ADVANCED COOLING R&D

Research and development on advanced cooling technology for power plants is focused on several targets. For reducing water consumption in wet cooling systems, research is aimed at less evaporative loss in cooling towers, more efficient and compact liquid-cooled heat exchangers or condensers, and more efficient once-through cooling designs. For dry cooling systems, research has focused on reducing condensing temperatures by improving the air-side heat transfer coefficient without significantly increasing ACC size or air-side pressure drop (fan horsepower), and developing improved methods for control of flow-assisted corrosion inside the tubes.

In this arena, EPRI is pursuing early-stage, high-risk concepts and developing advanced technologies with game-changing
potential for reducing freshwater withdrawal and consumption and improving energy conversion efficiency at existing power plants.

Since 2011, the Water Use and Availability Program within EPRI’s Technology Innovation Program has released three global Request for Information solicitations and conducted innovation scouting to help identify ideas with breakthrough potential. Among the 168 proposals received to date, 12 projects have been initiated, involving wet, dry, and hybrid cooling technologies. In addition, EPRI has recently consolidated ongoing research efforts into a Water Management Technology Program, which conducts advanced research across several fronts to improve power plant water use efficiency, decrease withdrawal rates, and reduce pollutant discharges.

A major focal point for future research is a new Water Research Center (WRC), at Georgia Power’s Plant Bowen, a 3500-MW coal-fired plant. This first-of-its-kind, industry-wide resource offers a pilot-scale infrastructure for conducting scaled-up, plant-based water research. The WRC provides electric generating companies, research organizations, and vendors with access to a field demonstration facility that has treatable water, monitoring and analysis facilities, and specialist staff. It is hoped that research conducted at the WRC will uncover insights on best practices for sustainable water management and meeting wastewater restrictions.

EPRI research on advanced cooling includes the following select technology investigations.

Thermosyphon Cooler System

Hybrid cooling systems typically incorporate conventional wet cooling towers and air-cooled condensers, with the latter operating the majority of the time and the former employed to mitigate performance penalties at high ambient temperatures. A novel hybridization concept, developed by Johnson Controls, applies a dry-heat-rejection technology, called thermosyphon cooling (TSC), which was originally developed for space conditioning in buildings. TSC units, consisting of an evaporator and an air-cooled condenser, pre-cool the hot water from the steam condenser prior to the wet cooling tower.

By reducing the heat load on the cooling tower, TSC hybrid systems have the potential to reduce annual evaporative losses, makeup water requirements, and blowdown volumes by up to 75% without sacrificing electrical output on the hottest summer days. Relative to other dry cooling options, TSC technology promises easier, more flexible, lower-cost integration at existing plants and in new builds in incremental, modular sections, with minimal plant outages required.

Ongoing design and modeling research is addressing issues of scale-up, cooling tower integration, and cost and performance relative to other cooling configurations for conceptual 500-MW plants at five U.S. locations with differing climates. Also, a pilot-scale system, incorporating a 1-MW equivalent size TSC unit and cooling tower, is being tested at the Water Research Center. The project will determine how much water can be saved by operating a TSC unit in series with a conventional wet cooling tower. Researchers will also determine the energy penalty incurred and the most effective means for scale-up.

Dew-Point Cooling Tower

The cold water return temperature of traditional recirculating wet cooling towers can be limited by the temperature and humidity of the ambient air. To address this issue, EPRI, in collaboration with the Gas Technology Institute (GTI), is investigating a concept called dew-point cooling to attempt to reduce the cold water return temperature further. This technology enhances the standard tower performance by constructing dry channels between wet channels in the tower, with a thin-walled fill material, and exploiting evaporative cooling on the wet side of the fill to cool the ambient air passing over the dry side. This pre-cooled air is then used for contact evaporative cooling with the condenser water.

Dew-point cooling offers the potential to improve the water efficiency as well as the overall efficiency of thermal power plants with conventional wet and hybrid wet-dry cooling towers. Preliminary evaluations indicate that tower fill replacements that allow the pre-cooling of ambient air could significantly reduce evaporative losses and makeup water requirements.
Eco-WD Cooler

The Eco-WD Cooler (wet-dry cooling tower), developed by EVAPCO, has the potential to conserve water and energy at power plants by employing an innovative wet-dry cooling tower technology.

This cooling tower technology works in wet-dry mode during the hot summer months and in dry mode the remainder of the year. In wet-dry mode, hot water is initially cooled through air-cooled heat exchangers and further cooled through heat exchanger bundles sprayed with treated water. In dry mode, the spray system is turned off, and the system uses no water for evaporative cooling. In addition, the Eco-WD Cooler has a limited visible condensate plume in wet-dry mode and no visible plume in dry mode. The technology could be easily retrofitted to plants currently using all-wet cooling.

Research currently underway at the WRC is gathering performance and operation data under varying loads and year-round weather conditions, and is demonstrating the cooler’s ability to conserve water and energy and to reduce plume visibility.

Hydrophobic Condenser Tube Surface Treatment

The design of steam condensers is based on filmwise condensation, since condensing steam will form a water layer on the surface of the condenser tube. This film of condensed water acts as an additional barrier to the heat transfer process. Significant enhancement of the heat transfer efficiency can be achieved by forcing the condensate to bead up into droplets, which can be swept off the surface by the steam flow, a process known as dropwise condensation. However, to date, there has not been a reliable means of generating dropwise condensation under industrial conditions for long periods, since the required coatings and surface modifications deteriorate with use.

NEI Corporation has developed a hydrophobic surface treatment, called SuperCN™, which has shown potential for promoting dropwise condensation in industrial condensers. The treatment results in a durable, micron-thick coating on condenser tubes, leading to dropwise condensation. Research currently underway is investigating the application characteristics and customer incentives of the hydrophobic surface treatment technology.

Results indicate that the hydrophobic coating can be applied to the shell side of an existing, in-place heat exchanger with a flow coating method in a cost-effective way. The coating was shown to have significantly better abrasion and scratch resistance than a pristine stainless steel substrate. In testing, the coated tube maintained its high hydrophobicity after three months of durability testing, with alternating conditions of continuous condensation and ammonia vapor conditioning. A cost–benefit analysis of the coating technology also suggested that potential savings are available from the application of hydrophobic coating to surface condenser tubes.

Hybrid Dry/Wet Dephlegmator

The chief disadvantages of dry cooling systems are power capacity reductions and efficiency penalties during periods with hot temperatures. EPRI is sponsoring research at the University of Stellenbosch in South Africa to address this issue. The research is focused on developing a new design for the part of an ACC called the dephlegmator, which provides a secondary condenser that facilitates vapor flow through the primary condensers, and flushing them of any non-condensable gases.

This research project proposes to develop a novel hybrid (dry/wet) dephlegmator (HDWD) that would replace the conventional all-dry dephlegmator unit in an ACC. The HDWD consists of two stages; the operating mode of the second stage can be controlled in response to changing ambient conditions. During periods of low ambient temperature, when air cooling is sufficient, the second stage is operated dry. During hotter periods, deluge water is sprayed over the plain tubes, and the second stage is operated as an evaporative condenser.

It is believed that this technology has the potential to increase power production on the hottest days as compared to conventional ACCs. It would also use less makeup water than wet cooling tower systems and less water than currently used by dry cooling with evaporative pre-cooling of the inlet air.

The EPRI project aims to further develop the design concept, perform modeling and experimental investigations of various options, and conduct technical and economic feasibility studies.

COLLABORATIVE OPPORTUNITIES WITH EPRI

In 2013, EPRI and the National Science Foundation (NSF) released a joint solicitation to advance dry and dry-wet hybrid cooling technologies for power plant applications. The project is a US$6 million joint collaboration, which aims to attract the top talent to power plant cooling innovation and fund five to 10 projects. Award notifications will be announced in early 2014.

EPRI is also collaborating with its domestic and international utility members on its advanced cooling research. For example, in 2013, Eskom hosted an EPRI tour of the utility’s dry cooling
facilities in South Africa. The EPRI team visited operating indirect (Kendal) and direct (Matimba) dry cooling systems as well as new state-of-the-art ACC systems under construction at Medupi and Kusile. These experiences provided by Eskom served as an important benchmark in setting standards for researching the next generation of dry cooling technologies.

**CASE STUDY: ESKOM’S APPLICATION OF DRY COOLING TECHNOLOGY**

In South Africa, with its historically scarce water resources, Eskom has been a technological leader in dry-cooled coal-fired power plants for more than 30 years.

The utility operates both the world’s largest direct-dry-cooled (Matimba Power Station) and indirect-dry-cooled (Kendal Power Station) plants. All fossil-fueled new-build Eskom power plants are dry cooled, and the utility is in the process of constructing new dry-cooled plants at Medupi and Kusile. In 2010–2011, the Eskom fleet consumed a total of 327 million m³ of water for power generation. Without innovative, efficient cooling systems in place, the consumption would have been 530 million m³.

Matimba Power Station has six units with a total installed capacity of about 4000 MW. Using direct dry cooling, the plant reduces water consumption to about 0.1 L/kWh (0.1 m³/MWh). This level is approximately 19 times less than an equivalent wet-cooled power plant. Matimba uses about 3.5 million m³ of water per year, compared to an equivalent wet-cooled power plant, which would use 50 million m³.

Medupi Power Station, currently under construction, will surpass Matimba as the largest direct-dry-cooled plant. Medupi will have six units with a total installed capacity of approximately 4800 MW. The footprint of the ACC at Medupi is 108 x 669 m, or the equivalent of 10 football fields. The design at Medupi incorporates a number of lessons learned at Matimba, including extended spacing between the ACC and turbine hall to minimize impacts from wind.

Kendal Power Station has six units with a total installed capacity of about 4116 MW utilizing indirect dry cooling. The plant employs six natural-draft dry-cooling towers, each 165 m tall. Water from a standard surface condenser is circulated to the towers, where it enters a series of heat-exchange elements at the base of the cooling shell. Air enters the bottom periphery of the towers, is heated by passing over the heat-exchange elements, and rises in the tower, pulling in cooler ambient air from the bottom. The system does not require fans. Water consumption for the power plant is about 0.08 L/kWh (0.08 m³/MWh).

Eskom calculates a number of significant energy and cost penalties for dry cooling. One penalty involves increased power demand for cooling fans. At each of Matimba’s six units, the dry cooling system uses 48 fans that are 30 ft (~10 m) in diameter. Fan operation corresponds to an auxiliary power demand of 72 MW, or 2% of the plant’s total generating capacity. In addition, generation performance at a dry-cooled plant is sensitive to meteorological conditions. In particular, high ambient temperature and high winds can result in reductions of generating capacity of up to 10–15%.

