Urbanization, City Growth, and the New United Nations Development Agenda

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A round the world, people are moving to urban centers in unprecedented numbers. As pointed out in this issue’s cover story, over the next 15 years the global population is expected to increase by 1.1 billion with nearly all of this growth concentrated in cities. The United Nations (UN) projects that over 6.3 billion people will live in urban centers by 2050. While the challenges experienced by many fast-growing cities should not be understated, people are moving to cities in droves because of the chance to improve their quality of life—economically, socially, and environmentally. Urbanites have much better access to basic services such as electricity, clean water, hospitals, and waste disposal. These benefits, as well as increased employment opportunities and access to better schools, make it abundantly clear why the world is on the move to cities.

There are several pillars under which coal supports urbanization. The most important is providing baseload electricity, which explains increasing coal use in rapidly urbanizing areas such as India and the Association of Southeast Asian Nations (ASEAN). Population concentration offers an opportunity to deploy large-scale, low-cost power plants that can support not only urbanization and modernization, but also job-driving industrialization.

Electricity is not the only link between coal utilization and urbanization. Steel and cement are two vital building blocks for urban centers, and the production of both at scale requires large coal inputs. In fact, the steel industry consumed about 1.2 billion tonnes of coal in 2013. Coal is also the fuel of choice for cement production, which currently uses 350–400 million tonnes each year.

Providing improved quality of life for those choosing to move to cities is a key objective for most governments, but there is also strong case to balance this goal with environmental protection. Urban centers, in fact, can offer major environmental benefits. For example, the unsustainable harvesting of biomass for cooking fuel and heating largely observed in rural areas, and associated with dangerous indoor air pollution, is much less prevalent in urban centers.

Although energy use in cities is higher, it can also be much more efficient with proper urban planning. One of the best opportunities for getting the most out of energy sources is combined heat and power generation. As profiled by an article in this issue, Germany has been applying this technology in large and small cities for decades. In addition, other high-efficiency, low-emissions technologies can be applied to the large coal-fired plants powering cities. While there are certainly challenges associated with widespread urbanization, they are vastly outnumbered by the opportunities.

This issue of Cornerstone offers several articles that explore the many areas in which coal is linked to urbanization. On behalf of the editorial team, I hope you enjoy it.
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Cover Story
Urbanization, City Growth, and the New United Nations Development Agenda
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Urbanization is a global trend and the world’s cities will absorb nearly all population growth in the near future. Cities will be an important consideration in planning the new UN development goals, and if urban centers can rise to the challenge, they offer an opportunity to improve living conditions for billions while balancing protection of the natural world.
In September 2015, member states of the United Nations (UN) will meet in New York to finalize a new global development agenda that will guide the international community’s efforts to eradicate poverty, reverse global trends toward unsustainable patterns of consumption and production, and protect and manage the environment over the next 15 years. For the past 15 years, the international community’s efforts have been guided by the UN’s Millennium Development Goals (MDGs), the eight-point agenda adopted by member states in 2000 that focused on eradicating extreme poverty and hunger, achieving universal primary education, promoting gender equality and empowering women, reducing child and maternal mortality, halting the spread of HIV/AIDS, ensuring environmental sustainability, and strengthening global partnerships for development, by the target date of 2015. The world has made notable progress in reducing extreme poverty over those years, in large part because of the remarkable economic growth that China has achieved. Some countries look set to attain all or most of the MDGs prior to the 2015 deadline. Overall, however, progress has been uneven both within and between countries and regions. At the same time, signs of global climate change and environmental degradation have become increasingly visible and the international community has come to recognize that global goals and targets for sustainable development need to be reprioritized in order to give environmental objectives a somewhat higher profile.

Cover Story

Urbanization, City Growth,

By Barney Cohen

Chief of Branch, Population Division, Department of Economic and Social Affairs, United Nations

“Cities are currently home to just over half of the world’s population and virtually all of the 1.1 billion increase in global population projected over the next 15 years is expected to occur in urban areas.”

In September 2015, member states of the United Nations (UN) will meet in New York to finalize a new global development agenda that will guide the international community’s efforts to eradicate poverty, reverse global trends toward unsustainable patterns of consumption and production, and protect and manage the environment over the next 15 years. For the past 15 years, the international community’s efforts have been guided by the UN’s Millennium Development Goals (MDGs), the eight-point agenda adopted by member states in 2000 that focused on eradicating extreme poverty and hunger, achieving universal primary education, promoting gender equality and empowering women, reducing child and maternal mortality, halting the spread of HIV/AIDS, ensuring environmental sustainability, and strengthening global partnerships for development, by the target date of 2015. The world has made notable progress in reducing extreme poverty over those years, in large part because of the remarkable economic growth that China has achieved. Some countries look set to attain all or most of the MDGs prior to the 2015 deadline. Overall, however, progress has been uneven both within and between countries and regions. At the same time, signs of global climate change and environmental degradation have become increasingly visible and the international community has come to recognize that global goals and targets for sustainable development need to be reprioritized in order to give environmental objectives a somewhat higher profile.
WHY MANAGING CITIES HAS BECOME A TOP PRIORITY

In designing the new global development agenda, it will be important for policymakers to understand and account for the nature and extent of the major demographic changes likely to unfold over the next 15 years and how such changes can be expected to contribute to or hinder the achievement of the new sustainable development goals. Much will depend, for example, on how well countries manage their cities. Cities have always been focal points for economic activity, innovation, and employment. Historically, most cities developed because of some natural advantage that they possessed in location related to ease of fortification or transportation, access to markets, or access to raw materials. Today, cities play a central role in creating national wealth, enhancing social and economic development, attracting direct foreign investment and manpower, and harnessing both human and physical resources in order to achieve gains in productivity and competitiveness. Cities also offer other advantages that are important for achieving sustainable development. Higher population density associated with urbanization provides an opportunity for governments to deliver basic services such as water and sanitation more cost-effectively to greater numbers of people. Higher population density may also be good for minimizing the effect of humans on local ecosystems. Despite the high rates of urban poverty found in many cities in low-income countries, urban residents, on average, enjoy better access to education and health care, as well as other basic public services such as electricity, water, and sanitation, than people in rural areas. For example, it has been estimated that 94% of urbanites have access to electricity compared with only 68% of rural residents.2

The challenge, of course, is that as cities become ever larger, managing them inherently becomes increasingly complex. A basic determinant of the world’s ability to achieve the post-2015 development agenda will be the quality of governance at all levels. In this context, it is important to note that the structure and organization of urban governance has itself undergone significant changes over the recent past, resulting in solutions to urban problems increasingly being sought at the local rather than the state or national level. This has created an urgent need to strengthen the capacity of local governments charged with solving new and persistent environmental and social service challenges that accompany rapid urban growth so that the benefits of urban living are shared equitably. In many cities, unplanned or inadequately managed urban expansion has led to urban sprawl, pollution, environmental degradation, and, in some cases, heightened exposure to the risk of natural hazards (e.g., floods and landslides). Future urban expansion needs to be undertaken in a more sustainable and inclusive manner, and needs to be accompanied by a reduction in the number of slum dwellers, an expansion of infrastructure to ensure greater access to basic services for the urban poor, and the implementation of policies that preserve the natural assets within cities and surrounding areas, protect biodiversity, and minimize tropical deforestation and changes in land use.

TRENDS IN URBANIZATION AND CITY GROWTH

Cities are currently home to just over half of the world’s population and nearly all of the 1.1 billion increase in global population projected over the next 15 years is expected to occur in urban...
areas. For that reason, the United Nations Population Division has published a new resource, *World Urbanization Prospects: 2014 Revision [Highlights]*. The report contains the latest official UN estimates and projections of urban and rural populations for major areas, regions, and countries of the world from 1950 to 2050 and estimates and projections to 2030 of all urban agglomerations with 300,000 or more inhabitants in 2014. As such, it was created to provide important insights into the size and characteristics of future urban challenges and opportunities.3

As the report makes clear, urbanization has proceeded rapidly over the past 60 years. In 1950, more than two-thirds of people worldwide lived in rural areas and slightly less than one-third resided in urban areas. In 2014, 54% of the world’s population lived in urban areas, and the coming decades will not only see continued global population growth but also continued urbanization so that all of the growth in global population over the next 15 years is projected to occur in urban areas. Furthermore, those projections show that urbanization, combined with the overall growth of the world population, could result in the addition of another 2.5 billion people to the global urban population by 2050, at which time the world is expected to be one-third rural and two-thirds urban—almost the exact opposite of the situation observed in the mid-20th century (see Figure 1).

Just over the brief span of the next 15 years, the timeframe for the implementation of the new UN development agenda, the world’s urban population is projected to expand 28%. All regions, with the exception of Europe, are projected to increase the size of their urban population by at least 15%—with Africa and Asia projected to have the largest increases of 63% and 30%, respectively (see Table 1).3 Perhaps not surprisingly, given the size of their populations, the greatest urban growth is expected to occur in India, China, and Nigeria. Taken together, these three countries are projected to account for 37% of the total growth of the world’s urban population between 2014 and 2050. By 2050, India is projected to have added an additional 404 million urban residents, China an additional 292 million, and Nigeria an additional 212 million.

The new UN report differs from previous versions because, for the first time, estimates and projections from 1950 to 2030 are provided for all urban agglomerations with populations currently over 300,000. Previously, data were reported only for cities with over 750,000 residents. Although there is obviously much uncertainty about the future course of urbanization and city growth, and, in particular, the exact trajectory of any given city or urban area, the broad trends across regions and across city sizes over a 15-year time horizon can be expected to be reasonably robust and are very clear: The world’s fastest growing cities are located in Africa and Asia and tend to be medium-sized cities of between one and five million residents.

Given the projected increase in the global urban population, it is not surprising that the world is projected to experience not only an increase in the absolute number of large cities, but that the largest cities are projected to reach unprecedented sizes. “Mega-cities”, conventionally defined to be large urban agglomerations of 10 million or more, have become both more numerous and considerably larger in size. In 1990, there were 10 such mega-cities, containing 153 million people. By 2014, the number of mega-cities had nearly tripled to 28, and the population that they contain had grown to 453 million inhabitants, accounting for roughly 12% of the world’s urban dwellers. While Tokyo, currently the world’s largest urban agglomeration with 38 million inhabitants, has grown at an annual rate of roughly 0.6% over the last five years, other megacities such as Delhi (with 25 million residents) and Shanghai (with 23 million) have been growing at more than 3% per annum over recent years. Such rapid growth is creating significant challenges for local authorities charged with delivering essential services. Rounding out the list of the top 10 largest urban agglomerations are Mexico City, Mumbai, and Sao Paulo, each with around 21 million, Osaka with just over 20 million, Beijing with slightly under 20 million, and New York-Newark and Cairo, each with around 18.5 million inhabitants.

### Table 1. Urban population by major area, 2015 and 2030

<table>
<thead>
<tr>
<th>Region</th>
<th>Urban population 2015 (millions)</th>
<th>Urban population 2030 (millions)</th>
<th>Ratio of 2030/2015</th>
</tr>
</thead>
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<tr>
<td>World</td>
<td>3957.3</td>
<td>5058.2</td>
<td>1.28</td>
</tr>
<tr>
<td>Africa</td>
<td>471.6</td>
<td>770.1</td>
<td>1.63</td>
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<td>Asia</td>
<td>2113.1</td>
<td>2752.5</td>
<td>1.30</td>
</tr>
<tr>
<td>Europe</td>
<td>547.1</td>
<td>567.0</td>
<td>1.04</td>
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<tr>
<td>Latin America and the Caribbean</td>
<td>502.8</td>
<td>595.1</td>
<td>1.18</td>
</tr>
<tr>
<td>Northern America</td>
<td>294.8</td>
<td>339.8</td>
<td>1.15</td>
</tr>
<tr>
<td>Oceania</td>
<td>27.9</td>
<td>33.7</td>
<td>1.21</td>
</tr>
</tbody>
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SMALL CITIES, BIG AGENDA

While there is no doubt that large cities will play a significant role in absorbing future anticipated growth, the new report also makes clear that at least for the foreseeable future the majority of the world’s urban residents will continue to live in far smaller urban settlements. In 2014, close to one-half of the world’s urban population lived in settlements with fewer than 500,000 inhabitants whereas only around one in eight lived in the 28 mega-cities with 10 million inhabitants or more. Although the percentage of the urban population living in relatively smaller urban settlements is projected to shrink over time, even in 2030, the anticipated final year for the implementation of the soon-to-be-adopted new UN development agenda, small cities and towns will still be home to around 45% of the population. Typically, residents of small cities in developing countries suffer a marked disadvantage in the provision of basic services, including provision of piped water, sanitation, and electricity, compared to residents of medium or large cities. Furthermore, researchers have found that in developing countries, rates of poverty are typically higher in smaller cities than in medium or larger cities, and that infant and child mortality are negatively proportional to city size.

Given the role that will be played by small cities in accommodating future population growth, improving the provision of basic services in such cities must remain a priority.

FROM MILLENNIUM DEVELOPMENT GOALS TO SUSTAINABLE DEVELOPMENT GOALS

It has long been recognized that the size, composition, and spatial distribution of human populations can substantially affect the likelihood of achieving sustainable development goals. Over 20 years ago, in 1994, the International Conference on Population and Development’s Programme of Action pointed out that unsustainable consumption and production patterns were contributing to the unsustainable use of natural resources and environmental degradation as well as to the reinforcement of social inequities and poverty. In designing the new post-2015 development agenda, member states of the UN need to ensure that efforts to improve the quality of life of the present generation are far-reaching, broad, and inclusive, but do not compromise the ability of future generations to meet their own needs. Accomplishing these ambitious goals will depend on identifying strategies to expand access to resources for growing numbers of people, eradicate poverty, increase standards of living, reduce unsustainable patterns of consumption and production, and safeguard the environment.

Cities have become the principal venue for attempting to achieve the goals and targets of the new development agenda. Consequently, one of the central challenges over the next 15 years is finding means to take full advantage of the potential benefits of urbanization and city growth in ways that lessen the obvious potential negatives. The realization by the international community that, alongside poverty reduction, environmental objectives must feature more prominently in any new list of global goals and targets suggests that attention to issues of energy use and energy efficiency are likely to attract much more attention than ever before. Continued urban population growth combined with rising standards of living suggests that energy use and greenhouse gas emissions will be much higher in the future, unless there is concerted action to reduce them. Therefore, one essential element of the new sustainable development agenda will be to encourage local authorities to invest in new cleaner energy infrastructure relying on high-efficiency, low-emissions fossil-fuel technologies and utilize new technologies that take advantage of alternative energy sources.

DISCLAIMER

The views expressed in this article are those of the author and do not necessarily reflect those of the United Nations.

REFERENCES

The High Cost of Divestment

By Benjamin Sporton
Acting Chief Executive, World Coal Association

Since 2012, when 350.org launched its “Fossil Free” campaign, there has been an increasing global campaign to divest fossil fuel assets, particularly coal. The approach has been supported by some institutions that have divested, while rejected by others. For instance, in February 2015, despite an expert panel supporting continued investment, NBIM, the manager of Norway’s sovereign wealth fund, announced it had divested a number of fossil fuel companies from its portfolio.

In contrast, a number of other high-profile organizations have resisted calls for divestment. Harvard University, Brown University, the University of Oxford, and the Wellcome Trust, among others, have released statements questioning the rationale of the campaign. Indeed, the President of Harvard, Drew Faust, who controls the university’s $32 billion endowment, stated: 1

“Divestment is likely to have negligible financial impact on the affected companies. And such a strategy would diminish the influence or voice we might have with this industry. Divestment pits concerned citizens and institutions against companies that have enormous capacity and responsibility to promote progress toward a more sustainable future.”

As the divestment campaign has grown in exposure, proponents have begun to suggest that the financial valuations of energy companies may be damaged by strict international climate policies. Campaigners suggest that in order to avoid the potential impacts of climate change, governments must adopt policies consistent with limiting global average surface temperature increases to 2°C above pre-industrial levels. This scenario would require deep structural changes to the business model of conventional energy companies. In effect, they argue, it would render large volumes of coal and hydrocarbon reserves “unburnable”. The concept continues that stock market valuations of fossil fuels are overvalued creating a “carbon bubble”. Under these circumstances, campaigners have begun to pressure governments and institutions to divest their financial holdings from companies that explore, produce, market, and/or exploit fossil fuels.

However, with deeper analysis, it is clear that the movement is built on unsubstantiated claims and flawed logic.

“As demonstrated by the projected growth of coal, stepping away from the fossil fuel industry does not mean that the demand for fossil fuels goes away.”

COAL: FUELING THE FUTURE

Calling for divestment from coal does not recognize the reality of growing energy demand, the continuing role of coal, and the importance of technology in enabling coal use to be compatible with global efforts to reduce emissions. Coal has accounted for nearly half of the increase in global energy use over the past decade. In terms of energy, the 21st century has been built on coal. In the early part of this century, coal’s global contribution alone has been comparable to the contribution of nuclear, renewables, oil, and natural gas combined (see Figure 1). 2

The latest figures from the BP “Statistical Review of World Energy” show that coal’s share of global primary energy consumption in 2013 reached 30.1%—the highest since 1970. 3

There are 1.3 billion people in the world today who live without access to electricity; 2.6 billion people rely on traditional fuels, such as dung and wood, for cooking. No doubt that is why, according to the World Resources Institute, 1199 coal

FIGURE 1. Incremental world primary energy demand by fuel, 2000–2010

Gas Oil Nuclear Total non-coal Coal

Mtoe (million tonnes of oil equivalent)
plants (representing 1,401,278 MW) are anticipated across 59 countries, many of them in the developing world. This is because coal is the most affordable, easily accessible, and reliable source of power.

Alongside its vital role in electricity generation, coal is also an indispensable ingredient for building modern infrastructure, such as transport systems, equipment, and high-rise buildings, to support urbanization and economic development. The materials used in these projects—steel, cement, glass, and aluminum—are highly energy intensive. Coal’s social value was highlighted by Christina Paxson of Brown University in her response to calls for divestment when she said, “A cessation of the production and use of coal would itself create significant economic and social harm to countless communities across the globe.”

Forecasting Future Demand

At the core of divestment campaigns are forecasts about the future demand for fossil fuels. Investors and policymakers rely on energy projections from a variety of independent sources and these shape investment decisions. Leading energy forecasters, such as the IEA, all suggest that coal will have a central role to play in energy generation and in industries, such as steel production, for decades to come. Even under the IEA’s New Policy Scenario (see Figure 2), which assumes all government promises on funding renewables and building nuclear power plants are implemented, coal consumption increases by around 17% through to 2035 and there is little change in the global energy mix. Coal continues to make up 25% or more of primary energy demand—as it was in 1980, and as it has been for most of the past 30 years. This will also be 25% of an energy pie that IEA projects to grow by 40% over the next quarter century.

The Flawed Logic of Divestment

Divestment campaigns assume investors do not understand the risks associated with the investments they undertake and, as such, they are incapable of pricing the risk within their portfolios. There are risks for every business and future demand conditions may result in losses given current business models and business strategies. The fossil fuel industry is not unique in this. However, divestment campaigns seem to be based on the argument that investors are somehow oblivious to the risks. Investors have known about climate change since at least 1992, when the United Nations Framework Convention on Climate Change (UNFCCC) was negotiated.

In fact, a University of California study has refuted claims that the so-called “carbon bubble” will soon burst. The study found that rational investor expectations of future cash flows derived from fossil fuel assets have already adjusted for the likelihood of global action to reduce CO₂ emissions.

Investors may not value the risks to the level that divestment campaigners would like, but it is an unsubstantiated claim that markets ignore these risks. An appropriate response to any risk is a well-diversified portfolio.

Challenge to Environmentally Conscious Investments

Divestment campaigns pressure investors to divest fossil fuel stocks irrespective of whether they have good or bad Corporate Social Responsibility (CSR) indicators. All fossil fuel companies are grouped together—no benefit is given to companies with a good CSR performance.

However, environmentally conscious investors are able to ensure responsible corporate behavior through the adoption of CSR programs that enhance environmental outcomes. For instance, investment has led to developments in cleaner coal technologies, such as high-efficiency, low-emissions (HELE) coal-fired power plants and carbon capture, use, and storage.
(CCUS), which have made a significant contribution to reduce global CO₂ emissions. The potential of CCUS is evidenced by the Boundary Dam coal-fired power station in Canada. This pioneering project will reduce greenhouse gas (GHG) emissions by one million tonnes of CO₂ annually, the equivalent to taking more than 250,000 cars off the road each year.

