The Role of Business and Industry in COP21

Nick Campbell
Long-time Business Member at International Climate Negotiations
Our mission is to build understanding and gain acceptance for the fundamental role coal plays in powering modern economies. We engage with global thought leaders and policy makers to position coal as a responsible and progressive industry by demonstrating that coal and 21st Century coal technologies are critical to achieving a sustainable and low emission energy future.

Benjamin Sporton
Chief Executive,
World Coal Association

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The international scientific advisory body on climate, the Intergovernmental Panel on Climate Change (IPCC), has set a clear goal for delegates at COP21: Construct an international agreement to limit global temperature rise to 2°C. In fact, the IPCC’s recommendations have been clear for years, yet each year the concentration of greenhouse gases in the atmosphere continues to increase. Having the technical backing for a global goal on climate has, to date, proven insufficient to yield a workable agreement. The reason is likely differing perspectives and competing objectives for negotiators, including avoiding infractions on national sovereignty, maintaining national economic growth, advancing poverty alleviation, financing low-emissions technologies, ensuring a fair playing field, and more.

Still, there is hope that a growing number of national and regional governments and industry players believe reducing emissions is important, not just for the environment, but also to protect sustainable development. The collaborative R&D and international knowledge sharing being demonstrated by SaskPower and its first-of-a-kind Boundary Dam CCS project is just one example.

The cover story in this issue, written by a long-time attendee of COP meetings, makes a strong case for the importance of engagement with business and industry, which will provide technical solutions and financing and can contribute to an agreement at COP21 and the resulting emissions reductions. For example, much of the innovation in recent years in low-emissions technologies can be applied to the coal industry, such as high-efficiency, low-emissions (HELE) power plants, integrated gasification combined cycle, and circulating fluidized bed combustion, just to name a few. The development of carbon capture, utilization, and storage saw a major advancement with the startup of the Boundary Dam project in 2014. With further development, even CO₂ capture from air could play a role to counteract historical emissions. With numerous technologies in the development pipeline, it is critically important that negotiators and regulators do not attempt to choose technological winners and instead support a suite of technologies.

There are about 1.3 billion people with no electricity today and coal and other energy sources will be needed to provide it to them. Many of these people live in developing Asia and other locations where there are considerable coal reserves. Thus, as developed countries continue to rely on coal and developing countries expand coal use, engagement on technology development is imperative for emissions reductions. COP21 provides a real opportunity to create a framework to accelerate technology development and deployment. The coal industry is engaged and is already pursuing a first step through increasing the application of HELE technologies.

This issue of Cornerstone is focused on the opportunities and challenges associated with COP21. On behalf of the editorial team, I hope you enjoy it.
FROM THE EDITOR
Balancing Objectives at COP21
Liu Baowen, Cornerstone

VOICES
Considering the Contribution of Technology Ahead of COP21
Benjamin Sporton, World Coal Association

Discounting Innovation Could Undermine Climate Objectives
Robin Batterham, University of Melbourne

SaskPower’s Case for Carbon Capture and Storage
Michael Monea, SaskPower

Deploying Clean Energy in Asia: An Exclusive Interview With Ashok Bhargava of the Asian Development Bank
Holly Krutka, Cornerstone

ENERGY POLICY
Economic Development Status Is a Lingering Challenge for COP Negotiations
Jeremy Bowden, Cornerstone

Don’t Count Coal Out of a Lower-Emission U.S. Energy Mix
Fredrick Palmer, Green Coal Solutions, LLC
Frank Clemente, Penn State University

Exploring the CCS Roadmap Landscape
Jiang Wenhua, Shenhua Science and Technology Research Institute

Cover Story
The Role of Business and Industry in COP21
Nick Campbell

In December 2015, world leaders will gather in Paris to attempt to forge the global agreement on climate that has been elusive to date. Written by a representative of industry stakeholders at numerous COP negotiations, this issue’s cover story explains why COP21 can be successful and how business and industry have a key role to play in this success.
STRATEGIC ANALYSIS
Considering the Challenge of China’s COP21 Commitments: An Exclusive Interview With Jonny Sultoon of Wood Mackenzie
Li Xing, Cornerstone

Lignite Rides the Rails in Europe
Jeffrey Michel, Independent Energy Consultant

Commercial Recovery of Metals From Coal Fly Ash
Lucinda Tolhurst, Lucid Insight Ltd

TECHNOLOGY FRONTIERS
Reducing Energy’s Footprint by Producing Water and Storing CO₂
Thomas A. Buscheck, Lawrence Livermore National Laboratory
Jeffrey M. Bielicki, The Ohio State University

The Case for Carbon Capture From Air
Klaus Lackner, Arizona State University

Finding Opportunities for CCUS in China’s Industrial Clusters
Zhang Jiutian, Zhang Xian, Peng Sizhen
Ministry of Science and Technology

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Climate change has clearly become a major international issue. Stakeholders from around the world and from all sectors are now focused on how to minimize the impacts of climate change as the potential economic and development impacts are enormous.

There have been a number of international attempts over the years to tackle climate change. In the course of these negotiations, the way in which the world characterizes itself has changed from a binary one with developed and developing countries to one with developed countries, developing countries, and new emerging economies. The only international agreement on climate issues, the Kyoto Protocol, was created in the outdated binary world. It has proven to be insufficient—more needs to be done and by more nations. The next major opportunity lies ahead with the upcoming Conference of the Parties (COP) to be held in Paris in December. This meeting, COP21, is the culmination of years of work to build the foundation for an international agreement on climate.\(^1\)

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**The Role of Business**

“COP21 is the culmination of years of work to build the foundation for an international agreement on climate.”

By Nick Campbell

Former Chairman, BusinessEurope Climate Change Working Group and International Chamber of Commerce Climate Change Working Group

Chairman, European Fluorocarbon Technical Committee

Co-Chairman, European Chemical Industry Council Climate Change Strategy Implementation Group
As the originators of a major proportion of greenhouse gas (GHG) emissions (the bulk of which is for products and services for society), business and industry are inextricably linked with the climate change issue. However, business is also the provider of solutions: the technology of the future and much of the finance to enable the transformation to a low-carbon economy. How business works with the climate change negotiation process, in particular COP21, and contributes to the most economically sound and efficient approach to transition to a low-carbon future are vital to successfully reaching an efficient, comprehensive global agreement on climate.

THE IMPORTANCE OF COP21

To be held 1–11 December 2015, COP21 is the culmination of the international climate negotiations since 2005 (see end of article for more information). The four years of discussions since the COP in Durban in 2011 have resulted in the development and adoption of a draft negotiating text, compiled at the February 2015 meeting in Geneva. This original 86-page text was revised at a negotiating meeting in Bonn in June. The co-chairs of the group responsible for the negotiations issued a new text on 24 July that will undergo further revision in two subsequent meetings (also in Bonn) from 31 August–4 September and 19–23 October. The goal of these later meetings is to streamline and drastically shorten the working text into a form that Ministers can use to reach a final deal in Paris.

A strong driver behind the work of the governments under UNFCCC has been the reports of the Intergovernmental Panel on Climate Change (IPCC). Its 5th Assessment, published in 2014, reported an increased certainty in anthropogenic impacts on climate and the need for concerted global action. While there has been much debate around the exact wording used by the IPCC (and, in fact, the role of IPCC in general), a clear message has evolved from the group: Climate change is real and action must be taken to both prevent and reduce its impacts.

COP21 provides the opportunity for governments to “walk the talk” and to demonstrate that they can work together to tackle the risks of climate change while protecting economic growth and development. National and regional actions are important, but collective action is vital. International collaboration can lead to enhanced action as well as avoid competitive...
market distortions that can result from nations taking actions unilaterally. The developed world has agreed that it must lead the way, but rapidly growing emerging economies must closely follow. Nothing less than a binding comprehensive global agreement in Paris will be sufficient.

KEY CHALLENGES IN REACHING A DEAL

There are three main challenges to finalizing an international deal at COP21: reaching agreement on emissions reductions, adaptation to the impacts of climate change (current and future), and the financing of actions. Going into the final Ministerial negotiating sessions, the negotiating text must be high level if a final agreement is to be reached. Many of the details will be developed in separate decisions, or processes will be initiated to develop modalities and procedures to allow future implementation (e.g., a process to develop rules for the use of market mechanisms to help compliance with emission reduction commitments).

One essential aspect that must be tackled in any agreement text drafted in Paris is related to reviewing progress and ratcheting up ambitions as the commitments agreed to in Paris are unlikely to be enough to meet the emission reduction goals as outlined by the IPCC.

The devil will be in the details. Extensive (and possibly extended) discussions on many topics will be necessary. A few of the most important topics and the key questions to be answered are listed in Table 1.

THE ROLE OF BUSINESS

Business has a vital role in the fight against climate change. Many companies are affected by climate change and have already taken adaptation actions. For example, some power generators have planned for changes in cooling-water supplies. Business will provide the technologies that will enable society to move toward a low-carbon economy. Business will

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**TABLE 1. Key questions that must be answered at COP21 to reach an agreement**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Key Questions to Be Answered at COP21</th>
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<tbody>
<tr>
<td><strong>Intended Nationally Determined Contributions (INDCs)</strong></td>
<td>What should be included (economy-wide or sectors of the economy)?</td>
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<td>What time period should they cover?</td>
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<td>Should they be annual or multi-year?</td>
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<td></td>
<td>How frequently should they be reviewed? Etc.</td>
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<tr>
<td><strong>Adaptation</strong></td>
<td>Should there be a global target?</td>
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<td>Should the current institutions be augmented/changed?</td>
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<td>Should loss and damage be included within adaptation or as a separate topic within the new agreement?</td>
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<tr>
<td><strong>Review/Timing</strong></td>
<td>When and how often should the agreement made in Paris be reviewed?</td>
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<td></td>
<td>Against what parameters and by whom should it be reviewed?</td>
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<tr>
<td><strong>Monitoring, Reporting, and Verification (MRV)</strong> (considered a vital part of the new treaty)</td>
<td>What should be the frequency of reporting?</td>
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<td>What should be reported?</td>
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<td>How should the reported data be reviewed and by whom?</td>
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<tr>
<td><strong>Means of Implementation</strong></td>
<td>• Finance: How should action be funded (i.e., through public or private finance)?</td>
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<td>How is the role of markets?</td>
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<td>How should the $100-billion Green Climate Fund (which was agreed upon by Heads of State in Copenhagen in 2009) be mobilized to assist developing countries to take action and, more specifically, from where should the funding come?</td>
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<td>• Technology: How should low-emission technology processes be disseminated to aid emissions reductions and development?</td>
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<td>How should this be financed?</td>
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<td>How can intellectual property rights (IPR) be protected?</td>
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<tr>
<td></td>
<td>• Capacity Building: How should capacity to take action and institutional structures be built in developing countries?</td>
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<td>Should there be an overall institution managing capacity building?</td>
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also provide much of the financing to enable adoption of existing and new technologies. Business will continue to innovate and develop new products for the future as well as improve current process and operating procedures to reduce energy consumption and improve efficiency. For example, carbon capture and storage, including utilization (CCS and CCUS), will play a vital role in a low-carbon future, especially in the least-cost approach to climate change mitigation.3

Business is expected to have a major role in providing investment to finance the transformation to a low-carbon economy through investment institutions and banks. How the use of markets for compliance will be permitted within the 2015 agreement will be instrumental in the provision of finance. The Clean Development Mechanism under the Kyoto Protocol provided a great incentive for business participation in developed and developing countries alike and generated thousands of emissions reduction projects. These projects involved both large and small companies and ranged from improved cook stoves to renewable facilities. Insurance companies will also play a major role in adaptation to climate change and risk assessments of future impacts.

However, creating the drivers for business to take these actions is a very real challenge. Transition to a low-carbon economy will require considerable investment from companies; this investment is juxtaposed against the need to generate a profit/return for shareholders. A key question that must be answered in Paris is whether the benefits and opportunities in a low-carbon economy are worth that investment.

“Transition to a low-carbon economy will require considerable investment from companies; this investment is juxtaposed against the need to generate a profit/return for shareholders.”

The answer will vary vastly depending upon the sector(s) in which a company operates. Consider, for example, different sectors within the energy industry. Clear advantages can be observed for companies that are developing technologies for and manufacturing renewables. However, what are the benefits for companies, such as those in the coal industry, that produce an essential, but higher-CO₂, energy source? There will be companies throughout the spectrum being advantaged or disadvantaged by a move to a low-carbon economy. Clearly governments need to take into account not only the environmental, but also the developmental, social, economic, and employment impacts of their commitments.

The recent Business & Climate Summit, held 20–21 May in Paris, generated a number of key messages that are being fed back into the international climate-negotiating process. This event gave a window into the business and industry perspective on climate negotiations as it was attended by 1500 mainly business delegates, including a large number of CEOs, across a broad range of sectors. The key takeaways from the Summit can be summarized as follows:

1. Leading businesses are already taking action to build a prosperous low-carbon economy of the future.
2. Many businesses are already setting their own internal emissions reduction targets, using internal carbon prices in their investment analyses, increasing energy efficiency, innovating new materials, products and services, aligning their procurement toward low-carbon electricity, and working with suppliers to reduce emissions within their supply chains.
3. Many recognized that more can be done.

Those businesses present at the Summit also called for an ambitious global climate agreement with appropriate policies from national governments to include ambitious, measurable, and verifiable national commitments, a cooperative mechanism to increase ambition over time, and transparency and

UN Secretary General Ban Ki-moon at COP20 in Lima, calling on the Parties to announce emission targets ahead of COP21. (AP Photo/Martin Mejia)
accountability mechanisms. There were calls for the use of carbon pricing as a tool to achieve the least-cost global net emissions reductions. Many companies called for a global carbon price but, in equal measure, it was stressed that such tools should be implemented by governments where appropriate and that careful design and implementation was needed to avoid market competitive distortions. There is no “one-size-fits-all” solution.

The considerable discussion on funding stressed the need for strong support for innovation and deployment of new technologies, including the financing of clean energy research and development and the protection of intellectual property rights. The need for public and private funds to leverage private-sector finance and to de-risk investment toward low-carbon assets, especially in developing countries, was seen as particularly vital.

Finally, there was a call to integrate climate into the mainstream economy through using trade and investment rules to encourage climate action, to support education and training, particularly in developing countries, as well as opening consultative channels to enable decision-makers to get the best possible information from those in the business community.

Many business groups as well as many groups that claim to represent business have developed and championed positions on the outcome of the Paris meeting. Depending upon the motivations and members of the groups, there are many nuances between these positions, but also a number of key messages. These include:

- Develop an ambitious, predictable, and comprehensive global agreement.
- Protect economic growth and development.
- Understand that many businesses support a carbon price as an important tool to drive the transition to a low-carbon economy.
- Ensure there is no distortion of competitiveness in the global market.
- Encourage innovation.

"COP21 will not be a final action, but it will be an important part of a multi-decadal process and the business community will help define and find the stepping stones needed along the journey."

**CONCLUSION**

Based on my experience attending past climate negotiations and representing various business groups, I believe COP21 will be a success. The enormous efforts by the French government as the Presidency of the conference combined with the drive of many parties to come to a new agreement will ensure this success. As with all recent COPs, whether negotiations are finished in the early hours of Saturday morning, 12 December, or run into the next day remains to be seen.

The foundation of the agreement has already been laid: controls by all countries on their GHG emissions based on INDCs, actions on adaptation, and financing for actions. Still, the work has just begun. The implementation of the structures around basic agreements will take several years to put in place to be ready for the implementation of the new agreement on 1 January 2020. The transformation of the global economy to a new low-carbon future—which has, in some areas, already started—will receive a boost from the outcome of COP21. Of course, COP21 will not be a final action, but it will...
be an important part of a multi-decadal process and the business community will help define and find the stepping stones needed along the journey.

REFERENCES


A BASIC HISTORY OF THE CLIMATE CHANGE NEGOTIATION PROCESS

COP21 in Paris will be the 22nd COP to the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC was adopted at the 1992 Rio Convention and entered into force on 21 March 1994. Today there are 196 Parties.

The Convention was augmented in December 1997 at COP3 in Kyoto, Japan, with a protocol in which industrialized countries and those in transition to market economies took on emissions caps. The global emissions cap for six GHGs was an average of 5% below 1990 levels with the first commitment period set as 2008–2012. Specific targets varied from country to country. The Kyoto Protocol entered into force on 16 February 2005 and now has 192 Parties, but a number of key Parties were not fully committed and did not fully ratify it (e.g., U.S.) or did not join the second commitment period (e.g., Canada and Japan).

From 2005 to 2012, the Parties to the Kyoto Protocol negotiated further commitments for Annex I Parties for the years 2012–2020. Two working groups aimed to develop a new agreement ahead of COP15 in Copenhagen, Denmark, in December 2009. However, in a meeting in which there was considerable mistrust between the Parties the Copenhagen Accord was only the “noting” of an agreement.

While the goal of a new agreement was not achieved in 2010, much of the trust lost in Copenhagen was rebuilt, thanks in large part to the dedication and tireless diplomacy of the Mexican Presidency. The 2010 COP in Cancun, Mexico, formally recognized the need for deep cuts in global emissions to limit the global average temperature rise to 2°C. Much groundwork on establishing institutions for the technology and financial mechanisms that would be necessary to implement any global agreement was also laid at the Cancun COP.

The following year at COP17 in Durban, South Africa, there was an agreement to establish a second commitment period under the Kyoto Protocol, 2013–2020. Since COP17, much discussion and little action has taken place in the attempt to understand Parties’ relative positions and the scope of what could be viable in the new climate agreement. For example, at COP18 in Doha, Qatar, in December 2012, an agreement was reached on the amendments to the Kyoto Protocol to establish its second commitment period.