**WEAKENING THE ENERGY/WATER RELATIONSHIP**

As energy and water demand grow, there is a tremendous incentive to reduce the water required for energy generation. Cooling water is currently the largest draw of water for thermal power plants, so it has been the focus of a large amount of water-saving technology development; the projects discussed in this article represent only a sampling of the ongoing efforts globally. 👑

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Coal combustion can lead to the formation of sulfur dioxide ($\text{SO}_2$) and small amounts of sulfur trioxide ($\text{SO}_3$). Further amounts of $\text{SO}_3$ are generated in the selective catalytic reduction (SCR) system, which is widely used for NO$_x$ control. These oxides can lead to environmental and health problems. Consequently, both international and national regulations have been implemented that limit the amount of sulfur oxides ($\text{SO}_x$) and other pollutants that can be emitted from coal-fired power plants. A wide range of commercial flue gas desulfurization (FGD) processes are available to remove $\text{SO}_x$ from the flue gas. Wet scrubbing is by far the most common system with over 80% of installed capacity worldwide. However, these systems require large supplies of water. FGD technologies that reduce water usage are becoming more important due to the large number of systems being installed globally. This will increase pressure on power plants to lower their water consumption.

"FGD technologies that reduce water usage are becoming more important due to the large number of systems being installed globally."

**FGD AND WATER CONSUMPTION**

Large amounts of water are consumed within a coal-fired power plant for cooling purposes, FGD makeup, boiler makeup, and other uses. The amount consumed varies depending on the type of plant (subcritical, supercritical, or ultra-supercritical), the cooling system employed, the FGD system, and other factors. Cooling is responsible for most water usage at many plants. The FGD unit is the second-largest consumer of water, closely followed by the boiler. Adding a CO$_2$ capture (amine-based) system increases the FGD makeup water consumption by ~45–50% for both subcritical and supercritical plants. This is partly because a very low flue gas SO$_x$ level (<10 ppm) is needed to avoid contamination of the amine solvent.

For sites utilizing a dry/air cooling system instead of a wet tower, or once-through seawater cooling, the water consumption of the FGD wet scrubber is proportionally much higher: It can easily be responsible for 40–70% of the total site water usage. This article is focused on FGD processes that consume less than 60% of the amount of water used in conventional limestone wet scrubbers.

**SEMI-DRY SCRUBBER TECHNOLOGIES**

Dry scrubbers are the second most common FGD system installed on coal-fired power plants with less than 10% of global installed capacity. Two principal types of dry scrubbers are in use today:

- Spray dry scrubbers (SDS), also called spray dry absorbers or lime spray dryers
- Circulating dry scrubbers (CDS)

Both of these systems use a calcium-based reagent (calcium hydroxide) which is introduced as a slurry in SDS or, in some...
CDS designs, as a dry powder with separate injection of water. All of the water introduced into the SDS/CDS vessel is evaporated, and therefore no wastewater is generated. So although they are termed dry scrubbers, they do, in fact, consume water and are more accurately classified as semi-dry FGD systems. They typically consume approximately 60% less water than wet scrubbers.\(^2\)

**Spray Dry Scrubbers**

Around 40 GW of coal-fired capacity worldwide are equipped with SDS, the majority of which are installed in the U.S. In the SDS process (see Figure 1), a concentrated lime slurry is introduced into the top of the absorber vessel through rotary atomizers or dual fuel nozzles. These atomize the slurry creating a fine mist of droplets containing the reagent, which reacts with SO\(_2\) and SO\(_3\) in the downward flowing flue gas to form calcium sulfite and sulfate. Simultaneous cooling of the flue gas occurs.

The flue gas exits the absorber and passes through the particulate collector where the reacted sulfur compounds, fly ash, and unreacted sorbent are removed. The clean flue gas is then emitted to the atmosphere through the stack. A portion of the solid products collected from the bottom of the scrubber and the particulate collector is typically mixed with wastewater from elsewhere in the plant and recycled back to the scrubber to improve sorbent utilization, as well as to promote droplet drying in the SDS vessel. The flue gas typically takes ~12–15 sec to pass through the scrubber.

**Circulating Dry Scrubbers**

The total global capacity of utility units using CDS is ~15 GW.\(^3\) There are units in Europe, Asia (in particular China), and the U.S. Unlike SDS, CDS are upflow reactors in which the flue gas and calcium hydroxide reagent are introduced at the bottom of the reactor. The removal of SO\(_x\) can take place either in a fluidized bed [circulating fluidized bed (CFB) scrubbers and gas suspension absorbers] or in an entrainment process (NID™).
Circulating Fluidized Bed Scrubbers

A flow diagram of the CFB system at the Dry Fork power plant near Gillette, Wyoming, U.S., is given in Figure 2. The flue gas enters the CFB reactor through a bank of venturis. These increase the velocity of the flue gas before it mixes with the dry hydrated lime (calcium hydroxide) and recycled solids to create the characteristic fluidized bed. The fluidized bed allows a high degree of contact between the flue gas and solids for the desulfurization reactions to occur. In some designs, the fresh sorbent and recycled solids are injected above the venturis, whereas other designs introduce them below the venturis. Just enough water is sprayed into the fluidized bed to both humidify and cool the flue gas to the optimum level for the desulfurization reactions to occur, but no more than can be fully evaporated. Therefore no wastewater is produced.

A multistage humidification system has been applied in China in which the water is injected at several levels. This approach distributes the water more evenly throughout the reaction zone, and the time that the humidity content is above the critical moisture point is extended. This increases the effective residence time for the desulfurization reactions. SO₂ removal efficiency increased by over 1% when the water was injected in two stages, while the total water consumed was the same as that consumed in single-stage humidification.5

The Gas Suspension Absorption process was developed in Denmark by FLS Miljø (now FLSmidth) and is installed on only a few power plants. The process is similar to CFB scrubbers but has an integral cyclone for recirculating the solids via a recirculation box to the fluidized bed reactor.

NID™ System

Alstom’s Novel Integrated Desulfurization (NID™) technology is installed on over 60 coal-fired power plants in Europe, Asia, and the U.S. The unique feature of NID™ technology (see Figure 3) is its J-shaped duct reactor, which has a square cross section and is integrated with a pulse jet fabric filter or, less commonly, an electrostatic precipitator. Fresh reagent and the solid products collected from the fabric filter are hydrated in the humidifier mixer by the addition of water. The humidified calcium hydroxide mixture is then injected near the bottom of the NID™ absorber into the upward flowing flue gas. With the high solids-to-water ratio, evaporation occurs rapidly, cooling and humidifying the flue gas, while flash drying the particulates. No water is sprayed into the absorber, unlike CFB scrubbers. The chemical reactions and drying times within the absorber take less than 2 sec.7

How Do Semi-Dry Scrubbers Compare?

The water consumption of the different types of semi-dry scrubbers is similar, and they all consume about 60% less water than wet scrubbers. SDS are typically used on small-to medium-sized units burning low- to medium-sulfur coals. CDS can be applied to larger units burning low- to high-sulfur coals. Single-unit CFB scrubber designs of up to 750 MW are now available.6 SO₂ removal efficiency is 90–98% for SDS, and over 98% for state-of-the-art CDS, a value approaching that for wet scrubbers. In addition, dry scrubbers remove nearly 99% of SO₃, over 95% of the HCl, HF, and other acid gases, and over 95% of mercury (especially if a mercury sorbent is also used). An advantage of the systems over wet scrubbers is that they capture more SO₃ and oxidized mercury. Wet scrubbers typically capture only about 50–80% of oxidized mercury—a pollutant that is now being regulated.

Both SDS and CDS systems have a good turndown capability, enabling operation at low loads, and there is no significant difference in their load-following ability. A CDS system, though, consumes more reagent than a SDS for the same conditions of coal sulfur and SO₂ removal efficiency.3 Power consumption is similar at less than 1% of a power plant’s output. This is lower than the ~1.2 to 2% consumed by wet scrubbers. Although investment costs are lower for SDS and CDS than for a similar-sized wet scrubber, operating costs are generally higher mainly due to the higher sorbent costs: Lime is more expensive than limestone. Unlike wet scrubbers, dry scrubbers produce no wastewater (and hence no wastewater treatment facilities are required), and the by-products are dry and therefore more easily handled. Unfortunately, there is no market for the by-products, whereas saleable gypsum is produced in the limestone wet scrubbing processes. Disposal of the by-products can be expensive.
DRY TECHNOLOGIES

Dry sorbent injection processes offer the least water consumption of the FGD processes discussed. They consume no water, or only a minimal amount if the sorbent needs hydrating or the flue gas is humidified to improve SO₂ removal efficiency. They account for roughly 2% of installed FGD capacity worldwide. The sorbent can be directly injected at several locations, as shown in Figure 4; actual injection locations will be plant specific because not all of the units shown are necessarily present in every power plant. Unlike the wet and dry scrubber processes, the flue gas is not passed through a separate desulfurization vessel—the sorbent is injected directly into the furnace (furnace sorbent injection, FSI), the inlet to the economizer (economizer sorbent injection, ESI), or duct (duct sorbent injection, DSI). Hence there is a smaller footprint and thus the technology is easier to retrofit. The solid reaction products, unreacted sorbent and fly ash, are collected in the downstream particulate control device.

Sorbent injection systems are one of the simplest and cheapest commercial FGD systems to install and operate. The major cost is the sorbent itself. Limestone or hydrated lime (calcium hydroxide) is commonly injected into the furnace as these sorbents can withstand the high temperatures within the furnace. Hydrated lime has been employed for ESI, but the process is little used today. A wider range of sorbents can be used for duct injection. These include calcium- and sodium-based reagents, and can be injected dry, as a slurry, or, in some cases, as a solution (sodium sulfite/sodium bisulfite solution). Generally, sodium-based sorbents are more reactive than calcium-based ones, resulting in a higher SO₂ removal efficiency. But they are more expensive. A co-benefit of FSI and DSI is the capture of some of the HCl, HF, and mercury in the flue gas, although this does depend on the sorbent used. The by-products are dry, and thus are relatively easy to handle and manage; no wastewater is produced. Sorbent injection systems are best suited to small- or medium-sized power plants (depending on the sorbent) burning low- to medium-sulfur coals, and where only a moderate SO₂ removal efficiency is required.