Stepping away from the fossil fuel industry does not mean that the demand for fossil fuels will go away, it just means that environmentally conscious investors lose any influence they have over the operation of those companies.

By definition, divestment requires a change in ownership of assets: Institutes and individuals may sell their shares but can only do this if other institutes and individuals buy these same shares. In other words, divestment does nothing to affect the demand for or use of fossil fuels.

THE ROLE OF TECHNOLOGY

The large mitigation potential of cleaner coal technologies, including HELE coal plants and CCUS, invalidates the central argument of divestment campaigns. Coal can be, and in many cases already is, used in a sustainable way through the use of modern technologies. Investing in cleaner coal technologies is often criticized as a means for the coal industry to “smuggle” its products into a low-emissions future. The reality is that cleaner coal technologies are needed because coal demand will continue and, thus, coal is part of our energy future. Raising the global average efficiency of coal plants from 34% to 40% with today’s off-the-shelf technology would save two gigatonnes (Gt) of CO₂ each year. This is more than the total annual CO₂ emissions of India—the third largest CO₂ emitter in the world.

In addition to the significant benefits from reducing CO₂ emissions, modern HELE plants can almost eliminate emissions of nitrogen oxides (NOₓ), sulfur dioxide (SO₂), and particulate matter (PM). Real solutions to climate change will come largely through technological change and action on all low-carbon options. CCUS will be a key technology to reduce CO₂ emissions, not only from coal, but also gas and industrial sources. The IEA has estimated that CCUS could deliver 14% of cumulative GHG emissions cuts through to 2050 and that climate change action will cost an additional US$4.7 trillion without CCUS. However, in comparison to other low-carbon technologies, CCUS is underfunded. The Global Subsidies Initiative has reported that renewable energy projects (excluding hydroelectricity) receive US$27 billion in public funds every year. In comparison, in the decade since 2005, only US$12.2 billion has been available to fund CCUS demonstration—in total.

DIVESTMENT IS LIKELY TO HARM FINANCIAL GOALS

Funds subscribing to the objectives of the divestment campaign will incur three types of costs: trading, diversification, and compliance.

Trading costs refer to the outlays involved in selling fossil fuel securities and purchasing new compliant stocks. In addition, many exchanges are also liable for exchange fees and taxes. A recent study titled “Fossil Fuel Divestment: A Costly and Ineffective Investment Strategy” by Professor Daniel R. Fischel suggests that these processing and execution costs are approximately $0.18 per $100. Professor Fischel suggests that U.S. universities would incur costs of $40.2 million for processing and execution.

Investment risk is best mitigated by a diverse asset portfolio. Restricting or eliminating fossil fuels from investments will likely reduce the average return. Again, Fischel’s study provides compelling evidence to support this argument. The study assessed a portfolio containing energy stock against a portfolio with no energy stock from 1965 to 2014. In addition to a reduced return of 0.7% per year, the assessment found that the portfolio that did not have energy assets was more susceptible to volatility.

Finally, divestment compliance is a complex process that is highly sophisticated and demanding. Thus, it comes with commensurate resource and cost burdens. More than simply divesting from fossil fuel companies, policy may demand that investments are withdrawn from index and commingled funds and moved to actively managed funds. Assessments suggest this would cause management fees to double. To address these compliance concerns, portfolio managers are beginning to offer funds with “green” objectives. Industry reviews,
however, indicate that mutual funds with an environmental focus come with higher management fees.

Independently the various costs associated with divestment are substantial. Cumulative costs, however, are significant and may impair the objectives or even function of endowments and pension funds. Divestment by tertiary organizations is especially counterintuitive, given their role in providing solutions to energy and climate issues through research and grants.

CONCLUSION

The direct impacts of fossil fuel divestment are unlikely to be significant; this view is grounded in financial logic. In contrast, however, the indirect impacts of campaigners should not be discounted.

Perhaps most significantly, divestment would lead to responsible investors leaving the energy industry. As demonstrated by the projected growth of coal, stepping away from the fossil fuel industry does not mean that the demand for fossil fuels goes away. Instead, a more likely scenario is that environmentally conscious investors will lose any influence they had over the operation of those companies. Indeed, this outcome was highlighted by Jeremy Farrar, Director of the Wellcome Trust, who responded to the recent Guardian divestment campaign by stating:

We use our access to boards to encourage them to adopt more transparent and sustainable policies that support transition towards a low-carbon economy. And we adopt the same position with companies that consume fossil fuels as we do with the companies that supply them. Carbon emissions are driven by both supply and demand: it makes no sense to devote attention purely to one side of this equation. This maximises our influence as investors.

The divestment campaign threatens the coal industry’s investments to improve environmental performance, starting with the potential to reduce 2 Gt of CO₂ emissions each year with off-the-shelf efficiency increases. This is why the World Coal Association has recently published a concept paper on launching a global Platform for Accelerating Coal Efficiency (PACE) to support the deployment of HELE technologies. Moreover, deployment of HELE is a critical step on the pathway to the deployment of CCUS technologies. As shown by the Intergovernmental Panel on Climate Change, this is a vital development if global temperature increases are to be kept below 2°C.

REFERENCES


A copy of the WCA’s PACE concept paper can be downloaded from the WCA website: www.worldcoal.org
South Africa’s Road to Growth Is Paved With Coal

By Nikki Fisher
Coal Stewardship Manager, Anglo American Coal

South Africa is already largely urbanized. Today, nearly two thirds of South Africans live in urban centers. Although the rate of urbanization is slower in South Africa than some other emerging economies, it is projected that 77% of the country’s population will reside in urban areas by 2050.¹ Energy from coal is intertwined with urbanization in South Africa in two important ways. First, in urban centers, baseload coal-fired power plants provide electricity to support much-needed industrial growth and the employment opportunities created. Second, coal-fired power plants have directly supported the development of several urban centers, especially in the Mpumalanga region.

Since 1990, the percentage of South Africans living in urban centers has increased from 52% to 65%. The demand for electricity, and the coal that makes up 93% of South Africa’s electricity generation, has grown at similar rates during this period (see Figure 1). Urbanites consume more electricity than their rural counterparts due to higher levels of access and more money to pay for services. The disparity is considerable: On average, urban households in South Africa consume 4800 kWh each year while rural households consume about 800 kWh.²

Today, South Africa’s electricity sector is facing considerable challenges—including a lack of sufficient, reliable baseload power—that could impact urbanization and overall economic growth. South Africa has also made climate commitments.

All options are being explored as different energy sources will be called upon to make progress on increasing electricity generation while meeting the country’s climate goals. Thus, the South African Coal Roadmap (SACRM) was prepared to explore the activities and interventions needed for the coal industry to maximize its contribution to the country in the face of an uncertain future.

“South Africa’s electricity sector is facing considerable challenges—including a lack of sufficient, reliable baseload power—that could impact urbanization and overall economic growth.”

A NATION CONSTRAINED

South Africa is currently facing an electricity crisis deemed to be one of the country’s greatest challenges over the last 20 years. Rolling blackouts began in November 2014 and the power supply system will continue to be under extreme pressure, with an imminent risk of load-shedding of up to 2000 MW at any time for at least the next two to three years.

This is not the first time that the country has experienced rolling blackouts. In 2007/2008, several months of load-shedding occurred, which motivated the recommissioning of three previously moth-balled power stations and a strong demand-side energy efficiency drive. Coupled with the global financial crisis and subsequent in-country economic downturn, the result was decreased electricity demand and temporary relief of pressure on the grid. Even so, ensuing grid constraints have resulted in slower economic development estimated at roughly R300 billion (~US$25 billion) or 10% of the potential economic growth.³

Economists’ estimates about the economic impact of the controlled blackouts on the country vary between R6 billion⁴ and R20 billion per month⁷ (US$0.5 billion and US$1.65 billion,
respectively) for Stage 1 load shedding (i.e., 1000 MW load shed). These estimates are based on the day-to-day impact on business of running generators, changing shifts, and lost work time; the less conservative estimates include the long-term costs of job losses, stunted economic growth, and less investment in the country.

The inability of the country to meet electricity demand has led to downward revisions of the economic growth forecast by the South African Reserve Bank from 2.5% to 2.2% for 2015. Several ratings agencies have also downgraded the country’s credit rating, which has had a negative impact on investor confidence in the economy.7

**“Despite South Africa’s energy challenges, the country is working to balance its development and climate priorities.”**

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**THE ROLE OF COAL**

In 1994, the majority of South Africans did not have access to electricity. Since then an ambitious electrification program has increased the proportion of electricity users in the total population from 36% to 84%.8 This electrification program would not have been as widespread without low-cost electricity, which, in turn, could not have been achieved without coal as a fuel source. It is because coal is abundant, accessible, secure, reliable, and affordable that it is the cornerstone of energy in South Africa—today coal is used to produce 93% of electricity and 30% of liquid fuels. In excess of 60 billion tons of coal resources and reserves remain in South Africa.

The nation benefits from the coal industry in several ways apart from its contribution to affordable electricity. It is the mining industry’s top revenue earner, ahead of platinum and gold. At a time when the current account deficit is precarious, the country can ill afford to lose revenue from coal exports. Moreover, the coal industry as a whole employs 83,000 people in a country with a 25% unemployment rate, with employees earning a combined $1.6 billion in salaries and wages.

With the majority (i.e., 72% in 2014) of South Africa’s primary energy coming from coal and given its demonstrated benefits to the economy, new coal-fired power plants were planned. The greatly anticipated new 4800-MW coal-fired power stations, Medupi and Kusile, were originally anticipated to start coming online in 2012. However, both projects have been plagued by construction delays and budget overruns. The first unit of Medupi was synchronized onto the grid on 2 March 2015 and is expected to deliver roughly 780 MW onto the grid by June 2015. Neither plant will be running at full capacity before 2020.

As a consequence of these delays, Eskom has been running many of the existing, aging power stations beyond their expected lifetimes and delaying scheduled maintenance to keep the lights on; this has led to breakdowns, unplanned maintenance, and a severely constrained system. Almost one third of Eskom’s 45 GW of installed capacity is presently offline due to planned and unplanned maintenance.7 Despite the new capacity that has come online, including an increase in non-Eskom power production by 8.5% from 2013 to 2014, overall production has decreased by 1%.9

The large build program, primarily funded through tariffs, resulted in the electricity price in South Africa increasing 78% between 2008 and 2011, and it will continue to rise in real terms for several more years. The National Energy Regulator of South Africa (NERSA) approved a 12.7% increase in the electricity price for Eskom for the 2015/2016 financial year.10 This has significant impacts on affordability and continued access to electricity for many households and on energy-intensive businesses.

**SOUTH AFRICA’S ENERGY CHALLENGES WILL REQUIRE CONTINUED COAL USE**

The SACRM was developed and published in 2013 as a means to explore the activities and interventions that the coal industry should undertake to maximize its contribution to the country in the face of an uncertain future. Despite South Africa’s energy challenges, the country is working to balance its development and climate priorities.

The SACRM is the only place that comprehensive information about the coal value chain has been compiled into a single document. Four scenarios, shown in Figure 2, were developed. These scenarios were based on the local and international response to climate change as a framework for developing the roadmap.

According to the Roadmap, the country will need a total of between 85 and 125 GW of installed capacity by 2040, depending on the level of renewable energy in the mix, up from 42 GW in 2010.11

**THE FUTURE OF COAL IN SOUTH AFRICA**

To encourage economic growth and build a thriving society, energy security is a priority. Under all of the scenarios modeled in the SACRM, including the “Low-Carbon World”,

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7. Despite South Africa’s energy challenges, the country is working to balance its development and climate priorities.

8. In 1994, the majority of South Africans did not have access to electricity. Since then an ambitious electrification program has increased the proportion of electricity users in the total population from 36% to 84%.

9. This electrification program would not have been as widespread without low-cost electricity, which, in turn, could not have been achieved without coal as a fuel source. It is because coal is abundant, accessible, secure, reliable, and affordable that it is the cornerstone of energy in South Africa—today coal is used to produce 93% of electricity and 30% of liquid fuels. In excess of 60 billion tons of coal resources and reserves remain in South Africa.

10. The nation benefits from the coal industry in several ways apart from its contribution to affordable electricity. It is the mining industry’s top revenue earner, ahead of platinum and gold. At a time when the current account deficit is precarious, the country can ill afford to lose revenue from coal exports. Moreover, the coal industry as a whole employs 83,000 people in a country with a 25% unemployment rate, with employees earning a combined $1.6 billion in salaries and wages.

11. With the majority (i.e., 72% in 2014) of South Africa’s primary energy coming from coal and given its demonstrated benefits to the economy, new coal-fired power plants were planned. The greatly anticipated new 4800-MW coal-fired power stations, Medupi and Kusile, were originally anticipated to start coming online in 2012. However, both projects have been plagued by construction delays and budget overruns. The first unit of Medupi was synchronized onto the grid on 2 March 2015 and is expected to deliver roughly 780 MW onto the grid by June 2015. Neither plant will be running at full capacity before 2020.
South Africa cannot afford early retirement of existing power stations. In line with this, the lives of many of the existing coal-fired power stations have been extended and are now scheduled for closure between 2030 and 2040. New power stations will be required to replace this capacity and, to meet demand growth, clarity is required on technology options that will be used. The SACRM makes some recommendations for actions necessary to keep the lights on.

**Coal Roadmap Recommendations**

*Secure contracts for continued coal supply to existing power stations and invest in new mines.* Impending coal shortfalls for the existing power stations are a serious risk to energy security. Dubbed the “coal supply cliff”, a massive shortage (in excess of 60 million tons) in coal supply is anticipated from 2018. The reasons for this are several. When the current fleet of power stations was commissioned, long-term supply contracts were signed for the life of the power station (usually 40 years). The lives of many of these power stations have since been extended, and most power stations have been run at loads higher than originally expected when the coal supply contracts were signed. In addition, some of the resources have not been as extensive as originally assumed. The recommissioning of the three moth-balled power stations in 2008 also created additional and unexpected demand for coal. The majority of the new coal resources that could potentially fill the supply gap require extensive exploration and feasibility studies before mines can be opened and supply contracts signed.

The cost of mining is increasing, due to coal being sourced from lower-quality deposits with higher operating costs associated with increased processing requirements and longer transport distances. In all scenarios in the SACRM, the price of coal to Eskom will increase. Agreement must be reached on a coal price mechanism and a fair rate of return on investment being sought by mining companies to encourage investment in new mines. The most viable model for a domestic supply coal mine is for it to be a multi-product mine that benefits from the higher returns possible on the export market. Figure 3 shows the disparity between export and domestic tonnages and prices for 2012.

*Open new coal fields.* Traditionally, the coal supply has come from the Central Basin, where the majority of the coal-fired power stations are located. All scenarios in the SACRM show that high-grade utility coal from the Central Basin will be very constrained from the mid-2020s onward and essentially depleted by 2040. During this time, just one mine switching from domestic to low-grade export supply could create an immediate domestic coal shortfall. To reduce this risk, it is prudent to open alternate sources of coal, of which the largest...
and most likely resource is the Waterberg coalfields. As rail, transmission, and water infrastructure from this area to the power stations in the Central Basin is lacking, and given the long lead times required for construction of such infrastructure, the SACRM recommends that access to the Waterberg be enabled without delay.

Resolve coal transport challenges to Central Basin power stations. In 2010, roughly 22% of the coal supplied to Eskom was delivered via road. The externalities associated with road transport include damage to roads, increased road accidents and fatalities, and increased air pollution leading to human health impacts. To address this, Eskom is undertaking a road-to-rail migration together with Transnet Freight Rail. A shift from road to rail will impact the trucking companies and associated jobs and these impacts must be carefully considered and minimized.

Align policy and licensing procedures. Investment in new mines requires a supportive and enabling regulatory environment. The current regulatory situation relating to complex environmental permitting requirements under multiple laws (and consequently multiple government departments) creates extensive delays and affects the timely delivery of mining investments. Alignment and certainty of regulatory and permitting procedures for new mines is critical.

Other policies where certainty is needed include statements made by the Department of Mineral Resources regarding coal as a strategic resource, which may limit coal exports and impact negatively on investment; carbon tax or other carbon pricing mechanisms; Broad-Based Black Economic Empowerment requirements and interventions to prevent hoarding of rights and situations where a resource may be urgently needed for Eskom supply, but is not a priority for the mining company that holds the rights.

The mining “majors” (Anglo American, BHP Billiton, Glencore, Exxaro, and Sasol) account for 85% of coal production in South Africa and 90% of the supply to Eskom. The remaining supply is from smaller players. Eskom now requires that 55% of their supply be sourced from black-owned businesses. The capacity of these smaller businesses to fund and develop mines may be limited, which indicates that there is a strong need for cooperative business partnerships between either Eskom or the existing majors and the smaller players.

Provide clarity on new electricity build. The future of electricity in South Africa is governed by the Integrated Resource Plan for Electricity 2010–2030 (IRP). The IRP included 9 GW of nuclear power by 2023; however, the program for investment and development of nuclear power is far behind the schedule required to have it online by 2023. A revision of the IRP is due for publication in the near future, and clarity is needed on new and replacement baseload generation as well as who is to take responsibility for the new build. The Renewable Energy Independent Power Producer Programme has been successful, bringing 1700 MW capacity on to the grid, and expedition

It is recommended that transition plans are in place for communities that have developed around power plants now slated for closure.
of the baseload Independent Power Producer Programme (IPP), for both coal and gas, will help to ensure energy security if favorable market conditions are created for the IPPs.

Investment in electricity infrastructure ranges from R930 billion in the “More of the Same” scenario to R2060 billion in the “Low-Carbon World” scenario because of the higher capital cost of renewable technologies, which may decrease over time, and because of the additional installed capacity required due to the lower load factors of renewables. The higher capital costs are offset by lower operating costs, a diversified investment mix, and a more resilient grid. However, increased nuclear and renewables in South Africa’s energy mix is likely to result in higher electricity prices which may put additional strain on an emerging economy.

Mitigate impacts and the transition to a low-carbon economy.

In the longer term, the role of coal in the electricity mix will be dependent on the ability to mitigate the environmental impacts of coal-fired power generation.

Transition to a diversified grid will help to mitigate emissions, as can the improvement of power station efficiency, which will significantly reduce emissions per unit of power compared to the existing fleet. The demonstration of technologies such as underground coal gasification and high-efficiency combustion is also important. Carbon capture and storage (CCS) may also help to reduce emissions, but CCS in South Africa is in its infancy and any mitigation potential would only be realized in the long term.

Plan for closure. At least six power stations will close in the Mpumalanga region before 2040. The resulting job losses could ultimately lead to the decline of the existing urban centers that have developed around the coal-mining and power-generating region. It will be important to create diversified industries in this area and to undertake capacity building as well as skills development for the people in those areas to help to mitigate these impacts.

PLANNING FOR ACTION

South Africa is currently best represented by the “At the forefront” scenario, where ambitious (albeit conditional) climate change commitments have been made. Continuing on this trajectory could have serious implications for global competitiveness, employment opportunities, and energy security. The outcome of COP21 and the country’s Intended Nationally Determined Contributions committed to at COP21 will play a large role in determining our energy future.

South Africa is on the precipice of a crisis. Careful planning and prompt action are essential for a future where electricity demand can be met, economic growth takes place, and a just transition to a lower-carbon economy is possible.

REFERENCES


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The phenomenon of “urbanization”, or population shift from rural to urban areas, is occurring at an unprecedented rate in India. According to the 1901 census, the population residing in urban areas in India was 11.4%. This number steadily increased post-independence and by 2011 had reached 31.2%, with continued urbanization on the horizon. Based on the growth rates observed between 2001 and 2011, by the end of 2015 the population of Mumbai is projected to stand at 25 million, Delhi and Kolkata at 16 million each, while Chennai, Bengaluru, and Hyderabad will each have 10 million residents. According to a 2007 United Nations “State of World Population” report, 40.8% of India’s population is expected to reside in urban areas by 2030. In absolute terms, this means that the country’s urban population will increase from 340 million to nearly 600 million over the next 15 years.

To put these numbers into perspective, while quickly growing, India’s share of urban population is lower than that of some other emerging market countries, including China (48%), Mexico (78%), South Korea (83%), and Brazil (87%). With the exception of China, India is much larger than these other emerging economies, thus the actual number of people in urban areas in India is already large and growing.

“Rather than as an insurmountable challenge, India should view urbanization as an opportunity to save energy, reduce emissions, and improve the quality of life of its people.”