In Warsaw, Poland, at COP19, the Intended Nationally Determined Contributions (INDCs) were formed. Using the INDCs gives each Party the opportunity to develop their own strategies and goals for reducing emissions. That these emission reduction goals are being developed by the Parties individually is a critical difference from the Kyoto Protocol. The INDC approach means that the new 2015 agreement will be based on a bottom-up national pledge system, rather than negotiated top-down targets. On the finance side, the Warsaw International Mechanism on Loss and Damage and the Warsaw Framework for REDD+ were established to assist countries dealing with the impacts of climate change and support major initiatives to prevent deforestation, respectively.

The most recent meeting, COP20, in Lima, Peru, focused on the preparation of the draft negotiating text of the 2015 agreement, as well as what should be included in specific INDCs. The Lima Call for Climate Action, while pushing forward the process, did little to advance the substance within the negotiating text, except for creating two extra negotiating meetings in 2015 leading up to COP21.

NOTE

A. COP6bis was held in 2001 following the inconclusive COP6 in The Hague in 2000.
As 2015 draws to a close, one event will stand out in the calendars of all those connected to the energy industry. COP21 begins in Paris on 30 November—and, for two weeks, delegates will work to achieve a universally binding agreement on the climate. The United Nations Framework Convention on Climate Change (UNFCCC) Conference has been held annually since the Berlin Mandate in 1995; however, the build-up to the Paris convention has certainly been more intense than in previous years. The ongoing divestment campaign and the G7 leaders’ recent commitment to phase out carbon emissions by the end of the century shows there is real ambition ahead of Paris. This ambition, however, cannot ignore the reality that energy from coal, oil, and gas will be vital to global development ambitions. In order to succeed, any climate agreement must gain the backing of all UN member states and it is unrealistic to expect the world’s many developing countries to abandon the most reliable and affordable sources of energy available to them. For many countries, that means coal will be part of their energy mix for decades.

“"We are now at a point where action can be taken to dramatically reduce CO₂ emissions without reducing the affordability or reliability of people’s energy sources.”"

China is the most obvious example of a country that has rapidly developed using coal. Over the past three decades the country has connected 99% of its population to the grid and seen its economy grow at an astonishing rate. China is now renowned for its exports. None of this development would have been possible without the use of coal, of which it has plenty. Many other countries in the region also have access to considerable coal reserves and they will likely follow China’s lead. In Southeast Asia, coal consumption is projected to rise...
by 4.8% a year through to 2035, and coal production is set to grow by 2.4% in the same period. With this forecast in place, it would be irresponsible for ministers at COP21 to ignore the role that cleaner coal technologies need to play in mitigating CO₂ emissions.

It is vital that funding and attention are turned toward cleaner coal technologies. High-efficiency, low-emissions (HELE) technologies and carbon capture, use, and storage (CCUS) have the potential to dramatically reduce emissions from coal-fired power generation, while still meeting the demand for coal.

HIGH-EFFICIENCY, LOW-EMISSIONS TECHNOLOGIES

HELE technologies can increase the efficiency of coal-fired power plants to such an extent that some two gigatonnes (Gt) of CO₂ emissions could be cut each year. Such an emissions reduction could be achieved by increasing the current global average efficiency of the world’s coal fleet from 33% to 40% with off-the-shelf technology. To put that figure in some context, reducing CO₂ emissions by 2 Gt is the equivalent of running the Kyoto Protocol three times over, or equal to India’s total annual CO₂ emissions.

Bringing this technology to all new coal-fired power plants would have a huge impact in reducing CO₂ emissions around the world, while retaining the two characteristics that make coal such an attractive energy source: its affordability and its abundance. HELE technologies are the most logical way to target both energy access and the climate, treating those issues as integrated priorities. Therefore, HELE technologies should be recognized by climate negotiators in Paris as essential and requiring international support.

CARBON CAPTURE, USE, AND STORAGE

Carbon capture, use, and storage (CCUS) is another key technology that has much potential to reduce CO₂ emissions while maintaining the affordability and availability of coal, other fossil fuels, and biomass and waste. In the process of CCS/CCUS the CO₂ can be stored or, alternatively, used in enhanced oil recovery (CO₂-EOR), a process which has been in use for decades. CO₂-EOR is important because it can provide a useful revenue stream to reduce the cost of early large-scale CCUS demonstrations. The recent success of SaskPower’s Boundary Dam Carbon Capture Project in Canada demonstrates that CCUS is both viable and affordable for electricity from coal.

BOUNDARY DAM CARBON CAPTURE PROJECT

Operational since 2014, Boundary Dam is the world’s first commercial-scale post-combustion coal-fired CCS project, and a benchmark of what can be achieved using this technology. Located near Estevan, Saskatchewan, Boundary Dam provides a reliable baseload of 110 MW of electricity a year, while also reducing annual greenhouse gas emissions by one million tonnes of CO₂, equivalent to taking a quarter of a million cars off the province’s roads. Much of the captured CO₂ at Boundary Dam is used in CO₂-EOR at nearby oil fields, while some is stored as part of the Aquistore Project at a depth of 3.4 kilometers in a layer of brine-filled sandstone. Added to this, the process also captures 100% of the plant’s SOₓ emissions and 56% of its NOₓ emissions, again proving just how valuable a tool advanced technologies are in reducing the environmental impact from coal.

PACE

While climate change is obviously a significant challenge, economic development and poverty alleviation are also key issues facing much of the world. Coal has a track record of fueling economic development, and reliable energy is vital to improving the lives of people in the developing world; however, this does not mean that we have to follow an unsustainable path. Low-emission technologies, such as HELE and CCUS, provide us with the opportunity to tackle all three of these issues simultaneously, using the same solution.

This vision was the inspiration behind the World Coal Association’s “Platform for Accelerating Coal Efficiency” (PACE) initiative. PACE envisages that, for all countries choosing to use coal, the most efficient power plant technology possible is deployed. The overriding objective would be to raise the global average efficiency of coal-fired plants, minimizing CO₂ emissions while maintaining legitimate economic development and poverty alleviation efforts. As urbanization increases and
countries look to develop their economies, we cannot ignore that demand for affordable, reliable energy will continue to grow. It is crucial that those at COP21 in Paris recognize not only this fact, but also the huge potential of both HELE technologies and CCUS. We are now at a point where action can be taken to dramatically reduce CO₂ emissions without reducing the affordability or reliability of people’s energy sources. This is an opportunity which must be taken for the sake of both the environment and the 1.3 billion people who live each day without proper access to energy.⁶

OPPORTUNITIES FOR CHANGE

The criticism leveled at fossil fuels has grown over recent years, particularly as the divestment campaign has gained momentum. In order to maximize the possibility of achieving the world’s two degree Celsius (2°C) target, action must be taken immediately. Countries like India, Indonesia, and many more in the region will see the progress China has made over recent decades and be aware that coal-fired generation is, for them, a critical part of their path toward economic growth and development. It may seem simpler for the international community to wish away coal’s role in the energy mix, but that is not a realistic prospect. Indian Power Minister Piyush Goyal has previously described coal as playing an “essential role” in his $250-billion plan to provide “Power for All” by 2019, and the International Energy Agency (IEA) forecasts coal’s share in the total Indian energy supply to rise from its current 43% to 51% by 2035.⁷ Obviously, India shows no sign of slowing down the rate of its coal consumption, which makes it clearer still that 21st century coal technologies are vital to any hopes of a global climate agreement. It would be foolish to expect a country such as India, with the world’s second largest population, to turn its back on coal, giving up its opportunity to develop in an affordable and reliable way. A similar story can be told for many other emerging and developing economies in Asia.

CONCLUSIONS

COP21 in Paris is being heralded by some as the last chance to avoid irreversible climate change, but the task of generating a consensus among a group of countries at very different stages of their development will be monumental. Affordable and reliable sources of energy are critical to development and this makes coal the logical choice for many developing and emerging economies. Such countries will not support an agreement that hampers their ability to develop. However, advancements in technology provide a pathway to compromise. HELE technologies and CCUS offer the potential for energy needs to be met, while also making huge reductions in global CO₂ emissions. It is only by treating climate and development objectives as integrated priorities that we will successfully overcome these global challenges. 

REFERENCES

Discounting Innovation Could Undermine Climate Objectives

By Robin Batterham
Kernot Professor of Engineering, University of Melbourne

Many observers maintain high hopes for the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) to be held in Paris this December. Meeting these aspirations would mean that an international agreement has been reached that will set all nations on a path to serious emissions reductions.

Despite goodwill among the parties, to reach 21 conferences and still find global emissions set to skyrocket from around 37 billion tonnes of CO2 per year today to 46 billion tonnes of CO2 per year by 2035 is telling. Put simply, and without denying anthropogenic impact on climate is measurable, 21 conferences and a rise of 25% over the next couple decades suggests that current messages on climate risks and emissions reduction scenarios, particularly of the more extreme variety, are not having sufficient impact to overcome the headwinds facing a global agreement on climate.1

COP21 will occur with a sense of urgency, albeit in a cyclone of conflicting opinions, interests, and rhetoric. At such an important moment, it is worthwhile to pause and consider some realities about the world’s energy system, the challenges it faces, and how these challenges might be overcome. In this way arguments about fault and responsibility (i.e., how, how much, by whom, who will pay, etc.) can be sidestepped and negotiations can start from common ground.

COP21 is unlikely to be the last step for the world to reach a final agreement on its exact emissions goals. However, broad agreement already exists that anthropogenic inputs to the climate are observable. Further, there is considerable support for minimizing emissions.

If we start from this common ground, the nature of the dialogue changes to focus on how much and who will pay. This is familiar territory. We make such commitments in our everyday lives when we prioritize our own limited resources toward education, infrastructure, support for the arts and sports, etc. The difference with minimizing global emissions, however, is that strategies to minimize emissions have access to a growing base of low-emission technologies on which they can rely.

“IT IS TECHNOLOGICAL INNOVATION THAT WILL EVENTUALLY DRIVE EMISSIONS DOWN.”

EXPLORING THE POSSIBILITIES OF TECHNOLOGY DEVELOPMENT

In the world of climate and energy, promissory notes and aspirations are abundant. The recent meeting of G7 leaders in Bavaria, for example, targeted zero emissions by 2100. Such an objective implies that negative emissions will be required because emissions are largely inevitable from some sectors or industries, such as cement and metal production. Negative emissions are possible. For example, power generation achieved by co-firing biomass and coal with carbon capture and storage (CCS, which includes CCUS for the purposes of this article) is one of the very few large-scale approaches to realizing negative emissions. Others have focused on achieving negative emissions by capturing CO2 directly from air (see article on page 55); although the costs for this approach would likely be higher than CCS from power plants, it maybe be a worthwhile technology to have at our collective disposal.
There are some basic truisms around technology and innovation that deserve consideration. First, the cost of delivering a product falls in real terms as a result of innovation. This conclusion is supported by data covering hundreds of years and numerous examples (see Figure 1). Comparing the production rate of various goods versus a nominal sales price (in $/tonne) yields a strongly linear relationship when plotted on a log-log plot.

The second point is that existing technologies inevitably face replacement. Computers are a classic example. For the same price, computational power continues increasing. This has happened not solely because a particular technology has continuously improved, but also because new technologies have been introduced. For example, few computer users today are familiar with the ferrite core memory used in the 1950s. For those that weren’t around then, computer memory was made by hand by threading fine wires through tiny ferrite cores and 8 kb of memory was quite impressive.

LOW-EMISSIONS TECHNOLOGY INNOVATION

There are many examples where innovation and learning by doing have reduced the cost of environmental technologies. For example, the delivered costs of solar cells and offshore wind have already fallen and are projected to continue to do so for quite some time. As renewables have become less expensive, their potential role in emission reductions has increased, but even so they make up only one tranche of the required emissions reductions. Alone, renewables are not enough, and the discussion at COP21 must reflect that fact. High-efficiency power plants, CCS, and other technologies for fossil fuels must be included in the discussion.

There are also many historical examples of cost reductions in the coal-fired power plant sector. One such example, which is often compared directly to CCS, is the development of wet desulfurization scrubbers for coal-fired power plants in the U.S. where capital costs decreased by about half as the deployment of the technology grew. According to the Global CCS Institute, current cost estimates show that coal with CCS could be less expensive than other low-emissions options, such as electricity from biomass, wind offshore, solar PV, and solar thermal. This cost comparison did not factor in high reliability and any capacity to follow electricity demand. Perhaps with greater application and innovation, costs could be further reduced.

“There are many examples where innovation and learning by doing have reduced the cost of environmental technologies.”

Reducing the cost of emissions control is certainly not limited to the U.S. Emissions control technologies have been developed and applied more recently in China (see Table 1), where the costs of producing increasingly clean power using coal also continue to fall. Various companies in China have been installing ultra-low emissions technologies to coal-fired power plants. These plants boast world-class technologies: ultra-supercritical boilers with CO₂ emissions up to 30% lower (courtesy of the higher operating efficiency) as well as SOₓ, NOₓ, and particulate matter removal systems. These high-efficiency, low-emissions (HELE) plants are hugely important, although CCS and CCUS will be necessary for the deep cuts in emissions needed to support international climate goals.

Some of the ultra-low emissions plants in China are quite large, up to 1000 MW per boiler, with the result that the economic

FIGURE 1. Commodity price versus global production

Note: The author acknowledges the contribution of Prof. Peter Seligman, University of Melbourne, to the generation of this data and figure.
penalty for this low emission performance is less than 0.35 US₵/kWh. On-grid costs in China from such plants, including the emissions controls, provide electricity at about half the cost of natural gas-fired electricity in the country. These plants are truly state of the art and I encourage anyone that has the opportunity to visit one to do so. Based on my experience, it is more like visiting an aerospace operation than a power station, such are the standards of design and cleanliness of operation.

Considering the gains being made through the application of HELE technologies in China, the role of CCS takes on a new meaning. Despite the glamorous and oft-repeated tales of how a single invention went on to change the world, the majority of technological takeovers are the result of incorporating leading edge technologies, often in combination, to yield marked improvements. Mobile phones are not a single invention, nor will be the low-emissions energy mix of the future.

In addition to CCS, there are other potential ground-breaking technologies in the pipeline. The recent efforts to use both heating and cooling of turbine blades are a case in point. Such technology allows coal-fired power stations to spin up to meet demand at a rate similar to a gas-fired power station, thereby turning coal into a fast-change load-following energy source. The use of coal directly injected into diesel engines (DICE) also allows rapid start-up. Both technologies would allow for more renewables into a grid. DICE also delivers a higher efficiency than existing coal-fired plants and could be coupled with CCUS.

### PROGRESS DOES NOT ALWAYS MEAN NEW

One is reminded that, in terms of timing, there are many projections of how existing fossil fuel and nuclear power plants must be phased out, because they have reached the end of their economic lives. To me, this is somewhat wishful thinking in that, unless mandated, most plants can be renewed as brownfield sites meaning that their economic lives can be extended.

In fact, brownfield economics are often more attractive than greenfield economics. For example, the total refurbishment of the Boundary Dam brown coal-fired power station in Saskatchewan...
retrofitted with CCS shows that an old asset can be rejuvenated, that emissions can be reduced, even for brown coal, by 80%, that the first-of-a-kind risks have been overcome and, importantly, it is producing very real insight into the costs of CCS.

It is quite reasonable to expect that CCS/CCUS costs will follow a downward trajectory similar to other low-emissions energy technologies. In fact, the first steps to reducing costs of CCS/CCUS are ready to be realized. The owners and operators of SaskPower’s Boundary Dam project are already suggesting that the full-scale costs of the next plant will be 30% lower.

“CCS is just as likely to help deliver our 2050 targets even more economically than a wholesale flight to renewables.”

LETTING INNOVATION RUN ITS COURSE

It is technological innovation that will eventually drive emissions down. The Organisation for Economic Co-operation and Development (OECD) has done some interesting work in terms of what drives innovation in low-emissions power generation. Their working definition of “clean energy” includes solar, wind, small and large hydroelectric, geothermal, marine, biomass and waste-to-energy power plants, carbon capture and storage (CCS) technologies, and energy-efficient technologies such as smart grids and electric vehicles. According to their recent report: “Production and activities in the solar-PV and wind-energy sectors are increasingly reliant on imported intermediate inputs. Policies aimed at protecting domestic manufacturers may thus hinder the profitability of downstream activities, e.g. by raising the cost of inputs.” In essence, the most effective route for innovation is to encourage international competition.

The OECD results and the language are clear: “Policies that promote open, competitive and demand-driven markets for clean energy will support the continued cost reductions needed for a cost-effective transition to a low-emissions energy system, reducing the amount of public incentives needed to scale up the deployment of clean technologies.”

Recent and detailed modeling of the Australian electricity market out to 2050 suggests that, in the absence of a price on carbon or other forms of support for low-emissions technologies, deep abatements are still possible. It is only a case of how much the market is prepared to bear. Brear et al. suggest that for 80% reduction by 2050 compared to 2000 levels, CCS and nuclear are highly competitive in Australia.

The lesson from history is that the route to low emissions is primarily about technology. To predict which technologies will evolve, which will emerge, and the rate and the costs is unlikely to be successful. Against this proposition we need to be generous in our thinking and allow a wide range of activities. CCS is just as likely to help deliver our 2050 targets even more economically than a wholesale flight to renewables.