The main drawback of the sorbent injection processes is their lower SO₂ removal efficiency compared to wet and semi-dry scrubbers. Injecting sodium-based reagents, such as sodium carbonate-based ones, into the duct can remove only ~70–90% of SO₂, but 90–98% of the SO₃. SO₂ removal efficiency with calcium hydroxide is lower. Power consumption is low, ~0.2% of the plant’s output. Capital costs are less than for semi-dry and wet scrubbers, but operating costs can be high, mainly due to the cost of the sorbents.

MULTI-POLLUTANT SYSTEMS

Multi-pollutant processes remove several regulated pollutants in one system and may be more cost-effective than installing a series of traditional systems that remove the same number of pollutants. Two of the commercial systems that effectively consume negligible amounts of water are the ReACT™ and SNOX™ processes. Additional processes, such as the CEFCO process, which has only been demonstrated at pilot scale, and Cansolv®, are discussed in the full report by Carpenter.²

ReACT™ Process

The ReACT™ (Regenerative Activated Coke Technology) process has been, or is being, installed on coal-fired units in Japan, Germany, and the U.S. It employs a dry activated coke sorbent which is regenerated. Over 99% of SO₂ and SO₃, 20–80% NOₓ, >90% of mercury (both elemental and oxidized), and ~50% of the remaining particulates are removed in the process when burning low- to medium-sulfur coals.⁸ The ReACT™ system is installed after the particulate control device.

The process consists of three stages: adsorption, regeneration, and by-product recovery (see Figure 5). The flue...
gas enters through the side of the adsorber where it passes through the bed of coal-derived activated coke that is moving slowly downward. \( \text{SO}_2 \), \( \text{SO}_3 \), \( \text{NO}_x \), and mercury are removed by the sorbent through adsorption, chemisorption, and catalytic reactions. Ammonia is injected into the duct upstream of the adsorber and into the regenerator to promote the removal of \( \text{SO}_2 \) and \( \text{NO}_x \). The clean flue gas exits the adsorber and is released through the stack. The activated coke takes \( \sim 80–120 \) hr to pass through the adsorber and the residence time for the flue gas is \( \sim 10 \) s. The spent sorbent is then passed into the top of the regenerator where \( \text{SO}_2 \), nitrogen, water, and mercury are released. The \( \text{SO}_2 \)-rich gas flows upward where the mercury is readсорbed by the activated coke. The mercury is removed with the activated coke during planned outages every few years. After cooling, the regenerated activated coke is screened to remove fines and captured fly ash, and returned to the adsorber. The \( \text{SO}_2 \)-rich gas exits the regenerator and passes to the by-product recovery unit. Here, the \( \text{SO}_2 \) is converted into a saleable product, such as sulfuric acid or gypsum.

No water is added to the system as no flue gas humidification or saturation is required. As a result, only 1% of the water required by limestone wet scrubbers is consumed. Power consumption is lower than wet scrubbers at \(-0.7\%\) of the plant’s gross output. No liquid wastes are produced. Mercury can be recovered from the activated coke and the spent activated coke can be sold and utilized in other applications. However, ReACT™ may not be economical for high-sulfur coals.

**SNOX™ Process**

The SNOX™ process, developed in Denmark, is a dry regenerative catalytic process that removes up to 99% of \( \text{SO}_2 \), \( \text{SO}_3 \) and \( \text{NO}_x \) and essentially all of the remaining particulates.\(^8\) The flue gas exiting the particulate control device is reheated in a heat exchanger to \(-400^\circ\text{C}\) and ammonia is injected before it enters the SCR reactor (see Figure 6). Here \( \text{NO}_x \) is catalytically reduced by ammonia to nitrogen and water. The flue gas is then heated and \( \text{SO}_2 \) is catalytically oxidized to \( \text{SO}_3 \) in a second reactor. Later designs have integrated the two catalytic reactors into a single vessel. The flue gas exiting the oxidation reactor passes through the hot side of the heat exchanger where it is cooled as the incoming flue gas is heated. \( \text{SO}_2 \) reacts with water in the flue gas to form sulfuric acid vapor, which is then condensed into 94–95% concentrated sulfuric acid in the WSA (Wet Sulfuric Acid) condenser.

The process was designed for high-sulfur fuels and thus is more cost effective for high-sulfur coals. No water is consumed in the process and saleable sulfuric acid is produced. The process also recovers heat from the flue gas. It has been estimated that, for a 500-MW coal-fired power plant, the heat recovery would be more than the supplemental power needed for the SNOX™ plant, and could provide a potential net gain equivalent to 8 MW.\(^{11}\)

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**FIGURE 5. ReACT™ process**\(^8\)

*Note: The numbers 1, 2, and 3 represent the streams that reenter the process.*
CONCLUSIONS

There are a number of commercial low-water FGD systems available that are suitable for coal-fired power plants in areas where water is scarce. These are either essentially dry, such as the sorbent injection, SNOX™, and ReACT™ processes, or have a relatively low water usage. Moreover, technologies that produce a low-temperature flue gas with low SO₂ and water vapor contents, such as ReACT™, could lower CO₂ scrubbing costs, if future regulations require CO₂ to be captured.

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Water is indispensable to human survival. In recent years, due to climate change, population growth, environmental pollution, and other factors, the lack of freshwater resources in many countries and regions has become a greater concern. Water scarcity is increasingly affecting global sustainable development; hence resolving water shortage problems has become a common focus of nations around the world.

With abundant seawater on Earth—accounting for more than 97% of the total water volume—desalination has been demonstrated as an option to turn the vast oceans to a major potential source of freshwater. The widespread application of desalination is feasible and could be an important component of solving the global water crisis.

TODAY’S DESALINATION INDUSTRY

Large-scale development of desalination technology began in the mid-20th century, when it was primarily used in the Middle East, a region with extreme water scarcity. As desalination technology matured, application gradually expanded geographically. According to statistics from Global Water Intelligence and the International Desalination Association, as of June 2013 about 17,277 desalination plants had been built globally, reaching a total freshwater production capacity of 80,900,000 m³/d. These projects include a seawater desalination capacity of about 47,730,000 m³/d—about 59% of the total capacity—addressing water supply problems for more than 100 million people worldwide.

“Desalination has been demonstrated as an option to turn the vast oceans to a major potential source of freshwater.”

China, in particular, is facing water scarcity, with per capita water resources at only one-fourth that of the global average. In recent years, desalination technology has developed rapidly in China, and major progress has been achieved in research and development, equipment manufacturing, and water production capacity. Desalination equipment made in China has been exported to countries such as Indonesia and India. According to statistics from the Desalination Branch of China Water Enterprises Confederation, as of October 2013, China had constructed a seawater desalination capacity of 858,600 m³/d, mainly supplying municipal users and the power industry (see Figure 1).¹

For energy, China employs primarily coal-fired power generation. Most power plants are located in regions with extreme freshwater scarcity. Water consumption is a key factor that can affect the efficiency of power generation and could restrict the development of power plants. Water shortages are especially serious in the northern areas of China, and the siting of new power plants in many northern regions must be based on access to adequate water resources. In recent years, new power plants built in coastal areas have adopted industrial closed-loop water systems, direct seawater cooling condensers, and other water-saving measures. Even so, there remains a huge demand for freshwater. For example, Shenhua’s Hebei Guohua Cangdong Power Plant has four coal-fired units currently in operation, with a combined electrical capacity of 2520 MW. Direct seawater cooling is used for all the condensers. Approximately 3,200,000–4,400,000 m³ of freshwater is
consumed every year as feedwater for the four boiler units, as well as desulfurization and other processes. This massive water consumption requirement is completely filled through desalination, achieving zero consumption of freshwater and effectively converting this power plant into a supplier of freshwater to help alleviate water shortages in the surrounding regions (see Figure 2 for a photo of the desalination facility). At the same time, cogeneration of power and water can effectively reduce the production costs for both water and electricity. When power plant water consumption demand is met through desalination, the building of power plants in coastal areas is no longer restricted by whether freshwater resources can be obtained on land. This approach is conducive to the development of coal-fired power generation that is harmonious with the environment.

CURRENT STATUS OF DESALINATION TECHNOLOGIES

Chief Desalination Technologies

The water supply for desalination is not influenced by the seasons or by the climate, and thus can be considered a good-quality, stable water source. Today, desalination is mainly based on two technical routes: 1) distillation desalination based on multi-stage flash evaporation (MSF) and/or low-temperature multi-effect distillation (MED) and 2) membrane desalination based on seawater reverse osmosis (SWRO).

In MSF, heated seawater is evaporated in multiple flash chambers with sequentially reduced pressure; the condensed vapor is freshwater. In the MED process, multiple evaporators connected in series are used to evaporate seawater: The vapor from each previous evaporator is turned into heated vapor for the next evaporator and then condensed into freshwater. In SWRO, seawater is pressurized to force water to pass through osmotic membranes while the salt does not pass through. The main technical parameters of these three desalination technologies are shown in Table 1.

Due to high energy consumption, the share of MSF technology in the desalination market has been declining year by year. MED and SWRO are being widely applied in newly built desalination projects. MED and SWRO both have advantages: Equipment investment and water production costs for SWRO are lower, but this technology has a higher requirement in terms of the quality of the seawater. The pre-treatment technology is rather complex and its adaptability to seawater temperature is poor. It has no obvious advantages in investment and operational energy consumption when applied in northern China with lower seawater quality. MED technology has a wider adaptive range for seawater temperature and water quality, and is characterized by high heat transfer efficiency, low pre-treatment requirement, simple operation, high reliability, and good water quality, although the capital costs are higher.

Technical Advantages of MED

The “low-temperature” in low-temperature MED refers to its highest evaporation temperature, which is generally lower than 70°C. Since the heat that is input can be used repeatedly, the process offers high thermal efficiency, low energy consumption, and low water production costs. Additionally, due to the low-temperature characteristic, the equipment experiences reduced scaling and corrosion and very high operation reliability. MED technology is especially suitable for power and water cogeneration projects; it can use exhaust

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<th>Main Technical Parameters</th>
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from the low-pressure steam turbine to reduce water production costs, an approach that also offers important technical advantages. MED technology has received increased attention in recent years, with a constantly expanding installation scale and continuously increasing market share. From 1997 to 2002, MED only accounted for about 25% of desalination by distillation. Between 2003 and 2008, its share of the world market for desalination by distillation grew to 42%. In 2013, MED technology accounted for ~33% of China’s total desalination capacity (see Figure 3).1

COGENERATION OF POWER AND WATER

Major Benefits

Cogeneration of power and water is known as dual-purpose water production in the international desalination industry and is the preferred option for desalination for coal-fired power plants. Employing this form of cogeneration can significantly reduce desalinated water costs and investments and it has become the principal model for existing large desalination projects.