Urbanization and economic growth are often intertwined—in India, urbanization has kept pace with economic growth. From 2001 to 2011, the country’s GDP grew at a rate of about 8% per year, comparing favorably with the rate of 5.5% observed over the previous two decades. Recently, India’s Finance Ministry estimated that the country’s economic growth could increase to as much as 8.5% in the coming fiscal year, which could make it the world’s fastest-growing large economy. About 75% of India’s GDP is concentrated in its cities.

Urbanization has occurred rapidly in India and has offered improved quality of life and more opportunities. However,
this has been accompanied by challenges that include insufficient energy, lack of urban infrastructure, and poor delivery of basic services, resulting in undesirable environmental impacts, congestion, and urban sprawl. Reportedly about half of all manufacturers in India lose power for five hours a week—slowing the momentum of some of the country’s most important employers.5

URBANIZATION DRIVERS AND CHALLENGES

Research and analysis reveals that the principal underlying causes of urbanization in India are socially, economically, and politically driven. Industrialization results in employment opportunities and the ability to have greater specialization within the workforce. Access to the technology, education, and better infrastructure, as well as growth of the private sector, available in an urban environment can lead to an improved standard of living and greater opportunity for increasing one’s income. Indian urbanization has occurred since the partition of the country and has accelerated due to an increase in birth rates. As the government has worked to expand infrastructure and basic services there has been a corresponding expansion in urbanization. In addition, the 11th Five-Year Plan (2007–2012) specifically promoted urbanization. As India attempts to achieve faster and more efficient growth, cities will inevitably continue to play an important role as the principal engines of economic growth.

The opportunities afforded by urbanization are most readily realized when careful urban planning is in place. If urban infrastructure and planning are unable to keep up with the rate of urbanization, the consequences can be considerable. The rapid rise in urban population in India has had several unforeseen or unplanned consequences such as the increase in slums, poor standard of living for some, air quality issues, urban sprawl, traffic, and environmental degradation (see Figure 1). There are also the classic problems arising from an unmanaged and unintended rapid population increase, including unemployment, changes in family and social structures, and increasing crime rates. India’s urbanization has indeed placed tremendous demand on the country’s resources.

Thus, proper planning is needed to address the challenges associated with urbanization and realize the full potential of the benefits of urbanization occurring in the country. Urban planning is critically important in many areas, like providing reliable access to energy with lower environmental impact and clean transportation fuels with adequate transportation planning.

ENERGY TO SUPPORT URBANIZATION

Today, energy consumption in India is the fourth largest after China, the U.S., and Russia. Increasing industrialization and urbanization will require much more energy for an already-underserved country.

FIGURE 1. Challenges presented by urbanization in India
A major benefit to urban centers, and thus perhaps a strong driver for urbanization in India, is access to electricity. In its “World Energy Outlook 2011,” the International Energy Agency reported that the electrification rate in India’s urban areas was about 94%, whereas it was only 67% in rural areas (2009 data). Without access to electricity and modern cooking fuels, over 80% of the nearly 900 million people living in rural India rely on traditional biomass for cooking. Thus, India has become the largest consumer of fuel-wood in the world, as a result of which an estimated 41% of India’s forest cover has been degraded over the last decade. This rate of consumption is about five times higher than what can be sustainably removed. Moreover, biomass or dung burned indoors releases dangerous particulate emissions that are considered a major health risk.

Even though most residents of cities have electricity access, much more capacity is needed to serve the growing urban populations, provide access to all, and support continued industrialization. Thus, it is worth considering how different energy sources will contribute to India’s future power mix and how best to ensure that the environmental impact from energy production and utilization is minimized.

India’s electricity mix in 2011 and as projected in 2030 is shown in Figure 2. While efforts to increase capacity will likely focus on increasing energy from all sources, the push for renewables has been particularly strong of late. The government has set a target of 175 GW of renewable energy capacity by 2022 to help India increase electricity capacity while decreasing carbon intensity. India has a tremendous locational advantage to develop solar energy and is doing so through investment in large solar projects, solar parks, micro grids, and rooftop solar. Similarly, wind power capacity is increasing and now contributes nearly 2% of the national power needs. High capital costs and land-intensive installations are some of the barriers to this option. Although economically viable in India, hydro power has not been fully exploited to its potential of about 150 GW, primarily because of ecological concerns (e.g., flora and fauna displacement) apart from the unreliability of this energy source in case of droughts and other potential external influences.

In terms of resources, India has the world’s fourth-largest coal reserves. Figure 2 reveals coal’s continuing fundamental role in power production. It also contributes over 50% of the country’s primary energy and is used for cement and steel production in substantial quantities.

Given that about 35% of India’s population still lives without access to electricity, the approach to addressing energy demand must be multi-pronged. Coal, which is the mainstay source, needs to be explored as a clean, domestic technology.

India’s coal-fired power plants must become more reliable, coal mining practices must be improved to be safer and reduce their environmental impact, and coal utilization must have much lower emissions, water usage, etc. We believe investments in clean coal should be encouraged in addition to clean and renewable energy sources such as solar, wind, hydro, and nuclear.

**ADDRESSING CHALLENGES IN URBAN TRANSPORTATION**

Although economic development is anchored by both urbanization and industrialization, urbanization itself is a major determinant of energy use, including energy use related to transportation. In urban areas, activities which traditionally relied on manual labor shift to relying on energy-intensive modern transportation technologies. Personal transportation remains the largest area of change in energy use and produces 40% of total national CO₂ emissions.

Vehicle ownership, vehicle use, modal split (i.e., percentage of travelers using a form of transportation), and fuel economy are the major determinants of road-transportation energy use. As workforce specialization and employment opportunities increase during urbanization, the movement of goods, food, and people increases accordingly. Thus, urbanization increases not only the quantity of passengers and goods, but also the distances over which they are carried.

As wealth increases, people migrate to personal modes of transport thus tilting the scales in favor of fuel-powered options in cities. Careful planning of city transport needs is particularly important as urbanization gathers momentum and cities must address rising internal transport needs. These needs must be met in a manner that economizes energy and also avoids congestion and pollution (see Figure 3). Thus, transport-sector energy consumption can be reduced by promoting safe, low-cost mass transportation systems over both rail and road. This approach requires close cooperation among
different government departments and the use of carefully
designed systems of taxes and cross subsidies to encourage
optimal transport development.

Automobiles can also be run with reduced emissions and
lower environmental impact. The ever increasing number of
vehicles and rising fuel requirements have, in recent decades,
compelled research on alternative sources of transportation
fuels. This has led to the emergence of many potential alterna-
tives, such as biodiesel, methanol, ethanol, butanol, dimethyl
ether, diethylene, bio-ethanol, coal-derived synthetic natu-
ral gas (SNG), Fischer–Tropsch diesels, hydrogen, straight
vegetable oils (SVO), and hydro-treated vegetable oil (HVO).14

In addition to alternative fuels, electricity-based transporta-
tion is also an option. The retail prices of petrol and diesel are
relatively high in India, making electric cars more economical.
However, these are economical alternatives to diesel only
when there is an escalation in international crude oil prices.
Under such a scenario, SNG could have tremendous scope
to meet the transport-sector requirements utilizing the coal
available in India.

Over time, many techniques and methods have been devel-
oped and continue to be improved in terms of yield, costs, and
sustainability. It is becoming increasingly important to study
the feasibility of substitution of crude oil/petroleum with alter-
native options, which are available or can be produced locally
on a substantial scale for commercial utilization. Although sev-
eral alternatively derived fuels have potential, the relative high
cost in comparison to petroleum presents a major obstacle in
their widespread use. Thus, these options need to be further
explored and production technologies must be improved to
meet both quality and feasibility requirements.

POLICY SUGGESTIONS FOR RATIONALIZED
ENERGY USE IN THE URBANIZATION OF INDIA

Rather than as an insurmountable challenge, India should
view urbanization as an opportunity to save energy, reduce
emissions, and improve the quality of life of its people. To
meet these goals, the following policies should be adopted:

- Frame preferential policies and provide more financial sub-
sidies to develop unconventional and renewable energy
sources. For example, to ensure environmental protection,
the government should promote the innovation, research,
and development of decentralized wind power and hydro-
power by exploiting local resources.
• Existing major energy resources, such as coal, should be developed with high-efficiency, low-emissions technologies. More than lip-service funding also must be provided.

• To accelerate the extensive application of highly resource-efficient and environmentally sound technologies in urban areas, the government should promote technological innovation and capital flow through policy incentives and financial support, such as designing intelligent transportation systems, promoting energy-efficient vehicles for mass transport, improving road conditions, and developing proper road management systems. In addition, the government should encourage implementing financial subsidies and preferential tax policies, such as a consumersavings-based model for mass-transit.

• Rail transport should be overhauled and technologies should be developed to optimally utilize existing resources in developing advanced, efficient rail systems.

• Recognizing that industrialization will continue to play a big role in urbanization, the government should fund and support energy-conserving production technologies. Also, the government should introduce energy-efficiency indicators and regulations to enforce and commercial energy consumption.

• Sustainable urbanization should become a focus through devolution of power to local government so as to enable better environmental legislation that is enforceable. For example, any policy aiming to curb the impact of urbanization on energy demand must address the associated externalities of urban sprawl and automobile dependency.

• Energy research results in major public benefits—such as economic competitiveness, national security, and environmental protection—that are not necessarily strong motivations for the private sector. Thus, the government of India should support energy research to advance development of near-zero emissions from its energy sector including solar, wind, carbon capture and storage, and low-energy nuclear reactions.

Higher quality of life can be realized in tandem with appropriate policies. As aptly put by Isher Judge Ahluwalia (Chair, Indian Council for Research on International Economic Relations): 4

"Deficiencies in urban planning and management have to be overcome if India’s urban environment is to meet the rising expectations of an expanding urban population and provide an urban environment consistent with rapid, inclusive, and sustainable growth."

REFERENCES


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Throughout history, instances of societal paradigm shifts have occurred as widespread urbanization and industrialization have rapidly taken hold. Such transitions have demanded a shift in energy sources, the amount of energy consumed, and the way in which energy is used. Perhaps the most well-known historical example took place in late 18th—early 19th century England as cities grew rapidly and the regional society shifted from one founded on agriculture to one based on industry. Higher density energy sources, primarily coal, displaced biomass and the Industrial Revolution was born.¹

In modern times, the most prominent example of a rapid societal shift through urbanization is undoubtedly China—a country that has grown to be an economic powerhouse in only a few short decades. Urbanization, industrialization, and increased energy consumption have underpinned this growth. The increase in industrial production in China has been astounding. According to the United Nations, China’s total industrial production in 2007 was about 62% of that of the U.S. By 2010, however, China had overtaken the U.S. to be the world’s largest industrial producer and by 2012 China’s industrial output was about 126% of that of the U.S.² From 2007 to 2011, as China’s cities grew, the country’s per capita primary energy consumption rose from 1551 to 2029 kgoe (kg oil equivalent).³ This energy was, and continues to be, largely based on China’s massive indigenous coal resources—67.5% of China’s primary energy came from coal in 2013.⁴

“The annual average energy consumption of the urban population in China is about three to four times that of the rural population.”

CHINA’S CURRENT STATE OF URBANIZATION

As China has industrialized, its cities have grown as workers have moved from rural areas to urban centers looking for a chance at improved employment and life prospects. The
number of Chinese urbanites recently surpassed those living in rural areas, which is a considerable milestone in a country of 1.35 billion people.

The urbanization rate in China continues to increase (see Figure 1). It grew about fivefold from 10.6% in 1949 to about 53% in 2013. During this time the number of cities also increased from 193 in 1978, the beginning of China’s reform and opening-up, to about 660 in 2012.\(^5\),\(^6\)

As shown in Figure 1, much of the increase in China’s urbanization has occurred over the last two decades.\(^7\) In the particularly rapid period of growth since 1995, the urban population has nearly doubled.\(^8\) Despite a recent slowdown in the country’s economic growth, with 46% of the population still living in rural areas there is reason to believe that urbanization will continue in China.

THE TIE BETWEEN URBANIZATION, INDUSTRIALIZATION, AND ENERGY

Many of China’s new urbanites have found employment in various industries, such as the country’s large manufacturing sector, as a result of which the percentage of employment outside agriculture increased from 47.8% to 68.6% over the last two decades.\(^9\) Industrialization, better access to energy, and more income to spend on energy has in turn driven up energy consumption. From 1995 to 2013 a clear correlation can be observed between urbanization and energy use: As the urbanization rate nearly doubled the per capita energy consumption also doubled. According to estimates, the annual average energy consumption of the urban population in China is about three to four times that of the rural population.\(^10\) Therefore, as urbanization is an ongoing trend, energy consumption can also be expected to grow.

While the most rapid growth has occurred recently, urbanization, industrialization, and energy consumption in China have been linked for the last half century (see Figures 1 and 2). In terms of the energy consumed by primary (i.e., agricultural), secondary (i.e., heavy industries, manufacturing, and construction), and tertiary (i.e., service-based) industries, China’s secondary industries consume about 70% of the country’s energy (this statistic includes residential use) and contribute about 50% to the gross domestic product (GDP).\(^11\)

During the recent phase of rapid urbanization in China (1995–2013), correlation coefficients between the urbanization rate and economic growth, industrialization and economic growth, and energy demand and economic growth were calculated to be 0.92, 0.99, and 0.97, respectively. Urban areas contributed about 70% of the country’s total economic growth—about two times that contributed by rural areas (see Figure 3).\(^12\)

The vast majority of China’s wealth is held within cities. From 1995 to 2013, the total fixed asset investment in China grew by a factor of nearly 21 (see Figure 4).\(^9\) This was especially true for the proportion of urban fixed asset investment, which approached 98% of the total fixed asset investment.\(^9\) The scale of investment grew by a factor of about 26 over this time frame, while GDP grew about tenfold—largely supported by the country’s urban centers (see Figure 5).\(^9\)
Although further urbanization and energy consumption are on the horizon, clearly China will not follow its recent growth and energy consumption trajectories indefinitely. Like many other large urban areas, especially those in emerging economies, China’s cities face challenges, including problems with air quality, traffic and congestion, and overcrowding. In fact, a transition has already begun in China. The country now looks to make its industries and cities smarter through increased informatization, while focusing on new forms of industrialization and urbanization that can help address the major challenges faced by its cities.

The term “new industrialization” refers to the widespread use of information to promote and improve high-tech industrialization. It is believed that transitioning to higher tech manufacturing can result in increased economic returns, reduced resource consumption (including improved energy efficiency), minimized environmental degradation, and optimized employment. Similarly, “new urbanization” refers to improving the quality of urbanization by focusing on urban environments that are people-oriented, including better walkability, access to public transportation, and more green space.

There should be considerable opportunity to implement such changes in existing and new cities. While some may believe that urbanization and the associated increase in energy consumption may be leveling off in China, this seems unlikely considering the sheer size of the population that is not yet urbanized. In addition, there are plans in the pipeline to build out urban centers. For example, the Chinese government has recently announced that it is looking to urbanize large areas along the Yangtze River, and looks to designate about 317,000 square kilometers for the proposed project. This proposed development is an example of the government’s desire to bring larger urban centers and the associated opportunities to the middle of the country, which to date have mostly been enjoyed by coastal China. This new project could be an ideal opportunity to implement new urbanization and new industrialization.

“Although further urbanization and energy consumption are on the horizon, clearly China will not follow its recent growth and energy consumption trajectories indefinitely.”

RECOMMENDATIONS FOR CHINA’S NEXT GENERATION OF URBANIZATION AND ENERGY USE

China has made progress toward a new paradigm of improved urbanization and energy consumption, but much remains to be done. In this new phase of development, the fundamental transition from an economy driven by secondary industries to one driven by tertiary industries will accelerate. As the country moves toward growing the service sector there will be efficiency improvements and changes in China’s energy mix—a mild decoupling of GDP and energy consumption could occur as has been observed in other countries. The energy industry, which is founded on the country’s coal resources, is facing multiple new challenges and must also adapt.

The most important challenge to China’s energy sector is to minimize the environmental impact associated with its growth. Thus, the 12th Five-Year Plan made recommendations to optimize urbanization, industrialization, and sustainable economic growth in China—the 13th Five-Year Plan is expected to include similar recommendations. With the development of new urbanization and new industrialization as well as...
industrial restructuring and upgrading, the Plans suggest that the conventional, extensive, and inefficient use of fossil fuels should be phased out and replaced with high-efficiency, low-emissions (HELE) technologies.

According to research by Shenhua Science and Technology Research Institute, coal is expected to account for about 55% of the primary energy mix in China in 2035, and thus there are no foreseen fundamental changes expected in the energy mix. Therefore, the country’s investment in upgrading its coal-fired fleet of power plants to improve efficiency and reduce emissions makes sense.

Other technologies now exist that could also reduce the environmental footprint of coal utilization. In China, and elsewhere, coal is primarily utilized through combustion. However, there is much value in coal conversion strategies, such as gasification and direct coal conversion, which focus on the functional nature of coal as not only a source of fuel but also as a raw material (i.e., making full use of the elemental C and H in coal for heat generation and chemical synthesis). Such an approach can expand on China’s production of coal-to-gas, coal-to-oil, coal-based olefins, and coal-based ethylene glycol, while meeting demand for electricity and thermal energy.

In addition to improving coal utilization, the Chinese government has committed to strongly back development of alternative energy and renewables, as was highlighted in the 12th Five-Year Plan and is expected in the 13th Five-Year Plan. For example, there is a concerted effort to actively develop hydropower, nuclear power in a safe and effective manner, and wind energy; accelerate the diversified use of solar; actively develop shale gas and shale oil; advance other forms of alternative energy (e.g., biomass and geothermal); and promote the application of a distributed energy system. In the future, alternative energy and renewables will play a more prominent role in supporting the national economy as well as new industrialization and new urbanization.

TECHNOLOGY OPPORTUNITIES

Industrialization and urbanization are common threads woven throughout historical and modern societal development and are largely dependent on sufficient access to high-density energy. For this reason, and because coal is widely distributed geographically, dramatic increases in coal production and utilization are often associated with major societal transitions, such as the rapid urbanization and industrialization experienced in China.

The described societal shift has helped China to lift hundreds of millions of people out of poverty and provide energy access to nearly all of its people in just a few decades. The country is almost certainly the world’s most successful example of successful poverty alleviation. Coal has been the principal fuel behind this shift. However, China’s coal fleet grew quickly and is not fully equipped with modern emissions control technologies. Thus, the country is working to improve the efficiency and reduce emissions from its vast coal-fired power fleet.
Looking to China’s example, other countries and regions around the world are also urbanizing and industrializing. Many of these countries are also quickly growing their coal-fired power fleets. Today, with a suite of HELE technologies available, there is a real opportunity to ensure that these plants will use the best possible technology options. With greater international support, it is likely that the use of such technologies will increase and thus reduce the environmental impact of coal in countries that desperately need more energy. Therefore, some of the challenges associated with urbanization, industrialization, and increased energy use that have been observed in the past could be avoided in the future.

REFERENCES
ASEAN Urbanization and the Growing Role of Coal

By Jude Clemente
Principal, JTC Energy Research Associates, LLC

Although global economic growth may have stalled recently, a number of regions characterized by clusters of emerging economies are poised to become drivers for a renewed wave of growth. One of the most prominent such areas can be found in Southeast Asia, where regional cooperation and a desire to improve standards of living could strengthen the urbanization and industrialization already in progress.

Founded in 1967, the Association of Southeast Asian Nations (ASEAN) now has 10 member states: Thailand, Myanmar, Laos, Vietnam, Malaysia, Singapore, Indonesia, the Philippines, Cambodia, and Brunei. ASEAN is home to about 630 million people today, with a growing population expected be above 785 million by 2050.1 As it expands, the ASEAN population is increasingly concentrated in urban areas.

Urbanization brings higher productivity because it concentrates economic activity and gives rise to massive economies of scale that lower costs. In Asia, for instance, urban productivity is more than 5.5 times that of rural areas.2 According to the UN, “No country in the industrial age has ever achieved significant economic growth without urbanization.”3 Thus, emerging ASEAN is urbanizing as its economies develop. The percentage of people living in urban areas is projected to increase from about 47% today to 56% in 2030 and then 67% in 2050 (see Figure 1).