AIMING FOR THE BULLSEYE

Emissions reductions with reasonable economics and impact should be our collective target. This is all doable and should include all options, CCS being quite attractive on economic grounds. The discussion should be about how much we can afford to pay. Given the lack of global progress on emissions reduction to date, perhaps this is also what the wider population has already told us.

REFERENCES

SaskPower’s Case for Carbon Capture and Storage

By Michael Monea
President, Carbon Capture & Storage Initiatives, SaskPower

Nearly a year has passed since SaskPower had the pleasure of inaugurating the Boundary Dam Carbon Capture and Storage (CCS) project. As the world’s first commercial-scale post-combustion CCS project at a coal-fired power plant, Boundary Dam represents a major step forward for environmentally sustainable coal power and for the future of the power and oil industries.

Bringing the first-of-a-kind project to fruition has required a sustained commitment. Following extensive analysis, feasibility studies, community outreach, and regulatory evaluation, the Boundary Dam project was built over the course of three years. Approximately 1700 contractors and employees of SaskPower worked continuously for a total of nearly five million man-hours. CCS at Boundary Dam Power Station is now an important part of SaskPower’s electricity generation fleet and of Saskatchewan’s proven track record in technological innovation.

THE VALUE OF DIVERSIFIED GENERATION

Currently, about 44% of SaskPower’s electricity comes from coal. Coal is reliable and the costs are stable. Centuries’ worth of coal reserves lie under Saskatchewan and are an important part of the province’s economy. Thus, coal is an attractive energy source for SaskPower as we have a plentiful supply near our three coal-fired power stations. The coal we burn is western Canadian lignite, which has a lower heating value and lower percentage of sulfur.

New Canadian greenhouse gas regulations came into effect on 1 July 2015. Essentially, the regulations require existing and new facilities to operate with the same emissions as natural gas-fired plants: 420 tonnes CO₂/GWh. Prior to modification, Boundary Dam’s Unit #3 emitted 1110 tonnes CO₂/GWh, but at 90% capture the plant will, at full capacity, operate at 140 tonnes CO₂/GWh—essentially four times less carbon emissions than a natural gas facility.

“One of the most common questions we hear is, “Why wouldn’t you invest in renewables like wind and solar, rather than CCS?” We know our customers are interested in renewables, and we’re interested too. About 25% of our current available capacity comes from renewable sources, and that number is growing. For example, our goal is to have 10% of capacity via wind by 2020 and about 20% by 2030.

However, our renewable capacity will need baseload generation to ensure reliability—our customers expect the power to be there when they need it. The intermittent nature of wind and the fact that it can’t currently be stored economically means that it needs to be balanced with other power sources. In essence, we need electricity sources we can control, such as gas and coal that are available 24/7 and are not impacted by weather. CCS makes possible low-emission baseload power to support our renewable assets.

Similar to financial planning, our best option for power generation is a balanced portfolio. That gives us the best opportunity to maintain competitive electricity rates and continue to provide reliable and sustainable electricity to our customers. It’s important we don’t rely too heavily on one source, but rather maintain a balance that will serve us today as well as over the long term. CCS is part of maintaining that balance.
PROJECT ECONOMICS

When we began evaluating CCS, we compared it against the next best alternative: natural gas. Assumptions were made on the initial investment required, current borrowing rates, internal rate of return, and the cost of coal and natural gas to determine if CCS could be competitive. The true benefit came from our province’s abundance of coal, a fuel source with an affordable, stable price. Natural gas prices can fluctuate dramatically, making the return on investment less certain.

The business case we put forward also considered the ability to secure purchasers for Boundary Dam’s by-products: CO₂, fly ash, and sulfuric acid. SaskPower was able to secure contracts for all three by-products.

SaskPower has a 10-year contract in place for the sale of CO₂, Boundary Dam’s main by-product. It will be used for enhanced oil recovery (CO₂-EOR) in nearby oilfields. CO₂-EOR production has been used in Saskatchewan since the early 2000s. EOR has a significant impact on oil production, labor, community economics, and provincial royalties in Saskatchewan. Based on one oil industry example, the benefits from CO₂-EOR using CO₂ from Boundary Dam are estimated to be

• CAD$850 million capital investment over 10–15 years
• 20–30-year project life
• 47 million barrels incremental oil recovery
• CAD$481 million (est.) in crown (government) royalties and production
• CAD$241 million in corporate income taxes
• CAD$65.7 million in resource surcharge
• 4850 person-years of direct employment

Thus, the application of CO₂-EOR in Saskatchewan has not only prolonged the life of oilfields in the province, but secured economic benefits well into the future.

The other by-products are also important to the CCS business case. Fly ash is used in the concrete industry, and SaskPower sells 100% of the fly ash produced by all the units at Boundary Dam Power Station.

All 10,800 tonnes of sulfur dioxide produced at Boundary Dam Unit #3 will be captured and converted to 96% pure sulfuric acid (about 1.5 truckloads per day). This will be sold primarily for industrial purposes, including fertilizer, as well as to meet SaskPower’s internal needs.

While some of these by-products are relatively small contributors to the business case, they are important environmentally.

As with any first-of-a-kind project, ours represents a sizeable investment (approximately CAD$1.467 billion), and it paves the way for improvement and cost reductions through economies of scale and efficiency gains on future projects. In fact, we’ve already identified savings of 20–30% on any future project based on what’s been learned at Boundary Dam. Thus, CCS costs will continue to decrease.
CO₂ STORAGE

Storage is a critical component in the CCS process. SaskPower’s Carbon Storage and Research Centre hosts Aquistore, an independent research and monitoring project that will further demonstrate that storing CO₂ deep underground is a safe, workable solution to reduce greenhouse gas emissions.

The geological storage of CO₂ will take place 3.4 km (2.1 miles) deep in a layer of brine-filled sandstone. Aquistore is managed by the Petroleum Technology Research Centre (PTRC), which will conduct comprehensive measurement, monitoring, and verification prior to injection, during injection, and throughout the storage project. Aquistore will receive approximately 350,000 tonnes of CO₂ over the course of the project.

Our province already has experience with CO₂ storage, due to our Weyburn-Midale storage project (also managed by the PTRC) in southeast Saskatchewan. Under that project, approximately 25 million tonnes of CO₂ have been successfully stored and monitored.

POWERING THE FUTURE

Now that CCS at Boundary Dam has been operational for nearly a year, we are pleased to see that the process is working even more efficiently than expected. We’ve already captured more than 300,000 tonnes of CO₂ at the facility, compressed it, and sent it to nearby oilfields for CO₂-EOR.

To date we’ve been fine-tuning the CO₂ capture plant. Once it reaches full capacity in its second year of operation, the plant will capture up to one million tonnes of CO₂ annually. At a capture rate of 90% the results are equivalent to taking approximately 250,000 vehicles off the roads every year, well beyond many comparable projects around the world.

The power plant unit has performed more efficiently than expected and may produce closer to 120 MW, compared to the design value of 110 MW, once running at full capacity. Unit #3 of Boundary Dam Power Station is producing power for 100,000 homes and businesses, while emitting about four times less CO₂ than a comparable natural gas plant.

Boundary Dam is not SaskPower’s only CCS investment. In June, we launched the Carbon Capture Test Facility (CCTF) at Shand Power Station (also near Estevan). This first-of-its-kind project will offer a unique platform to allow international partners to test and develop new technologies in carbon capture. SaskPower is committed to sharing knowledge gained constructing and operating Boundary Dam.

This project is a joint venture with Mitsubishi Hitachi Power Systems, who will be the first to test and perfect its post-combustion process for market. Once this is complete, other companies will have the opportunity to access the facility.

Designed to accommodate a wide range of processes, CCTF initially will provide an evaluation of the energy demand, long-term stability, collection efficiency, operation, maintenance requirements, and reliability of amine-based, post-combustion technologies.

As we continue to operate our CCS projects and gain unique knowledge, we welcome governments, organizations, and industries to learn about our experiences. We also offer a virtual tour at saskpowerccs.com/tour for those who can’t visit in person to provide in-depth information on our process and viewing of the critical components of the project.

In addition to offering tours, SaskPower has formed a global consortium to share our knowledge with the private sector, government institutions, universities, and nonprofit organizations that want to learn more about our expertise in CCS. The consortium will share information we have gathered on significant cost reductions, training, construction, and commissioning, to name a few. Information can be found at saskpowerccs.com/consortium

As global power production increases and other countries look to develop coal power, the world is looking to us to see how they can do so in a more environmentally sustainable way. We are extremely proud of what we have achieved, and look forward to the opportunity to share our success.
Deploying Clean Energy in Asia:
An Exclusive Interview With Ashok Bhargava of the Asian Development Bank

By Holly Krutka
Executive Editor, Cornerstone

As Director of the Energy Division in the East Asia Department of the Asian Development Bank (ADB), Ashok Bhargava oversees energy-sector operations in the People’s Republic of China (PRC) and Mongolia. He is an electrical engineer with a Master’s Degree in Business Administration and has more than 33 years of energy-sector experience in the Asia-Pacific region and more than 13 years’ experience in the PRC energy sector.

His direct ADB project experience includes innovative, first-of-its-kind, low-carbon technology projects such as integrated gasification combined-cycle (IGCC), concentrated solar power (CSP), carbon capture, utilization, and storage (CCUS), shale gas, and distributed renewable energy. As Team Leader, he processed the PRC’s first multi-tranche financing facility (MFF) in 2006 and its first IGCC power plant in 2010.

Currently, Mr. Bhargava is also Chair, Energy Sector Group, providing leadership and guidance to ADB’s energy-sector operations. He represents ADB in the Carbon Sequestration Leadership Forum, the Global CCS Institute, and the Clean Energy Ministerial CCUS working group.

An Australian national, Mr. Bhargava worked with a large-infrastructure consulting firm, a multinational power company in Australia, and a large public-sector generation utility in India, prior to joining ADB.

Q: What are the objectives of the Asian Development Bank that ultimately drive its investment decisions?

A: The Asian Development Bank (ADB) was founded in 1966. It has 67 member countries of which 48 are regional and 19 are non-regional members. ADB aims for an Asia and Pacific free of poverty. While it has achieved a significant reduction in extreme poverty, approximately 1.4 billion people in the region are still poor.

Since its inception, ADB has been dedicated to improving people’s lives in Asia and the Pacific. By targeting its investments wisely, in partnership with its developing member countries and other stakeholders, ADB aims to alleviate poverty and help create a region in which everyone can share in the benefits of sustained and inclusive growth.
ADB assistance is provided through loans, grants, policy dialogue, technical assistance, and equity investments. Our individual investments are rigorously assessed on a set of quality dimensions to check their strategic fit with our country partnership strategies and national programs, their development outcomes and impacts, techno-economic feasibility, social and environmental safeguard compliances, risks, achievability, and sustainability of development outcome and impacts. In 2014, ADB’s operations totaled nearly US$23 billion, including co-financing of US$9 billion.

Q: What percentage of funding from ADB is directed toward energy-related programs? Can you explain how adequate, affordable, and reliable power is important to achieve sustained and inclusive growth?

A: Energy is a core priority area of ADB assistance and operations throughout the region. During the period 2008–2014, about US$28 billion, or a quarter of total ADB financing, were for energy-related programs. In 2014, out of the total ADB financing operations of US$23 billion, about a quarter—US$6.6 billion—were for energy-related projects. Since 2009, ADB has targeted an annual commitment of US$1 billion lending for clean energy, which has since doubled from 2013 to US$2 billion annually.

About 600 million people in the Asia-Pacific region lack access to basic electricity. There are strong correlations between access to electricity and poverty. Under ADB’s Energy for All initiative, we are supporting regional governments’ goals and targets to provide universal access to electricity. So far, ADB assistance under Energy for All has directly brought electricity to more than 10 million homes that did not previously have electricity. A 2010 independent study on rural electrification in Bhutan found that electrification of households (i) increases nonfarm income, allowing families to pursue microenterprises; (ii) improves health conditions by reducing the use of polluting sources of energy, such as fuelwood, kerosene, and candles; and (iii) supports education for children by allowing for safer travel to and from school and the completion of homework at night.

Reliable and adequate electricity supply is essential for the economic growth and well-being of people across the region. Many countries in the Asia-Pacific region face chronic electricity shortages that constrain economic growth. As an illustration, acute electricity shortages in Pakistan of up to 20 hours per day have crippled economic growth, leading to civil strife and factory closures. One estimate suggests that the lack of electricity is causing at least a 2% reduction in Pakistan’s gross domestic product.

Q: ADB supports projects for electricity production from diverse sources. Can you describe the benefits of a diverse energy mix in the region?

A: A diverse source of electricity is essential to overcome demand-supply variability during the course of the day and seasons. Hydropower and natural gas plants are commonly used to supply peaking electricity because they can start and generate electricity up to their full load capacity very rapidly. But unlike coal, natural gas and hydropower resources are

The ADB aims to reduce poverty through inclusive growth in the region.
unevenly distributed across the Asia-Pacific region. Moreover, importing and transporting natural gas are capital intensive. Thus, coal is also used in many countries for peaking power.

Diverse sources for electricity production are also an energy security imperative. Since electricity demand is rising rapidly across the region, many large economies with considerable coal reserves have used coal to rapidly build up new capacity. Many countries in the region also rely on fossil fuel imports to produce electricity. Yet, they have substantial indigenous renewable energy sources which they can deploy. Moreover, growing environmental and climate change constraints are also driving investments in new and alternative sources of electricity production. ADB promotes a diversified energy mix with a higher share of renewable and low-carbon sources to meet the goals of reliable electricity supply with minimal environmental and climate change footprints.

Q: Can you elaborate further on any other high-efficiency, low-emissions, coal-fueled projects currently being supported by the ADB and the importance of such technologies?

Hydropower plants are being deployed, where possible, as part of a diverse energy mix supported by the ADB.

ADB approved financing for a coal-based supercritical plant at Jamshoro with enhanced pollution control measures to reduce emissions. The first of two 660-MW units is entirely financed by ADB in partnership with the Islamic Development Bank with the second unit expected to leverage further co-financing. On completion, the two units will produce 8400 gigawatt hours (GWh) of electricity each year. This will allow fuel cost savings of US$535 million annually due to avoided HFO import. ADB also launched a high-level study to assess the potential for carbon capture and storage (CCS) in Pakistan and sought design provisions in the project for potential CCS retrofit when it is economically feasible. In short, ADB financing not only addressed the core-sector problem of capacity shortages but leveraged introduction of a highly efficient, low-emissions plant, representing the first time such a plant will be installed in Pakistan.

Q: In 2013, loans were approved to support the Jamshoro Power Generation Project in Pakistan. Can you describe this project, its benefits, and the reasons to support it?

A: Under its Energy Policy 2009, ADB has been selectively supporting new coal-based power plants in its developing member countries after a careful consideration of alternate scenarios. Project-specific investment decisions for coal-based plants are made when the economic rationale is overwhelming. In 2012, in Pakistan, heavy fuel oil (HFO) was the major source (34%) of electricity in the generation mix followed by hydropower (32%), natural gas (26%), nuclear (5%), high-speed diesel (1.65%), and coal (0.07%) with the balance made up of wind power and power imports. The demand-supply gaps for electricity were continuously increasing and resultant electricity shortages were crippling the economy. In addition, HFO reliance was driving up the cost of electricity and worsening the electricity sector’s financial health. With the dwindling domestic gas supply and much longer gestation period for hydropower, new coal-based capacity was found to be the least-cost option and most suitable economic choice to urgently address the demand-supply gap.

A Pakistani shopkeeper rents lanterns to keep his business open during electricity load shedding.
A: Apart from climate change impacts, the prevailing poor air quality in urban areas mainly in coal-dependent large economies such as India and the PRC is a growing concern. Modern high-efficiency, low-emissions (HELE) coal-based electricity generation plants with enhanced pollution control measures can address these twin challenges. On one hand, improved efficiency will reduce carbon footprints; on the other hand, some advanced HELE plants can approach the criteria air pollution levels of a traditional natural gas plant. In the PRC, ADB financed the first 250-MW integrated gasification combined-cycle (IGCC) power plant at Tianjin, which is in successful operation. If coal continues to be a fuel of choice for electricity generation, HELE plants offer a pragmatic policy approach to address the energy trilemma of energy security and access, economic development, and environmental issues. Combined with CCS, these plants can cut carbon dioxide (CO₂) emissions significantly. ADB is currently appraising a pilot CCS project at the Tianjin IGCC plant.

Q: The ADB has recently supported several CCS-focused projects in developing countries. Can you explain why the development of CCS is critical for the ADB-covered region?

A: Fossil fuel dependency in Asia, especially on carbon-intensive coal, is well known and documented. ADB’s developing member countries include some of the largest coal consumers globally, such as the PRC, India, and Indonesia. Thereby these countries are some of the largest CO₂ emitters. These countries have prioritized energy efficiency improvement and aggressive renewable energy deployment to reduce growth of their CO₂ emissions. The PRC now invests more in renewable energy capacity addition than in coal-based power plants and aims to cap coal use by 2020. However, weaning away from coal has been rather slow. In fact, significant new capacity for coal-based power plants will come online in the next 10–25 years. Since CCS is the only near-commercial technology that can cut up to 90% of CO₂ emissions from coal-based plants, CCS becomes essential for meeting anticipated long-term CO₂ emission goals in the PRC and other similar large economies of the region.