There are many benefits to integrating power plant operation and desalination. First, since coal-fired power plants can be water-intensive, the use of desalination to produce freshwater can meet the power plant’s freshwater needs. Second, when the desalination process uses the plant’s low-grade steam, it provides the heat needed for desalination, simultaneously providing cooling for the plant. This results in an increase in the plant’s efficiency and reduces desalination costs. Third, the water produced from desalination is high in purity, and further softening (i.e., removing calcium and other metal ions that could cause buildup) is simple compared to other sources of water. Thus the cost of using desalinated water as boiler feedwater would be lower than water that must be treated with a traditional water-softening process.

In addition, during cogeneration of electricity and water, the power plant’s cooling water discharge facilities can be shared with concentrated seawater from desalination, which reduces project capital investments. Finally, when the concentrated seawater is mixed with the power plant’s circulating cooling water for discharge, it can reduce the impact on oceans because the discharge temperature will be lower.

MED Technical Innovation and Application of Cogeneration

For newly built and expanded coal-fired power plants within the Shenhua Group that are distributed in coastal areas with water resource scarcity, the demands for desalination technologies are constantly increasing. Driven by the company’s strategic development needs, Shenhua Guohua has selected the MED desalination technology that is suitable for cogeneration of power and water. Through research, development, and application, Shenhua Guohua now has proprietary, large-scale MED equipment and has mastered the design of such equipment.

The large-scale MED equipment developed by Shenhua Guohua uses a horizontal-pipe falling film evaporator (see Figure 4 for the full process). The generator turbine exhaust steam enters the heat exchanger for the first effect (i.e., stage) evaporator as heating steam and condenses after releasing sensible and latent heat; some of the seawater is evaporated after absorbing heat. The steam from the first evaporator is guided into the second-stage evaporator and condenses in the next stage, a step which is repeated for each sequential evaporator, to yield several times more condensed water than can be obtained from single-stage evaporation. When the generator exhaust has a higher temperature and pressure, a thermal vapor compressor can be used to increase the pressure of some of the low-pressure steam generated through seawater evaporation and transfer it to the first stage as the heating source, which can greatly improve the efficiency and reduce the costs of water generation.

The technical crux of low-temperature MED desalination includes efficient heat transfer, material selection and corrosion control, discharging non-condensed gas, avoiding scaling, good product water quality, etc. The technical research and development strategy of Shenhua Guohua consists of mastering all these key technological aspects so as to provide desalination equipment that can meet user demands, mainly including guarantees on performance indicators, operational costs, reliability, and service life. Through R&D the mechanisms
of vacuum heat transfer and flow with small temperature differences and multiphase flow have been mastered. In addition, large-scale MED design and key equipment structure design methods have been obtained to develop large-scale MED series equipment that can produce 12,500–25,000 m³/d of freshwater.

Through research on MED heat transfer and flow characteristics, a heat transfer and flow resistance coupling calculation method has been established, and heat transfer and flow characteristics computational software for large low-temperature MED equipment has been developed. This software provides effective tools for the selection of MED working media parameters and the optimized design of the heat exchanger. Meanwhile, MED technical parameter selection and calculation software has been developed as well. This software can work out a large number of technology schemes as well as conduct a techno-economic analysis targeting the initial conditions and user demands of different projects, to obtain the technical configuration with optimal economics.

The MED evaporator is a large thin-walled vacuum container. Shenhua Guohua cooperated with manufacturers in China to overcome technical problems—such as welding and deformation control in large thin-walled containers, expansion of thin-tube plates, installation of large tube bundles, installation and deformation correction of the flow guide plates, avoidance of acid pickling, field assembly and welding of multiple-effect evaporators—and formed a comprehensive set of standards in enterprise manufacturing techniques. Through the overall development effort, large-scale MED installation, troubleshooting strategies, and new technologies involving start-up, operation, normal shutdown, and emergency shutdown have been mastered. In addition, domestic industrial standards have been established. At the same time the desalination anti-sludging agent and the chemical cleaning system and method independently developed by Shenhua Guohua have reduced the operational costs for MED equipment.

The MED technology that was independently researched and developed by Shenhua Guohua has been successfully applied to Shenhua’s Hebei Guohua Cangdong Power Plant for the cogeneration of power and water project; one 12,500-m³/d unit and one 25,000-m³/d unit are currently operating, both of which were domestically manufactured. The exhaust steam from the turbine of the coal-fired power generator is used as a heat source for desalinating water, which meets not only the needs of the power plant, but also provides water for the Port of Huanghua in Cangzhou, Hebei, as well as industrial users in nearby steel plants. As the quality of the water produced through desalination is higher than other sources of freshwater, the cost for follow-up water treatment is reduced, and the desalinated water offers a price advantage for industrial users.

At present, Guohua Cangdong Power Plant’s annual external freshwater supply capacity is close to 10 million m³, which has effectively relieved the freshwater resource scarcity in the Port of Huanghua.
THE CHALLENGES OF DESALINATION TECHNOLOGY

The cost of energy is the most important factor influencing the cost of desalinated water. For example, in MED technology, when the designed ratio of product water quantity to heating steam consumption reaches 10 (e.g., about 0.1 tonne of steam is consumed for every 1 m$^3$ of freshwater produced) about 1.2 kWh is also used and the energy cost accounts for about 40–50% of the water production cost. Therefore, reducing energy consumption for desalination is an important focus. There are two central aspects to reduce energy consumption: First, develop new desalination technologies and equipment. Second, integrate and optimize desalination technologies and make the most rational allocation of resources to maximize efficiency in energy utilization, and even achieve zero discharge in the desalination process. For example, heat-membrane cogeneration technology—the use of a combination of distillation methods and membrane methods (namely, MED-SWRO or MSF-SWRO)—meets different demands in water quality, lowers desalination costs, and improves the energy utilization rate.

In addition to saving energy, it is also possible to utilize unconventional energy resources and renewable energy, such as solar, wind, geothermal, and tidal energy, to reduce the consumption of traditional fossil fuels. The Perth Seawater Desalination Plant, which began operation in 2007 and uses wind energy, has a freshwater production capacity of 144,000 m$^3$/d, accounting for 17% of the total water supply of Perth. It is the largest desalination plant in the world powered by renewable energy.

The need to continue advancement of the desalination industry, while placing greater emphasis on minimizing environmental impacts, is receiving increased attention. Many large-scale coastal power plants applying desalination in northern China have begun discharging concentrated seawater to salt fields to make salt. In addition, some research and application related to extraction of raw materials such as potassium, bromine, and magnesium from concentrated seawater is ongoing. There have also been developments in promising technologies with reduced brine discharge volumes, such as forward osmosis technology. Forward osmosis uses the hyperosmosis drive liquid to extract freshwater from seawater through a selectively permeable membrane: The discharged brine concentration can reach over 20%, which is conducive to the follow-up recovery processing of the salt water resource. Forward osmosis technology has demonstrated promise in development projects.

OUTLOOK

Desalination is an important means of providing a sustainable supply of freshwater. However, it continues to face challenges in reducing costs and increasing operational efficiency. We believe the necessary future developments and improvements to desalination technology are as follows:

1. The industry must develop new processes, new equipment, and new materials to additionally reduce the cost of desalinated water. Larger-scale MED and SWRO desalination plants must be demonstrated.
2. Through the integrated application of new technologies and new processes, the scope of application of desalination can be expanded. Desalination will be incorporated into national or regional water supply systems in China, making it possible for desalinated water to be transported long distances to municipal water supply systems and even be integrated into the modern agricultural sector.
3. In the future, greater emphasis will be placed on the concept of zero discharge in the desalination industry. The industry should strive to reduce energy consumption and brine discharge, as well as create a recycling industry chain and reduce the impact on the marine environment, through the integration of technologies and comprehensive utilization of resources.
4. The cogeneration of power and water is the best option to solve the freshwater needs of thermal power plants in coastal areas. The integration of desalination with power plants creates the possibility of converting a thermal power plant from a water consumer into a freshwater supplier to nearby coastal cities.

With further improvements, desalination technologies can play a greater role as a convenient, energy-efficient, and environmentally friendly means of providing freshwater to meet the world’s growing demand for freshwater and water security.

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Moving Coal Up the Value Chain

By Daman Walia
President and CEO, ARCTECH Inc.

Sahika Yurek
Branch Chief, Turkish Coal Enterprises

Energy projections have shown that coal will be needed to meet today’s and tomorrow’s energy demand. However, overcoming the challenges facing the coal industry, whether legislative, technical, or from activist opposition, will require a shift in traditional thinking around coal conversion; options beyond combustion and liquefaction should become a larger component of the coal conversion industry. Specifically, we believe that employing biotechnology overcomes these challenges by creating clean energy while producing higher-value products that meet the needs of the large agriculture and environmental protection and remediation markets.

HUMAXX MICGAS™ BIOREFINERY

One example of such biotechnology is the HUMAXX MicGAS™ biorefinery, which uses termite-derived microbes to convert mined coal in anaerobic bioreactors to hydrogen-rich methane biogas, carbon-rich organic humic liquid for agriculture use, and a solid coproduct that can be used to adsorb (i.e., remove) toxic contaminants from wastes and waters. For unmineable coal seams, bioconversion can occur in the seam itself and the biogas can be recovered gradually.

This biotechnology utilizes every component that makes up coal. Even heavy metals, such as mercury (Hg) and arsenic, which must be captured in other coal conversion processes, become part of the solid coproduct; these metals remain permanently bound and are not released. One of the main products, methane, can be used to generate electricity or converted to other low-carbon liquid fuels or chemicals.

Another major product, organic humic acid, is sold to the agricultural industry for use as a soil amendment, a practice that is gaining recognition globally. For example, in the U.S., organic humic products have received approvals from the Environmental Protection Agency and the Department of Agriculture and are also supported by various trade organizations. In China, the Bureau of Agriculture recently set standards for the agricultural use of humic acid. Humic acid for this purpose is under the trademark Actosol® (a liquid organic humic fertilizer).

“This technology allows the coal industry to follow the successful business model employed by petroleum companies for decades...”

In addition to being a soil additive, humic acid can also be converted into products that adsorb toxins, such as heavy metals, as well as products that facilitate waste recycling. Such products are currently in use under the trademarks HUMASORB® (a multipurpose contaminant adsorber) and Actodemil® (for waste recycling). These products are being proven in real-world applications (visit www.arctech.com for additional details). For example, it has recently been demonstrated that HUMASORB® can remove CO₂, SOₓ, NOₓ, Hg, and other trace metals from coal combustion and gas streams; spent HUMASORB® can also be converted into a water filter.