 ASEAN POISED TO BECOME A GLOBAL ECONOMIC POWER

On 31 December 2015, the implementation of the ASEAN Economic Community will “transform ASEAN into a single market and production base, a highly competitive economic region, a region of equitable economic development, and a region fully integrated into the global economy.”4 Per the Asian Development Bank, ASEAN will emerge as a rival even to the European Union and become a “truly borderless economic community by 2030.”5 From 2014 to 2030, ASEAN’s real GDP (in 2010$) is projected to more than double to US$5.2 trillion, with an average annual expansion of $180 billion per year.6 ASEAN could even enter a high-growth phase, leading to a tripling of per capita income by 2030, raising quality of life to levels enjoyed today by OECD countries. With a median age of about 28, a young population gives ASEAN an advantage in terms of economic prospects and labor pool.7

“In Southeast Asia … regional cooperation and a desire to improve standards of living could strengthen the urbanization and industrialization already occurring.”

This growth, and the resulting expanding middle class with more purchasing power, is contingent on much more energy to support industrialization and urbanization. Urbanites consume more energy because they typically have higher incomes and more money to spend as well as better access to services. For example, the World Bank reports that urban residents in China consume about 3.6 times more energy than those living in rural areas.8 In ASEAN, this means that demand for coal, as a principal energy source in the region, is projected to increase. In addition, coal will be needed to support increased steel and cement production also associated with urbanization.

FIGURE 1. ASEAN continues to urbanize.1
THE ROLE OF COAL IN ASEAN GROWTH AND URBANIZATION

The role of coal in ASEAN is, and will continue to be, particularly strong because the Asia-Pacific region is the nexus of the international coal market. BP reports that this region boasts nearly 33% of the world’s proven coal reserves. Indonesia is by far the largest global exporter of thermal coal used for electricity and nearby Australia is the largest exporter of metallurgical coal for steel. Since 2000, as the urban population has expanded by over 120 million people, ASEAN’s coal production has leaped from about 110 million tonnes (Mt) to over 575 Mt, with Indonesia and Vietnam leading the expansion. The key coal importers in the bloc are Thailand, Malaysia, and the Philippines. In the short term, IEA expects ASEAN coal production to further increase to 660 Mt in 2019, nearly all of which is the thermal variety used for electricity.

Electricity for Urbanization and Industrialization

Today, ASEAN is a developing region, characterized by considerable poverty and low levels of social development. For example, access to electricity is far from universal. The International Energy Agency (IEA) reports that 135 million people in ASEAN—over 20% of the population—have no access to electricity. Indonesia, with 255 million people, generates 170 TWh of electricity per year, compared to 203 TWh for Illinois, U.S., with less than 13 million residents. About 70% of Myanmar’s 54 million people have no access to electricity whatsoever. Around 280 million ASEAN residents rely on traditional biomass for cooking, resulting in indoor air pollution deemed to be the “deadliest environmental threat.” Thus, lack of access to power affects all aspects of life and correlates to a shorter lifespan (see Figure 2). With modern energy access, standards of living will be higher, including improved childhood survival, nutrition, drinking water quality, and educational opportunities.

The amount of electricity needed to address the enormous challenge in ASEAN will be met by increasing generation from all sources (see Figure 3). Coal consumption is growing the fastest due to its abundance in the region, scalability, reliability, and lower costs.

Today, global oversupply has driven thermal coal prices to five-year lows, even as the coal build-out in Asia continues. Some 75% of the thermal capacity, and nearly 40% of total capacity, now under construction in ASEAN is coal fired. Moreover, high reliability means that baseload coal supplies 31% of actual generation while accounting for just 22% of total capacity. This reliability is a major reason coal accounts for almost 70% of all electric power in developing Asia. As pointed out by World Bank President Jim Yong Kim, “There’s never been a country that has developed with intermittent power.”

FIGURE 2. Electricity use and life expectancy
IEA projects that coal use in ASEAN will rise from about 200 Mt today to 300 Mt in 2020 and to 535 Mt in 2035, extending its share of the primary energy mix from about 16% to nearly 30%. The power sector accounts for 52% of the increase in primary energy demand in ASEAN. Overall, IEA estimates that, by 2035, 50% of all power generation for ASEAN will be coal fired, compared to 18% in 1990 and 31% today.

Relying on coal for industrialization, urbanization, and to increase energy access has been common in developing Asia. ASEAN watched China lift 650 million people out of poverty since 1990, the most effective poverty alleviation campaign in human history. From 1990 to 2011, China’s electricity use per capita per year increased from 511 kWh to 3300 kWh today—China’s electricity generation was about 75% fueled by coal in 2014. Similarly, India relied heavily on coal to reduce the number of people without electricity by 100 million from 2008 to 2012.

As it builds its coal-fired power sector, ASEAN has an opportunity to deploy modern technologies and thus minimize the environmental impact of coal-based power production. Increasing the efficiency and plant size at existing and new stations is at the heart of any clean-coal strategy. IEA notes that the average coal plant efficiency is at 34% in ASEAN, just above the global average. However, supercritical (SC) plants have become the standard for large-capacity boilers and can achieve efficiencies of 40–45%. A single percentage-point improvement in the efficiency of a conventional pulverized coal combustion plant results in a 2–3% reduction in emissions of CO₂, NOₓ, and SO₂.

China has been focused on increasing the efficiency of its coal-fired fleet, effectively demonstrating that electricity from these plants is affordable. About 25% of China’’s coal fleet has SC or ultra-supercritical (USC) steam parameters and about 75% of its capacity is from plants with a generation capacity above 300 MW. The cost of electricity from China’s coal-fired power plants is about 0.4 yuan/kWh and the cost for incorporating ultra-low emissions technologies is about 0.005–0.01 yuan/kWh for new plants and 0.01–0.02 yuan/kWh for retrofits. Natural gas combined-cycle plants can provide electricity for about 0.59–1.23 yuan/kWh in China (depending on natural gas prices).

Similarly, IEA has concluded “coal has the cheapest generating costs in Southeast Asia over the range of assumptions analyzed” (see Figure 4). ASEAN is cooperating on advanced coal technologies with its more experienced +3 Dialogue Partners: China, Japan, and South Korea. Developing Asia will be stepping up its “efforts to develop cooperation programs, promote policies on clean coal technologies (CCT), such as high efficiency coal-fired power generation, the upgrading of low-rank coal technologies, carbon capture and storage (CCS), coals making, coal gasification, coal liquefaction and develop the industry in the region.” For example, all existing coal-fired power plants in Peninsular Malaysia now use SC technology. The 2100-MW Manjung power station complies with World Bank standards, while the upcoming Janamanjung 5 plant will utilize highly efficient USC technologies.
As shown in Figure 3 (see “Other” line), the deployment of renewables is also beginning to ramp up in ASEAN. Thus, coal-fired power plants will require the flexibility to back up intermittent wind and solar power. Modern coal plants are well suited to this task and can change from full load capacity to 50% in less than 15 minutes. A 1000-MW plant can provide a 30–40-MW load change each minute, and this flexibility continues to improve.

Electricity from these new coal-fired power plants could be distributed throughout the region. ASEAN’s economic growth, increased trade, and need for more energy have sparked the move to a regional power interconnection. The ASEAN power grid will connect the national grids, upgrade energy security, increase supply, and lower electricity costs. By 2025, there will be up to 19,600 MW of cross-border power purchase and 3000 MW of energy exchange through the cross-border interconnections.

**Coal for Steel and Cement**

ASEAN urbanization will also mean increasing demand for steel and cement—coal is important for the production of both. In the period 2014–2020 alone, the World Economic Forum estimates that ASEAN has US$8 trillion in new infrastructure needs.

Coal must be used to produce new steel, much more of which will be needed for urbanization in ASEAN. According to OECD, ASEAN-6 (the six major and older nations in the ASEAN) steel-making capacity will reach over 51 Mt this year, up nearly 75% since 2007. Steel consumption has increased from 44 Mt to around 70 Mt since 2006, and is projected to further increase 8% in 2015.

Transport infrastructure can also be a major steel consumer as about 55% of the weight in a car comes from steel. Aluminum, another important material for automobile production, is energy intensive, often relying on coal to provide the electricity. Today, ASEAN’s car ownership rates are still quite low, with tremendous demand potential (see Figure 5). All ASEAN nations except Singapore, Brunei, and Malaysia are at or below the $2500–10,000 per capita income bracket, the level at which the International Monetary Fund judges that car ownership grows twice as quickly as incomes. One university
study projected ASEAN reaching 127 cars per every 1000 people by 2030.\textsuperscript{32}

ASEAN is projected to continue to grow as a key vehicle production base for the world’s biggest car manufacturers, particularly given its proximity to the fastest-growing markets of China and India. Thus, ASEAN’s automotive industry has expanded rapidly, growing its share of global car production from 2.3\% in 2002 to nearly 7\% today. In 2015, ASEAN countries will produce over four million vehicles—about 7\% more than last year.\textsuperscript{31} Indonesia is expected to become both the biggest producer and the biggest consumer of cars in the bloc. Thailand’s domestic market is less dynamic, but the country is exporting more cars than the rest of ASEAN combined.

Coal is also a major fuel source in cement production, taking approximately 200 kg of coal to produce one tonne of cement; about 300–400 kg of cement is needed to produce one cubic meter of concrete.\textsuperscript{34} Four nations produce 85\% of ASEAN cement.\textsuperscript{35} Jakarta is one of the fastest growing cities, in terms of construction, in the world, and Indonesia is now the largest cement producer in the bloc, producing over 65 Mt and growing 9–12\% per year. Thailand has seen nearly 20\% yearly cement output growth that will be bolstered by an average annual construction growth of close to 5\% through 2020.\textsuperscript{36} Vietnam has been ASEAN’s largest cement producer and now wants to utilize more coal in production because of high local availability. By 2020, Vietnam’s cement industry will have a capacity of 130 Mt. Over 5\% annual GDP growth has Malaysia consuming over 20 Mt of cement a year. Overall, ASEAN cement production growth is expected at 7–8\% per year.\textsuperscript{37}

\section*{REDUCING THE ENVIRONMENTAL IMPACT OF ASEAN COAL USE}

Unprecedented urbanization in ASEAN and around the world means coal will continue to play a fundamental role in the production of electricity, steel, and cement. As recognized by the Center for Strategic and International Studies, “the question is not about whether to continue using coal, but how to make it compatible with international and national climate goals.”\textsuperscript{38} The commercialization and deployment of the next generation of clean coal technologies—such as CCS, SC/USC advanced coal-fired power plants, and integrated gasification combined-cycle technologies—will propel ongoing environmental improvement and steady progress toward the ultimate goal of near-zero emissions.\textsuperscript{39}

Clearly, the ASEAN region is increasing coal-fired power capacity to meet its energy needs. Lacking international support, less efficient, higher-emissions plants will be built, and these plants will not be CCS ready. IEA explained these risks in its 2014 “World Energy Investment Outlook”:\textsuperscript{40}

\textit{If development banks withhold financing for coal-fired power plants, countries that build new capacity will be less inclined to select the most efficient designs because they are more expensive, consequently raising CO$_2$ emissions and reducing the scope for the installation of CCS.}

Thus, as ASEAN and other regions develop and urbanize, there is an opportunity to ensure that the coal-fired power capacity being built, which will operate for decades, is equipped with the state-of-the-art high-efficiency, low-emissions technologies.

\section*{REFERENCES}

STRATEGIC ANALYSIS


Urbanization and steel intensity go hand in hand. In the preliminary stages of a country’s urbanization, steel intensity increases with the need for new infrastructure for improved connectivity, efficient use of natural resources, and creation of sophisticated transport hubs. Increased population density means taller buildings requiring more high-quality steel. Demand for machinery also increases as more of the population urbanizes to find employment industries that are steel-intensive.

The steel intensity curve explains the long-term drivers for steel use (see Figure 1). The first stage of the curve during an emerging economy’s rapid growth is the most steel intensive, driven largely by high levels of government investment that boost construction and infrastructure demand. In many rapid-growth markets, which are in Stage 1 to the left of the steel intensity curve, steel consumption will continue to be driven by the growth of their construction and infrastructure sector. The steel intensity curve stabilizes or starts to decline at around US$15,000–20,000 GDP per capita as a country becomes more developed and urbanization rates begin to decline (Stages 2 and 3).

Integrated steel-making (i.e., non-recycled steel) is primarily based on iron ore and coking coal (i.e., metallurgical coal). For each tonne of steel that is produced, about 1400 kg of iron ore and 800 kg of coal are required. Due to this, the production of steel is the second largest use of coal after power generation.

Over 70% of steel produced in 2013 was generated using direct coal input, leading to the use of 1.2 billion tonnes of coal—about 15% of total global consumption.

“Considerable scope remains for growth in global steel demand in the medium to longer term.”

Although steel remains a large market for coal and iron ore, the current reality of a slowing global market is reflected in forecasts for minimal demand growth in 2015. It is therefore likely that the raw material markets will remain oversupplied, with pricing flat for at least the next two years (see market projections in Table 1). This prolonged period of low prices is likely to push higher-cost suppliers out of the market.

While there are concerns that China—as a key driver for growth in global steel demand—may have reached peak steel demand far earlier than previously forecasted and now has a lower growth outlook for the next two to three years, steel producers and raw material suppliers should not be deterred. Considerable scope remains for growth in global steel demand in the medium to longer term. This will come through urbanization and industrialization in other rapidly growing markets as well as from other downstream sectors. Once these trends gain traction, an uptick in raw material markets is likely.

CHINA’S CHANGING DEMAND

Over the last 10–15 years, urbanization and industrialization in China has been a significant driver of global steel demand. The Chinese government has been investing in infrastructure, which has helped drive economic growth. The steel-intensive nature of infrastructure has driven the creation of vast steel production capacity within China, which in turn has fueled demand for coking coal and iron ore.

Import demand for coking coal in China has been growing rapidly in recent years, at almost 30% in 2012 and 40% in 2013. Similarly, seaborne iron ore demand from China increased by 10% per year in the past three years to reach about 917 Mt in 2014. To meet this continued demand, iron ore and coal miners have significantly increased supply capacity.
In 2014, however, this trend in growing demand came to an abrupt halt, with China’s coking coal imports falling by just over 17% and growth in iron ore demand moderating to around 3%. This is largely due to significantly lower Chinese steel demand growth in 2014. This, combined with new production coming online, has led to an oversupply in both the coking coal and iron ore markets with an ensuing drop in prices. Some market commentators believe that China may have already reached peak coal with both supply and demand for coal as a whole contracting by about 3% in 2014. With such a significant slowdown in demand, there are concerns that China has also reached peak steel sooner than expected. Chinese steel demand grew by only 1% in 2014 as compared to 6% in 2013. The World Steel Association revised its forecasts to predict even slower growth in 2015 (see Figure 2).

Considering the relationship between urbanization and steel, there is actually considerable scope for further steel demand from China. The percentage of China’s urbanized population still lags that of developed nations (see Figure 3). China’s current steel per capita consumption also shows upside when compared with peak steel per capita consumption of other markets.

EY expects, however, that there may be a period of imbalance and slower steel intensity growth, as China’s policies are likely to focus on human-centered urbanization (i.e., in response to the demands of the people), with new urban planning models centered on technology and sustainability. China is also beginning to focus on sustainable growth based on consumer demand (i.e., market forces), rather than centrally planned investment that has relied on the metals and other industries as drivers of economic growth.

From a downstream demand perspective, this means there is likely to be less investment in the property sector, which represents a downside risk for the steel sector and raw material producers. An estimated 30% of Chinese steel production goes into the property market. As floor space sold in the first quarter of 2015 was down 9.2% year-on-year over the same period in 2014 and building starts are down 18%, this is also impacting steel demand.

However, growing consumer demand for manufactured goods and cars shows significant growth potential for steel demand. For example, growth drivers for China’s automotive industry include low vehicle density, rising replacement demand due to increasing affluence, an increase in auto exports, and increasing sales as GDP increases (see Figure 4).

China plans to implement emission standards (China IV) similar to Euro IV standards. Under them, vehicles that fail to meet the standards will be banned from sale. This will drive light-weighting of vehicles, which will drive the production of higher-quality flat steel, such as advanced high-strength steel in China. However, it will also bring the possible threat of substitution with lighter materials, such as aluminum.

### INDIA’S URBANIZATION WILL REQUIRE MORE STEEL

Ongoing rapid urbanization in India will drive steel-intensive growth in the country. The Indian government is investing heavily in infrastructure and has laid plans to boost domestic steel capacity to 300 Mt per annum by 2025. Indian steel companies have made investments of US$35.4 billion over the last seven years to increase steel capacity. Steel demand in India is also increasing, with estimated growth of 5% to 83 Mt and a further 4.8% to 87 Mt in 2014 and 2015, respectively.

To cater to this wave of increased steel production, the country must focus on augmenting its domestic coking coal sources by making better use of its domestic reserves. By 2025, 63% of the 300-Mt steel capacity in India is expected to be in coal-intensive blast furnaces. To meet steel production targets, 170 Mt of coking coal per year will be required. With limited coking coal resources, India is set to overtake China as the world’s largest overall coal importer in 2015 and 2016. Most of this supply will come from Australia, which supplied 85% of coking coal imports to India in 2013.

### TABLE 1. Range of broker forecasts for steel raw materials (% growth in demand)

<table>
<thead>
<tr>
<th>Raw material</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coking coal</td>
<td>–1.68 to 0%</td>
<td>–0.3 to 10%</td>
<td>1.7 to 4%</td>
<td>1.69 to 5%</td>
</tr>
<tr>
<td>Iron ore</td>
<td>0.7 to 1.7%</td>
<td>1.2 to 3.4%</td>
<td>1.5 to 1.9%</td>
<td>1 to 1.6%</td>
</tr>
</tbody>
</table>
Unlike coking coal, India has sufficient iron ore reserves to cater to its domestic steel industry. In the past, India has produced around 216 Mt of iron ore per year, far more than its rate of domestic consumption of around 100–105 Mt. In recent years, however, the Indian government imposed bans on iron ore mining to combat illegal mining—this step reduced domestic supply. The government is, however, planning to auction off iron ore assets, which will improve the domestic availability of iron ore. Indian iron ore producers have the required infrastructure and logistics to ramp up production quickly to meet domestic steel sector demand in the next few years.

STEEL DEMAND GROWTH IN OTHER RAPID-GROWTH MARKETS

Increasing urbanization in Turkey and Mexico over the last 30 years has led to high per capita steel consumption in both countries. The urban populations in Turkey and Mexico have increased from 52.4% and 69% in 1985 to almost 73% and 79%, respectively, in 2014. As a result, per capita steel consumption in both Turkey (~450 kg) and Mexico (~225 kg) is higher than many other emerging economies. The two countries already have steel-making facilities; however, over 70% of steel produced in both countries is through electric arc furnaces, which recycle steel and therefore rely heavily on scrap steel and energy, rather than iron ore and coking coal. Thus the reliance of these countries on the seaborne iron ore and coking coal markets will be limited if this trend continues.

Similarly, the growing size of the Indonesian and Nigerian urban populations indicate that the usage of steel could increase in coming years, particularly due to demand from the infrastructure and construction sectors (see Figure 5). Steel consumption has already picked up in Indonesia. Africa as a whole represents a future growth opportunity for the global steel sector, particularly in terms of infrastructure. African and Indonesian steel production is currently relatively small. Indonesia relies on coking coal imports for domestic steel production at present. Africa has only 3.7% of proved global coal reserves, the majority of which are located in South Africa. Africa therefore is likely to rely on imports if it builds up a domestic steel industry to support its growing infrastructure needs.

THE FUTURE OF STEEL AND URBANIZATION

With forecasts for increasing urbanization in many parts of the world, industrialization and an increasing need for infrastructure will drive steel-intensive growth for the foreseeable future. In the short term, however, a period of slower steel demand is projected until China’s rate of economic growth

FIGURE 3. The extent of urbanization and peak steel intensity in major steel-producing regions

FIGURE 4. Vehicle density by country highlights the growth potential in the automotive sector.

FIGURE 5. An increasing proportion of the population will be urbanized in Indonesia and Nigeria
does not constitute advice, and should not be relied on as such. Professional advice should be sought prior to any action being taken in reliance on any of the information. Liability limited by a scheme approved under Professional Standards Legislation.