ADB has set up a CCS-dedicated fund with contributions from the Global CCS Institute and the UK government to support capacity development, undertake strategic analyses to identify a role for CCS in its developing member countries, implement pilot CCS projects to enhance understanding of CCS, and prepare large-scale fully integrated CCS projects. In the PRC, a roadmap for CCS demonstration and deployment was recently finalized which identified significant low-cost (<$25/ton CO₂) opportunities to demonstrate CCS. It also highlighted the essential role of CCS in the low-carbon portfolio of technologies to meet an anticipated long-term carbon-constrained world.
Economic Development Status Is a Lingering Challenge for COP Negotiations

By Jeremy Bowden  
Contributing Author, Cornerstone

Tensions between rich and poor countries have long been among the key fault lines preventing any significant global agreement on climate change. At the heart of the issue is the perception of relative responsibility and, especially for poorer countries, a strong desire at the national level to find a balance between development and climate goals. Representatives of poorer countries readily point out that more wealthy countries are to blame for nearly all historical emissions. Relatively undeveloped economies have low historic emissions and their current per capita emissions intensities have yet to catch up with those in rich countries. In addition, poverty levels in developing countries are much higher and economic development is therefore a priority. Thus, developing countries claim that richer countries should make the first substantial cuts, as well as pay significant compensation (financial and through technology transfer) to support emissions cuts in developing countries.

Most developing countries assert their right to grow their economies using fossil fuels, a path already taken by most developed countries. Due to its low cost and widespread geographical distribution, the energy source of choice for developing countries is often coal. If developing countries’ emissions are to be curbed, wealthier countries would be required to provide financial support, so that adopting low-emission technologies would not stall much-needed economic growth.

The argument from developing countries is not unfounded. A recent study in the *Environmental Research Letters* journal showed that, based on per capita calculations, the UK is most responsible on a historic basis for greenhouse gas (GHG) emissions, followed closely by the U.S., Canada, Russia, and Germany (see Figure 1). China, currently the world’s largest emitter, lies in 19th position for cumulative emissions.

“Tensions between rich and poor countries have long been among the key fault lines preventing any significant global agreement on climate change.”

Juxtaposed to this position is the trend, often highlighted by richer countries, of rapid industrialization and rising emissions in the developing world. They accurately point out that unless action is taken by all, the international goal of limiting a global temperature increase to 2°C will be unachievable.

**FIGURE 1.** Historical GHG emissions per capita (non-dimensionalized by maximum from UK)
A major hurdle is the concern from some richer nations that burdening their economies with heavy environmental regulations might disadvantage them when competing with deregulated markets. Thus, an approach to maintain transparency between Parties, a challenge in and of itself, is a vital component of international collaboration on climate change mitigation. This may be particularly challenging as China, for example, has fought against emissions monitoring as part of the United Nations process.2

India’s position can also provide key insight into the challenge. The country has about 300 million people without any access to electricity. Prime Minister Modi has committed to eliminating energy poverty as quickly as possible and is therefore developing the country’s vast solar and coal resources. While the country’s emissions will certainly grow in the near term, India is looking for help to pay for increased renewables and high-efficiency, low-emissions (HELE) coal-fired power plants. In fact, the Indian Environment Minister recently said that a global deal on climate in 2015 will depend on commitments to finance from developed countries.3

The allocation or transfer of public funds from richer countries must compete with other domestic, shorter term demands. Some corporations—particularly in the U.S. and recently in Japan—have discouraged their governments from signing on to any commitments for fear of damaging established interests and investments. Finding the right political balance at the national level to support international negotiations could be a major concern.

A paramount challenge for the Paris negotiations is that any deal must be adopted by all Parties. The agreement from the last round of climate talks, COP20 at Lima in 2014, highlighted the divide by economic development status. The 2014 talks simply reflected the positions of the two camps, with statements that included calls by developing nations that industrialized nations should take the lead in reducing emissions as well as those from industrialized nations that all parties have a responsibility to reduce emissions. The deal lists a number of policy options reflecting current disputes, on which negotiators will have to compromise to reach a final agreement at COP21. Such an agreement would include specifying national contributions and commitments needed to achieve the global target.

While a divide remains between countries of different development status, the gap may be lessening. It is particularly notable that the U.S. and China, the world’s two largest emitters, held separate talks in the run-up to COP21. Perhaps the U.S.-China commitments can lay the groundwork for a larger agreement in Paris. Although the challenge is daunting, and many critical details remain to be worked out, Parties of different development statuses are taking steps toward the global agreement on climate that has been elusive for so long.

“The right political balance at the national level to support international negotiations could be a major concern.”

UNDERSTANDING EMISSIONS TRENDS

Some progress is being made in curbing emissions in developed countries already. For example, up to 2013 the U.S. decreased emissions for five consecutive years, before an increase of 2.5% that year. Other OECD countries also mainly show decreases or minor increases below 2%. The EU’s CO₂ emissions, which started to decrease in 2006, continued to decrease by 1.4% in 2013, at a faster rate than what was observed in 2012. CO₂ emissions in emerging economies mainly increased in 2013. For example, increases were observed in India (4.4%), Brazil (6.2%), and Indonesia (2.3%). Based on commitments made to date, emissions from India and China combined are predicted to account for nearly three times that of the EU and U.S. combined by 2030—well over one third of the world’s total emissions, according to a recent report from the Economic & Social Research Council Centre for Climate Change Economics and Policy.4

However, looking at net emissions and general trends does not tell the entire story. It is also important to consider per capita emissions, which are generally significantly lower in
emerging economies. Even in China, the world’s manufacturing center (some of whose emissions could be considered exported as companies have shifted their manufacturing work to the country), in 2013 the emissions per capita level of 7.4 tonnes per person exceeded the mean EU level of 7.3 tonnes for the first time, but still remained under half the U.S. level of 16.6 tonnes. Notably, China has been successfully decreasing the emissions intensity of its economy—by 3.1% in 2013.

Emission trends give yet another example of how the divide is clear. There are many Parties that will not be able to commit to major reductions in emissions in the near term and reducing emissions versus business as usual will require financial support. This is due not to a lack of will or concern about climate change, but rather to a greater concern to eradicate poverty.

**INDCS: RAISING THE STAKES**

In advance of COP21, countries are indicating publically their intended post-2020 climate action commitments in the form of Intended Nationally Determined Contributions (INDCs). According to the agreement reached in Lima, INDCs must be “fair and ambitious” in light of a country’s historical responsibility, current level of emissions, emissions trajectory, per capita emissions intensity, and financial capability. However, exactly how the INDCs should be worked out remains in dispute. In 2014, calculators aimed at evaluating what level of cuts various countries should make were released by researchers, but have not gained widespread support. Other suggestions to assess how much countries should cut emissions include a concept spearheaded by Brazil, which puts each one in a series of three “concentric circles”, with the poorest on the outside contributing the least in terms of cuts, while at the center are the richest and longest term emitters, which should contribute the most. While this approach attempts to blur the lines between Parties’ economic development status, the fundamental barriers remain.

Another fault line revolves around INDC scope. The EU and the U.S. have been unable to agree on what year to compare their emissions reductions against (1990 for the EU and 2005 for the U.S.), but both want the INDCs to be largely focused on tackling their own emissions. However, developing countries are pushing for pledges to include aid for adaptation and mitigation, without which they would have insufficient means to finance low-emission development. In fact, INDCs from poor countries often include two commitments: what could be done with financial support and what they could afford to do without it.

There has been movement to provide support to poorer countries. A Green Climate Fund has been set up providing US$10 billion per year, along with other conduits, such as the Clean Development Mechanism (CDM), which allows industrialized countries to invest in climate-friendly projects in poor countries and earn carbon credits in exchange to help meet their

Low-emission technologies, including high-efficiency power plants and CCS, must be important building blocks to achieve emissions reductions.
targets. Overall the financial transfer from all sources in the rich world to developing countries is pencilled in to rise to US$100 billion a year by 2020, although such commitments may not be fully backed in the INDCs for COP21. There is also the matter of from where the $100 billion in low-carbon financing will come. National leaders have stressed that contributions from the public sector (i.e., taxpayers) will be minimal, but the question remains as to whether the private sector can and will provide this level of funding and under what mechanisms.

Although their relative magnitude may be difficult to decipher, the INDCs are being submitted—29 submissions representing 57 Parties had been filed at the time this publication went to press. The world’s three largest emitters have all submitted commitments. The EU’s INDC puts forward a legally binding commitment to reduce its overall emissions at least 40% below 1990 levels by 2030. The INDCs of the U.S. and China largely reflect their previous talks—with the U.S. committed to reducing emissions 26–28% by 2025 and China reducing carbon intensity of GDP by 60–65%, both compared to 2005 levels. Other large emitters that had submitted INDCs at the time of publication include Russia, Mexico, and Canada.

THE ROLE OF LOW-EMISSION TECHNOLOGIES

Regardless of their relative economic development status, all Parties will need increased deployment of low-emission technologies to meet commitments made at COP21. The International Energy Agency has outlined six tranches required to limit climate change to 2°C at the lowest costs. These include renewables, carbon capture and storage (CCS) (including utilization), improved demand and supply side efficiency, end-use fuel switching, and increased nuclear power. While all tranches are important, according to the IPCC, if CCS is not included in the low-emission energy mix, the costs will increase more than if any other tranche is limited—to the tune of a 138% increase in costs (median estimate).6 HELE technologies may also be an important step toward deployment of CCS.

The move to deploy low-emission technologies has already begun and, in some cases, emerging economies are leading the way. For example, China is already the world’s largest investor in renewables, with plenty of space to increase renewable utilization. In addition, the country is replacing smaller, inefficient coal-fired power plants with larger, high-efficiency units. The country also looks to transition its economy toward more growth in the less energy-intensive service sector. However, even if China’s coal use is capped by 2020 as has been suggested, it is likely to be capped at an amount over 3.5 billion tonnes per year, highlighting the need to utilize clean coal technologies to meet any climate commitments. China is already working to improve the efficiency of its coal fleet, and has recently increased its involvement in carbon capture, utilization, and storage research.

“Regardless of their relative economic development status, all Parties will need increased deployment of low-emission technologies to meet commitments made at COP21.”

TOUCH AND GO

COP21 may not deliver the deep, universal commitments hoped for by some. However, if it can provide a framework under which the world can work together to deploy low-emission technologies, reduce emissions over time, and help the poorest countries to grow their economies, then it could be considered a monumental success.

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Don’t Count Coal Out of a Lower-Emission U.S. Energy Mix

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Frank Clemente
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The 21st Session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) will be held in Paris in December 2015. The goal of COP21 is to achieve a legally binding and universal agreement on climate, capping anthropogenic greenhouse gas emissions by 2020 and reducing them to near zero toward the end of the century. The U.S. administration has assured its fellow COP21 negotiators that its commitments are achievable and legal and that it is pursuing national-level policies, such as the Clean Power Plan (CPP), to support those commitments. However, policies at the national level have technical challenges based on the current generation mix and transmission grid, face considerable legal opposition, and must withstand the test of time far longer than the current administration will be in office. Under all circumstances, the authors of this article believe the U.S. should increase the role of cleaner coal technologies as a principal component of achieving its international climate goals while ensuring the country and electricity consumers can continue to rely on a diverse, reliable, and cost-effective energy mix in a low-emissions future.

“While the COP21 negotiations are unlikely to deliver specifics in how emissions reduction commitments will be achieved, the regulatory framework in the U.S. is already unfolding…”

THE EVOLVING U.S. ENERGY MIX

The ability of the U.S. to meet any commitments made at COP21 is largely contingent on its energy sector. While energy demand in the U.S. has been mostly flat in recent years, there is reason to believe that growth will be observed over the long term. For example, the U.S. population continues to grow. The

While the U.S. has relied on coal for decades, the country still has extensive proven coal reserves (shaded).
United Nations Population Division projects that there could be nearly 80 million new Americans by 2050. In essence, another population “boom” is yet to come. In the past, the U.S. has relied heavily on coal to meet growing demand. For example, when the U.S. added 105 million people to the population during 1970–2010, coal production increased 100%—by over 500 million tons used each year—and coal provided half of the incremental electric power. Today the incremental additions will be more diverse—the U.S. Energy Information Administration’s Annual Energy Outlook (AEO) 2015 projected that incremental electricity capacity will be split equally between renewables and natural gas combined cycle. However, the same AEO projected that electricity generation from coal will remain largely flat and still provide over 1660 billion kWh in 2040. By comparison, in 2040 renewables and natural gas combined would contribute about 1200 and 805 billion kWh, respectively (projections exclude the relatively small role of combined heat and power in the U.S.). These projections are not inclusive of any regulations, including the CPP.

COP21 AND THE CLEAN POWER PLAN

Through its intended nationally determined contribution, the U.S. has committed to reduce emissions 26–28% by 2025, compared to 2005 levels. Under the U.S. Constitution, if COP21 produced a binding treaty that required the U.S. to meet this commitment, ratification by two thirds of the U.S. Senate would be required. Based on the current makeup of the U.S. Senate, ratification of such a climate treaty is extremely unlikely. Thus, the U.S. administration and negotiators have been careful to avoid any use of the word “treaty”, and as a result any agreement reached by the U.S. will not be binding by definition. Instead, national-level regulations are being advanced through the Environmental Protection Agency (EPA). Namely, the CPP as well as several other measures that are primarily focused on heavy duty vehicles, end user efficiency, and other approaches outside the scope of this article.

The CPP was issued by the executive branch through the EPA under the Clean Air Act and was released on 3 August 2015 after four million comments on the proposed version had been submitted, demonstrating intense societal interest in the U.S. electric sector and coal-based electric generation. The CPP sets a goal to reduce carbon emissions from the power sector 32% below 2005 levels by 2030. To accomplish the emissions reductions the EPA directs the states to compose their own plans to meet compliance based on various low-emission electricity generation technologies, including renewables, energy efficiency, natural gas, nuclear, and carbon capture and storage (CCS)—with CCS requirements being lower compared to the CPP proposal. States must submit their initial plans to achieve the emissions reductions to the EPA by September 2016 and two-year extensions can be requested to allow for additional time to finalize the plans. The compliance averaging period begins in 2022.

“A robust coal-generation presence in a diverse energy mix helped the U.S. maintain lower electricity rates historically, while reliably meeting demand.”

The U.S. Energy Information Administration previously projected that the proposed CPP would decrease the role of coal in the U.S. electricity mix (no projections were available as this article went to press for the revised CPP). Natural gas gains could be displaced by some renewables as the CPP aims to have renewables account for 28% of electricity capacity in 2030.

A robust coal-generation presence in a diverse energy mix helped the U.S. maintain lower electricity rates historically, while reliably meeting demand. Renewables are not able to provide baseload electricity and natural gas has been subject to historical price spikes, will require additional pipeline infrastructure to continue to grow, and cannot easily be stored in the case of a major demand increase (such as the extreme cold snap experienced in early 2014 that sent natural gas prices soaring). Thus, even under the restrictions from the CPP, coal will be maintained in the U.S. energy mix.

Notably, the CPP faces legal challenges and many people are of the view that it will not withstand legal scrutiny, particularly...
given the constitutional questions that have been raised. With 26 states voicing opposition and both states and organizations set to bring lawsuits against CPP, litigation will begin immediately. Due to the time involved with filing and completing such lawsuits, it is highly unlikely that the CPP will actually be finalized until after President Obama’s tenure in office is over. Phase 1 emissions reductions (20%) are due by 2022 and Phase 2 emissions reductions are due by 2030 (32%). Since the CPP was not passed by Congress and signed into law by the president, it is subject to the will of future presidents. There will be two presidential elections by 2022 and four by 2030. Will all those elected president between now and 2030 fully support the implementation of the CPP? If not, it may not be fully executed and could be reversed. Thus, although the recently released CPP has been termed “final”, considerable challenges remain.

FINDING A ROLE FOR CLEANER COAL TECHNOLOGIES

The U.S. has been a global leader in the development and deployment of cleaner coal technologies. Coal-based electricity in the U.S. has increased 183% since 1970, while regulated criteria emissions decreased about 90% per unit of generation.\(^7\) The same level of success can be achieved using low-carbon emission coal technologies.

New pulverized-coal combustion systems utilizing supercritical technology achieve much higher efficiencies than traditional plants. Ultra-supercritical plants offering even higher efficiencies are now considered state of the art, but the U.S. has only one such operating plant. Using such technologies, there is much room to increase the energy efficiency of the U.S. fossil fuel fleet. For example, the overall thermal efficiency of the U.S. fleet of coal-fired power plants is only about 33%, although the best 10% of plants in the country have an efficiency of 37%. Boosting the efficiency of the U.S. fleet to 36% would reduce emissions 175 million tonnes per year.\(^8\) Though the current regulatory framework may not fully incentivize it, high-efficiency coal-fired power plants could play an important role in reducing emissions. In addition, improving the efficiency of U.S. coal-fired power plants could serve as a steppingstone to development of CCS (and CCUS with utilization), which is broadly recognized as a prerequisite to meeting global climate policy goals.

Seven of the 14 CCS projects operating in the world are on U.S. soil. Although progress on CCS has been slow, the U.S. is a leader in the development of the technology. The country must find a way that CCS on coal and natural gas facilities can contribute to a low-emissions future. This approach would enable reliable, domestically produced, safe baseload generation even under carbon emission constraints much stronger than the U.S. has committed to ahead of COP21.