Through conversion to the various products, the patented MicGAS™ biotechnology can lead to zero-waste coal conversion. An integrated flow schematic for both mined coals and unmineable coals is shown in Figure 1. There are several options for carrying out this biotechnology, including using only mined coal, using only unmineable coal in the seam, or a combination of both in an integrated process. For mined coal, Steps 1–3 are carried out in bioreactors. For unmineable coal seams, coal is converted in situ into methane-rich gas, which is then extracted from the seam. In an integrated version of the process, the methane-rich gas from the unmineable coal seam is sent to above-ground bioreactors containing mined coal and then all the gas can proceed through Steps 1–3.

During Step 1, microbes convert solid coal into soluble organic liquids, such as acetate. In Step 2 the liquid, along with gases that are produced, are contacted with methane-producing...
microbes that hydrogenate the acetate and CO₂ into methane-rich gas. In Step 3 the methane-rich gas is then separated from the humic-rich coal residue; this coal residue is then subjected to digestion by aerobic microbes followed by chemical extraction and separation into liquid and solid humic acid. The liquid and the solid humic acid are then formulated into agricultural and environmentally useful products. Step 4, which is only applied to unmineable coal seams, includes injection of Mic microbial inoculants and nutrients directly into the coal seam. Step 4 has been termed MicGAS™ in situ.

Depending on the characteristics of the unmineable coal seam, injection and multiwall recovery wells or directional wells can be utilized to increase proliferation of the microbes and nutrients, taking advantage of new drilling techniques developed and currently employed for coal bed methane and shale gas extraction. Once sufficient microbes are established in the target coal seam, only nutrients must be added to maintain long-term methane-rich gas production. As is shown in Figure 1, no humic acid products are produced in Step 4, but in the integrated process the methane-rich biogas containing CO₂ can be sent through the above-ground bioreactors to further convert CO₂ to methane and increase the amount of gas, if desired. Current estimates indicate that about 10–25% of the carbon in mined coal can be converted to methane-rich gas while the remaining carbon is converted into organic humic acid products.

When the in situ biotechnology is applied to unmineable coal seams, the production of the methane-rich gas occurs over time. However, this approach takes advantage of the coal seam as a large, natural anaerobic geobioreactor. Large volumes of coal can be treated without incurring the capital costs of the bioreactors; there is a much lower cost associated with drilling.

As noted, the in situ approach can be deployed as a stand-alone process for producing only methane-rich gas. However, the integrated approach, wherein methane-rich gas from the unmineable coal seam is sent to above-ground bioreactors, provides increased production of economical methane-rich gas, while also producing higher value humic acid products. It also provides the flexibility to use both mined and unmineable coal, ensuring a reliable fuel source. Water usage in above ground reactors is about one cubic meter for every ton of coal, and it is completely utilized in the process without producing any wastewater. All the process water and the water contained in the coal become part of the organic humic products, which provides moisture when the humic products are added to soil.
PRODUCT VALUE

As is shown in Figure 1, the two primary yields from the HUMAXX™ biorefinery are methane and humic acid products. This technology allows the coal industry to follow the successful business model employed by petroleum companies for decades: Produce large volumes of low-value energy products and lesser volumes of (comparatively) high-value non-energy products. The overall economics are based on the sum total of the value generated from both products: low-carbon fuel and humic-acid derivative products.

The value of the products is of even greater interest when considering that the raw material could be coal that is otherwise unmineable, and therefore of little value. This represents a major opportunity in some areas. For example, the U.S. Geological Survey estimates that there are about 9.5 trillion tons of coal resources in the U.S. (including Alaska), but the vast majority of these resources are not economically and/or technically recoverable.\(^2,3\)

Low-Carbon Fuel

The methane from the process can be used directly for clean energy production or can be converted to other clean fuels using techniques practiced commercially today. The energy security value and economic benefits of producing clean, low-carbon fuels from coal are already well known, so they are not explored further in this article. It is worth noting, however, that there are many regions where coal is abundant and natural gas prices are high; in such cases there may be a particularly strong incentive to employ biotechnology-based coal conversion.

Humic Acid Product: Agricultural Use

The usefulness of humic acid for increasing soil fertility has been recognized for centuries. In recent years there has been an upsurge in scientific research on humic acid as well as a general increase in interest in improving soil for agricultural uses and environmental protection. Because coal originates from plant matter, it is a rich source of humic acid and the MicGAS™ biotechnology offers a means to take advantage of it through the production of Actosol®, which is currently being used at farms in the U.S., Egypt, and China.

Humic Acid Product: Environmental Remediation

The helix-like structure in humic acid gives it versatile characteristics, including the ability to adsorb toxic compounds during environmental remediation applications. Examples of applications include cost-effective removal of metal and organic toxins from contaminated waters, recycling of industrial wastes, and even the safe disposition of dangerous chemical agents and explosives.

HUMASORB®, a multipurpose adsorber made from lignite-derived humic acid, is currently being demonstrated for removing contaminants from acidic mine drainage, industrial wastewater discharges, and municipal sewage wastewaters as well as radioactive contaminants from nuclear power plants. Based on market analysis of these two sectors in the U.S., it is estimated that almost 500 million tons of coal per year would be required to produce enough HUMASORB® to be used for this amount of environmental remediation.

Humic Acid Product: Carbon Storage

Experts have determined that the soil organic matter is the fourth-largest storehouse of carbon after sedimentary rocks, fossil fuels, and oceans.\(^4\) In the MicGAS™ process, most of the carbon is converted into humic products, meaning that it does not enter the atmosphere. (In addition, it should be noted that the clean fuels produced offer a low-carbon intensity energy source.) However, there is an added benefit: When added to soil, carbon-rich humic acid increases growth in plant matter, which effectively removes carbon from the atmosphere.\(^4\) In this way, when applied to mined coal the process can actually be considered carbon negative, which will enable it to be readily applied in a carbon-constrained world.

CASE STUDY: APPLICATION ON TURKISH LIGNITE

Turkish lignite is generally high in ash and moisture content and thus is very low in calorific value. Ash content ranges from 20–50+% and moisture can be as high as 50%. Lignite accounts for almost 90% of Turkey’s coal resources and is primarily used for power generation. Turkey imports almost 90% of its natural gas and oil, incurring high costs and reducing energy security. For this reason Turkey has a national interest in supporting technology development and deployment that will allow the country to utilize its vast lignite resources to improve energy security and reduce overall energy costs.

The application of a HUMAXX MicGAS™ coal biorefinery is a natural fit. In collaboration with Turkish Coal Enterprises, the largest coal mining company in Turkey, the technology was demonstrated on mined lignite from the Bursa and Mugla-Husamlar mines and also lignite from a deep unmineable lignite coal seam in Mugla-Husamlar.

For the demonstration test the coal samples were ground until they were a typical size for pulverized coal. The samples were
then subjected to digesting with anaerobic microbes and proprietary nutrients in anaerobic bioreactors for approximately 35 days. About 250 gallons (i.e., 0.95 m$^3$) of water per ton of coal was utilized. This water requirement is similar to some estimates for coal-based thermal generation, but much lower than traditional coal-to-liquids conversion. However, this water is not actually consumed in the HUMAXX™ process; water in the coal as well as the process water is retained in the organic humic products. When the humic products are eventually added to soil, the retained water replaces some of the water that would otherwise be provided during agricultural production.

Almost 60 m$^3$ of methane-rich biogas was produced per ton of lignite during the demonstration. The undigested residue coal, now enriched in humic acid, was subjected to digestion by aerobic microbes, followed by chemical extraction to obtain organic humic acid. Water-soluble liquid humic acid was formulated into three products: Actosol®, an organic humic fertilizer; HUMASORB®-L, a liquid adsorbent; and A-HAX, a reagent for the Actodemi® process of waste recycling. The solid residue was chemically cross-linked into a water-insoluble HUMASORB®, a multipurpose water filter. All of the coal was used in the various products, resulting in zero waste.

In addition to the mined samples, the HUMAXX MicGAS™ coal biorefinery technology was also tested on unmineable Turkish lignite. Feasibility tests were conducted with Mugla-Husamlar lignite in a simulated deep seam geobioreactor. The demonstration resulted in the production of about 10 m$^3$ of methane-rich gas per ton of coal on a yearly basis. This in situ approach of bioconverting coals into gas results in a slower conversion rate, and thus lower volumes of methane-rich gas in the short term, but it can continue over several years.

All the organic humic products produced during the demonstration tests were then evaluated for their applicability for agriculture, water treatment, and wastes recycling needs in Turkey.

Feasibility tests were conducted in which HUMASORB®-CS made from the Turkish lignite was compared with the HUMASORB®-CS made from U.S. lignite for its stability under highly acidic and alkaline pH conditions, as well as for removal
of metals from spiked waste waters (important characteristics for use of this product as a water filter). Table 1 presents select test results in which the HUMASORB products were able to remove metals from wastewater. An important implication of the demonstration results is that the biotechnology process can be applied to coal from very different geographies and a similar product can be yielded.

A-HAX™, a product of the Actodemil® technology, was demonstrated to officials of MKEM, the Turkish Armed Forces explosive manufacturing enterprise, as a reagent for safe destruction and recycling of manufacturing wastes of a propellant as well as highly explosive TNT. These tests resulted in complete chemical destruction of both compounds, and in the production of nitrogen-rich organic humic fertilizer. The resulting fertilizer was proven to be free any residue of explosives or toxins and was used for seed germination and plant growth.

Based on the demonstration results, a detailed design for a HUMAXX MicGAS™ coal biorefinery processing 110,000 tons of coal per year was developed, including the capital and O&M costs. The estimates were made for Turkey-based operations. Recognizing the retention time requirement of 35 days for the anaerobic bioconversions in Step 1 and 2, low-cost bioreactors were designed based on dome tanks often used in other industries to store large volumes of liquids. For the full design, these reactors had a footprint of about 25–40 acres, depending on the existing coal handling infrastructure. Although the footprint of biotechnology-based gasification is large compared to thermal gasification, the overall footprint of the biorefinery is smaller because it does not require front-end air separation, back-end gas cleanup, conversion to syngas, and large wastewater treatment equipment—all of which are required for thermal coal conversion.

A total value chain analysis for conversion of Turkish lignite was completed (see Figure 2), which included the mass balance from coal to products and costs and values derived from experience in selling these products from ARCTECH’s prototype production plant in Virginia, U.S. Market analysis of use of the MicGAS™ coal biorefinery products for the energy, agriculture, and environmental market sectors of Turkey revealed that the large, growing needs for the various end products means that a biorefinery processing 110,000 tons of coal per year would meet less than 20% of Turkey’s market demand.