**REFERENCES**

9. Internal EY Analysis
The Rise and Potential Peak of Cement Demand in the Urbanized World

By Peter Edwards
Editor, Global Cement Magazine

Cement is the binder that holds together urban centers around the world. To make it, limestone, sand, and other additives are combined in rotating kilns at temperatures of up to 1450°C. This process yields a granular intermediate known as clinker, which is then ground in mills to produce cement powder. The final cement mix will include around 5% gypsum and may also include other non-clinker mineral by-products like limestone, slag, and ash from coal-fired power plants. The process of making clinker, and hence cement, demands around 100–350 kg of coal per tonne of clinker. Thus, the cement industry has historically been a major user of fossil fuels, especially coal.

Since 1950 the cement industry has seen massive growth as our world has urbanized. From 133 million tonnes (Mt) in 1950, production has increased more than sevenfold to one billion tonnes (bnt) in the 33 years to 1983 (see Figure 1), before hitting 2 bnt in 2004, 3 bnt in 2010, and 4 bnt in 2013. In 2014 around 4.2 bnt of cement were produced.

China topped the list of cement-producing nations in 2014 at about 2.5 bnt, which was an incredible ~60% of global production. The second-largest producer, albeit an order of magnitude smaller, was India at 280 Mt. A number of other countries produce substantially less, but are similar to each other in production scale. Although each country in this cluster is far smaller than China and India in terms of cement production, they actually represent very large cement industries. The top producers in 2014 are shown in Table 1.

Another important group of countries includes those with cement industries that are seeing the most rapid growth. In this category, China and India are joined by relative minnows such as Sudan, Peru, Nigeria, Turkey, Colombia, and Brazil. The “fastest risers” between 2003 and 2013, most of which are developing countries, are shown in Table 2. The speed at which their cement industries are growing has more than made up for the recent contraction in mature markets, such as the EU and the U.S. Additionally, several countries listed toward the bottom of the table have cement industries that are both large and rapidly growing.

“Cement is the binder that holds together urban centers around the world.”

CEMENT SELF-SUFFICIENCY MEANS BUSINESS FOR DEVELOPING NATIONS

It is pertinent that many of the largest and fastest-growing cement industries are now in the developing world, but this should not come as a surprise. As the economy of a given country develops, cities become more prosperous than surrounding rural areas, leading to inward migration and urbanization. This inexorably leads to increased demand for building materials, including cement. Indeed, for many developing countries, self-reliance in cement production is a major industrial target as it reduces the reliance on imports, reduces the cost of construction, and facilitates further development of the economy through improved infrastructure. In the case of some countries it is even possible to show strong positive correlation between GDP and cement consumption over time.

With the majority of the 2.5 billion new urban inhabitants projected to be in Africa and Asia in the period to 2050, it is the
countries in these continents, their regulations, and populations that will most strongly influence future cement demand, the efficiency of the production process, and the types of fuels used. It is not, therefore, a great leap to conclude that the global cement production curve will continue to rise in the coming years. So the real questions are how fast will the industry develop in the future and how will its appetite for coal and other fuels change?

**IMPACT OF SOFTER CHINESE DEMAND**

When attempting to forecast future cement demand it is important to realize that the past decade was anomalous. Chinese growth, which has recently been typified by wild over-construction, is by far the largest single factor behind rising global cement consumption over this period. However, slowing Chinese economic growth and the fact that China is now actively removing older and less efficient cement plants mean that Chinese production is unlikely to increase at the same rate as has been observed in the recent past. It may even fall in the next few years if the central government pulls the appropriate levers.

Without such rampant capacity addition in China, other countries would have to see an incredible step-change in their demand and urbanization rates to maintain the gradient seen from 2003 to 2014 (see “Fast” line in Figure 2 for a projection to 2050). Such an extrapolation is unadvisable as it predicts a more than tripling in cement production levels by 2050 to around 13.5 bnt/yr. This scenario is highly unlikely.

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**TABLE 1. Top cement-producing nations in 2014**

<table>
<thead>
<tr>
<th>Country</th>
<th>Cement production (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2500</td>
</tr>
<tr>
<td>India</td>
<td>280</td>
</tr>
<tr>
<td>U.S.</td>
<td>83</td>
</tr>
<tr>
<td>Iran</td>
<td>75</td>
</tr>
<tr>
<td>Turkey</td>
<td>75</td>
</tr>
<tr>
<td>Brazil</td>
<td>72</td>
</tr>
<tr>
<td>Russia</td>
<td>69</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>63</td>
</tr>
<tr>
<td>Indonesia</td>
<td>60</td>
</tr>
<tr>
<td>Vietnam</td>
<td>60</td>
</tr>
<tr>
<td>Japan</td>
<td>58</td>
</tr>
<tr>
<td>Egypt</td>
<td>50</td>
</tr>
<tr>
<td>South Korea</td>
<td>48</td>
</tr>
<tr>
<td>Thailand</td>
<td>42</td>
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<tr>
<td>Mexico</td>
<td>35</td>
</tr>
<tr>
<td>Pakistan</td>
<td>32</td>
</tr>
<tr>
<td>Germany</td>
<td>31</td>
</tr>
<tr>
<td>Italy</td>
<td>22</td>
</tr>
</tbody>
</table>

**TABLE 2. Select rapidly growing national cement industries between 2000 and 2012**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>2000 production (Mt)</th>
<th>2012 production (Mt)</th>
<th>Growth from 2000 to 2012 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sudan</td>
<td>0.28</td>
<td>3.5</td>
<td>1260</td>
</tr>
<tr>
<td>2</td>
<td>Peru</td>
<td>0.65</td>
<td>8.1</td>
<td>1250</td>
</tr>
<tr>
<td>3</td>
<td>Nigeria</td>
<td>2.5</td>
<td>16.4</td>
<td>656</td>
</tr>
<tr>
<td>4</td>
<td>Kazakhstan</td>
<td>1.175</td>
<td>7.6</td>
<td>647</td>
</tr>
<tr>
<td>5</td>
<td>Estonia*</td>
<td>0.09</td>
<td>0.5</td>
<td>556</td>
</tr>
<tr>
<td>6</td>
<td>Bangladesh</td>
<td>0.98</td>
<td>5.1</td>
<td>520</td>
</tr>
<tr>
<td>7</td>
<td>Iraq</td>
<td>2</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>Tajikistan</td>
<td>0.05</td>
<td>0.234</td>
<td>468</td>
</tr>
<tr>
<td>9</td>
<td>Qatar</td>
<td>1.2</td>
<td>5.5</td>
<td>458</td>
</tr>
<tr>
<td>10</td>
<td>Vietnam</td>
<td>13.3</td>
<td>60</td>
<td>451</td>
</tr>
<tr>
<td>11</td>
<td>Turkmenistan</td>
<td>0.45</td>
<td>1.9</td>
<td>422</td>
</tr>
<tr>
<td>12</td>
<td>Oman</td>
<td>1.24</td>
<td>5.2</td>
<td>419</td>
</tr>
<tr>
<td>13</td>
<td>Ethiopia</td>
<td>0.9</td>
<td>3.5</td>
<td>389</td>
</tr>
<tr>
<td>14</td>
<td>China</td>
<td>597</td>
<td>2210</td>
<td>370</td>
</tr>
<tr>
<td>15</td>
<td>Latvia*</td>
<td>0.3</td>
<td>1.1</td>
<td>367</td>
</tr>
<tr>
<td>16</td>
<td>Kenya</td>
<td>1.3</td>
<td>4.6</td>
<td>354</td>
</tr>
<tr>
<td>17</td>
<td>Zambia</td>
<td>0.348</td>
<td>1.2</td>
<td>345</td>
</tr>
<tr>
<td>18</td>
<td>Cambodia</td>
<td>0.3</td>
<td>0.98</td>
<td>327</td>
</tr>
<tr>
<td>19</td>
<td>Pakistan</td>
<td>9.9</td>
<td>32</td>
<td>323</td>
</tr>
<tr>
<td>20</td>
<td>Colombia</td>
<td>3.5</td>
<td>11</td>
<td>314</td>
</tr>
<tr>
<td>21</td>
<td>India</td>
<td>95</td>
<td>270</td>
<td>284</td>
</tr>
<tr>
<td>22</td>
<td>Saudi Arabia</td>
<td>18</td>
<td>50</td>
<td>276</td>
</tr>
<tr>
<td>23</td>
<td>Egypt</td>
<td>24.1</td>
<td>46.4</td>
<td>191</td>
</tr>
<tr>
<td>24</td>
<td>Russia</td>
<td>32.4</td>
<td>61.5</td>
<td>190</td>
</tr>
<tr>
<td>25</td>
<td>Indonesia</td>
<td>27.8</td>
<td>51</td>
<td>183</td>
</tr>
<tr>
<td>26</td>
<td>Turkey</td>
<td>35.8</td>
<td>63.9</td>
<td>178</td>
</tr>
<tr>
<td>27</td>
<td>Brazil</td>
<td>39.2</td>
<td>68.8</td>
<td>176</td>
</tr>
<tr>
<td>28</td>
<td>N/A Global</td>
<td>1600</td>
<td>3800</td>
<td>238</td>
</tr>
</tbody>
</table>

*EU member data, for 2003 to 2012*
A more likely outcome is a gradual reduction in the rate at which new production is added in the coming years. A better growth rate “baseline” to take, might be that seen in the period between 1983 and 2003. Over this 20-year period, Chinese growth was much more in line with trends observed in other countries today—global production increased at an average of 42 Mt per year. If this growth rate is extrapolated starting at the present, a projected 5.7 bnt/yr of cement will be produced in 2050.

CHANGING FUELS AND THE ROLE OF COAL

The cement-making process benefits from steady production conditions, which ensure both process efficiency and high-quality cement. Traditionally this has meant that most plants relied on coal as their fuel of choice because it burns consistently, has high calorific value, and is easy to handle compared to some other fuels. The cement industry uses around 5% of the coal produced globally every year.11 While this is much less than the steel or power industries, coal remains the largest single component in the overall fuel mix used by the cement industry, using on the order of 330–350 Mt of coal per year.8 Oil and gas have also been used but have traditionally been limited to countries with large natural reserves.

Although consistency is a major requirement for the fuel used to make cement, the fact that thermal energy represents 30–40% of overall costs for the cement industry has increasingly led to a search for lower-cost fuels. In the past 25–30 years this has led to the rise of the use of alternative fuels, a term used to describe any non-fossil fuel that has sufficient calorific value for cement production. The drivers for the use of any alternative fuel will often include legislation that demands reduced CO₂ emissions, the impact of landfill taxes and bans, and the price of alternative fuels relative to conventional fuels. In some situations cement producers are even paid a gate-fee to take certain types of hazardous wastes. Thus, in some locations wastes are being increasingly used by the cement industry.

For example, there has been a significant transition away from fossil fuels in places like the EU (from 97.6% fossil fuels in 1990 to 69.2% in 2012) and the U.S. (from 95.9% in 1990 to 83.8% in 2012).12 In these regions, decades of waste management expertise can be used to sort and supply calorific waste from municipal and industrial sources. It is these same markets where the cost of traditional fuels is the greatest and where minimizing environmental impact is a priority. In select developing markets, biomass wastes such as rice husks, olive kernels, and wood waste are also used to supplement traditional supplies.

“...The cement industry uses around 5% of the coal produced globally every year...”

AN ALTERNATIVE TO ALTERNATIVES

Despite the desire of some to move away from coal, cement facilities using alternative fuels and non-coal fossil fuels remain a minority. While the Cement Sustainability Initiative (CSI) stated that the use of alternative fuels saw a sevenfold increase between 1990 and 2012, the overall rate only rose from 2% to 14% of total fuel use.12 Notably, CSI’s research included far greater coverage of Europe than other regions, meaning that the true extent of alternative fuel use is likely to be much lower than their data suggested. Coal continues to supply the vast majority of thermal energy in major markets like China and India. There was, for instance, strong bidding from cement producers for reallocated coal blocks in India in February and March 2015, highlighting the high strategic importance of the resource over a multi-decade horizon.13

Indeed, in some regions, the trend for fuel choice is currently toward coal. Previously, major oil- and gas-producing countries provided subsidies for those fuels. However, this is increasingly not the case. The curtailment of Egyptian fuel-oil subsidies for the cement industry in 2014 has led to a flurry of investment in coal-feeding systems. Similar moves could be seen in other countries if the oil price (and revenue) continues to be low.

Even with the rise of alternative fuels and low oil and gas prices, coal clearly has a very large role to play in the cement industries that will help build the new cities of the 21st century. Assuming 5.7 bnt per year of cement production in 2050...
and 350–400 Mt of coal at current production levels, coal consumption for the cement industry would be 475–540 Mt in 2050.

**FACTORS THAT COULD DAMPEN CEMENT’S DEMAND FOR COAL**

It is possible that cement industry coal demand may be lower than some projections. A number of factors could act as a damper. First, 35 years is a long horizon over which the use of alternative fuels could grow in developing countries, which have pressing waste management problems in many major cities. As inhabitants of these countries demand the same living conditions as those in developed countries, there could be more waste as well as higher levels of waste processing. This would give rise to the opportunity to use far higher levels of waste as an alternative fuel in many markets that are currently unable to do so.

Second, advances in cement kiln technology are driving higher efficiency as older plants are replaced (e.g., transitioning from wet to dry process kilns and also the addition of pre-heaters/pre-calciners). This effect is particularly noticeable in India, which has one of the youngest cement industries in the world. Despite its current low alternative fuel rates, the Indian cement industry has very high thermal efficiency. For older plants, efficiency could also be increased via the use of thermal energy recovery systems, which can generate electrical energy from process waste heat. Such installations can improve efficiency by up to one third and are already prevalent in China. Low returns on investment are currently preventing this technology from gaining a foothold elsewhere.

Third, the clinker factor: The percentage of clinker in the final cement product has been reduced over the past two decades from 83% in 1990 to around 75% in 2012, according to the CSI. This means that 25% of the cement is a non-clinker mineral and thus not as energy-intensive as clinker, which lowers the fuel requirement. Once again, however, the fact that the CSI data include a bias toward Europe may be placing an over emphasis on the extent of this change.

**PEAK CEMENT**

Cement demand will only increase for an individual country up to a certain level of urbanization. Past this level, frequently quoted as 600 kg per capita per year, most countries enter a “repair and maintain” stage. In developed countries this trend is reinforced by low population growth rates. To see this effect, we need look no further than the EU28, the U.S., and Japan. The cement industry of each of these developed regions produced 12–34% less cement in 2012 than it did in 2000. As each economy achieves the “repair and maintain” level of development, demand for cement will be reduced in an increasing number of countries, causing growth in global cement demand to fall. After this point, it is conceivable that
global cement demand, and by extension the amount of coal it requires, will peak. However, whether or not this could occur by 2050 remains to be seen.

What is certain, however, is that whatever happens to the cement industry over the next 35 years, coal will play a very important role as the primary fuel source. Although other technologies and fuels may each take a small bite out of the demand for coal, the sector will continue to consume vast quantities of this vital fuel.

NOTES

A. Coal calorific content of 30 GJ/t, clinker specific energy of 3530 MJ/t, and clinker factor of 80% gives coal consumption of 94 kg/t at 100% efficiency. The process is not 100% thermally efficient and an estimate has been made to represent this.

B. 7.7 Mt of coal $\times 0.05 = 385$ Mt.

REFERENCES


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Cogeneration Plants Close to Town Get the Most Out of Coal in Germany

By Stefan Schroeter
Contributing Author, Cornerstone

An increasingly urbanized global community affords greater opportunities for the most efficient means to extract energy from coal and other fuels: combined heat and power (CHP) plants. CHP is not new. Some of the world’s first power plants were CHP facilities and they continue to be deployed globally today. Plant size, electricity output, and heat provided are site specific and the electricity and heat output can vary throughout the year as more heating is needed during colder months. Germany is an example of a country that has been relying successfully for decades on a mix of large and small CHP facilities, many of which are coal fired.

For generating electricity at the highest overall fuel usage efficiency, CHP plants are unsurpassed. While the most modern simple-combustion coal-fired power stations deliver a maximum efficiency of 46%, much of the energy in the fuel is not effectively utilized and thus leaves the power plant as waste heat. To get the most energy out of fuels, it therefore makes sense to consider the supplementary use of waste heat from power generation. Through careful planning and collaboration with urban centers, operating a CHP plant can result in 90% of the fuel’s energy being productively utilized.

When supplying municipalities with energy, it is clearly preferable to locate CHP plants as close as possible to, or even within, city limits. Their capacity and performance can be adapted to the heating demand of the service area. Waste heat from the power plant, which might otherwise be released through the stack or cooling devices, can instead be used to heat water. The combined heat and power cogeneration mode insures that the fuel will be used at high overall efficiencies of up to 90%. The heated water can then be conveyed over a short distance to the urban heating network. As a result, the required investments in existing district heating connections remain moderate.

“Through careful planning and collaboration with urban centers, operating a CHP plant can result in 90% of the fuel’s energy being productively utilized.”

In almost all parts of Germany, smaller CHP plants can be an effective fit for energy utilization. While large, modern coal-fired power plants provide relatively high electrical efficiencies, CHP facilities of varying sizes are able to achieve high fuel use efficiencies and can be suited to meet the needs of both large and small urban areas.

In Germany, large, high-efficiency coal-fired power plants are often sited in the vicinity of hard-coal and lignite surface mines or at coal ports to avoid transport costs. CHP is only a limited option for these plants as large cities are too distant to justify the cost of overland heating circuits. In addition, the immense quantities of waste heat produced by a large-scale power plant far exceed the thermal requirements of many cities and industrial complexes.

For these reasons, the fuel use efficiency of such power plants is only marginally improved by municipal or industrial heat deliveries, while the electrical efficiency can slightly decrease.

Four German coal-fired CHP plants are chronicled in this article. These plants were selected because three of them...
represent typical facilities found throughout Germany that differ from each other in terms of their size and fuel use efficiency. The remaining plant, Chemnitz, is a rare example of a municipal lignite-fired plant from the days of the German Democratic Republic that has survived to continue providing heat and power today. The operating information for these four plants is summarized in Table 1.

LIPPENDORF LIGNITE-FIRED PLANT PROVIDES ELECTRICITY AND DISTRICT HEAT TO LEIPZIG

Operated by the Swedish state-owned energy corporation Vattenfall, the advanced-technology Lippendorf lignite-fired power plant in Saxony, Germany, has provided utility heating since 2000. The CHP plant configuration has an electricity capacity of 1782 MW, generated at an electrical efficiency of 41.7%. In 2014, Lippendorf provided up to 330 MW of heat, primarily to the Leipzig Stadtwerke city utility service area. Heated water is transported from the plant through a 15-km insulated underground pipeline. Under this arrangement, the municipal utility is able to cover half the district heating requirements in the city of 550,000 inhabitants. A significantly lesser 1.6% of the heated water is routed from Lippendorf to the nearby municipalities of Böhlen and Neukieritzsch. In 2014, these supplemental district heating services raised the overall fuel use efficiency at Lippendorf to 44.07%.

NEW HARD-COAL POWER STATION BEGINS DISTRICT HEATING

An example of a newly built CHP plant is the hard-coal-fired power station at Lünen, in North Rhine-Westphalia. This plant was recently profiled by *Cornerstone* because it boasts one of the highest electrical efficiencies of any power plant in the world. Construction of the plant was fully completed in 2014 by Trianel GmbH. The original electricity-only configuration with a generation capacity of 750 MW had already achieved an efficiency of 45.95%. Since November 2014, plant operation has been modified so that up to 35 MW of excess heat are being fed through a 617-m pipeline into the Stadtwerke Lünen utility heating network. This thermal energy from the plant covers 93% of the district heating needs of Lünen—a medium-sized city with 85,000 inhabitants. The remaining thermal energy for district heating comes from several small-scale biogas plants. Through the conversion from electricity-only to CHP, the utilization efficiency of the hard coal has been improved. Using the 35 MW of formerly wasted heat increased the overall fuel utilization efficiency of the power plant to 47.51%. The associated reduction in electrical efficiency is reduced only insignificantly to 44.96%, the electrical capacity to 736 MW.