**“Improving the efficiency of U.S. coal-fired power plants could serve as a steppingstone to development of CCS...”**

U.S. COAL IN THE PAST, PRESENT, AND FUTURE

Coal has played a strong role in the U.S. historically for good reason. Reliable and affordable power from coal gave U.S. manufacturers a strong advantage. Indeed, the American Heartland was built and continues to rely on coal. Of the contiguous 48 states, 31 obtain more than 25% of their electricity from coal and 17 states obtain more than 50% of their electricity from coal.\(^9\) Thus, large segments of the country will be disproportionately impacted by dramatic decreases in coal power generation. Even the full closure of America’s coal-fired power plant fleet, a scenario not considered feasible by any major energy forecasting organization, would result in only a 1/20\(^{th}\) of one-degree temperature change globally.

While the COP21 negotiations are unlikely to deliver specifics in how emissions reduction commitments will be achieved, the regulatory framework in the U.S. is already unfolding as the CPP moves forward. We urge those negotiators, as well as domestic regulators, to consider the important role that coal has and will continue to play in the U.S. and elsewhere. Based on our decades of experience, the authors of this article believe that the U.S., like every other country, is going to put in
place policies that are in the best interest of its citizens. In our opinion, that means that the U.S. is going to use more coal in the future than it does today, and minimize the environmental impact with 21st century technologies. Cleaner coal technologies have delivered in the past and can do so again to ensure coal can be a part of a low-emissions future.

REFERENCES


THE NATIONAL COAL COUNCIL OFFERS A WEALTH OF DATA

One of the most significant resources available to understand the importance of coal to the welfare of the American people resides in a series of reports the National Coal Council (NCC) has prepared and submitted to the Secretary of Energy over the last decade. Based in Washington, D.C., the NCC was established in 1984 as a Federal Advisory Committee to the U.S. Secretary of Energy. The NCC provides advice and recommendations to the Secretary on general policy matters relating to coal and the coal industry. The NCC’s Coal Policy Committee develops prospective topics for the Secretary’s consideration. Over the past decade the Council has produced a series of eight extensive empirical studies. These reports, prepared by leading coal and energy researchers, have dealt with the full range of scientific and engineering aspects of coal technologies, including coal utilization, environmental control, and coal conversion.

Studies of the National Coal Council (2006–2015)

2006: Coal: America’s Energy Future
2007: Technologies to Reduce or Capture and Store Carbon Dioxide Emissions
2008: The Urgency of Sustainable Coal
2009: Low-Carbon Coal
2011: Expedited CCS Development: Challenges & Opportunities
2012: Harnessing Coal’s Carbon Content to Advance the Economy, Environment, and Energy Security
2014: Reliable & Resilient - The Value of Our Existing Coal Fleet
2015: Fossil Forward - Revitalizing CCS: Bringing Scale and Speed to CCS Deployment

The work of the NCC has extensively documented the unique attributes of America’s coal resources: e.g., abundance, accessibility, affordability, security, versatility, sustainability, and amenability to cleaner coal technologies. Much of this information is transferable to the world at large. For more information, visit NCC at www.nationalcoalcouncil.org/
Exploring the CCS Roadmap Landscape

By Jiang Wenhua
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In the months leading up to the COP21 international climate negotiations, it is important to consider how potential emissions reductions can be met at the lowest cost. Widespread deployment of high-efficiency, low-emissions (HELE) technologies could reduce emissions immediately. Implementation of HELE technologies can also increase the efficiency of power plants and industrial facilities, which can partially address the energy penalty associated with carbon capture and storage (CCS, including utilization).

CCS has been recognized as an important technology to meet climate goals. Both the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) have reported that mitigation costs will be considerably higher without CCS (i.e., 70–138% higher using median estimates). This is because CCS is necessary to drastically reduce emissions from a wide range of industries, including the production of power from coal and natural gas, iron and steel, cement, chemicals, and natural gas processing, and also because negative emissions can be accomplished through the combination of biomass, including co-firing of biomass with coal, and CCS. By minimizing the total costs associated with climate change mitigation, the deployment of CCS increases the chances of meeting international climate goals without sacrificing vital development objectives.

“While roadmaps may show the way to CCS deployment, their recommendations and timelines must be followed if the technology is to reach its full potential.”

Despite its importance as an emission mitigation option, the development and deployment of CCS is lagging behind that of some other low-carbon technologies, both in terms of financial support and level of deployment (i.e., number of CCS demonstrations). A number of roadmaps have been generated by various governments and research institutions that offer insight on approaches to get CCS development and deployment on track. This article focuses on reviewing select roadmap goals to compare how CCS is faring globally and in some key nations.

IEA SETS THE STANDARD

In 2009 the IEA published its CCS Technology Roadmap and then followed up with a revised version in 2013. The underlying message of the document was well explained by the Agency Executive Director at the time, Maria van der Hoeven: “It is critical that governments, industry, the research community and financiers work together to ensure the broad introduction of CCS by 2020, making it part of a sustainable...”
future that takes economic development, energy security and environmental concerns into account.”

The IEA’s roadmap was consistent with limiting climate change to 2°C, which would require the widespread application of CCS, including 950 GW of coal- and natural gas-fired power generation equipped with CCS as well as widespread implementation in the iron and steel manufacturing sectors. The IEA recognized the need to bring down costs to make this a reality. Thus, the 2013 roadmap called for at least 30 large-scale (defined as at least 800,000 tonnes per year for power plants or 400,000 tonnes per year for other facilities) CCS projects by 2020 (down from 100 in the 2009 roadmap), routine use and storage of over 2000 million tonnes per annum (Mtpa) in 2030, and 7000 Mtpa in 2050 (see Figure 1).

Currently 14 large-scale CCS projects are operating and another eight are under construction. The total CO₂ capture capacity of these 22 projects will be 40 Mtpa when they are all operating. With another 14 projects in a late stage of development, it is conceivable that the IEA roadmap goal of 30 projects can be met, but several of the projects could be at risk and may require greater financial support to advance to construction and operation.⁴

THE U.S. AT THE FOREFRONT

The U.S. could be considered a leader in CCS advancement, with seven of the 14 projects operating today occurring in the country (and these seven projects having a CO₂ capture capacity of around 20 Mtpa). Although the U.S. government does not have an official roadmap for deployment of CCS, it has set a goal to reduce national emissions by 26–28% in 2025 and 83% in 2050 (both compared to 2005 levels).⁵ The government has not itemized how the emissions will be reduced, but has clearly supported CCS to date as part of a low-emissions strategy. Recently, the U.S. administration’s key regulatory effort to reduce the country’s emissions from the power sector, the Clean Power Plan (CPP), was released in its final form. The CPP specifically mentions CCS as an emission reduction option. However, considering CCS still is at a demonstration phase, it will be difficult for the technology to play a large role in emission reductions in the U.S. in the near term without strategic support.

To set goals on CCS development and cost reductions, the U.S. Department of Energy’s National Energy Technology Laboratory (DOE NETL) has published various CCS technology development roadmaps. The carbon capture research timeline from the 2013 CCS technology development roadmap is provided in Figure 2.⁶

CCS progress in the U.S. has been mixed, with many important recent developments in 2014. For example, the DOE’s Illinois Basin-Decatur Project crossed the benchmark of having successfully injected one million tonnes of CO₂ into a saline aquifer. In addition, large projects such as the Kemper IGCC facility (582-MW pre-combustion capture) and the Petra Nova Carbon Capture Project (240-MW post-combustion capture) are expected to be operational in 2016. In addition, the Obama administration called for $2 billion in tax credits for carbon capture projects in its budget. At the same time, the DOE suspended federal funding on its $1 billion investment in FutureGen 2.0, which would have been the nation’s first commercial-scale oxy-combustion project. In general, the U.S. appears committed to supporting the development and deployment of CCS nationally and abroad. For example, China and the U.S. have been collaborating on various clean energy technologies through the Clean Energy Research Center, and CCUS collaboration was specifically mentioned in the U.S.-China Joint Announcement on Climate Change.

FIGURE 1. CCS technology development pathway from the IEA CCS Technology Roadmap
Canada has made considerable contributions to the advancement of CCS. Recently all eyes have been on the world’s first commercial-scale post-combustion CCS project, hosted by the Boundary Dam coal-fired power plant in Saskatchewan, which began operation in October 2014 and at full capacity captures around one million tonnes of CO₂ each year. That project represents a tremendous step forward in CCS applied at coal-fired power plants and is also serving as a database for how to execute future projects at a lower cost.

Long before the Boundary Dam project was operational, Canada began considering the prospects of CCS. Canada’s CCS Technology Roadmap (CCSTRM) was published in 2006 with the purpose of identifying technologies, strategies, processes, and integration system pathways needed for large-scale deployment of CCS in Canada. Importantly, the roadmap highlights Canada’s world-class storage sites as well as clusters of emissions sources that can help to optimize technology deployment. While Canada has not updated its roadmap in recent years, the country’s leadership on CCS and support of the Boundary Dam project demonstrates a clear continued commitment to the technology.
CAN UK CCS BECOME A REALITY?

In 2012 the UK’s Department of Energy and Climate Change (DECC) published a CCS development roadmap and backed this with the potential for financial support. While the government made the commitment to “work with industry to make CCS a reality”, and made £1 billion available, among other financial mechanisms, to support the capital expenditure for early CCS projects, it also made it clear that CCS must be made to be cost-effective and competitive with other low-carbon technologies. Thus, the UK CCS roadmap focused on identifying cost reductions through learning-by-doing and knowledge sharing.

UK electricity market reform (EMR) could play a critical role in supporting CCS development in the country. EMR aims to provide investors with a transparent, long-term, and stable investment environment for low-carbon energy technologies, as well as to ensure national energy security. Three policy instruments in the market reform—feed-in tariffs with contracts for difference (CfDs), a carbon price floor, and emission standard performance—have the most direct impact on CCS. The basic mechanism of CfDs is a pre-identified strike price to the generator for all eligible electricity generation. This strike price will operate against a reference wholesale market price: If the reference wholesale market price is lower than the strike price, the generator will be paid the difference between the two prices, whereas if the reference price is higher than the strike price the generator will have to pay back the difference. The carbon price floor aims to provide long-term certainty about the cost of carbon in the UK electricity generation sector and send clear pricing signals toward low-carbon generation. An emissions performance standard became law in 2014 at a level of 450 g CO₂/kWh—requiring any new coal-fired power plants to use CCS.

The roadmap highlighted several advantages that UK has for advancing CCS: extensive geological storage capacity, especially under the North Sea; already existing clusters of emissions sources, such as power and industrial plants (these facilities could potentially share CCS infrastructure, such as pipelines); expertise in the offshore oil and gas industry that could be transferrable to the area of CO₂ storage; and long-standing excellence in academic CCS research. The ultimate goal of this roadmap is to achieve cost-competitive CCS technology to a point that would enable widespread private-sector investment in CCS power stations and industrial facilities in the 2020s without government subsidies.

Potentially, UK commercial-scale CCS deployment could make major advances in the near term. Two projects have been shortlisted under the UK CCS Commercialisation Programme. The Peterhead Project in Aberdeenshire would capture about 1 Mtpa annually from an existing natural gas combined-cycle plant and store it under the floor of the North Sea. The White Rose project would capture about 2 Mtpa from a new 448-MW (gross) oxy-combustion coal-fired power plant. As these projects move forward they represent a major advancement toward deployment of CCS following the recommendations in the country’s technology development roadmap.

CHINA SPRINGS INTO ACTION

In recent years there has been a notable uptick in China’s interest and engagement on reducing emissions (both criteria emissions and CO₂). For years the country has been replacing smaller, inefficient boilers with HELE technologies and has actively increased the efficiency of its coal-fired power plant fleet. It has also been working to diversify its energy mix to include more renewables, natural gas, and nuclear. China has made it clear that in the near term it plans to focus on CCUS as some revenue is necessary to move projects forward.

In 2011 the Ministry of Science and Technology (MOST) and the Administrative Center for China’s Agenda 21 published the China CCUS Technology Development Roadmap, which outlined policies and actions necessary to advance CCUS in China. Although not a roadmap by title, in 2013 the National Development and Reform Commission (NDRC) published a notice stating that “all regions and departments should strengthen support and guidance for CCUS pilot and demonstration, based on the climate change program in the national 12th Five-Year Plan...” Six primary working tasks were listed in the notice, including:

1. Develop pilot and demonstration projects along the CCUS technology chain.
2. Develop CCUS demonstration projects and sites.

China’s approach to increasing its actions on climate change is supported by roadmaps, national plans, and early projects.
3. Explore and establish financial incentive mechanisms.
4. Strengthen strategic research and planning for CCUS development.
5. Promote CCUS standards and regulation.
6. Strengthen capacity building and international collaboration.

There are many research, pilot, and demonstration-scale projects underway in China. One of the largest such projects is Shenhua’s 0.1-Mtpa CCS demonstration project in Ordos, Inner Mongolia, with 245,000 tonnes of CO₂ stored to date.

In terms of large projects, the Global Carbon Capture and Storage Institute (GCCSI) reports that there are 11 such projects at various stages of completion (none are operating yet).

GLOBAL PROGRESS

Despite roadmap goals and the progress made in some key projects, the overall development and deployment of CCS is behind schedule, but within reach of IEA’s 2013 roadmap goals. Regulatory drivers and policy and funding parity, under which CCS would be funded on par with its emissions reduction potential compared to other low-carbon technologies, are generally lacking. While roadmaps may show the way to CCS deployment, their recommendations and timelines must be followed if the technology is to reach its full potential.

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OTHER CCS DEVELOPMENTS

Some countries with large CO₂ emissions do not have active CCS roadmaps. For example, while India’s per capita emissions remain much less than those in developed countries, the gross national emissions could grow rather quickly over the next decade as the country attempts to bring electricity to all its people, highlighting the importance of employing HELE technologies. Although India does not have an official CCS roadmap, with assistance from GCCSI, India conducted a CCS scoping study in 2013. The subsequent report concluded that CCS is a viable mitigation option in India, but the lack of reliable storage data leads to uncertainty. In addition, very few studies have quantified the overall cost of capturing and storing CO₂ in India. Financial risks and legal liabilities for CCS development are also under-studied. Thus, there is a strong need for capacity building among all links in the CCS industrial chain if India is to consider CCS in the future.

Australia also does not have a current national CCS roadmap but has three large-scale projects in various stages of planning and execution and boasts a strong history of research in the area. The Gorgon CO₂ Injection Project, the world’s largest CO₂ injection project into a deep saline formation, could begin storing as much as 4 Mtpa after 2016 and be a leader in the field.

Considering the Challenge of China’s COP21 Commitments: An Exclusive Interview With Jonny Sultoon of Wood Mackenzie

By Li Xing
Executive Editor, Cornerstone

As Research Director of Global Coal Markets for Wood Mackenzie, Mr. Sultoon directs analysis and research for various aspects of the global coal market. His areas of expertise are in short- and long-term demand forecasting for the international coal markets, competition between fuels in the power generation sector, corporate analyses of the major producers and utilities, and fundamentals-based price forecasting for the coal market. He previously served on Wood Mackenzie’s European Gas and Power Research team after five years with Gas Strategies Consulting. Mr. Sultoon holds a BA and MA in Physics from the University of Oxford, UK.

Wood Mackenzie, a research and analytics group, since its acquisition of a coal-focused group in 2007 has been developing forecasts around global coal markets. China, in particular, has a dynamic coal market, which has grown rapidly until very recently. Lately, China’s coal market has been weak and could be further affected by regulations and the country’s commitment on climate. China’s commitments for COP21 may not be surprising as they largely reflect the landmark joint announcement in November 2014 between Presidents Obama and Xi Jinping. A key element of that announcement, and of China’s Intended Nationally Determined Contributions (INDCs), is President Xi’s pledge that “carbon pollution will peak some time before 2030”. This commitment was followed up separately in June 2015 by a further set of pledges, namely:

- Cut CO₂ emissions per unit of GDP by 60 to 65% by 2030 from 2005 levels;
- Increase non-fossil fuel in primary energy consumption to around 20% by 2030;
- Achieve 200 GW of wind power capacity by 2020;
- Achieve 100 GW of solar power capacity by 2020;
- Increase the proportion of concentrated and highly efficient electricity generation from coal;
- Lower coal consumption of electricity generation from newly built coal-fired power plants to around 300 grams coal equivalent per kWh;
- Strengthen research and development (R&D) and commercial demonstration for low-carbon technologies, such as energy conservation, renewable energy, advanced nuclear power technologies and carbon capture, utilization, and storage, and to promote the technologies utilizing CO₂ to
enhance oil recovery and coal-bed methane recovery;
• Build on carbon emission trading pilots, steadily implement-
ing a nationwide emission trading system and gradually
establishing the carbon emission trading mechanism so as to
make the market play the decisive role in resource allocation.

Cornerstone sat down with Mr. Sultoon to discuss the funda-
mentals of coal consumption in China, the major challenges
he sees with the country’s COP21 pledges outlined above, and
the role technology can and should play.

Q: With China’s recent economic slowdown and transitioning
ergy mix, do you believe the historical, fundamental link
between coal and the country’s development is weakening?

A: China’s thermal coal market appears to be at a turning point.
After a decade-long period of untrammeled growth—supported
by economic advancement, migration of workforce to coastal
provinces, higher standards of wealth, and growth in imports
of raw materials to serve China’s massive industrial complex—
Chinese coal demand has softened. A complex set of reasons is
at its heart: slowing GDP growth (to around 7%), transformative
change in the drivers of growth, wildly shifting energy consump-
tion patterns, increasing penetration of non-coal-fired capacity
(hydro and renewables), implementation of strict environmen-
tal targets across coastal provinces, and a concerted effort to
relocate energy-intensive industries to the interior.