THE FUTURE OF CLEAN COAL CONVERSION

The HUMAXX MicGAS™ coal biorefinery approach offers an approach of moving the coals up the value chain, meeting the growing needs for clean energy, food, and water, while eliminating pollution and climate impact concerns from coal use. We believe it is the future of clean coal conversion and provides a comprehensive solution for meeting the basic requirements of rapidly increasing population and the burgeoning economies. In our opinion, it offers an approach for propelling the second industrial revolution with coal use, just as steam production from coal combustion helped to propel the first industrial revolution two centuries ago.

REFERENCES


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WATER: A PRECIOUS COMMODITY

Water was once thought of as the great unlimited resource. However, the competing demands of agricultural, industrial, and domestic uses, combined with a changing climate, now threaten dwindling supplies. Mining is a water-intensive industry, and coal is often found in regions of the world where water is scarce. Restricted availability in water-limited regions requires mining companies to view water as a strategically important, non-renewable resource.

Limited water availability poses a significant risk to the industry, both in terms of security of supply for routine operations and for long-term sustainability. Water supply shortages not only impact the sustainability of current and future operations, but can add to project and operational costs and risk. As a consequence, the value of water must be integrated into business processes and decisions.

In South Africa, coal mining has historically been concentrated in the Mpumalanga Highveld. In this area, mining and agriculture are the largest users and compete with domestic users for water resources. eMalahleni is a municipality of 510,000 people in a water-stressed region of northeastern South Africa. One of the fastest growing urban areas in the country, it has faced considerable difficulties in meeting increasing demand for drinking water. The city lies within the Olifants River Catchment—one of the regions in which Anglo American has been working with internationally recognized research institutions to develop long-term climate models. The results, projected up to 2050, suggest that there is potential for a reduction in mean annual rainfall in this area.

THREE-TIER STRATEGY

Through a number of initiatives, Anglo American is focusing on understanding the value of water to the business, both financially and in the broader sense. The company has an ambitious 10-year strategy that is split into three distinct steps. The first step, Be Disciplined, is about getting the basics right. The second step, Be Proactive, encourages operations to go beyond compliance. The third, Build Resilience, takes us to being part of broader, catchment-level water solutions. Our intention is to achieve “water neutrality” at our new mines by 2030. Implementation of this strategy is being realized through our initiatives in three focus areas: improving operational excellence, investing in technology, and engaging and partnering with our stakeholders.

Water management has to start at home. Mines must ensure legal compliance, identify risks, set targets, build capacity, and identify and communicate with stakeholders.

“The eMalahleni Water Reclamation Plant is a flagship sustainability project that has demonstrated how the success of a project lies in the strength of the engagement and partnerships.”

In the eMalahleni region of South Africa Anglo American has found a way to use excess mine water to fill its own needs, create jobs, and provide clean water to the local community. These homes were built under phase 1 of the project.
Through a robust bottom-up process of identifying and assessing water-saving opportunities, and understanding local water risk, quantitative reduction targets have been set for every Anglo American-managed operation. Site-level Water Action Plans (WAPs) are developed to help achieve these targets, informed by local water basin priorities in the context of legal and regional basin management. The WAPs are meant to link the internal water management to the external basin-level developments and risk areas. This includes addressing the implications of climate change, providing for social needs, encouraging collective actions, and guiding stakeholder engagement activities.

In terms of technology, investment in water treatment and related technology innovation is paramount. A focus on appropriate technology solutions that minimize water consumption, maximize recycling and reuse, decrease energy consumption, improve water management infrastructure and design, and also address water quality challenges is required.

Engagement on water ranges from hosting multi-stakeholder water dialogues at mines, participating in water basin forums, playing an active role in the Carbon Disclosure Project’s (CDP) Water Disclosure Project, as well as working with national and international industry representative bodies on regional and global water policy issues (e.g., International Council on Mining and Metals). This engagement is fundamental if water is to be managed as a strategic resource at all levels.

Investment in partnerships and community-linked projects is also important. The eMalahleni Water Reclamation Plant is a flagship sustainability project that has demonstrated how the success of a project lies in the strength of the engagement and partnerships. This effort has received significant recognition throughout the international community, including being named the recipient of the World Coal Association’s 2013 Award for Excellence in Environmental Practice (for more information visit www.worldcoal.org/international-coal--climate-summit-2013/wca-leadership-and-excellence-awards).

**EMALAHLENI WATER RECLAMATION PLANT**

Anglo American’s Thermal Coal workings in the water-scarce area around eMalahleni contain approximately 140,000 million liters of water—a figure that is rising by over 25 million liters each day. Too little water on the surface is a problem for communities. Too much water underground is no less of a problem for a mining company. The eMalahleni Water Reclamation Scheme (EWRS)—situated in the Witbank coalfields of the Mpumalanga province—has turned a major liability into a valuable asset that has created far-reaching benefits for the environment, the local community, and its feeder collieries. The plant was originally intended to provide a solution to the operational, safety, and environmental challenges associated with rising underground mine water. Today it represents a world-class sustainable development project with far-reaching benefits for the surrounding communities.

A decade of research and development efforts went into mine water treatment technologies (including desalination), which was aligned with the central government’s mine closure and rehabilitation strategy. In addition, research and development efforts were also focused on the requirements of local authorities which included employment, development, and environmental objectives. The research involved dialogues and partnerships with all of the major mining companies in the Highveld coalfields as well as South Africa’s power utility, Eskom.

Following this decade of research and development, Anglo American’s Thermal Coal (Thermal Coal) business invested US$54 million into building the EWRS, which was designed to treat the water from its local operations. Thermal Coal also entered into a mine water supply agreement with BHP Billiton Energy Coal South Africa (BECSA), who supplies up to 15% of water input into the EWRS plant. In addition, Anglo American put into place the infrastructure needed to deliver the treated drinking water directly into the water-stressed eMalahleni Local Municipality’s system. The parties concluded a bulk drinking water supply agreement; the scheme was commissioned in 2007. See Figure 1 for the six steps that are the basis...
of Thermal Coal’s process used at the EWRS plant.

Under the EWRS project two competing global resource companies came together to solve a common problem, and provided a sustainable solution that continues to benefit the communities that reside around their mining operations.

The EWRS plant desalinates rising underground water from Thermal Coal’s Landau, Greenside, and Kleinkopje collieries, as well as from BECSA’s South Witbank mine. By doing so, it prevents polluted mine water from decanting into the environment and the local river system, while also alleviating serious operational and safety challenges.

The plant currently treats 25–30 million liters a day. Some of this is used in Anglo’s own mining operations, but the bulk of it supplies 12% of the city’s daily water need. Since it was first commissioned in 2007, the facility has treated in excess of 50 billion liters of contaminated underground mine water to pristine quality, 35 billion liters of which have been supplied to the critically water-stressed eMalahleni local municipality. The plant is aiding the provincial government in meeting its Millennium Development Goal to ensure that no household goes without a potable, reliable, and predictable water supply.

Additionally water is piped to Greenside, Kleinkopje, and Landau collieries as well as various nearby Thermal Coal service departments for domestic use and for mining activities such as dust suppression. This has taken pressure off the local municipality, which is constrained in its ability to meet the demand of all its users. The plant also supplies eight million liters of potable water per day to Zibulo mine, an Anglo Inyosi Coal project, BECSA’s Klipspruit mine, and the Phola coal-washing plant, a joint venture between the two mining companies.

Research has shown that, in the Mpumalanga Highveld, more water is stored in underground mines than in the three major surface dams that feed the area. An important distinction between the surface and mine water is that these underground stores do not evaporate. As a result, what was formerly a liability, with the operation of the EWRS plant, can now be regarded as a significant untapped resource. This is a clear indication that water reclamation, especially in this area, will form a prominent part of our future.

**Zero Waste**

The ultimate goal of the EWRS plant is to become a zero-waste disposal facility. Besides the plant having a water recovery rate of more than 99% and very low brine volumes, the 200 tons of gypsum by-product that is produced daily at the plant can be turned into a low-cost, high-quality construction material which, subsequent to rigorous testing and approval, has
been used to construct 66 houses for local Anglo American employees, with an additional 300 houses currently under construction. South Africa’s backlog in low-income housing delivery, combined with the construction boom in recent years, makes alternative building materials derived from waste particularly attractive. In addition, it offers an opportunity to further stimulate local employment through the establishment of a community-based enterprise that will manufacture and distribute these gypsum-based products to local builders. Currently, the plant produces more high-purity gypsum by-product than can be consumed by the local construction industry, so it is also sold to cement and agricultural industries, reducing the solid waste disposal required at the plant.

Although brine volumes are very low, it still presents a management challenge and, as such, Thermal Coal is investing in research and development of brine management and treatment technologies.

**Social Benefits**

As noted, the plant is aiding the provincial government in meeting its United Nations Millennium Development Goal to ensure that every household will have access to reliable and predictable drinking water. With the help of the plant, the percentage of homes without drinking water has been reduced from 14% to 2%.

Apart from benefiting the local community by supplementing the low domestic water supply, the EWRS plant has created a number of job opportunities. During the construction phase, between 650 and 700 temporary jobs were created, while 40 permanent positions were created for plant operation. Historically Disadvantaged South Africans make up 86% of the workforce, while 91% have been sourced from surrounding communities in an area of high unemployment.

**Recent Developments**

In July 2011, Anglo American approved an investment to increase treatment capacity to 50 million liters a day (with a maximum capacity of 60 million liters); this second phase is expected to be operational before the end of 2014.

Once complete, the expanded plant will manage water from up to six coal mines, some of which will soon reach the end of their lives. This includes mines owned by a competitor mining company. A holistic approach to dealing with the water problems of the entire region is needed; therefore, Thermal Coal is collaborating with other mining companies through various forums to identify regional opportunities to address the water problem.

The project has been designed to take into consideration the remaining 20-to-25-year life of contributing mines, and to cater for post-closure liabilities, which will require the desalination of mine water in excess of 30 million liters per day. The plant will continue to run long after mine closure.

The project is replicable and is being examined by six of Anglo American’s 10 Thermal Coal operations. In fact, it has already been replicated at Optimum Colliery, a mine now owned by Glencore Xstrata, who commissioned a 15 million liters per day plant in June 2010 to the east of eMalahleni. Another similar project is being implemented just outside Middelburg with other projects in the Highveld Coalfield in various stages of project development based on the same model as the eMalahleni plant.