In principle, the power plant steam turbine system could provide up to 160 MW of district heat. Trianel is negotiating with

<table>
<thead>
<tr>
<th>Plant</th>
<th>Commissioned</th>
<th>Fuel(s) as delivered</th>
<th>Electrical capacity, MW</th>
<th>Heating capacity, MW</th>
<th>Electrical efficiency, %</th>
<th>Total fuel use efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lippendorf</td>
<td>2000</td>
<td>Crude lignite</td>
<td>1782</td>
<td>330</td>
<td>41.72</td>
<td>44.07</td>
</tr>
<tr>
<td>Lünen</td>
<td>2014</td>
<td>Hard coal</td>
<td>750</td>
<td>35</td>
<td>44.96</td>
<td>47.51</td>
</tr>
<tr>
<td>Chemnitz</td>
<td>1985–1998</td>
<td>Crude lignite, gas, heating oil</td>
<td>234</td>
<td>475</td>
<td>24.30</td>
<td>58.80</td>
</tr>
<tr>
<td>Bautzen</td>
<td>1980–1995</td>
<td>Pulverized lignite (gas and heating oil are secondary fuels)</td>
<td>2</td>
<td>40</td>
<td>19</td>
<td>78</td>
</tr>
</tbody>
</table>
additional potential customers for such heating services. The company estimates that the total fuel utilization efficiency would exceed 50% if the full 160 MW of heat were being provided.

Trianel has not stated what investments have been needed to establish waste heat utilization and distribution. The company estimates a payback time well in excess of 10 years for these expenditures.

VERSATILE LIGNITE POWER AND HEAT GENERATION IN A SUBURBAN SETTING

The three lignite units comprising the CHP facility in Chemnitz, Saxony, were originally constructed from 1986 to 1990 at the north end of the city. The municipal utility Stadtwerke Chemnitz undertook comprehensive environmental retrofits between 1995 and 1998. The original lignite-fired Unit A was converted to run on natural gas and light heating oil. Lignite-fired boilers B and C were retrofitted with desulfurization equipment. The crude lignite is delivered by rail from an open-cast mine about 70 km away.

Both lignite-fired units are operated in a CHP configuration. Unlike the plants described previously, more than half of the plant energy output is used for heating rather than power production. Unit C operates throughout the year to generate 100 MW of electricity with a heating capacity of 140 MW. With its extraction-condensation turbine, it can provide varying levels of power generation as required to meet fluctuating demand. Similarly, waste heat is supplied as needed. Unit B operates exclusively in the cooler months of the year, delivering 67 MW of electricity and 165 MW of heat. Similar capacities are provided by Unit A, which is employed as a backup unit.

The Chemnitz CHP facility generates enough electricity for all 140,000 private households in the city and provides heat for about one third of the households. The current operator, Eins Energie (which succeeded Stadtwerke Chemnitz), declared an achieved electrical efficiency of 24.3% on average in 2014—notably lower than the electrical efficiency of the newer and larger plants. However, the overall fuel use efficiency was 58.8%, a figure that was reduced because Unit C generates electricity during the warmer times of the year when there is no commensurate demand for district heat.
Acceptance by the local community is critical for the success of CHP plants sited near residential areas. In the experience of the operator of the Chemnitz facility, the majority of the local population accepts the use of lignite and the plant. At one time, residents near the plant repeatedly complained about the noise level of the freight yard operations; more recently, the plant operator has worked to ensure that such disturbances are minimized.

**THE SMALL, EFFICIENT BAUTZEN CHP PLANT**

Dedicated in 1980 as a heating-only facility, the CHP power plant in Bautzen, Saxony, was reconfigured for CHP operation in 1995 with the required environmental control technologies. Pulverized lignite is now the primary fuel, delivered by tank trucks and discharged pneumatically into storage silos at the plant site.

One of the two boilers supplying the back-pressure turbine is fired with the finely ground lignite. If required, the second boiler can be added with natural gas or heating oil. The CHP plant primarily delivers 40 MW of heating energy, while electrical generation lies at 2 MW. The operator Enso reported an electrical efficiency of 19% and overall fuel use efficiency of 78%. Lying on the outskirts of the medium-sized city of 40,000, this CHP facility delivers heat to the municipal utility Energie- und Wasserwerke Bautzen.

Enso has employed the pulverized lignite-based CHP successfully for the last 20 years. It functions reliably and is accepted by the local inhabitants, even though a suburban housing complex sits only 250 m from the plant site. One reason is that many Bautzen residents are involved with the local lignite industry, either directly or indirectly.

Continued development of the pulverized lignite CHP technology used in Bautzen began in the 1990s by the regional mining company, Laubag. At that time, many eastern German cities were converting their older lignite-fired CHP plants to modern natural-gas-fired facilities, leading to a significant sales reduction for Laubag. The company had hoped that cities would prefer advanced lignite technologies as the basis of electricity and heating services. However, this expectation has only been partially fulfilled. Laubag’s successor, Vattenfall Europe Mining, currently supplies 10 municipal CHP plants with pulverized lignite. The most recent plant was converted to use this processed domestic fuel in 2010.

**EFFICIENT ENERGY THROUGH COGENERATION**

Whether large or small, urban centers provide an opportunity for greater deployment of combined heat and power production. While Germany has a long history employing CHP, this technology also offers benefits around the world. As energy demand continues to grow, it is worth considering how best to utilize precious energy resources. The flexibility and efficiency offered by CHP plants is one option that continues to carry merit.

**ACKNOWLEDGMENTS**

Much of the information in this article was provided by the CHP facility operators and owners. Their contributions are gratefully acknowledged.

**NOTES**

A. All electrical efficiencies are reported in terms of lower heating value (LHV).

**REFERENCES**


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As of the end of 2014, China had an overall power generation capacity of 1360 GW, of which fossil-based power made up 66.7% and non-fossil power contributed the remaining 33.3%. China is rich in coal, with relatively small oil and gas reserves. In fact, coal accounts for about 90% of the country’s total energy resources. As such, coal likely will remain the principal primary energy source for the foreseeable future. Although coal-fired power plants have provided the energy necessary to support the rapid and steady growth of China’s economy, these plants also contribute to emissions affecting air quality, including particulate matter (PM), sulfur dioxide (SO₂), and nitrogen oxides (NOₓ).

Shenhua Group has set a strategic target of building a world-class, coal-based, integrated energy company. As part of this goal, and according to the specific characteristics of China’s coal-fired power fleet, Shenhua Guohua Power Company (Shenhua Guohua) has researched, developed, and applied key environmental technologies. The company has been an early adopter of near-zero emissions technologies, demonstrating that high-efficiency, low-emissions technologies are affordable in China. Currently, the focus of near-zero emissions controls includes control of PM, SO₂, and NOₓ with mercury emissions being maintained quite low due to lower-mercury coal and co-benefits from other emission control systems. With continued research and development, the future application of near-zero emissions technologies could be further extended to include CO₂ capture.

"Continued application of near-zero emissions technologies at coal-fired power plants is consistent with the ultimate goal of efficient, low-emissions, and low-carbon development of energy in China."

At present, coal-fired power generation is the most mature, efficient, and economical large-scale source for electricity in China. Thus, continued application of near-zero emissions
TABLE 1. Key area emission limits and Shenhua Guohua targets

<table>
<thead>
<tr>
<th></th>
<th>$PM$</th>
<th>$SO_2$</th>
<th>$NO_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Limits for coal-fired power units</strong> (O$_2$ = 6%)</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td><strong>Limits for gas turbine units</strong> (O$_2$ = 15%)</td>
<td>5</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td><strong>Shenhua Guohua target for coal-fired units</strong> (O$_2$ = 6%)</td>
<td>5</td>
<td>35</td>
<td>50</td>
</tr>
</tbody>
</table>

EXPLORING THE CONCEPT OF NEAR-ZERO EMISSIONS

In 2011, an emissions standard for thermal power plants (GB13223-2011) was jointly issued by China’s Ministry of Environmental Protection and the State Administration for Quality Supervision and Inspection and Quarantine. The emissions limits for coal-fired power units and gas turbine units in key regions are listed in Table 1.

Shenhua Guohua has met the emission regulation limits stated in the standard as well as the “Air Pollution Prevention and Control Action Plan” published by the State Council. To play its role in reducing China’s haze problem, the company has chosen to implement steps to exceed the regulation requirements and achieve near-zero emissions, effectively operating at or below the regulated limits set for natural gas turbine units (see Table 1).

DEVELOPING A ROADMAP OF EMISSIONS CONTROL TECHNOLOGIES

Based on its emissions limit targets, Shenhua Guohua has evaluated advanced environmental protection technologies from China and abroad and has increased its investment in such technologies. The company has developed an innovation-driven technology roadmap to achieve near-zero emissions for power units combusting Shenhua coal (see Figure 1), which is characterized by a sulfur content of 0.4–0.8%, ash content of 7–16%, and a lower heating value of 21–24 MJ/kg. In addition, Shenhua’s coal includes relatively low mercury content, averaging 0.08 mg/kg compared to an overall average of 0.188 mg/kg in China.

The first link in the emissions control chain is a low-temperature economizer (LTE), which reduces the flue gas velocity and also reduces the resistivity of PM, increasing PM removal efficiency in the electrostatic precipitator (ESP). A wet electrostatic precipitator (WESP) is also used, with a PM removal efficiency of 70–90%. SO$_2$ emissions are controlled using high-efficiency wet desulfurization (FGD) equipment with a SO$_2$ capture rate of 98–99%. A combination of low-NO$_x$ combustion in the boiler and a full-load denitration system, which captures more than 85% of NO$_x$, is also used. The combination of all these technologies comprehensively minimizes the emissions...
of PM, SO₂, NOₓ, heavy metals, etc. Through applying these technologies, the coal-fired power plant emissions are not only lower than the regulation limits for coal-fired power units in key areas, but are also lower than the limits for natural gas turbine units.

**Key Technologies for PM Removal**

Using traditional equipment for PM removal, such as an ESP or fabric filter, PM concentration at the stack can be controlled below the required limit (20 mg/Nm³). However, to achieve the near-zero emission target of less than 5 mg/Nm³, multiple technologies with synergistic PM capture must be applied.

The combination of multiple PM-removal technologies as shown in the technology roadmap consists of three stages: traditional ESP (i.e., dry) or fabric filter, synergistic PM removal during desulfurization, and the WESP. The initial ESP (equipped with LTE and high-efficiency power) or fabric filter has a PM removal efficiency of 99.8–99.9%, and thus PM concentration using these options can be controlled to below 20 mg/Nm³. As a co-benefit, the FGD system will remove about 50% of the PM entering the system, although some gypsum droplets will be entrained by the flue gas. Therefore, at the outlet of FGD, PM can be held to 10–15 mg/Nm³. In the final step for PM control, the WESP downstream of desulfurization has a PM removal efficiency higher than 70%, and thus the PM emissions at the stack can be reduced to less than 5 mg/Nm³. As another option, if the FGD tower is equipped with a high-efficiency demister, its PM-removal efficiency will increase to approximately 80%, which would reduce PM emissions at the stack to less than 5 mg/Nm³, even without the WESP.

**Technical Solutions for Desulfurization**

In order to achieve the SO₂ emission target of less than 35 mg/Nm³, a desulfurization technology with removal efficiency higher than 98% is required. A technology consisting of a conventional spray tower, tray design, dual cycle absorption tower, series absorption tower technology, etc., was the research focus. For a conventional spray desulfurization tower, Shenhua Guohua utilized its own patented technology to prevent the flue gas from sticking to the walls. With this technology and an additional layer of spraying, capture efficiency can be greater than 98%, and the target of limiting SO₂ emissions to below 35 mg/Nm³ can be achieved.

To further improve on desulfurization, the use of seawater has also been researched and tested. At the company’s Zhoushan power plant, the desulfurization efficiency is higher than 99%.
using seawater, resulting in \( \text{SO}_2 \) emissions below 2.76 mg/Nm\(^3\). The company plans to increase investment in the research and development of this technology and aims for some of its coastal power plants to be retrofit with a seawater-based desulfurization system.

**High Efficiency and Full-Load Denitrification**

Based on research begun in 2010, Shenhua Guohua has decided to implement a combination of low-\( \text{NO}_x \) burners in the boiler and a full-load denitration system for limiting \( \text{NO}_x \) emissions.\(^5\) The \( \text{NO}_x \) concentration at the economizer outlet without any emissions control is about 100–200 mg/Nm\(^3\). If low-\( \text{NO}_x \) burners and staged combustion are used, as developed through cooperative R&D with partnering companies, the \( \text{NO}_x \) concentration at the economizer’s outlet can be limited to around 100 mg/Nm\(^3\). Then a selective catalytic reduction (SCR) system with a designed denitration efficiency of 80–85% is applied and the stack \( \text{NO}_x \) emissions can be limited to around 20–40 mg/Nm\(^3\), notably lower than the limit for natural gas turbine units.\(^6,7\)

**Mercury Removal**

Because the company uses relatively low-mercury coal, and as the existing flue gas purification equipment can remove some mercury, the mercury content of purified flue gas is quite low. The total mercury removal efficiency of the ESP and wet desulfurization system is approximately 25% and 50%, respectively, and thus the total mercury removal efficiency is about 75%. By the company’s calculations, the mercury concentration at the stack should be less than 10 μg/Nm\(^3\), based on the application of these technologies. According to measured data, the actual concentration can be even lower. For example, Shenhua Guohua’s Sanhe power plant has measured a stack mercury concentration of only 3–5 μg/Nm\(^3\), which is an order of magnitude less than the emissions standard limit of 0.03 mg/Nm\(^3\) (GB13223-2011).

**DEMONSTRATING NEAR-ZERO EMISSIONS**

In order to meet its own environmental requirements, Shenhua Guohua launched a “High-Quality Green Power Generation Plan” for existing coal-fired power units and a “Near-Zero Emission Project” aimed at newly built coal-fired power units. In 2014, Zhoushan No. 4 was commissioned to serve as a leading example for near-zero emissions from new coal-fired power plants. After that, Sanhe No. 1 and Suizhong...
No. 2 conducted comprehensive retrofits to achieve near-zero emissions. To date nine coal-fired power units in six different power plants have applied the necessary technologies to meet near-zero emissions targets (see Table 2).

**New-Plant Example: Zhoushan No. 4**

Placed into operation on 25 June 2014, Zhoushan power plant unit No. 4 was the first power plant with near-zero criteria emissions in China. The technologies applied at the plant include low-NO \(_x\) burners, SCR, ESP (upgraded with high-efficiency power, four conventional electrodes, and one rotation electrode), wet ESP, and a seawater desulfurization system. The emissions cuts of PM, SO\(_2\), and NO\(_x\) are 88%, 94%, and 80%, respectively, while the absolute amounts of emissions cuts are 96, 260, and 440 tonnes per year, respectively.

**Retrofitted Example: Sanhe No. 1**

Sanhe unit No. 1 was the first existing coal-fired power unit in China to be placed into operation (on 23 July 2014) with near-zero emissions retrofits. The technologies applied at Sanhe No. 1 combine low-NO \(_x\) burners, SCR, ESP (equipped with LTE and upgraded with high-efficiency power and four conventional electrodes), limestone-gypsum wet flue gas desulfurization, wet ESP, and a natural draft cooling tower (NDCT). The relative amounts of emissions cuts of PM, SO\(_2\), and NO\(_x\) compared with the key area emissions limits for coal-fired power units in the standard (GB13223-2011) are 75%, 82%, and 65%, respectively. The absolute amounts of emissions cuts of PM, SO\(_2\), and NO\(_x\) compared with the key area emissions limits for coal-fired power units in the standard are 94, 255, and 403 tonnes per year, respectively.

**ECONOMIC AND ENVIRONMENTAL BENEFITS ANALYSIS**

According to China’s recently passed regulations and laws, coal-fired power units must be equipped with environmental protection facilities such as PM removal, desulfurization, and denitration. For those coal-fired power units meeting environmental standards, the grid purchase price is subsidized. For PM removal, desulfurization, and denitration, the feed-in tariffs are RMB 0.2, 1.5, and 1.0 fen/kWh (0.032, 0.24, and 0.16 US₵/kWh), respectively. Therefore, coal-fired power units meeting all the environmental standards may have a total feed-in tariff of RMB 2.7 fen/kWh (0.43 US₵/kWh). Generally, retrofitting coal-fired power plants to achieve near-zero emissions increases electricity generation costs by RMB 0.5–2.0 fen/kWh (0.08–0.32 US₵/kWh). Calculating the investments for retrofitting of Sanhe No. 1 and Dingzhou No. 3, the incremental generating cost is RMB 1.0 and 0.6 fen/kWh (0.16 and 0.097 US₵/kWh), respectively.

From the perspective of net costs, while achieving near-zero emissions increases the generating cost for coal-fired power plants, the total generating cost remains far less than that of natural gas combined-cycle units. For example, in Zhejiang
Province where the Zhoushan power plant is located, the total generating cost of a natural gas combined-cycle unit is RMB 57.7 fen/kWh (9.3 US₵/kWh) while those for the near-zero emissions Zhoushan No. 4 are RMB 19.3 fen/kWh (3.1 US₵/kWh)—approximately one third of the total generating cost of a natural gas combined-cycle unit.

At present, more than half of China’s overall coal consumption is used in coal-fired power plants. Thus, reducing emissions from coal-fired power units can significantly reduce criteria emissions from the country’s coal utilization.8 Research and application of near-zero emissions technologies by Shenhua Guohua prove that the roadmap is feasible and the environmental benefits are significant. It is hoped that these practical demonstration projects can serve as an example to pioneer a new route for clean and efficient utilization of coal in China. In 2013, China’s total amount of PM, SO$_2$, and NO$_x$ emissions were 1.42 million, 8.2 million, and 8.34 million tonnes, respectively. Although coal-fired power plants are responsible for only a fraction of China’s total emissions, if all of the coal-fired power units in China apply near-zero emissions technologies over the next five years, starting in 2015, the total annual reduction of PM, SO$_2$, and NO$_x$ emissions would be 0.27 million, 1.55 million, and 1.54 million tonnes, corresponding to reduction rates of 19%, 18.9%, and 18.5%, respectively.9

CONCLUSION

Shenhua Guohua Power Company was one of the first movers on research, development, and deployment of near-zero emissions technologies for coal-fired power units in China. At present, nine of the company’s units have achieved internal emissions reduction targets and now exceed national regulations for gas-fired turbine units. All remaining units will be upgraded within the next five years. Shenhua Guohua has demonstrated that application of near-zero emissions technologies is technically and economically feasible and the environmental benefits are substantial in China.  

REFERENCES

The growing role of coal is especially prominent in many emerging economies where rapid urbanization and industrialization are driving the growth in energy demand. In fact, the equivalent of one 500-MW coal-fired power plant has come online every three days since 2010. The president of the World Bank has said that coal will be essential to helping Africa meet its demand for power and alleviate “energy apartheid.” Several nations leading the world in economic growth as well as some developed countries are relying heavily on coal-fired electricity.

As coal-fired power generation around the world increases, the necessity of limiting the emissions becomes increasingly vital. A range of emissions control technologies for all major emissions is currently commercially available. However, especially when power plants are retrofitted, these large pieces of equipment are often piecemealed together, resulting in marginal increases in both the cost of power and the amount of auxiliary power required. In emerging economies these technologies can be cost-prohibitive. Even in the U.S., where inexpensive natural gas has increased competition in the power market, some power plant operators have chosen to shut down coal-fired plants rather than retrofit them with emissions controls. Thus, having options for reducing the costs associated with comprehensive emissions control from coal-fired power plants is globally important to providing affordable, reliable, and low-emissions electricity.

“Three-stage gasification-combustion technology ... can be applied to new or existing power plants.”

The Ashworth Gasifier-Combustor, under development by ClearStack Power, LLC, is a low-cost air-blown coal gasification technique that dramatically reduces the major criteria emissions [e.g., NOx, SO2, Hg, air metal toxics, and particulate matter (PM)] from a coal-fired power plant when paired with an electrostatic precipitator (ESP). The technology also offers a smaller footprint and draws far less auxiliary power than traditional emissions controls.
ClearStack’s approach to emissions control is based on a three-stage gasification-combustion technology (see Figure 1), which can be applied to new or existing power plants. In the first stage, pulverized coal is gasified in air in an entrained-flow gasifier to form a mixture primarily of carbon monoxide (CO), hydrogen (H₂), water vapor (H₂O), and nitrogen (N₂, from the injected air). In the first stage limestone is added, which reacts with potential contaminants in the molten ash (i.e., slag) produced. The coal and limestone are fired downward into a molten slag bath, which results in the formation of PM in which the individual particles are larger than what would be created during combustion. When this technology is retrofit to existing power plants the first-stage gasifier takes the place of the burners and is thus fully integrated with the plant. Then, complete combustion occurs in the second and third stages.

The amount of air relative to the coal used in the first-stage gasifier is specifically selected to minimize emissions. For example, an oxygen-deficient environment minimizes NOₓ production from the nitrogen in the coal and also provides the optimal conditions to reduce emissions of sulfur (captured through reaction with the limestone), mercury, and other air metal toxics.