2013 likely saw peak coastal thermal coal consumption of 1.2
billion tonnes. In 2014 nationwide demand fell 2–3% y-o-y,
depending on accounting methods. There are a combination
of structural and cyclical factors at work in China’s complex,
dynamic, and regionally fragmented market.

China’s economy—historically intertwined with the coal
industry—is in a key phase of transition. The services sector

overtook industry to become the largest share of GDP in 2013,
and the slow, gravitational shift from China’s east to west is
well underway. In the short term, policy remains the key driver
of economic growth as the government balances between
supporting growth and implementing reforms.

As investment growth slows, we expect services to continue
to grow as a share of GDP as China rebalances its economy
toward domestic consumption and encourages the devel-
opment of higher value added activities such as R&D and
financial services. This transition from industry toward ser-
vices will have significant implications for China’s overall
energy demand growth as well as regional demand patterns
since most commodity demand—including that for power,
coal, and diesel—is heavily dependent on industrial growth.

Q: Can you give us a snapshot of the state of the major coal-
consuming industries in China?

A: China’s power market output in 2014 was approximately
5500 TWh, with 3.8% growth over 2013 levels. This gain
represents slower growth based on economic restructuring
and weaker heavy industrial output. For the first time ever,
elasticity—the ratio of change in electricity generation over a
period of time associated with a one unit change in GDP over
the same period—fell to 0.5. This “decoupling” effect is com-
plex. The growth in contribution of services at the expense of
industry is crucial as is the state of overcapacity in the
industrial sector. As that state of overcapacity remains while
the share of heavy industry falls a degree of decoupling is to
be expected. Going forward, we expect elasticity will appreci-
ate slightly at first but will remain at far lower levels than
historic norms. Overall, we forecast total electricity to rise by
an average y-o-y growth rate of 4.8% between now and 2030,
reaching 11,600 TWh. Although this is a doubling of electricity
generation, electricity usage would still reach just 8 MWh per
capita from 4 MWh per capita today, which is on a par with the
modern-day, energy-efficient performance in Germany and
Japan. This improvement is a tall order for a country 10–15
times more populous and at a much earlier stage of devel-
opment. A more obvious comparison would be with the U.S.,
undergoing its own energy-efficiency revolution, but starting
from a wildly inefficient 12.4 MWh per capita in 2015.

Looking at the industrial and non-power sectors, there is still a
large demand for thermal coal. The fuel is used to fire cement
kilns, generate electricity at smaller industrial boilers for heavy
industry and agriculture, and heat homes and commercial
properties. There is also demand from coal-to-chemicals con-
version projects in the interior of China. The non-power sector
represented nearly 50% of total thermal coal demand in 2014,
approximately 1.7 billion tonnes. To put that in context, the entire
U.S. power sector will represent only half that amount in 2015.
However, one key focus area behind environmental policy has been to target the less efficient non-power sector where energy efficiency of industrial boilers is low and emissions register high. Controls over cement production in northern regions, strict penalties for misuse, and shutdowns of under-utilized, inefficient boilers in heavy urban and industrial areas will reduce thermal coal demand in the non-power sector. In China’s Energy Development Strategic Action Plan released last November, the country aimed to raise the share of centralized coal power penetration in industry to over 60% from today’s 52%, by phasing out dispersed, small coal-fired facilities in commercial and industrial sectors.

Also, although the coal-to-chemicals conversion pipeline is strong, the recent fall in oil prices reduces the economic viability of those projects. In addition, such projects have tended to cluster in arid areas and the known high water requirement for conversion projects will add to cost and uncertainty. The April announcement of a Water Pollution Prevention and Control Action Plan will largely target the non-power sector and especially the chemical conversion sector. In July, the NEA set new stricter standards for coal conversion projects too, permitting a maximum limit of tonnes of coal for each tonne of oil or gas produced, as well as encouraging a reduction in the use of lower quality, high-ash, high-sulfur coals elsewhere. Finally, the Ministry of Environmental Protection recently rejected a Xinjiang coal-to-gas (CTG) project based on concerns regarding wastewater treatment and emission controls. CTG growth could be much lower than expected and there is much scope for reduced non-power demand for thermal coal.

Q: With coal consumption in the power sector to remain strong, improving the efficiency of coal-fired power plants could help China meet its goal of capping emissions by 2030. Do you feel that China’s goals related to supply-side energy efficiency can be achieved? A: While China’s contribution is a major milestone in climate negotiations, we believe there are major challenges related to peaking emissions by 2030. Doing so will require some dynamic shifts and could lead to widespread disruption across multiple segments.

First, looking specifically at China’s COP21 pledge to reduce the coal intensity of electricity from newly built coal-fired power plants to around 300 grams coal equivalent per kWh (gce/kWh) is important. We assume that the figure refers to “standard coal” having 7000 kcal/kg energy content, which is well above average coal kcal in China. We estimate that current norms for power plant energy intensity are around 320 gce/kWh on average and will improve in future. The country has already greatly improved the efficiency of its coal-fired power fleet, but more upgrades will be necessary to meet COP21 commitments.

Improving efficiency to 300 gce/kWh would require ultra-supercritical (USC) boilers as the norm, with water cooling instead of air cooling condensers (ACC) which typically result in a 4–5% energy penalty. However, coal-fired power units in provinces with limited freshwater (Shaanxi, Shanxi, Inner Mongolia, Xinjiang) are mandated to use ACC technology, which helps to save up to 80% of freshwater demand in power plants. Given that a typical ACC coal plant consumes 12–13 gce/kWh more fuel than units using conventional water cooling, a realistic new coal-fired plant in inland provinces (with ACC) would be around 315 gce/kWh. Elsewhere, integrated gasification combined-cycle (IGCC) is comparable to USC in efficiency terms, but is not a commercially-mature technology. Thus, while China has taken great strides in improving the efficiency of its coal-fired power plants, additional progress will be required to meet its goal of 300 gce/kWh as the norm.

Q: China’s INDCs covered the role of high-efficiency, low-emissions (HELE) technologies to reduce the country’s carbon...
emissions. Will the greater deployment of HELE technologies have an impact on air quality in China?

A: In addition to the carbon-focused pledges related to COP21, the country has also aimed to improve air quality by reducing criteria emissions. Realizing that the coal consumption reduction targets were very aggressive, government emphasis has been directed toward emission control equipment for utility-scale units. Provincial governments have also been very active, getting a better grip on implementation of ultra-low emissions technologies through the use of local policies. The attention so far has been focused in Beijing, Tianjin, and Hebei and the Yangtze and Pearl River deltas which are considered to be the most critical regions with air quality issues. Guangdong, Zhejiang, Shanxi, and Jiangsu provinces have announced specific policies to ensure that all grid-dispatched coal-fired power plants (existing or new-builds) greater than 600 MW in unit size (300 MW for Shanxi) comply with ultra-low emission standards for particulate matter (PM), SO₂, and NOₓ. Hebei, Shanxi, and Jiangsu will fast-track compliance in the 2015–2017 timescale while the implementation timeline for other provinces varies from 2017 to 2020. The emission levels are very stringent; similar to or even lower than gas-fired power stations. In return, the plants will receive a combination of incentives to cover additional CAPEX and OPEX requirements. Options proposed include preferential dispatch or tariff premiums for ultra-low emission units, direct subsidies on CAPEX, and dispatch award/penalty of 100–200 hours for compliance/non-performance. These steps should improve air quality in the affected regions.

Q: Deployment of non-coal sources of energy are an important part of China’s COP21 commitments. Do you see any challenges for that sector?

A: The goals of 200-GW wind and 100-GW solar capacity by 2020 are broadly comparable with our analysis and appear to be achievable; but what matters is generation output. Yes, the power sector is clearly shifting to lower emission energy sources, which are responsible for contributing more than half of new capacity additions over the past five years. But in terms of generation output, given de-rates, these levels will still be quite small compared to those from coal and hydro.

Hydro additions through dam hydro and pumped storage continue, with an on-average 20 GW of new capacity each year through to 2025. China has had great success commissioning large hydro projects commercially but guaranteeing repeated success given that the additions are slightly less than the equivalent of a Three Gorges Dam every year for the next decade looks to be a stretch, especially when considering the social implications and technical feasibility of designing and deploying that size of capacity repeatedly. What hydro does provide, though, is a summer peaking supply, and this has already begun to disrupt coal demand in key coastal provinces in a weak market.

Perhaps the greatest difficulty is around nuclear deployment. The lowering cost of building new wind and solar plants will, of course, be additive on a capacity basis, but to truly displace growth in baseload coal-fired generation, China will need to make good on its target of 200 GW of nuclear capacity by 2030, as outlined in its low-carbon roadmap in 2014. Following the Fukushima disaster in Japan, China tightened safety requirements for nuclear power. Approvals for new reactors in coastal regions were suspended and proposals for inland nuclear plants deferred until 2016 at the earliest. Though coastal approvals resumed in March 2015, nuclear faces an array of challenges throughout the value chain including limited domestic uranium supplies, unproven third-generation technology, fluctuations in quality and production capacity for key reactor components, a significant lack of experienced reactor operators, and limited capacity for spent fuel reprocessing and storage. In addition, the public debate on nuclear hasn’t started in earnest and the cost and social implications could be enormous. As of June 2015, 27 reactors were under construction and it is likely that nuclear capacity growth from 26 GW at the end of 2015 to 50 GW by 2019 can be achieved. But these limiting factors will constrain growth of nuclear power beyond that time. We tentatively forecast that China will add an additional ~155 GW by 2030 (180 GW total), but that may be optimistic and will, in any case, need to be greater if China is to successfully peak its CO₂ emissions no later than 2030.

Carbon capture and storage is another key technology that could dramatically reduce CO₂ emissions around the globe. Of all possible places in the world where CCS might be deployed on a significant scale, China seems most likely, given its policy-driven, rather than market-driven, approach to growth. Also, CCS is effectively labeled in one of the country’s COP21 pledges. However, the demonstration and deployment of the technology is currently occurring too slowly for it to play a major role in the near term. The considerable challenges that remain include high cost for post-combustion capture, lack of policy clarity in China, and attention increasingly diverted to other low-emission options. CCS is technically feasible, but it must quickly make major progress in order to make a real contribution to emission reductions.

All in all, China’s commitments ahead of COP21 look immensely challenging. For China to cap its emissions by 2030, the country will require a slowdown in economic growth to roughly 4.5% annually, a level which would reduce power generation growth. At 4.5% growth, many sectors and domains would be disrupted. Alternatively, it would need even lower carbon intensity such as could be achieved with a dramatic structural change to its fuel mix. The path will not be simple. 📝
Lignite Rides the Rails in Europe

By Jeffrey Michel
Independent Energy Consultant

Lignite, or brown coal, is a globally abundant low-grade carbonaceous fuel used predominantly in certain European and eastern Mediterranean countries for electricity generation, district heating, and industrial applications. Lignite has been historically delivered to power plants near the mining site, since its relatively high moisture and low energy content were thought to make wider distribution too expensive. However, this conventional wisdom no longer holds true in Europe, where rising prices, particularly for natural gas, are increasing the radius of economical transportation. In addition to supplying local power stations, the lignite mining regions have become rail and truck depots for deliveries to widely dispersed locations that were formerly the domain of other fuels.

Europe’s largest lignite producers include Germany, Poland, Turkey, and Greece (see Figure 1 for 2013 production rates from EURACOAL). Germany excavated 178 Mt in 2014, affirming its rank as the world’s leading lignite miner. Greece exhibits the highest per capita usage, with more than six tonnes per year extracted for each of its 11 million inhabitants (see Figure 2). Although outranked in lignite tonnage by a few other countries, the Greek economy is crucially dependent on local energy supplies impervious to foreign exchange rates.

The transportation of lignite enhances domestic energy security, providing a low-cost alternative to rising import dependency that currently stands at about 64% in Germany and 54% overall in the EU. The increasing diversity of lignite usage provides new perspectives for extraction, employment, and distribution despite greenhouse gas policy constraints on electricity generation. A market survey compiled by the Vattenfall subsidiary GMB in 2007 included 85 German municipal power and/or heating customers outside of the Rhineland mining region (dominated by RWE) that potentially could be served with transported dry lignite. An additional 250 industrial facilities were listed in the areas of energy production and mining, chemical and pharmaceutical products, plastics and textiles, paper, metal and vehicles, foodstuffs, and transportation. Thermal capacities ranged between 1 and 145 MW.

Construction and infrastructure are already established market sectors for transported lignite. The RWE subsidiary Rheinbraun Brennstoff (93.6 Mt in 2014) supplies three million tonnes of dry pulverized lignite (LEP) annually to over 600 asphalt-mixing installations throughout Europe. Large-volume shipments are also made to cement plants located at limestone formations between the Ruhr industrial region and the Alps. The Swiss Siggenthal cement factory north of Zürich receives two trainloads (1500 tonnes) of lignite per week from the Rhineland—a distance of 600 km. This direct route is preferable to loading Rotterdam coal from Rhine River barges in the city of Basel 60 km away, demonstrating that European lignite can offer competitive advantages over seaborne imports at distant locations.
STRATEGIC ANALYSIS

In Lusatia southeast of Berlin, Vattenfall Europe Mining (61.8 Mt) supplies various grades of pulverized lignite to 10 municipal power plants, which often cogenerate heat and power (CHP). The eastern German MIBRAG Mining Corporation (20.9 Mt) delivers lignite 40 km via rail from its Profen surface mine to the Schkopau CHP plant (2×450 MW_e) where it is used for both chemical production and railway electrical power generation (16 ⅔ Hz). Additional lignite deliveries have more recently been made, using 25-tonne trucks, from the company’s second United Schleehain mine to Profen for railway distribution.

MIBRAG is the primary lignite supplier for six power plants located between 40 and 402 rail kilometers from the Profen loading terminal. In addition, three sugar factories and one production facility for biofuels are served over distances of up to 120 km.

Smaller industrial customers also rely on transported lignite. For example, a power plant operated by Allessa Chemie using pulverized lignite recently entered service at Fechenheim east of Frankfurt, Germany. A similar facility will be completed next year by the WeylChem chemical company in nearby Griesheim. This plant will be capable of firing lignite, natural gas, or “white powder”, an inexpensive biomass substitute. Three truckloads of finely pulverized lignite per day will be supplied from the Rhineland about 200 km northwest near Cologne, with ash returned for mining reclamation.

An electronic capacity control limits both plants to 19.5 MW operation, alleviating the need to purchase EU Allowances (EUA) for emissions trading. Public hearings are also required only for capacities exceeding 50 MW, and environmental impact assessments per Directive 2014/52/EU above 300 MW.

LIGNITE CHARACTERISTICS

Lignite properties that are relevant to fuel usage, such as combustion heat, water, and ash, vary according to local geological conditions. Table 1 indicates the essential parameters of German lignite extracted by surface mining in the regions.
shown in Figure 3. The average calorific value of German lignite (Braunkohle) lies between 7.8 MJ/kg, which is the lowest grade in the Rhineland and in Lusatia, and up to 11.3 MJ/kg in Middle Germany near Leipzig. This soft (weich) brown coal exhibits high water content along with appreciable quantities of sulfur and ash, particularly in certain eastern German deposits.

Some Polish lignite is similar to Lusatian quality in seams that extend beneath the Oder River. The calorific value of higher density Czech brown coal (hnedé uhlí) south of the nearby Ore Mountain range in North Bohemia, however, lies between 11.6–20.56 MJ/kg. The respective grades of hard lignite comprise both dull brown coal (matt) and shiny brown coal (lesk) that may resemble black coal (černé uhlí). Lignite rail distribution is essential for maintaining widely employed district heating services in the Czech Republic. However, Germany remains particularly active in developing the decentralized lignite market in order to diffuse mining risks ensuing from the national energy transition (Energiewende).

The lignite shipped by rail is graded according to individual plant requirements. Since crude lignite is permeated with mining groundwater, and thus the pressure at the bottom of a stockpile will be higher, it may be delivered several times a week to reduce the possibility of spontaneous combustion in large stockpiles. Any moisture lost during transport can actually upgrade fuel quality. For instance, imported Middle German lignite has been rated at 12 MJ/kg in the Czech Republic, several percent higher than mining specifications.

Alternately, dried pulverized lignite (Braunkohlenstaub BKS, alternatively LEP or LignoPlus) with double the calorific value of 21–22.2 MJ/kg has a residual water content of only 10.5–11%, improving combustion characteristics and reducing freight volumes. For this grade of lignite, railway container cars or silo trucks (for smaller quantities) are used for transport.

Germany’s three miners also manufacture lignite briquettes with similar thermal characteristics for traveling grate furnaces and heating stoves. MIBRAG briquettes are pressed from low-sulfur RWE lignite delivered from the Rhineland. The Czech Republic has been importing 0.14 Mt of briquettes annually for the heating market.

<table>
<thead>
<tr>
<th>Production Region</th>
<th>Calorific Value MJ/kg</th>
<th>Water %</th>
<th>Sulfur %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhineland</td>
<td>7.8–10.5</td>
<td>50–60</td>
<td>0.15–0.5</td>
<td>2–8</td>
</tr>
<tr>
<td>Lusatia</td>
<td>7.8–9.5</td>
<td>48–58</td>
<td>0.3–1.5</td>
<td>2.5–8</td>
</tr>
<tr>
<td>Middle Germany</td>
<td>9.0–11.3</td>
<td>49–53</td>
<td>1.5–2.1</td>
<td>6.5–10</td>
</tr>
</tbody>
</table>

Sifted lignite is delivered in Germany for circulating fluidized bed boilers with about 19 MJ/kg and 19% water content.