The reclamation plant provides flexibility for the eMalahleni community and a degree of water security as it seeks to address long-term climate adaptation risks from altered precipitation.

There is no silver bullet solution to water management in the mining industry. It is only through a combination of reducing operational water use, increasing reuse and recycling, investing in research and technology development, and working with stakeholders that the industry will be able to deploy sustainable solutions to these challenges.

The first author can be reached at Nikki.fisher@angloamerican.com
PT Adaro Indonesia is working to become a leading Indonesian-based mining and energy group. To achieve this goal Adaro recognizes that it is essential to balance economic, environmental, and social considerations in all its activities and has instituted a Corporate Social Responsibility (CSR) program. Through proper engagement with stakeholders and careful evaluation of local needs, mining operations can have positive, significant impacts on the community near the mine that extend beyond the anticipated economic benefits.

A major concern for many areas in Indonesia is a lack of access to reliable, clean water. Many homes are not equipped with plumbing, so residents rely on wells or natural bodies of water, such as rivers. Unfortunately, natural bodies of water are not always dependable due to precipitation patterns. For instance, Kalimantan (Borneo) island has an equatorial climate characterized by wet and dry seasons which have remarkable disparity in precipitation.

This disparity and the related difficulties for the local community offer an opportunity for Adaro to deliver a positive impact. Adaro has opted to capture excess water and process it so it is suitable for use internally as well as by the local community. In this project Adaro has adopted the 3R principle—reduce, reuse, recycle—with regards to wastewater reutilization.

“A major concern for many areas in Indonesia is a lack of access to reliable, clean water.”

COLLECTION

In one of Adaro’s mines, rainwater accumulates in the pit sump (the area in the bottom of the open pit to collect surface runoff) together with the water generated by pit dewatering activities. This provides the mine with an abundant water supply year-round. The water collected in the sump is pumped out into a drainage system at volumes up to 300,000 m³/hr. The water must be pumped out continually to allow mining operation to continue. In the first step of the recycling process, excess water is moved to a series of settling ponds to allow the majority of suspended solids to settle and then small amounts of flocculant/coagulant agents are added as a final treatment to encourage further settling.

At this stage, the purpose of the treatment is to ensure that the water in the settling ponds meets the quality standard stipulated by national and provincial governments before being released to public water channels.

CONVERTING MINE WATER INTO POTABLE WATER

Not all of the water from settling ponds is released to the environment; a portion of it is further processed to meet the government’s quality standard for clean, potable water. This secondary treatment occurs at Adaro’s T-300 Water Treatment Plant (WTP), which was built in the Tutupan area in 2008.

Several processing steps are required at the T-300 WTP. The first step utilizes another settling pond to ensure that the water has a neutral pH. Any remaining suspended particles
are removed by further coagulation and flocculation, which is then followed by chlorination—a disinfecting process to kill potentially harmful bacteria, such as *E. coli*.

To ensure that the water is consistently safe for human consumption, the T-300 WTP is carefully monitored by Adaro employees who are responsible for the plant’s daily operations. Every month, a local government official checks the water quality against the drinking water standard set by the Indonesian Health Ministry. In addition to the official checks, Adaro regularly sends water samples to an accredited laboratory for a more thorough analysis.

Under current operations, the T-300 WTP is able to produce 72 m³ of clean water per hour. After it is processed, the water is stored in three tanks, two with 450-m³ capacity and one with 72-m³ capacity. Some of this clean water is consumed within Adaro’s mine. The remainder is distributed to the eight surrounding villages.

**MEETING COMMUNITY NEEDS**

Located on Kalimantan, the Tabalong and Balangan regencies are the sites of Adaro’s mining operations. Like the rest of the island, these regencies experience a monsoon climate with high rainfall during the wet season and drought conditions during the mid-year dry season. This variability affects water supply throughout the area. Deep artesian wells are too expensive for most local villagers; for this reason, some are forced to depend on untreated river water for their drinking water. These rivers are not necessarily reliable as clean water sources and do not meet the standard set for potable water. This condition inspired Adaro to share the clean water produced by T-300 WTP with the surrounding community.

Adaro’s clean water program was first conceived in 1997. At that time, all distribution of the potable water was carried out by trucks. Today, in collaboration with the local branch of the State Water Company, Adaro has installed pipelines that connect homes near the mining area to a master pipeline from the local water company. In 2010, a 10-km pipeline was installed by Adaro from the T-300 WTP to low-lying communities not served by the local water company. That pipeline now provides the first running water that these communities have ever experienced. Homes that have not been connected to the water pipeline are still served by trucks. The water treatment facility and this new pipeline cost Adaro a total of Rp 6.5 billion (~US$545,000).

Five years after the commencement of the T-300 WTP project, it supplies 1137 households with clean water through the 10-km pipeline network. An additional 5521 households are supplied using trucks. The total annual amount of potable water that is distributed is about 100 million liters. This accounts for 99% of the potable water in the Balangan district and 42% in the Tabalong district.

Initially villagers had some concerns about drinking recycled mine water. However, today they have fully embraced the treated mine water as a safe source of water for everyday use. Adaro considers this behavioral change of the villagers to be a key milestone; through outreach efforts, sanitary awareness has been improved and there is greater understanding that the water distributed by Adaro is more hygienic and safer than the river water on which communities previously relied.

**CONTINUED CORPORATE SOCIAL RESPONSIBILITY**

Based on its positive impact, the T-300 WTP project was selected as a runner-up for the World Coal Association’s 2013 Award for Excellence in Environmental Practice (for more information visit [www.worldcoal.org/international-coal–climate-summit-2013/wca-leadership-and-excellence-awards](http://www.worldcoal.org/international-coal–climate-summit-2013/wca-leadership-and-excellence-awards)). Although Adaro’s water sharing program has benefitted communities, the rate of potable water production is insufficient to keep up with local demand. Therefore, there are plans to increase the scale of production so that Adaro can fully meet the potable water needs of the community as well as those involved in the mining operations.

This clean water program is an important example of the many ongoing programs under which Adaro has combined environmental stewardship and conservation with community development projects. Through its CSR program the Adaro Group will continue to find ways to produce coal in a positive way that benefits the local community.

China

The China National Energy Conference was held on 13 January 2014 by the China National Energy Administration (CNEA). It was announced that the major energy-sector goals for 2014 include increasing energy efficiency, controlling energy consumption, optimizing the energy mix, and guaranteeing energy supply. According to Wu Xinxiang, Vice Chairman of the National Development and Reform Commission and Director of the CNEA, although growth in China’s energy sector will continue, with total 2014 energy consumption projected to be 3.88 billion tonnes of standard coal equivalent (tsce) (an increase of 3.2%), energy intensity is expected to decrease per unit GDP (to 0.71 tsce/10,000 RMB). The energy mix is also changing with the ratio of non-fossil energy expected to increase to 10.7% (the installed non-fossil power generation capacity will be increased to 32.7%); natural gas consumption is expected to increase to 6.5% and coal consumption is expected to decrease to 65%. Coal production in China in 2014 is expected to be about 2.5 billion tsce (out of a total energy production of 3.54 billion tsce). Even as the percentage of coal’s contribution in China’s energy sector shrinks in 2014, coal production is expected to grow by about 2.7%, driven by overall growth in the economy.

China recently released its 2013 Statistical Bulletin of National Economic and Social Development. According to the National Bureau of Statistics, China’s 2013 GDP was 56,884.5 billion RMB, an increase of 7.7% over 2012. Power generation in stalled capacity grew by 9.3% in 2013 to 1247.38 GW. In 2013, China’s raw coal production was 3680 million tonnes, an increase of 0.8%; coal imports (including lignite) were 327.08 million tonnes, up 13.4%. China’s total energy consumption in 2013 was 3750 million tsce, up 3.7% from the previous year. Coal consumption grew by 3.7%.

China’s Ministry of Environmental Protection is drafting a Water Pollution Prevention and a Control Action Plan; the goal of this Action Plan is to improve water quality.

Indonesia

Indonesia’s government will cap coal production at about 400 million tonnes in 2014, 5% less than 2013 levels, to address declining prices.

United States

The U.S. Department of Energy announced that it will provide $1 billion in funding to the previously stalled Future-Gen 2.0, which will be the world’s first commercial-scale, coal-fueled oxy-combustion CCS project.

Australia

Australia’s government will review its mandatory renewable energy target, which currently calls for 20% of energy to be drawn from renewable sources by 2020.
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

<table>
<thead>
<tr>
<th>Conference Name</th>
<th>Dates</th>
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<tbody>
<tr>
<td>Coaltrans China</td>
<td>Apr. 10–11</td>
<td>Shanghai, China</td>
<td>coaltrans.coal-china.org.cn/</td>
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<tr>
<td>Annual CCUS Conference</td>
<td>Apr. 29–May 1</td>
<td>Pittsburgh, PA, U.S.</td>
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</tr>
<tr>
<td>Power-Gen India &amp; Central Asia</td>
<td>May 5–7</td>
<td>New Delhi, India</td>
<td><a href="http://www.power-genindia.com">www.power-genindia.com</a></td>
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<tr>
<td>13th Annual European Coal Outlook</td>
<td>May 20–21</td>
<td>Nice, France</td>
<td><a href="http://www.ihs.com/info/events/european-coal.aspx">www.ihs.com/info/events/european-coal.aspx</a></td>
</tr>
<tr>
<td>International Pittsburgh Coal Conference</td>
<td>Oct. 6–9</td>
<td>Pittsburgh, PA, U.S.</td>
<td><a href="http://www.engineering.pitt.edu/pcc">www.engineering.pitt.edu/pcc</a></td>
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There are several Coaltrans conferences globally each year. To learn more, visit www.coaltrans.com/calendar.aspx

### Meeting Spotlight

#### Value of Coal Conversion

The National Coal Council is a federal advisory committee to the U.S. Secretary of Energy. On 26 February 2014, the National Coal Council and the Catholic University of America cosponsored a one-day Value of Coal Conversion (CTX) conference and Cornerstone covered the event. A range of topics was covered; for example, the many financial opportunities to advance CTX projects were discussed. In addition, several technical talks highlighted the ongoing RD&D in the field of CTX, such as the chemical looping process being developed at Ohio State or a small fluidized bed being employed for generating methanol from coal by Synthesis Energy Systems. The progress and underlying financial model of Summit Power’s Texas Clean Energy Project—a polygeneration facility that will produce electricity, urea, and CO₂ for EOR—was of particular interest. The agenda and presentations have been made available for download from: nationalcoalcouncil.org/ (Under Information > Presentations). One presentation highlighted that numerous project financing opportunities are available for those diligent enough to explore various government financing options within and outside the U.S. DOE. Companies may need to work outside the box to structure creative funding.