More oxygen is available for reaction in the second stage, the lower boiler furnace, to preclude NOₓ formation in that stage. Excess oxygen is used for combustion in the third stage of the technology, in the upper boiler, as the gases have cooled to a point that minimizes thermal NOₓ production. Using less excess air throughout the gasification and combustion processes also increases the overall plant efficiency.

**TABLE 1. Environmental benefits**

<table>
<thead>
<tr>
<th>Emission or benefit</th>
<th>Emission level</th>
<th>Reduction in emissions compared to baseline, %</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOₓ</td>
<td>≤0.095 lb/10⁶ Btu</td>
<td>~80%</td>
<td>Three-stage oxidation effect</td>
</tr>
<tr>
<td>SO₂</td>
<td>Depends on coal used</td>
<td>~95–100%</td>
<td>Ca/S ratio = 1 with fine limestone</td>
</tr>
<tr>
<td>CO</td>
<td>7–8 ppmvd (parts per million volumetric, dry)</td>
<td>~95%</td>
<td>@3% O₂ (Alstom modeling for T-Fired boiler)</td>
</tr>
<tr>
<td>Hg</td>
<td>Depends on coal used</td>
<td>~90–100%</td>
<td>Captured in slag/fly ash; leachate tests of slag and fly ash demonstrate 0 mg Hg/L in the leachate</td>
</tr>
<tr>
<td>Sb, As, Ba, Be, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Ag, Ti, V, Zn, and Mn</td>
<td>Depends on coal used</td>
<td>~100% (except 80% Mn)</td>
<td>Captured in slag and fly ash; leachate tests showed concentrations of Ag, As, Ba, Cd, Pb, and Se in the leachate were all below the U.S. EPA regulatory limit for both the slag and fly ash. Thus, slag and fly ash are nonhazardous to human health.</td>
</tr>
</tbody>
</table>

“Gasifying prior to combustion produces nonhazardous, salable inert slag and fly ash.”

TECHNOLOGY BENEFITS

Reducing Criteria Emissions

The principal objective of the Ashworth Gasifier-Combustor technology is to reduce emissions from coal-fired power plants in a cost-effective manner. Environmental benefits are listed in Table 1.

The approach of gasifying prior to combustion produces nonhazardous, salable inert slag and fly ash. Since selective catalytic reduction is not required (because NOₓ formation is avoided during combustion), chemicals like ammonia are not required. Similarly, since no water is sprayed into the flue gas as is the case with wet desulfurization scrubbers, no visible water vapor is observed at the power plant stack.

In addition to comprehensively reducing emissions, the technology also offers several co-benefits. Approximately 75% of the fly ash, or PM, is captured and removed with the molten slag produced in the gasifier. Because the PM generated is larger than what is created during combustion, the PM that is not removed with the slag is less harmful and also is more efficiently captured by an ESP, since larger particles are easier to capture. Thus, a
combined gasification-combustion approach would reduce plant emissions using the same ESP (in the case of a retrofit). For example, with a particular ESP using a voltage of 94 kV, employing the gasifier-combustion operation would yield an overall PM removal of 99.32 wt% compared to removal from flue gas from a conventional coal-fired unit of 94.96 wt% (see Table 2).

Another benefit is that the ash is more alkaline because limestone is mixed with the coal. Research has shown that the alkali and alkaline earth metal concentrations are important factors in reducing the resistivity of the fly ash (to improve the ease of capture).

Carbon Emissions

In addition to criteria emissions, the technology can reduce carbon dioxide ($\text{CO}_2$) emissions. First, it can be applied to biomass/coal mixtures, thus reducing carbon emissions. Up to 15% of the coal could be replaced with biomass. While conventional boilers can cofire some 10% biomass, the reactive alkalis, such as sodium and potassium, can decrease boiler tube life. In the gasification-combustion system under development, these compounds are mostly tied up with other minerals in the slag and thus not as much of a concern.

In addition, the required auxiliary power is far less than traditional emissions control options. When using the traditional emissions controls combination of low-NO$_x$ burners, selective catalytic reduction, and a wet FGD system, a 580-MW power plant might have 15 MW of parasitic energy consumption (meaning that the plant can only sell 565 MW), not including the ESP and other auxiliary power draws required by both systems. However, the only parasitic energy used by the Ashworth Gasifier-Combustor process is that for treatment and injection of the limestone. Thus, the parasitic energy for a similarly sized plant would be 0.5 MW instead of 15 MW and a 580-MW power plant could sell 579.5 MW of electricity. In addition, certain coals with high-calcium ash, such as some Powder River Basin coals, would not require limestone addition. In that case the auxiliary power for emissions controls could be negligible. With each improvement in efficiency the $\text{CO}_2$ emissions are decreased.

In the long term, if the technology is applied to new supercritical boilers that currently achieve 45–46% overall thermal efficiency, a power plant built with the Ashworth Gasifier-Combustor would be more efficient than a coal-based integrated gasifier combined-cycle (IGCC) power plant. It would also require less space and would be less expensive to install and operate.

Saleable By-Products

Since the advent of low-NO$_x$ burners and activated carbon injection for mercury capture, many coal-fired power plants that once sold their fly ash to the cement industry are no longer able to do so due to increased carbon content. As the Ashworth Gasifier-Combustor results in fly ash with 5 wt% carbon or less, it is suitable for sale to the construction industry. The slag from the first-stage gasifier could also be saleable since coal-fired cyclone boiler slag is currently used as a wear-resistant component in surface coatings of asphalt for road paving. Finer-sized slag could also be used as blasting grit and is commonly used for coating roofing shingles.

Preliminary Economics

Preliminary economics have been calculated for the Ashworth Gasifier-Combustor. For a retrofit, the costs are compared with a FGD scrubber to remove SO$_2$ and Hg plus selective catalytic reduction (SCR) for NO$_x$ control (see Table 3). The comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capital Cost, US$</th>
<th>$/kW$_{e}$</th>
<th>Incremental operating cost, $/yr</th>
<th>C/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashworth Gasifier-Combustor</td>
<td>$29,000,000</td>
<td>$145</td>
<td>$6,500,000</td>
<td>0.46</td>
</tr>
<tr>
<td>Selective catalytic reduction</td>
<td>$36,700,000</td>
<td>$183.50</td>
<td>$7,800,000</td>
<td>0.56</td>
</tr>
<tr>
<td>Wet desulfurization scrubber</td>
<td>$38,900,000</td>
<td>$194.50</td>
<td>$10,200,000</td>
<td>0.73</td>
</tr>
<tr>
<td>Total</td>
<td>$75,600,000</td>
<td>$378.00</td>
<td>$18,000,000</td>
<td>1.29</td>
</tr>
</tbody>
</table>
assumes the same environmental performance for the two emissions control options. A 200-MWₑ T-fired coal boiler firing run of mine bituminous coal was used as the basis for the retrofits. For calculation of operating costs, an 80% capacity factor was used. The capital and operating costs are based on 2015 U.S. dollars.

The Ashworth Gasifier-Combustor was calculated to be ~38% of the capital cost and 36% of the operating cost compared to the conventional emissions control technologies. Also, this analysis does not include any credit for other air metal toxics (80–100%) that are removed by the gasifier and/or greater ESP performance. In addition, because the ash and slag are saleable, the economics could actually improve further.

DEMONSTRATING THE TECHNOLOGY

The Ashworth Gasifier-Combustor was demonstrated at a 4-MWₑ scale at the Lincoln Developmental Center, in Lincoln, IL, U.S., on a coal-fired stoker (see Figure 2). The gasifier was incorporated into boiler operation. The gasifier design modifications were successful in increasing sulfur capture and reducing NOₓ emissions compared to the original two-stage Florida Power Corporation “CAIRE” gasifier-combustor to which ClearStack owns the rights and completed testing at the Foster Wheeler Development Center.

LOOKING FORWARD

Today this gasification-combustion technology remains under development. Currently, ClearStack is seeking a project partner in the U.S. to demonstrate the technology on an existing 20–75-MWₑ coal-fired power plant. The objective of the collaboration would be to retrofit the technology in order to meet the U.S. EPA Mercury and Air Toxics Standards. Depending on the environmental permit requirements, it will take 18 to 24 months to retrofit the technology onto an existing coal-fired plant in the U.S. Pending a successful demonstration, ClearStack will look to deploy the technology at power plants needing emissions control both in the U.S. and abroad.

NOTES

A. The Ashworth Gasifier-Combustor is applicable to coal-fired power plants of any size. A 200-MWₑ plant was chosen for the economic analysis because this represents the most likely near-term customers in the U.S.

REFERENCES


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Underground Coal Gasification: An Overview of an Emerging Coal Conversion Technology

By Cliff Mallett
Chairman, Underground Coal Gasification Association
Technical Director, Carbon Energy Limited

Fossil fuels undeniably remain the world’s principal source of energy. They have underpinned the growth of industry and standards of living for the last 300 years. However, finding ways to continue to utilize fossil fuels in a low-carbon and otherwise environmentally-friendly manner is a global priority.

Underground coal gasification (UCG) is one approach to energy production that may allow for emissions and other environmental impacts to be effectively managed. Decarbonization could be achieved by gasifying coal and reforming the syngas product to hydrogen (H₂, a clean energy carrier) and safely store the carbon dioxide (CO₂).

Coal gasification has been carried out for centuries. During the 19th and early 20th centuries numerous towns had their own gas works, responsible for making coal gas (i.e., syngas) from mined coal. The gas was piped to homes and industry. Coal gas, or town gas, is now referred to as syngas and is a mixture of energy gases such as H₂, carbon monoxide (CO), as well as methane (CH₄).

The development of carrying out gasification underground, UCG, can be attributed to researchers and innovators from around the world. The earliest recorded idea of producing energy by gasifying coal underground came from Sir William Siemens in the late 1800s. Working with his brothers, a coal gasifier was invented, which Siemens suggested be placed underground.

“The development of carrying out gasification underground, UCG, can be attributed to researchers and innovators from around the world.”

The subsequent major step in the development of UCG was in 1910 when patents were granted to an American engineer for UCG methods that closely resemble modern approaches. Then, in 1912, a British chemist, Sir William Ramsay, proposed gasifying coal underground as a way to avoid emissions from burning coal, which were resulting in air quality issues in cities at the time. He believed that this coal-derived syngas would be the fuel of the future.

Ramsay began preparations to trial UCG, but the outbreak of World War I derailed his plans. Interest in UCG was rekindled in the 1930s with the USSR conducting extensive experiments. However, the program was scaled back in the 1960s when the USSR discovered huge natural gas and oil reserves. More recently, momentum has grown yet again as countries including China, the U.S., Canada, Argentina, and Chile have commenced UCG projects.

AN UNDERGROUND APPROACH TO EXTRACTING ENERGY FROM COAL

Most coal-derived energy is obtained when the contained carbon reacts with oxygen (O₂), yielding CO₂ and releasing energy in the form of heat. If excess O₂ is present, combustion occurs with nearly all the carbon converted to CO₂. When coal is gasified in an O₂-deficient environment, some coal is
converted to heat and CO₂ and this heat drives the conversion of the remaining coal to syngas. Syngas generated from UCG contains about 80% of the energy that was in the original coal.

To gasify coal underground, O₂ or air is pumped down a borehole into a coal seam, the coal is gasified in a cavity created by the conversion of coal to syngas, and the syngas is extracted through a different (i.e., production) borehole. A number of underground gasifier designs have been demonstrated, the latest being from Australia-based Carbon Energy. In a demonstration project its technology provided consistently high-energy syngas over 20 months and demonstrated the same could be achieved from a single panel of coal for up to 10 years (see article on page 61 for further details).

THE ADVANTAGES OF UNDERGROUND GASIFICATION

The primary reason to gasify coal underground is the low cost of energy production. Estimates from UCG companies on the cost of producing UCG syngas range from US$1–3/GJ depending on the coal deposit and on whether air or oxygen is used as the oxidant.2,3 Additional UCG benefits include:

- It is applicable to very large, deep resources that can consist of low-quality coal not suited for conventional mining (normally conventional mining occurs above 1000 m). The estimated amount of usable coal at such depths could equal or exceed all current mineable coal resources and be a game changer for global energy supply.
- The energy is produced as syngas, which is readily cleaned using existing processes and transported via pipelines.
- Multiple uses exist for syngas, such as a fuel for power station gas engines to produce electricity, or chemical feedstock for the production of fertilizers, diesel and gasoline, and methanol derivatives such as olefins and plastics. Syngas can also be readily processed into natural gas.
- Compared to coalbed methane extraction from the same coal seam, UCG generates over 60 times more energy.
- UCG offers a small environmental footprint with little surface impact and minimal waste generation.
- The health and safety issues associated with people working underground can be avoided.

UCG IS SAFE AND CONTROLLED

Early 20th-century UCG trials resulted in significant lessons learned that allowed researchers and technology providers to improve the efficiency and environmental credentials of UCG. One of the major concerns related to UCG has been the ability to avoid affecting groundwater quality. Modern UCG technologies have evolved to ensure destruction of potential contaminants as part of the gasification and decommissioning processes, as well as managing operating pressures to protect groundwater.

A particular observation that evolved from early trials and subsequent research was the “Clean Cavern” concept. This is the process whereby the gasifier is self-cleaned via the steam produced during operation and following decommissioning (during decommissioning while the ground retains heat steam continues to be generated). Another important practice is ensuring that the pressure of the gas in the gasifier is always kept below that of the groundwater surrounding the gasifier cavity. Thus, groundwater is continuously flowing into the gasifier and liquids which could potentially contain chemicals will not be pushed out into the surrounding strata (see Figure 1). The pressure is controlled by the operator using pressure valves at the surface.

In addition, the high temperature in the cavity during gasification destroys many of the potentially contaminating organic by-products produced during the process. When operation of

![FIGURE 1. Operating UCG with a pressure lower than the surrounding area draws groundwater toward the gasifier.](image)
a gasifier is stopped, the groundwater pressure in the cavity is reduced to near atmospheric pressure (much lower than the surrounding pressure) to increase the volume of groundwater flowing into the cavity, which increases steam production. A significant percentage of remaining by-products are carried to the surface as vapor via the production well and combusted. This overall approach to UCG has now been successfully implemented at sites in the U.S., Spain, Australia, and South Africa.

Another historic concern related to UCG has been the ability to understand and predict ground subsidence. The UCG process creates a cavity similar to those found at conventional underground coal mines. These cavities are well understood thanks to conventional mining, and thus their behavior can be predicted accurately with modern 3D computer models. Similar to conventional underground coal mining, ground subsidence is predicted before UCG operations commence; if surface subsidence is predicted to significantly affect current or future land use or infrastructure, UCG will not proceed at that particular site.

One of the most rigorous long-term environmental evaluations of UCG pilot sites was carried out by the Queensland Government in Australia from 2008 to 2014. An Independent Scientific Panel appointed by the state government reviewed four years of UCG Pilot Project operations and concluded in the “Independent Scientific Panel Report on the Underground Coal Gasification Pilot Trials” (June 2013) that UCG “could be conducted in a manner that is socially acceptable and environmentally safe when compared to a wide range of resource using activities”.

Decommissioning and rehabilitation of an underground UCG gasifier cavity had not been attempted in the Queensland trials at the time of the ISP evaluations, but in late 2014, independent experts advised the government that Carbon Energy had successfully decommissioned its gasifier, and steam cleaning of the cavity resulted in the cavity posing no environmental or health risks. Groundwater quality will rapidly and naturally be restored to pre-project conditions and no active remediation is required.

**REQUIREMENTS FOR UCG**

Industrial processes require specific, controlled conditions for optimal and safe operation and UCG is no exception. The conditions required for operation of the underground gasifier are established through exploration, prior to construction or operation of a UCG panel. For example, proper UCG site selection is critical—several hydrogeological conditions must be satisfied before proceeding with construction.

First, the coal seam being gasified must be overlain by impermeable strata. The buoyancy of the gas forces it to move upward; thus, the gas will be lost unless the coal seam is capped by strata through which the gas cannot pass, such as shale or clay beds. Second, as coal seams always have some permeability and gas is able to move laterally through coal, the groundwater in the surrounding coal seam must be at a higher pressure than the pressure in the gasifier to prevent the flow of gas away from the gasifier cavity. These primary criteria are illustrated in Figure 2. Other characteristics also must exist at a suitable UCG site—for example adequate groundwater pressure for gasification to occur, coal seams of adequate thickness to maintain gasification temperatures, and appropriate separation from overlying and underlying water-bearing formations.

Field tests and digital modeling facilitate the development of hydrological models that can be used to predict risks to water supplies. Just as with subsidence modeling, if harmful effects are predicted in the exploration stage, UCG will not proceed.

Similar to other resource production industries, UCG requires appropriate pre-development exploration and investigations
to ensure that hydrogeological conditions suit the technology being applied.

**UCG IS AN EMERGING TECHNOLOGY**

Until recently, there have been few new developments in UCG. A commercial UCG plant has been running for many years in Uzbekistan; however detailed information on the operation or output of that plant has not been made public. Developed countries with accessible resources have chosen to access shallower coal deposits using traditional mining methods. Additionally, projects based on traditional approaches to UCG have struggled to produce a consistent, high-quality syngas.

Looking at almost a hundred historical UCG sites worldwide,

the main difficulties can be categorized as follows:

- Insufficient knowledge of the site geology
- Inability to drill boreholes with necessary precision
- Operating with inappropriate gasification parameters
- Lack of understanding of the impact of the gasification process on the surrounds of the underground cavity.

More recently, however, there have been major technological innovations which have addressed the issues encountered in previous UCG projects (see Table 2).

These advances facilitate proper site investigation, UCG design performance modeling, and identification of issues with respect to product gas or environmental impacts which demand specification or exclude the site as a UCG prospect. In addition, UCG operators now have access to real-time control of underground processes. This allows interpretation of changes in UCG performance and the design of appropriate responses.

Since 2000, long-term UCG pilots in Australia, China, and South Africa utilizing the technologies shown in Table 2 have successfully demonstrated that deep UCG can be low cost and environmentally benign. Results from these trials continue to demonstrate that UCG’s major challenges have been resolved and has led China to incorporate this technology into its Five-Year Plan process for resources and energy.

Recent progress and innovation have made it possible that UCG will be an important technology in the future energy mix. However, progress in nontechnical areas must be made with respect to the interrelated areas of government regulation, community understanding and engagement, and project financing.

Given that the production cost of UCG syngas can be significantly lower than that for production of energy by other

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**TABLE 2. Major technical innovations applied to UCG**

<table>
<thead>
<tr>
<th>Issue</th>
<th>Innovation source</th>
</tr>
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<tbody>
<tr>
<td><strong>Geology</strong></td>
<td>Advances in mining&lt;br&gt;• 2–3D seismic surveys for underground coal mines&lt;br&gt;• Computer-based geological models</td>
</tr>
<tr>
<td><strong>Drilling</strong></td>
<td>Advances in coalbed methane gas extraction&lt;br&gt;• Long-hole in-seam drilling methods to extract methane from coal seams before coal mining and for coalbed methane production</td>
</tr>
<tr>
<td><strong>UCG design and gasification process control</strong></td>
<td>Unique problem&lt;br&gt;• Development of proprietary new modeling and design capability as well as process methodology to give real-time control of operations&lt;br&gt;• Development of parallel controlled retracting injection point design</td>
</tr>
<tr>
<td><strong>Ground and water impacts around gasifier</strong></td>
<td>Advances in mining&lt;br&gt;• Coal mining strata and gas models for prediction of strata deformation and gas and water inflow into long-wall mines</td>
</tr>
</tbody>
</table>
means, and its demonstrated environmental credentials, UCG presents an opportunity for high-potential growth investors looking for approaches to generate low-emissions power, synthetic natural gas and other fuels, and chemicals from coal.

MEETING ENERGY NEEDS

Energy demands continue to grow globally, particularly in emerging economies in Asia and Africa. At the same time, there is pressure to minimize the cost and maximize the availability of energy supplies as well as the social imperative to reduce the environmental impact associated with energy.

The adaption and application of new petroleum and mining techniques have demonstrated that consistent supplies of high-quality syngas can be safely produced in commercial-scale UCG projects. Further progress and innovation in the field of UCG has been seen recently and several new commercial UCG projects are nearing commencement. Once the first commercial project is successfully established, I believe there will be an avalanche of follow-on projects, and the industry will become a valuable contributor to global energy production.