**LIGNITE ECONOMICS AND PROCESSING**

The manageable costs of lignite production are prerequisite to long-term contracts for distribution and use. Although mine-mouth prices for German lignite have risen from about €4/MWh, (per 3.6 GJ, roughly one third tonne) at the turn of the century to currently around €6/MWh, adjusted for calorific value and sulfur content, the continuing low cost is largely impervious to global energy markets. The effective fuel price at the most efficient (43%) plants is about €1.5 cents/kWh generated electrical power.

All grades of crude and processed lignite are considerably less expensive than natural gas, which is traded in Europe at over €20/MWh (US$7/MMBtu). The price difference between
lignite and natural gas does not include the additional benefits of reliable supply and energy security provided by domestic lignite. Thus, a number of relatively new gas plants are being retired in Germany due to rising fuel costs and declining yearly demand.

Naturally, moving lignite by rail increases the overall cost of utilization. Total charges for fuel, rolling stock, dispatching, and personnel easily make rail transport more expensive than the mined value of the lignite. Compared with the U.S., railroad costs per tonne·km are four times higher in Europe, while revenues are only twice as high.12 This can be partly attributed to the fact that passenger trains service accounts for 79% of the distance traveled on the European rail network (2007 data), which may put freight trains at a scheduling disadvantage. Even so, the total cost of the transported lignite is sufficiently low to make it a viable endeavor.

The EcoTransIT website permits transport energy expenditures to be calculated between European cities with rail connections.13 A diesel freight train requires roughly three liters of fuel per double kilometer. The energy expended for electric traction is similar when power generation losses are included. In all calculated cases, rail transport energy constitutes less than 1% of the delivered lignite energy content. Thus, from the standpoint of required fuel expenditures, the shipment of lignite by rail remains uncritical.

LIGNITE’S TRANSITION

Transported lignite is of growing importance in many parts of Europe. Smaller regional lignite power plants can supply both district heat and the grid power needed to offset varying renewable generation. Transported lignite provides municipal utilities and industrial parks with highly competitive fuel costs, durable supply reliability, and commensurate energy security. At a time when natural gas power plants in Europe can lack financial backing, lignite is taking to the rails in quantities previously unimaginable.

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A typical gravity-dumping railcar used for lignite transport with loading capacity of over 60 tonnes.
Coal is usually associated with its energy-producing components, mainly carbon and hydrogen, but many other value-added minerals and metals can be present. Commercial metal extraction from coal is not a new idea. Vanadium and silver extraction from enriched coal sources dates back to the 1800s, and germanium extraction is still active by companies such as Umicore.¹

When coal is combusted, some valuable components can be found in the fly ash captured by the electrostatic precipitators and/or fabric filters commonly applied at coal-fired power plants. Recently interest has increased in extracting metals from residue coal ashes, as concerns have grown over the overall management of fly ash, as well as environmental issues, and the risk of supply of certain compounds found in coal. For example, companies in China are expected to scale up alumina production from coal ash to over six million tonnes per annum over the next few years, while other players have been developing recovery processes for strategic metals such as vanadium, titanium, germanium, gallium, rare earth elements, and scandium. These metals are important in various sectors, such as electronics, optics, batteries, catalysts, automotive, and clean energy applications.

Annual production of fly ash may be as much as 1.5 billion tonnes globally.² The largest use for coal fly ash is for construction purposes, but data suggests that despite shortages of cementitious Class C fly ash in some regions, a considerable proportion of the total fly ash produced globally may be underutilized (e.g., used as low-value fill material) or unutilized.³,⁴ In addition, some of the leading players in metal recovery are developing routes to recover the bulk minerals as well as the metals, meaning that production of metals and construction materials is not necessarily mutually exclusive.

“Fully utilizing all the components in coal fly ash can support movement toward an increasingly circular economy.”

Although metal and mineral recovery from fly ash occurs globally, there are national-level policies that may make it more interesting or attractive in certain areas. For example, the U.S. Environmental Protection Agency’s new ruling on the management of power station coal ashes in December stated that fly ash would not be considered a hazardous material.
Despite the political, societal, and environmental drivers, uncertainty remains about the regulatory and economic aspects, and data are lacking on the full environmental footprint of the various metal recovery processes. Therefore, in a recent study titled “Commercial Recovery of Metals from Coal Ash – Global Review”, Lucid Insight reviewed the opportunities and challenges for metal recovery from coal fly ash. This independent review incorporates published data and insights from interviews with key stakeholders and experts globally to obtain a broad landscape of commercial activities, market drivers, and market barriers, and looks at some of the options for moving forward. This article provides a summary of key observations and conclusions from the comprehensive review.

**WHAT’S IT WORTH?**

The value of the metals in fly ash can vary greatly depending on the source of the coal (see Figure 1), and data are relatively sparse. However, analysis of available data suggests that scandium- and germanium-enriched coals may present the highest extractable value, based on prices at the time of the report (this excludes the very rare examples of precious-metal-enriched coals). A set of data from the British Geological Society of 11 coal ash samples showed that even the lowest level of scandium seen in these samples was worth nearly US$5000 per tonne of fly ash, with the more enriched ashes reaching over US$40,000 per tonne of fly ash, and the maximum germanium levels at almost US$3500.

The global scandium market is currently relatively small, at less than 15 tonnes per year in 2014, but developments in new applications, such as use in novel alloys and solid oxide fuel cells in batteries (e.g., for renewable energy storage), is predicted to boost demand considerably in coming years.

“Even the lowest level of scandium seen in these samples was worth nearly US$5000 per tonne of fly ash, with the more enriched ashes reaching over US$40,000 per tonne of fly ash...”

In addition, specific coals with enriched levels of dysprosium and yttrium may each return US$245 and US$210 per tonne of fly ash at the current market prices. Some groups in the U.S. are conducting research to identify coal seams with relatively high (>1000 ppm) rare earth elements (REE) content, which have attracted recent attention due to concerns over...
security of supply and growing demand. For example, Physical Sciences Inc. estimates that 10–15% of available fly ash could meet U.S. REE demand by 2020, even with the REE content of ash at much lower levels than in minerals, and accounting for both REE content variability and process yield.5

In addition, coal ash can be separated into different fractions to obtain those that contain higher levels of certain metals, which may present an opportunity for pre-treatment and segregation to increase the concentrations, resulting in more efficient processing. This is an area undergoing further exploration.6,7

**LEADERS IN COAL ASH METAL RECOVERY**

Table 1 lists examples of companies developing commercial processes for recovery of metals from coal ashes for reuse (further details are available in the full study). Currently, germanium—used as a semiconductor, as a catalyst, and to produce wide-angle camera lenses and objective lenses for microscopes—is the principal metal component recovered from coal fly ash commercially, with operating plants in China and Russia. In fact, in these countries specifically enriched seams are mined and processed to recover the germanium from the ashes. There are also several examples of commercialized alumina extraction from fly ash in China, again from enriched coals, although when surveyed several experts opined that these operations currently may not be profitable.8–10

**WHAT NEXT?**

Although metal extraction from coal ash is a challenging area, a number of companies appear to have technologies worthy of further interest, some of which are listed in Table 1. However,
STRAategic Analysis

the commercial success of these emerging players will depend on specific details around feedstock selection, process optimization and costs, logistics, metal markets, supply chain, etc. In addition, understanding the environmental impacts of metal recovery requires further investigation as there is little data comparing metal extraction from virgin materials to the recovery from these residues, an area being further evaluated by some players.

Several scenarios would help facilitate the current development of economically viable recovery of metals from coal ash, some of which are already being addressed by players, and these include:

1. Pre-treatments to increase metal concentrations to improve processing efficiency.
2. The ability to efficiently extract a range of valuable trace metal salts into a concentrate for further processing.
3. Centralized metal concentrate separation and processing facilities to benefit from economy of scale.
4. Ability to simultaneously recover both bulk materials, ideally for added value products, and metals to enable total utilization and revenues.

Fully utilizing all the components in coal fly ash can support movement toward an increasingly circular economy. The ultimate goal should be to cleverly segregate the different materials within the ash and utilize each component to its highest value, whether that be infill and commodity uses, functional materials for higher value applications in construction and the chemicals industry, or metal recovery.

NOTES

A. Selected metals were those estimated to be worth over $10 per tonne fly ash for maximum concentrations.
B. Sources of metal concentrations: Rare earth metal content estimated from laboratory analysis for ash from coal deposits in the U.S., Russia, China, and the Middle East and a range of concentrations measured from coal fly ash collected from power facilities in Europe, U.S., Mexico, and Spain as summarized by Mayfield and Lewis (2013). Also, unpublished data from analysis of power station fly ash from coals from Russia, Columbia, South Africa, U.S., UK, and unknown sources provided by the British Geological Survey.

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The full report or sections, with full profiles of players and technologies, can be obtained from www.lucid-insight.com/briefings. In addition, regular updates on Lucid Insight’s commercial and research developments are posted on Twitter @Lucid_Insight, the Lucid Insight blog: www.lucid-insight.com/blog, and the author can be reached at lucinda@lucid-insight.com
Reducing Energy’s Footprint by Producing Water and Storing CO₂

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The global energy sector faces many challenges, perhaps the two most important of which are reducing greenhouse gas emissions from fossil fuels, which made up over 86% of primary energy consumption in 2014,¹ and addressing the growing challenge of water scarcity. One key aspect of the landmark U.S.-China Joint Announcement on Climate Change is the consideration of a collaborative effort to engage on both challenges simultaneously through research, development, and demonstration of a CO₂ capture and storage (CCS) project that would produce freshwater.²

The U.S.-China Clean Energy Research Center’s (CERC) Advanced Coal Technology Consortium (ACTC) is an opportunity to leverage years of experience and research to investigate an emerging CO₂ capture, utilization, and storage (CCUS) technology called enhanced water recovery (EWR). To date, CCUS has been deployed by injecting CO₂ into petroleum reservoirs for enhanced oil recovery (CO₂-EOR). While CCUS/CO₂-EOR can make early contributions to reducing CO₂ emissions and raising revenue for first mover CCS demonstrations, the total scope is limited. For example, in the U.S., in the year 2013 alone, emissions were 6.7 billion tonnes of CO₂. For comparison, total storage capacity using “next generation” CO₂-EOR in the U.S. was estimated to be 45 billion tonnes of CO₂, with less than half (20 billion) considered to be economic at an oil price of $85/bbl, which would address the equivalent of three years of CO₂ emissions.³,⁴

“Producing brine has a number of operational benefits that enhance the efficacy of CO₂ storage, while simultaneously producing water that may help alleviate the stress in the water–energy nexus.”

Unlike CO₂-EOR, which has limited deployment potential in many regions of the world, EWR can be deployed in saline aquifers that are well distributed and close to CO₂ sources (e.g.,
EWR can be synergistically integrated with other emerging CCUS technologies that generate geothermal energy, as well as provide grid-scale energy storage. By removing brine from a saline CO₂ storage reservoir, EWR can augment the development, operation, and performance of CCS, while producing large quantities of water. In this article we discuss how EWR can be used to help manage environmental and financial risks during the stages of CCS development.

**KEY CCS CHALLENGES**

Despite the importance of CCS/CCUS for reducing global emissions, widespread deployment faces some considerable technical challenges. To overcome these, the U.S. Department of Energy (DOE) outlined four major goals for its Carbon Storage Technology Program Plan:

1. Develop and validate technologies to ensure 99% storage permanence (i.e., less than 1% of the injected CO₂ leaves the storage system due to leakage).
2. Develop technologies to improve reservoir storage efficiency, while ensuring containment effectiveness.
3. Support industry’s ability to predict CO₂ storage capacity in geologic formations within ±30%.
4. Develop best practice manuals for monitoring, verification, and accounting; site screening, selection, and initial characterization; public outreach; well management activities, risk analysis, and simulation.

In a CO₂ storage reservoir, overpressure is defined as fluid pressure that exceeds the original pressure before CO₂ is injected. Overpressure is the limiting metric for CO₂ storage capacity because it is the primary factor affecting risks such as induced seismicity, caprock fracture, and CO₂ leakage. These risks increase with overpressure. The three most important factors that influence overpressure are:

1. The quantity of CO₂ and the rate at which it is injected
2. The size of the storage reservoir “compartment”, determined by the geology
3. The permeability (i.e., ability of the CO₂ to move) within the storage reservoir

Geologic surveys, geologic logs, and core data from exploration wells provide information that can be used to estimate the size and permeability of the reservoir compartment. However, until injection or production wells are operated, and large quantities of fluid move into and/or out of the storage reservoir, estimates of CO₂ storage capacity and permanence may be subject to uncertainty.

Unlike CCUS/CO₂-EOR operations conducted at brownfield sites (pre-existing well-fields), CCS in a saline aquifer is typically a greenfield operation. Thus, there may be less geologic information, and little or no production and injection history available to estimate how much CO₂ can be safely and securely stored. The ZeroGen project in Australia is one prominent example of a problem resulting from insufficient knowledge about the storage reservoir. The project only advanced to the point of learning that the intended CO₂ storage reservoir had too little storage capacity. As a result, a key lesson learned from that project was that storage capacity estimates must be based on long-term, dynamic well testing. Thus, uncertainties about CO₂ storage capacity and permanence are key reasons why CO₂ storage is a primary technical hurdle for the commercialization of CCS, but this hurdle can be addressed through site characterization augmented with brine extraction.

Without adequate site characterization, which can take 5–10 years, CO₂ cannot be captured, transported, and stored routinely and reliably at large scale. Pore-space ownership and public acceptance are other key challenges. A deployment strategy that extracts brine prior to the injection of any CO₂ can address these challenges.

**THE MULTIPLE BENEFITS OF BRINE EXTRACTION**

Extracting brine from a CO₂ storage reservoir provides multiple benefits. First, extracting brine opens more pore space in the reservoir for CO₂ injection, resulting in less overpressure and less required post-injection monitoring for a given quantity of stored CO₂. In addition, more CO₂ can be injected without infringing on the pore-ownership rights of neighboring subsurface operations (e.g., other CCS sites).

Second, produced brine can be partially treated for industrial and saline cooling-water applications or desalinated to produce freshwater; it can also be used to extract valuable minerals, such as lithium. The efficacy of brine use depends on the location, because of differences in the chemical composition of the brine and applicable utilization options.

Third, when brine is extracted before CO₂ injection, the resulting pressure drawdown provides direct information about overpressure that will result from CO₂ injection. Hence, operational experience with removing brine reduces uncertainties about
CO₂ storage capacity and permanence, compared to when the first major well operation is CO₂ injection itself. This third benefit is valuable for both site selection and characterization. Reducing CO₂ storage uncertainty could be necessary prior to final commitments on CO₂ capture and transportation infrastructure.

Fourth, brine extraction maximizes storage resource utilization. A “one source, one sink” approach is unlikely given the current regulatory climate and cost of CO₂ capture. As brine removal increases CO₂ storage capacity, it can allow an individual sink to store CO₂ from multiple sources; thus, fixed development costs for that site (e.g., permitting, site characterization, monitoring) are leveraged for multiple sources, reducing CO₂ storage cost.¹⁶⁻¹⁸

Zero net injection—where the volume of the extracted brine is the same as the volume of the injected CO₂—minimizes interference with neighboring owners and users of underground pore space, and it also maximizes all of these benefits.

**Brine Extraction as a Pressure Management Strategy**

Brine extraction can be scheduled both before (Figure 1) and during CO₂ injection (Figure 2). It could also be scheduled after CO₂ injection (Figure 3), as part of a reservoir pressure management strategy aimed at reducing the required time for post-injection monitoring, while continuing to produce water.

For CCS operations, pre-injection brine extraction has three objectives: 1) minimize the total number of wells required for CCS deployment, 2) maximize the magnitude of overpressure reduction per unit of extracted brine, and 3) acquire pre-injection information on the reservoir from measuring pressure drawdown. When the same well is used first to extract brine and then to inject CO₂, pressure drawdown and the information gathered are greatest where needed most—the center of CO₂ storage.⁹ Measuring pressure drawdown in an adjoining deep monitoring well (Figure 1) provides additional information about the size of the reservoir compartment and CO₂ storage capacity. Measuring drawdown in a shallow monitoring well provides important information about the potential for CO₂ leakage through the caprock and, hence, CO₂ storage permanence.

CO₂ injection begins where pressure drawdown is greatest, which is where the brine was initially extracted (Figure 2). Then a second brine-extraction well can operate until CO₂ from the first well reaches the second well, at which time the second well may be repurposed for CO₂ injection (Figure 3).

Brine extraction may continue at a third deep well, depending on the CO₂ storage goals. Brine extraction could continue

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**FIGURE 1.** Brine extraction before CO₂ injection results in pressure drawdown, making room for CO₂ storage.⁹

**FIGURE 2.** The brine-extraction well shown in Figure 1 is repurposed as a CO₂ injection well and the deep monitoring well is repurposed for brine extraction.⁹
long after CO\textsubscript{2} injection has ceased. This strategy could nullify residual overpressure, limit pore-space competition with neighbors, and reduce the time required for post-injection monitoring to assure storage integrity.

Based on data from the Snøhvit CO\textsubscript{2} storage project that injected 1.09 million tonnes of CO\textsubscript{2} over three years,\textsuperscript{19,20} a retrospective reservoir modeling study evaluated the potential efficacy of extracting brine prior to injecting CO\textsubscript{2}.\textsuperscript{21} Hydrogeologic information and CO\textsubscript{2} injection-rate and pressure data provided by Statoil were used to calibrate a reservoir model to predict overpressure from CO\textsubscript{2} injection. The results of this model agreed closely with measured values during the three years of CO\textsubscript{2} injection (see Figure 4).