### GCCSI Third Annual America’s Forum

The Global CCS Institute held its Third Annual America’s Forum: Moving CCS Forward – Actions and Opportunities on 27 February 2014 at the Canadian Embassy, Washington, DC, U.S. The one-day meeting was jam-packed with speakers and panels. The overall theme of the event was characterized by the first keynote speaker Julio Friedmann, Deputy Assistant Secretary for Clean Coal, U.S. Department of Energy. Mr. Friedmann explained that although the last few years have been challenging for the CCS industry, there has been a promising uptick in activity led by CO₂-EOR (enhanced oil recovery), the commercial-scale Boundary Dam project that will be in operation later this year, and the fact that the world is on track to meet the goal of 100,000,000 tons/yr CO₂ abatement by 2020. Brad Page, CEO of the GCCSI, followed up with similar sentiments. He said that the advancement in CCS due to utilization for CO₂-EOR is necessary to move the technology forward. He said the current wave of 21 active projects will lead to technology cost buy down; for example, even prior to operation Mr. Page suggested that the costs for the “next Boundary Dam” would be at least 25% lower. He also suggested that one of the most important actions for the CCS community is to increase global
awareness, which is still quite low. Several other speakers also discussed the fact that CCS often is not given the same financial support as other low-carbon energy options.

From left to right: Sheila Riordon, Minister (Political), Embassy of Canada; Brad Page, CEO, Global CCS Institute; Julio Friedmann, Deputy Assistant Secretary for Clean Coal, U.S. Department of Energy.

Credit: Embassy of Canada

Materials Stewardship Toolkit – The International Council on Mining & Metals – The ICMM has released a toolkit to support its previous publication *Maximizing Value: Guidance on implementing materials stewardship in the minerals and metals value chain*. The toolkit is intended to assist ICMM members and others in understanding and implementing effective materials stewardship strategies while creating additional business value through identifying new opportunities in an increasingly competitive global market place. It can be downloaded at www.icmm.com

From the WCA

The World Coal Association has welcomed Whitehaven Coal as its newest member. Whitehaven Coal is a leading coal producer in New South Wales, Australia.

In recognition of his decade long global advocacy at the WCA on sustainable development and his work on coal and the environment, Milton Catelin, WCA Chief Executive, has won the 2014 Advance Global Australian Award in the Mining & Resource Category. For more information, visit advance.org

The WCA has released a video to highlight the winners of its inaugural Leadership & Excellence Awards, which were announced in November 2013. The new video is available at www.youtube.com/watch?feature=player_embedded&v=b6ID58GRu2Y

Recently the Norwegian Parliament considered a proposal that recommended the Norwegian Sovereign Wealth Fund divest its shares in coal companies. Speaking before Norway’s parliamentary Finance and Economic Affairs Committee, Milton Catelin said, “Banning investment in coal assets will do nothing to reduce demand for coal but will reduce investment in companies serious about addressing its environmental impacts and may lead to investment by companies less interested in pursuing cleaner coal technologies.” The Norwegian Parliament overwhelming rejected the proposal, although it could resurface again in the future.

Recent Select Publications

2014 World Energy Issues Monitor – World Energy Council – This study, which focused on South Africa, found that, for the first time, price volatility and recession have become the primary concerns among world energy leaders. Available at www.worldenergy.org/publications/2014

Carbon Capture – Jennifer Wilcox, Stanford – As an emerging field, carbon capture ranges over many disciplines; no single source previously existed that explains the fundamentals of gas separation and their link to the design process. This book is intended to be helpful for a range of potential readers, including undergraduate and graduate students, industrial personnel engaged in carbon capture, scientists, and engineers. This first-of-a-kind textbook focuses comprehensively on carbon capture and is now available in English and Chinese. www.springer.com/chemistry/industrial+chemistry+and+chemical+engineering/book/978-1-4614-2214-3

Norway’s Parliament
MISSION POSSIBLE: AN ENVIRONMENTALIST LOOKS AT COAL AND CLIMATE

Your article “Mission Possible: An Environmentalist Looks at Coal and Climate”, from the inaugural issue, recommends CCS for moderating the climate effects of coal combustion. However, this technology requires additional expenditures of fuel, cooling water, and infrastructure beyond the scope of timely implementation. The International Energy Agency has estimated a need for over 3000 CCS power plants and industrial facilities to achieve 19% of the CO₂ reductions required for limiting global warming to 2°C. On present coal usage trajectories, these installations would all have to be operational by the year 2030, which is an average of one CCS power plant every two days for the next 16 years. China and India are already dependent on foreign coal for electrical power generation. There is no economic rationale for them to increase these imports even further just to bury CO₂ underground. Here in Germany, 17 new lignite and coal-fired power plants will become operational between 2012 and 2020. Not one of them is equipped for CO₂ capture retrofitting, which remains a widely remote prospect due to restrictions on water withdrawal and pipeline routing. Enhanced oil recovery with CO₂ injection is detrimental to climate integrity, since greater net emissions result when the extracted hydrocarbons are subsequently burned. Any distant promise of CCS therefore conceals the ongoing accountability for fossil fuel usage. Geological carbon storage remains justifiable only when the coal is left in the ground to begin with.

Jeffrey Michel
Energy Consultant
German Energy Office of Energy Research

Response: Mr. Michel’s letter rightly points out the many challenges of ramping up CCS technologies but fails to note that other CO₂ mitigation options face equal or greater challenges. For example, displacing a 1000-MW coal plant at 80% capacity factor with wind turbines would require roughly 1200 2-MW wind turbines, occupying about 300 square miles in total. Hundreds of such installations would also entail significant additional expense and land use in the form of backup gas or coal power, each with its own emissions, or energy storage at unheard-of scales and at current per kWh costs roughly four times that of gas power. Regarding the CCS math, the latest IEA 2013 Roadmap calls for two gigatonnes of CO₂ per year sequestered via CCS by 2030. At roughly seven million tons of CO₂ per 1000 MW coal plant per year, that requires roughly 285 installations by 2030, or roughly 20 installations per year, well under the current annual coal build rate in China alone—ambitious, but not without historical precedent. If Mr. Michel wishes to bet the planet that wind, solar, and the like will displace the expected 3 TW of coal capacity expected to be installed by 2030, he is welcome to that bet; I’d suggest it is more prudent to hedge with lots of CCS capability.

Armond Cohen
Executive Director
Clean Air Task Force

CARBON CAPTURE AND STORAGE IS URGENT: AN EXCLUSIVE INTERVIEW WITH BRAD PAGE, HEAD OF THE GCCSI

CO₂-EOR is the only technology for CCS that has some concrete perspective in the future, thanks to the economic benefits from crude oil production. I recommend that readers review the Global CCS Institute’s study regarding this issue; 90% of planned CO₂ industrial storage sites are connected with CO₂-EOR.

Ľudovít Kucharič
Foreign Affairs Department at State Geological Institute of Dionyz Stur, Slovak Republic

Response: It is true that many, but certainly not all, projects—especially in North America—are partly supported by the additional revenue provided by EOR. But EOR is often not an option elsewhere in the world and CCS projects are nonetheless proceeding using deep saline aquifer storage (see Australia’s Gorgon project, for example).

A series of recent expert reports from the IEA, World Energy Council, and the UK Committee on Climate Change have made it clear that widespread adoption of CCS is vital if we are to keep global temperature increases below 2°C. Currently we know that the world is not on track to do so and it therefore essential that we adopt policies that support both CCS and a portfolio of other low-carbon technologies. Put simply, CCS must go beyond EOR uses to dedicated geological storage sites and this will require further policy action from governments.

Brad Page
CEO
Global CCS Institute

KEEPING COAL ALIVE ON THE CANADIAN PRAIRIES: CARBON CAPTURE AND STORAGE AT WORK IN SASKATCHEWAN

CCS projects are complex and challenging enough on their own, never mind without complete commitment and alignment. I believe this is where SaskPower has the largest added advantage from working on the inside of this
It’s the leadership of the business and the government (in this case, integrally linked as a crown entity) together in the project that has led to where they are now—which is on the brink. Without this leadership, the financial challenges and technical hurdles may have seemed insurmountable—as they have proven to be elsewhere around the world on several attempted CCS projects. I agree the success of Boundary Dam will go a long way to fueling (no pun intended) the momentum in the U.S. and hopefully Europe.

Devin Shaw
Manager
Strategic CCS Projects & Business Development
Cansolv Technologies Inc.

The development of CCS as a transition tool from fossil fuel over the next 30 years is essential and of world importance. It is important that other countries recognize this and follow the good example of Saskatchewan, Canada. It is also good that the momentum is building in the U.S., and hopefully now in the EU with changes to the current energy policies.

Michael Connell
Materials Manager
J. Murphy & Sons Limited

COP19: THE COBBLESTONE ROAD TO PARIS

It will be interesting to watch the climate change negotiations over the next two years. After 19 years of negotiations, the thorny issue of binding commitments to reduce emissions has still not been settled. This is a monumental challenge; reducing emissions is difficult and expensive, delivering uncertain benefits in the distant future. We should not be surprised that developing nations, which are struggling to meet the basic human needs of their people, are very reluctant to expend scarce resources or slow economic development to reduce emissions and, in so doing, have real and immediate impacts on their populations through further delaying access to modern economy, modern healthcare, modern education, etc. One can also understand why developed economies are reluctant to make commitments to significant emission reductions whilst the vast majority of projected emissions growth is from developing nations that cannot yet afford to reduce theirs. Reducing the total cost of low emission technologies is required to reduce the tension between emissions reduction and economic development. We have seen significant cost reductions in renewable energy generation thanks to sustained and very significant policy support (approaching one trillion dollars globally to 2020), which is encouraging. However, renewables alone can’t meet the large energy needs of modern economies. Hydropower, nuclear, and coal and gas with carbon capture and storage (CCS) are essential components of a low-emission energy mix. CCS has received policy support from governments, which is to be applauded; however, greater support, perhaps 20% of that enjoyed by renewable energy globally, is required to drive CCS down the cost curve. Perhaps a credible pathway to lower cost abatement through the development of an adequately funded program to commercialize CCS would make negotiating a meaningful emissions reduction agreement at COP21 in Paris less difficult.

Alex Zapantis
Principal Adviser
Product Stewardship
Rio Tinto Energy
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