NOTES

A. Dr. Cliff Mallett served as Chairman of the Underground Coal Gasification Association from 2013 to 2015. His tenure at that position concluded near the time of article preparation. Dr. Mallett is also Technical Director at Carbon Energy. Thus, some of the technical innovation discussed in the article is based on his direct involvement with Carbon Energy.

REFERENCES


The author can be reached at Cliff@carbonenergy.com.au
Carbon Energy Delivers Innovations in Underground Coal Gasification

By Morné Engelbrecht
Managing Director and CEO, Carbon Energy Limited

After decades on the fringes of world energy production, advancements in underground coal gasification (UCG) are proving the process can deliver high-quality syngas on a commercial scale with limited impact on the surrounding environment, at a lower cost than current coal-to-gas production in Australia.

Carbon Energy Limited, based in Australia, has built on many years of work by that country’s leading research organization, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to further develop and demonstrate a UCG technology that has satisfied stringent technical and environmental assessments by a panel of government-appointed independent scientists. Decommissioning and rehabilitation processes have also been assessed by the state environmental protection authority.

Today UCG is poised to become a valuable option to help meet future domestic and global energy demand because it offers an environmentally responsible and economically attractive means of extracting energy from otherwise unmineable coal.

COMMERCIALIZATION OF UCG

One of the stumbling blocks that has held UCG back from becoming a fully commercial industry has been the inability to extract a consistent-quality syngas required for continuous feed into the selected downstream industrial process (whether for fuel or fertilizer production, electricity generation, or other uses that require syngas as a raw feedstock).

UCG requires ignition (heating of the underground coal seam to high temperatures between 1200 and 1600°C) to initiate the gasification process, and the subsequent injection of an oxidant (e.g., air or oxygen and steam) to maintain the syngas production. Traditional UCG approaches have employed a “batch process” using vertical wells and requiring manual intervention and reignition approximately every 30 days. This causes fluctuations in temperature and syngas quality.

“UCG ... offers an environmentally responsible and economically attractive means of extracting energy from otherwise unmineable coal.”

Carbon Energy’s process, developed over more than 16 years of research and in-field trials, has been proven to address this issue by using a unique design that provides continuous automated gasification in a panel of coal to produce a high-quality syngas for up to 10 years (see Figure 1). This innovation, called the Controlled Retraction Injection Point (CRIP), was extremely important in achieving the consistently high-quality syngas that was produced continuously over many months during Carbon Energy’s demonstration at Bloodwood Creek in Queensland.

With horizontal in-seam injection and production wells, and an oxidant injection point that retracts as the coal face is gasified, the gasification process is maintained at a consistent temperature, which in turn produces consistent quality syngas. Moreover, a significant proportion of the potentially contaminating by-products produced with the syngas are destroyed in the path of the gasification face, contributing to the now-proven environmental credentials of the technology.

THE TIME FOR UCG IS NOW

Global primary energy demand is expected to rise 37% by 2040, according to the International Energy Agency’s “World Energy Outlook 2014.” With the world’s hunger for energy growing, unlocking new energy sources that are commercially
sustainable and are amenable to carbon capture techniques is a priority. Coal is predicted to remain a significant source of energy for the world given its widespread availability and low cost. UCG is a technology that is able to maximize the energy extracted from coal, while ensuring a small environmental impact and footprint.

Carbon Energy’s technology has improved on previous UCG methods and been shown to extract 60 times more energy than coalbed methane extraction on the same area of coal. It is also able to produce syngas from coal seams previously considered too deep and uneconomical for traditional coal extraction technologies. Carbon Energy’s recently completed demonstration at Bloodwood Creek was operated at depths of more than 200 meters below the surface; however, operation at far greater depths is also possible and commercially viable.

Rigorous scientific assessments and independent review have shown that potential environmental issues around waste and impacts on groundwater have also been overcome. With site selection methodology developed by CSIRO, refined engineering design to geothermal standards, and demonstrated operating protocols, it has been demonstrated that environmental impacts are kept to a minimum. With the physical footprint of the UCG operations contained to 50 hectares of land while recovering a significant volume of energy, good relationships are maintained with landholders. Together with the proven environmental credentials, this should assist Carbon Energy to achieve a social license to operate its unique technology.

BLUE GUM GAS PROJECT

Carbon Energy’s proposed Blue Gum Gas Project neighbors the existing demonstration site in the Surat Basin at Bloodwood Creek, about 200 km west of Brisbane, Queensland, Australia. Once government approvals are received, Carbon Energy will build and operate a commercial-scale UCG plant that will produce syngas which will be processed above ground to deliver pipeline-quality synthetic natural gas (SNG). The plant will produce 25 PJ of natural gas per annum, which is approximately 0.687 billion Nm³/yr natural gas equivalent, suitable for use by existing connected homes and domestic industries. SNG production is expected to commence within three years of the start of construction.

Carbon Energy’s focus on developing SNG over power or ammonia production has been driven by commercial demand. The domestic natural gas market on the east coast of Australia will see a significant increase in natural gas prices as the export of coal seam gas commences. East coast manufacturers are eager to find a low-cost natural gas feedstock. The Blue Gum Gas Project will be located near existing infrastructure enabling ready transport of natural gas to customers.

Carbon Energy operated a demonstration (pilot) project at Bloodwood Creek in Queensland from 2008 to 2012 in order to fine-tune the application of their unique technology, and to collect necessary data to submit to the state government for approval to operate the technology in Queensland. Although most of the syngas over the demonstration period was flared, the syngas was used to power generators, with power used on site and also exported to the local electricity grid.

The pilot-scale demonstration project involved operating two underground gasifiers. The “panels” of coal where the gasifiers operated were constructed at a depth of about 200 meters, are 500 meters long, and 30 meters wide, with an average thickness of 8–9 meters. A panel of this size has sufficient coal to produce syngas continuously for five years. However, as proof of concept of the technology was achieved after almost two years of continuous production of high-quality syngas from the second gasifier, further expenditure on the pilot was unwarranted and the demonstration project was decommissioned.

The commercial-scale project will simply replicate the panel module at the scale required for the project. In the case of the proposed Blue Gum Gas Project, around 40 of these panels will be required to generate 25 PJ of syngas per annum.

Environmental Review

An Independent Scientific Panel (ISP) was appointed by the Queensland government in 2009 to review and report on the pilot projects being conducted in the state at that time, focusing on the technical and environmental aspects of UCG technology. Technology developers were required to prepare a comprehensive report on their pilot projects and submit these reports to the ISP for review.
The final peer-reviewed ISP report on the pilot projects was released in July 2013. The government gave in-principle support to the ISP’s conclusions that the capability to commission and operate a UCG gasifier had been demonstrated, and that “the technology could, in principle, be operated in a manner that is socially acceptable and environmentally safe when compared to a wide range of other existing resource-using activities”. However, the government required that the technology developers demonstrate successful decommissioning prior to any approval being granted for a commercial-scale project. Essentially, this meant that Carbon Energy needed to provide evidence that gasification had ceased at the pilot project site and that any of the relevant environmental values affected by the underground coal gasification process (excluding surface facilities and landform, which would be addressed under normal processes) could be restored to a condition agreed to with the Department of Environment and Heritage Protection (DEHP). There was a particular focus on groundwater quality, which could potentially be impacted adversely by UCG by-products.

To meet the government’s requirement, Carbon Energy prepared a comprehensive Decommissioning Report and Rehabilitation Plan and submitted these documents on 29 August 2014 and 1 October 2014, respectively. Preparation of these documents involved a full site investigation by an independent Suitably Qualified Person for contaminated land assessment (as authorized under the Environmental Protection Act 1994), which in turn involved a drilling program for collection and laboratory analysis of decommissioned gasifier cavity water and core samples, core samples from new near-cavity boreholes, and baseline core samples. Analysis of the data from these new wells was in addition to analysis of results from the ongoing monitoring of groundwater quality from 24 monitoring wells surrounding the gasifier cavity and located in the target coal seam and overlying and underlying rock formations.

The Queensland DEHP has advised Carbon Energy that its expert consultants have completed the review of Carbon Energy’s Decommissioning Report and Rehabilitation Plan. This review will be referred to the Department of Natural Resources and Mines (DNRM), which is the lead agency in the matter of UCG policy, for a government decision on commercialization of the technology in Queensland.

**Decommissioning Plan**

The Decommissioning Plan was required to include:

- Evidence that gasification had ceased
- Quantification of any contaminant load
- Delineation of the zone of impact of any contamination
- Evidence that any contaminants were not increasing or moving outside of the lower-pressure zone maintained by Carbon Energy around the gasifier cavities.

The process data clearly showed that gasification stopped within 48 hours of initiating the shutdown procedure (see Figure 2). This was evidenced by changes in the composition of vented gas, which quickly returned to high percentages of natural methane gas with a sharp decline in the concentrations of hydrogen and carbon dioxide, and declining syngas flow rate and temperature.

Once gasification stops, it cannot start again naturally, due to the absence of oxygen 200 meters underground beneath a tightly sealed formation, with the UCG panel surrounded by groundwater.

The results of the groundwater quality investigation showed that:

- The majority of remaining UCG by-product was within the cavity.
- More than 90% of by-products were eliminated by steam venting during the shutdown procedure.
- Concentrations of remaining by-products are decreasing.

![Figure 2. Carbon Energy’s pilot-scale demonstration](image-url)
Both during operation and after decommissioning, pressure in the gasifier is maintained at a level below the regional groundwater pressure so that groundwater continuously flows toward and into the gasifier cavity. The pressure is controlled by Carbon Energy from the surface. This approach successfully contains UCG by-products within the small area of low pressure.

**Rehabilitation Plan**

As previously indicated, the purpose of the Rehabilitation Plan was to demonstrate Carbon Energy’s ability to restore the relevant environmental values of the site, those essentially being groundwater quality. Given the baseline quality of the groundwater (which is not fit for human consumption), the applicable environmental values for the Bloodwood Creek site were identified as stock watering and human health.

Based on the results of the site investigation, a risk assessment and highly conservative fate and transport modeling based on the applicable environmental values, it was concluded that the current groundwater conditions within the cavity do not pose harm to human health or the environment.

The independent Suitably Qualified Person under the Environmental Protection Act 1994 signed off on the Rehabilitation Plan, which concluded that:

- The low levels of remaining by-products will rapidly and naturally reduce to baseline levels.
- No environmental receptors are likely to be impacted.
- No active remediation is required.

Parameters have been proposed for a range of chemicals against which groundwater analysis will be assessed on a regular basis and reported to the government. Monthly reporting of groundwater results from the groundwater monitoring network will also continue.

**TAKING UCG TO THE NEXT STAGE**

Carbon Energy has demonstrated its technology is a significant advance in UCG, in producing consistently high-quality syngas that can support commercially viable downstream use. More than 100 years since the first suggestion of gasifying coal underground, Carbon Energy’s approach is an attractive, environmentally responsible, and economically viable means of utilizing the energy potential of coal considered too deep for viable conventional mining.

**REFERENCES**


For more information, please email askus@carbonenergy.com.au
**Movers & Shakers**

Arch Coal announced that John Eaves, President and CEO, has been elected to the position of Chairman of the Board and CEO following a planned succession process, replacing Wesley Taylor. In addition, Paul Hanrahan was named as the company’s Lead Independent Director.

Consol Energy announced that James Brock, previously COO of Consol’s coal division, will lead CNX Coal Resources, a new master limited partnership.

The International Energy Agency has named Paul Simons as its next Deputy Executive Director. Mr. Simons has served as a U.S. diplomat.

Orica announced that Alberto Calderon has been appointed as the Interim Managing Director and Chief Executive Officer, replacing Ian Smith, who held the position for four years.

**International Outlook**

**China**

China has announced plans to urbanize large tracts of land near the Yangtze River, which would host several energy and transportation projects.

China’s National Energy Administration recently released the Action Plan on Clean and Efficient Utilization of Coal Resources (2015–2020). The main targets of the plan are that the average coal intensity for new coal-fired power plants should be less than 300 g of standard coal per kWh; more than 70% of coal should be washed; industrial-scale modern coal-to-chemicals demonstrations should be completed; and the average efficiency of coal-fired boilers should be increased by 5% compared to 2013. Further targets have been set for 2020 and beyond.

**Germany**

The German Coal Importers Association (VDKi) has announced that hard-coal imports were at a record high of 56.2 million tonnes in 2014, an increase of 6.2% compared to the previous year.

**India**

India’s Power and Coal Minister, Piyush Goyal, announced that India and Japan will be collaborating on clean coal technology development and deployment.

India’s government announced that it would sell more of its stake in Coal India in the future. In addition, the government is continuing to sell coal blocks whose previous allocation was cancelled by the Supreme Court. After this third tranche, 45 of the total 214 blocks will have been sold.

**U.S.**

The U.S. Department of Energy announced that the Regional Carbon Sequestration Partnership has reached a milestone: Under the program, 10 million tons of CO$_2$ have been successfully stored.

**International**

As this issue went to press, nine out of 37 parties had submitted their Intended Nationally Determined Contributions (INDCs) in advance of COP21. The largest emitters to submit their INDCs are the EU (including Latvia), Russia, and the U.S.

**From The WCA**

**WCA Workshop**

On 1 June 2015, WCA held a workshop entitled “Building Pathways for Cleaner Coal Technologies” in London, England. The purpose of the meeting was summarized by the WCA Acting CEO, Benjamin Sporton, “Cleaner coal technologies can be seen on a continuum. Deployment of high-efficiency, low-emission (HELE) coal fired power generation now can lead to significant CO$_2$ mitigation benefits. HELE is a key first step to deployment of carbon capture, use, and storage technology that will be essential for all fossil fuels if global climate ambitions are to be met.”

The workshop included speakers from around the world sharing their experience with the demonstration of carbon capture, use, and storage and the deployment of other HELE technologies.
China Energy Focus 2014: Towards Clean Coal — China Clean Energy Fund — This publication includes a compilation of expert contributions on the different fields of clean coal technologies, such as criteria emissions controls, high-efficiency power plants, coal gasification and conversion, water conservation, and carbon capture and storage. In the near term, coal is expected to play a large role in China's energy mix, although the quantity and date of China's coal utilization peak is debatable. In any case, deployment of clean coal technologies was deemed critically important in China. To date, the environmental performance of China's fleet of coal-fired power plants has been substantially improved, whereas emissions from industrial boilers have yet to be reduced at the scale necessary. In the near term, the authors believe continued efficiency improvements and criteria emissions controls will be the major environmental focus. Although pilot and demonstration projects have been successful, policy changes will be needed to support widespread advancement of gasification and carbon capture and storage. The full report can be downloaded free of charge at www.cefc.org.hk/a-list/6465

Recent Select Publications

Climate Implications of Coal-to-Gas Substitution in Power Generation — Hermine Nalbandian, International Energy Agency Clean Coal Centre — In 2014 coal fueled 36% of the world’s electricity. To reduce carbon emissions some countries are looking to displace some of their coal-fired capacity by using more natural gas. However, recently several studies have looked at the implications of methane emissions on climate change when there is large-scale switching from coal to gas for electricity generation. Because methane, the main component in natural gas, is more a potent greenhouse gas compared to carbon dioxide (CO₂), it is a significant contributor to climate change. This is especially true in the near term (10–20 years). Studies have found that methane emissions from gas exploration, extraction, transmission, and distribution, unless controlled, could make the benefits of coal-to-gas substitution questionable, especially in the short term. This report reviews these studies and their findings. The report is available at www.iea-coal.org.uk/report/80574//83578/climate-implications-of-coal-to-gas-substitution-in-power-generation,-CCC-248

Global News

Key Meetings & Conferences

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

<table>
<thead>
<tr>
<th>Conference Name</th>
<th>Dates (2015)</th>
<th>Location</th>
<th>Website</th>
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<tbody>
<tr>
<td>China (Taiyuan) International Coal Industry Expo</td>
<td>22–24 Sep</td>
<td>Taiyuan, Shanxi, China</td>
<td><a href="http://www.cicne.com.cn/">www.cicne.com.cn/</a></td>
</tr>
<tr>
<td>China (Shanxi) International Coal Chemical Industry Exhibition</td>
<td>22–24 Sep</td>
<td>Taiyuan, Shanxi, China</td>
<td><a href="http://www.cisete.com/">www.cisete.com/</a></td>
</tr>
<tr>
<td>IEA CCC 11th Workshop on Mercury Emissions from Coal</td>
<td>17–20 Nov</td>
<td>Chennai, Tamil Nadu, India</td>
<td>mec11.coalconferences.org/ibis/MEC11/home</td>
</tr>
</tbody>
</table>

There are several Coaltrans conferences globally each year. To learn more, visit www.coaltrans.com/calendar.aspx
While I found a recent Cornerstone cover story interesting in its discussion of reducing global CO$_2$ emissions from the global coal-fired power plant fleet through USC and AUSC designs, I found myself wondering about the two primary options for coal plant efficiency improvements.

There are two types of efficiencies that apply to a typical Rankine cycle steam electric generating station: Carnot cycle efficiency and equipment efficiency. There is a mistaken impression in some quarters that the equipment, especially the steam generator or turbine, are the source of improved SC/USC/AUSC efficiencies.

According to Carnot a thermodynamic heat engine operates between a heat source and a heat sink where the heat available for conversion is determined by the difference in thermodynamic properties between the source and the sink.

A typical turbine steam path converts about 85% of the steam energy between the throttle valves and the used energy end point (UEEP). Consider two different plant options: 1) 2400 psig, 1000°F, 1460 Btu/lb and 2) 3100 psig, 1100°F, 1506 Btu/lb. Condenser back pressure is 4.0 inches H$_{g}$ (abs), 125 °F, 1064 Btu/lb. With a steam flow of 5,000,000 lb/h, $\Delta H$, and 85% efficiency case 1) will produce 493 MW and case 2) 550 MW.

Efficiency savings must be balanced with the additional costs incurred for equipment and materials that must handle both short and long term stresses. T/P91 & 92 are popular materials for USC, but has enough time and experience accumulated to predict long-term reliability? There are several vintage SC plants, however USC operates at higher temperatures which have an exponential impact on metallurgical reliability.

Heat rate and fuel carbon content are the important factors. Coal gets most of its energy from carbon, rather than hydrogen. For a typical power plant the equipment energy losses are distributed in this general manner.

About 10% to 15% of the fuel input is lost up the stack. About 5% is dry gas losses which depend on the amount of flue gas and temperature. About 5% is latent heat of water vapor from the products of combustion. This water vapor heat counts as a loss if HHV is used for the fuel heat content and does not count if LHV is used for the fuel heat content. The third 5% is from boiler radiation losses, unburned fuel, bottom ash heat, etc.

The turbine’s steam path is actually fairly efficient, converting about 85% to 90% of the steam between the throttles and UEEP mechanical energy (i.e., driving the generator).

The circulating water system that carries away the heat from the turbine’s condensing exhaust steam is the most misunderstood and neglected of the plant systems. This system carries 50% of the energy that entered the turbine throttles.

The heat rates for typical utility power plants frequently run as high as 5% to 10% above design. For decades utilities in the U.S. have been reluctant to pursue significant and expensive plant efficiency improvements because public utility commission mandated fuel/energy cost adjustment factors burden the utility with the costs while passing the savings on to the rate payer.

In the long term USC/AUSC designs will improve the coal fired fleet’s Carnot cycle efficiency and reduce CO$_2$ per megawatt hour.

In the short term there are significant potential efficiency improvements available in day-to-day operation and maintenance.

Nicholas Schroeter, PE
President and Master Navigator
Heat Rate Navigation Services, Inc.

Response: It is true that some decent benefits in coal-fired power plant efficiency can be gained by close attention to operation and maintenance. This should be part of best practices for all utilities. In my experience, some utilities are very attentive to this approach, while others can be less so. However, once one has “wring out” the last fractions of a percent by this route, equipment upgrades need to be considered to allow the higher steam temperatures and pressures needed for further efficiency improvements.

Ian Barnes
Associate
IEA Clean Coal Centre
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www.cornerstonemag.net
The World Coal Association has published a concept paper on establishing a global Platform for Accelerating Coal Efficiency (PACE).

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

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

The concept paper is available for download on the WCA website www.worldcoal.org or email PACE@worldcoal.org to request a copy.

The WCA has released the concept paper for stakeholder input and engagement. If you would like to provide feedback or discuss PACE in more detail, contact us at PACE@worldcoal.org.
Higher population density associated with urbanization provides an opportunity for governments to deliver basic services such as water and sanitation more cost-effectively to greater numbers of people.