The calibrated model was then used to simulate a scenario where a volume of brine equal to the injected CO\textsubscript{2} volume (~1.56 million m\textsuperscript{3}) was extracted over the three years prior to CO\textsubscript{2} injection. To continue the modeling exercise beyond the end of the actual Snøhvit CO\textsubscript{2} injection phase, it was assumed that the three-year CO\textsubscript{2} injection-rate schedule was repeated nine times during the 27 years following the end of the phase. It was also assumed that brine was extracted in the same time-varying fashion.\textsuperscript{21}

At the end of injection at Snøhvit, a peak overpressure of 7.63 MPa was reached; a goal of this modeling exercise was to determine how much additional CO\textsubscript{2} could be injected before this overpressure was reached if brine had been extracted. It was found that extracting a volume of brine equal to the volume of the injected CO\textsubscript{2} nearly doubled the time (and quantity of CO\textsubscript{2}) required to reach an overpressure of 7.63 MPa.\textsuperscript{21} On a volume-for-volume basis, brine extraction was found to be 94\% effective, the equivalent of not having injected 1.03 of the 1.09 (actual) million tonnes of CO\textsubscript{2}, which could enable an additional 1.03 million tonnes of CO\textsubscript{2} to be injected before the peak measured overpressure was reached.\textsuperscript{21}

This exercise also showed the value of brine extraction for site characterization. Pressure drawdown history is the mirror image of the overpressure history (Figure 4), and thus this technique provides useful information on overpressure that will result from CO\textsubscript{2} injection as well as on the CO\textsubscript{2} storage capacity. It is worth noting that three years of pre-injection brine extraction falls within the 5–10-year timeframe attributed to site characterization.\textsuperscript{13}

**Brine Extraction as a Site Selection and Characterization Strategy**

Extracting brine prior to CO\textsubscript{2} injection could be applied to several potential CO\textsubscript{2} storage sites to help identify the one that has the best combination of storage capacity, permanence, and efficiency. Brine extraction could then continue at the selected site until enough pressure data is collected and...
analyzed to assure investors, insurers, and, most importantly, the public that risk has been sufficiently reduced.

**The Benefit of Producing Water**

The inextricable link between water and energy has been termed the water–energy nexus. Every energy source requires water at some point in the supply chain.22,23 Thermal power plants fueled by coal, natural gas, and nuclear energy serve as the backbone of the modern energy infrastructure and such plants require substantial cooling, which is most often served by water.

EWR through brine extraction produces water as part of an integrated strategy to also dispose of CO₂ in the deep subsurface. Thus, thermal power plants begin producing water and some plants, such as those that employ low-water demand technologies like pressurized oxy-combustion or chemical looping with CCS (currently pre-commercialization), could become net water producers. However, brine that is produced from the deep aquifers suitable for CO₂ storage contains more dissolved solids and impurities than groundwater in shallow aquifers. Brine from saline aquifers is not usable without treatment. Based on preliminary estimates,10 treatment may cost ~0.3 US¢/kWh for zero net injection, possibly attractive in many water-scarce regions. Moreover, that cost can be offset by other savings (fewer wells, less monitoring, lower insurance costs) and the economic and permitting advantages that arise from reducing uncertainty. There may also be opportunities for synergistic integration of thermal power plants and water purification processes.8,24 Still, the net life-cycle benefits of producing water from CO₂ injection need to be investigated.25

The CO₂ storage site down-selection criteria, discussed in the previous section, can be broadened to include brine treatability (e.g., energy required and costs of treatment depend on the brine composition and intended application), as well as the proximity of a candidate site to arid regions.

A zero net injection strategy for reservoir pressure management can generate substantial quantities of brine (and product water after treatment) on a per MWh basis. A 1000-MW coal-fired power plant operating at 90% capacity and a 90% CO₂ capture rate produces 10–14.4 million m³ (8–11.6 thousand acre feet) of water per year while storing seven million tonnes of CO₂ each year.14

**U.S.-CHINA COLLABORATION AS A NEAR-TERM EWR OPPORTUNITY**

The potential of EWR was highlighted by its consideration for development in U.S-China collaboration efforts. Under the recent joint climate announcement, the U.S.-China CERC is considering EWR in connection with the GreenGen project in Tianjin, China. The Huaneng Corporation is planning to capture CO₂ at a coal integrated gasification combined-cycle (IGCC) power plant.26 The feasibility of injecting this CO₂ into a deep saline aquifer for permanent storage, while extracting an equivalent volume of brine to generate freshwater by reverse osmosis desalination, possibly using pre-injection brine extraction, was evaluated with promising results.27

**CONCLUSIONS**

Overall, challenges facing modern energy systems include reducing both CO₂ emissions and water intensity, while providing reliable, affordable, and secure energy. These challenges can be addressed simultaneously by injecting CO₂ for storage in deep saline aquifers while producing brine from the same aquifers. Producing brine has a number of operational benefits that enhance the efficacy of CO₂ storage, while simultaneously producing water that may help alleviate the stress in the water–energy nexus. CCS is a key tranche in the lowest-cost suite of technologies needed to limit global emissions and EWR could play an important role in advancing CCS. 🐠

**ACKNOWLEDGMENTS**

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The Case for Carbon Capture From Air

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Stabilizing the atmospheric carbon dioxide ($\text{CO}_2$) concentration requires the nearly complete elimination of all anthropogenic CO$_2$ emissions.\footnote{1} In the popular bathtub analogy that equates atmospheric CO$_2$ concentration with the water level in a tub, the water level is held constant by matching the input from the faucet with the outflow through the drain. Unfortunately—and contrary to the usual explanation—in the case of the atmosphere, the drain clogs as the faucet is turned down. Once the atmospheric concentration stops rising, the surface ocean and the biosphere find their balance with the new CO$_2$ level, and transport into the deep ocean will slow as the top layer of the ocean, which is close to equilibrium with the air, grows in size. Therefore, to meet international climate goals annual global emissions must approach zero. This is a tremendous challenge considering population growth and the existing energy infrastructure. If emissions cannot be fully eliminated or the atmospheric CO$_2$ concentration overshoots the limit considered safe by climate scientists, negative emissions will be required as an additional drain so that the tub does not overflow. In fact, in its latest report, the Intergovernmental Panel on Climate Change (IPCC) suggests that negative emissions (i.e., an anthropogenic drain) will be necessary to meet the international goal of limiting climate change to 2°C.\footnote{2}

“\textbf{If emissions cannot be completely eliminated or the atmospheric CO}_2\text{ concentration overshoots the limit considered safe by climate scientists, negative emissions will be required…”} \footnote{“If emissions cannot be completely eliminated or the atmospheric CO$_2$ concentration overshoots the limit considered safe by climate scientists, negative emissions will be required…”}

This poses a challenge for today’s energy engineers: Provide affordable energy for a rapidly growing world economy while eliminating all CO$_2$ emissions. This must also be accomplished without other environmental impacts, without creating energy shortages, and in the most economical way possible. Moreover, the time available for this radical transition is short. Thus, there is an urgency to introduce zero-emissions technologies across all energy sectors. This would include bold negative-emissions technologies for recovering and storing atmospheric CO$_2$ to cancel out residual emissions and, if necessary, actually reduce the CO$_2$ concentration in the atmosphere. Action is necessary, because learning by doing requires doing, and any delay will further increase the difficulty of stabilizing concentrations at a safe level.

**NO SMALL FEAT**

It is important to consider the scale of the challenge. Fossil fuel consumption could easily quadruple over the course of this century without global per capita energy consumption exceeding that of the U.S. today. With more than 80% of today’s energy derived from fossil fuels, virtually the entire energy system must change. In addition, the world may need to correct an overshoot that could easily be as large as 100 ppm, or 400 Pg of excess carbon. This is more than all emissions...
While all large-scale low-emission energy options are critical, each faces unique challenges.

of the 20th century. In any overshoot scenario carbon storage becomes unavoidable, and potentially a very large component of carbon management.

LARGE-SCALE LOW-EMISSIONS ENERGY OPTIONS

Solar, nuclear, and fossil energy are the three truly large-scale energy options for the future. Sunshine exceeds human energy consumption by four orders of magnitude, nuclear resources could supply thousands of years of power, and fossil carbon, even at increased consumption, could support global energy demand for several hundred years. However, none of the three large options are ready for a future carbon-neutral world. From a business perspective it is entirely rational to back a profitable technology, even if it cannot operate at global scale. From a policy perspective, however, the risk mitigation resulting from developing a global solution is very worthwhile, even if cobbling together a global energy system from many small sources may prove feasible. All energy options need to be pursued, but advances in these three fields are particularly important as each could result in an energy infrastructure that is sufficient to satisfy human needs.

The available options for stabilizing CO₂ can broadly be classified into three categories: improved efficiency, increased deployment of renewables and nuclear, and carbon capture and storage.

Acceleration of Efficiency Improvements

The first option is to do more with less energy and increase efficiency throughout the entire energy value chain. There are abundant opportunities on the demand side, from LED lighting to more efficient cars. There are also many opportunities on the supply side, from higher-efficiency power plants to cogeneration of heat and power. Improving efficiency can greatly reduce emissions, but it cannot achieve zero or negative emissions. Since efficiency improvements stem from a myriad of different advances, progress is unlikely to come from a few large projects, but more likely from broad-based economic incentives. It is worth noting that improving efficiency is already built into the IPCC’s business-as-usual scenarios and maintains global energy consumption projections typically one percentage point below the world’s GDP growth. To go beyond business as usual, energy intensity improvements must go much further.

“Since efficiency improvements stem from myriad different advances, progress is not likely to come from a few large projects, but more likely from broad-based economic incentives.”

Increased Deployment of Renewables and Nuclear

The second option is to expand the deployment of carbon-neutral energy resources, such as renewable and nuclear energy. If all fossil carbon resources were to be replaced with non-fossil energy, anthropogenic CO₂ emissions to the atmosphere would drop close to zero, but such a transition would be associated with huge costs, major infrastructure changes, and would likely take too much time to meet international climate goals. In addition, the intermittency issue of solar energy must be resolved in an affordable manner, and nuclear energy is saddled with the risk and legacy of Three Mile Island, Chernobyl, and Fukushima. While not comprehensive in the near term, renewable energy and nuclear energy, including fusion, are an important part of a low-emissions solution and need to be developed to create optionality in the energy sector.
Carbon Capture and Storage

The third major option is to capture and permanently dispose of CO₂. For carbon capture and storage (CCS) to be compatible with a zero-emissions world, it must include CO₂ capture from the atmosphere, since CCS does not capture 100% of emissions from fossil power plants.

Capture of carbon from the atmosphere, the surface ocean, or the biosphere makes it possible to create negative emissions that could recover past emissions or balance out remaining emissions that are difficult to capture by other means. This includes the fugitive emissions of a coal plant with CCS and its associated CO₂ storage as well as the CO₂ emitted from the transportation sector.

However, the path forward is challenging. Fossil energy can only contribute to a zero-emissions world if all CO₂ and other greenhouse gas emissions can be eliminated. CCS is not yet widely applied and its costs must be reduced.

“Through innovation, researchers hope to reduce the costs and find new pathways to enable direct air capture to play a role in a low-emissions future.”

THE POTENTIAL ROLE OF AIR CAPTURE

If none of these three options for stabilizing CO₂ emissions can be made to work, humanity would face the impossible choice between a climate disaster and a collapse of the world’s energy systems. Considering the risks, I believe current efforts and investment are far too lackadaisical.

My own focus has been finding ways of recovering CO₂ from the atmosphere by technical means.5,6 Recovering CO₂ from the environment by any means can help return the world to lower CO₂ levels and it can close the anthropogenic carbon cycle regardless of the original carbon source. This will require the large-scale use of carbon storage technologies. Importantly, use of carbonaceous liquid fuels in the transportation sector can only be sustained if it is fully matched by CO₂ recovery. For biofuels grown in open air, the recovery is automatic. For petroleum-based fuels, fuel from algae grown in closed bioreactors, or for synthetic fuels, the CO₂ must be recaptured. Ultimately, as long as fossil fuels are used, for every ton of carbon taken from the ground another ton will have to be stored in a net-zero emission world. Even without fossil fuels, for every ton of CO₂ injected into the air, another ton will have to be recaptured.

Direct capture of CO₂ from air is already practiced today, albeit on a much smaller scale, to purify breathing air on submarines or spacecraft, or the removal of CO₂ from air prior to its liquefaction. Thus, there is a foundation on which to build. Through innovation, researchers hope to reduce the costs and find new pathways to enable direct air capture to play a role in a low-emissions future. There are already several start-up companies demonstrating the feasibility of capture from air.

It is highly unlikely that the massive changes necessary to stabilize CO₂ in the atmosphere could be cost-effectively achieved by deploying a single technology. It is even less likely that scientists, engineers, business people, or policy makers could successfully pick the winner today. With hindsight, it is clear that some technologies have come down in costs by orders of magnitude since their inception and operate at scales initially thought to be impossible. Eventually many processes approach a “frictionless” cost that is dominated by raw materials and energy. However, such reductions in cost are not predictable. Rather than making policies based on current cost, which is meaningless, or hypothetical cost, which is unknowable, a better strategy is to develop technology options and make decisions as advantages and disadvantages emerge. Thus, direct air capture is among the global options that need to be developed.7

Perhaps the strongest motivation for developing direct air capture technologies would be the resultant uniform cost for...
Researchers are already working on air capture technologies, such as carpet-like ion exchange resins, that could reduce costs. Carbon emissions. Air capture, because it collects CO₂ after it has been emitted, can balance out any emission, at any time, and from any location. If there is no better technological option (e.g., as is likely the case for emissions from widespread air travel) air capture combined with storage or fuel synthesis can become viable where no other option is feasible. In most cases, it will be easier or cheaper to collect the CO₂ earlier in the energy chain (e.g., CCS at a coal-fired power plant), or it may be preferable to avoid making CO₂ in the first place by raising energy efficiency or by deploying near-zero carbon energy sources.

By making emissions reversible, air capture puts a price on CO₂ emissions as an option of last resort. If that price proves affordable, comprehensive carbon regulations become more palatable politically. With gradually tightening regulations that enforce a shrinking—and in the future perhaps even negative—annual carbon budget, air capture would provide an economic incentive for other low-emission technologies to reduce emissions at a lower cost. The policy value of air capture is not in the amount of CO₂ that it cancels out, but in its ability to set the marginal cost of CO₂ remediation. Even if the contribution of air capture to carbon mitigation remains small, its gradual cost reductions will likely spur advances in all other carbon-avoiding technologies.

HEDGING OUR BETS

How a zero-emissions world will develop is difficult to predict. Different technologies, including air capture technologies, will compete for various sectors of the market. In a zero-emissions world, regulations placing a price on CO₂ emissions directly or indirectly would ensure use of unabated fossil fuels is eliminated.

“By making emissions reversible, air capture puts a price on CO₂ emissions as an option of last resort.”

Rather than setting an artificial price for emissions, I propose that all CO₂, whether released accidentally or intentionally, must be recovered. This will provide a niche for air capture and it will set the marginal cost of carbon emissions. Whether this niche is large or small will depend on all other technologies that are under development and which will move forward if zero-emissions becomes an enforceable goal. Rather than prescribing an answer, I propose to set boundary conditions in which markets can find an optimal solution.

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The government of China considers addressing climate change to be of the utmost importance. Therefore, the country is exploring how to best approach low-emissions development through innovation and intends to do so even as it pushes ahead with urbanization and industrialization.

Recently China has placed a major emphasis on the research, development, and demonstration of carbon capture, utilization, and storage (CCS and CCUS), while also promoting energy conservation and reducing criteria emissions. Based on geography, economics, technical considerations, and other factors, the Administrative Center for China’s Agenda 21, responsible for carrying out China’s efforts under the United Nations Agenda 21 plans for sustainable development, has found that there are several optimal opportunities for CCUS in China. The best prospects are focused around pairing key industries responsible for 90% of the country’s emissions from coal use (i.e., coal-fired power, coal-to-chemicals, and steel and cement production) with specific CCUS opportunities to advance low-emissions technology deployment in the country.

“CCUS presents a key opportunity to enable cross-industry collaboration to form a framework for an emerging low-emissions industrial structure, thereby balancing China’s development and environmental objectives.”

CHINA’S ENERGY CHALLENGES

In late June 2015, China officially submitted its Intended Nationally Determined Contributions (INDCs) ahead of COP21.
The major commitments include peaking carbon emissions by 2030, while striving to do so sooner, and reducing CO₂ emissions per unit of GDP by 60–65%, compared to 2005 levels. These ambitious commitments demonstrate the country’s desire to be proactive on climate change mitigation. They also support domestic efforts to expand investigation and innovation of low-emissions development models and pathways.

When making its international commitments on climate and working to advance low-emissions technologies, China must take into account that it is a developing country with a population of more than 1.3 billion people. Thus, the country must balance sustainable economic development, poverty eradication, urbanization, industrialization, the desire to improve standards of living, limited resources and energy supplies, and environmental protection. In terms of reducing carbon emissions from coal, China has opted to focus largely on CCUS in the near term to provide some revenue and/or co-benefits from low-emissions technology deployment.

Addressing emissions from the coal-fired power sector is especially important, considering that China has large coal reserves with relatively small reserves of oil and natural gas. The country is working to expand deployment of many low-emission energy options, but it is not possible for China to fundamentally change its coal-based energy mix in the near future. Any drastic change in the energy consumption structure would inevitably worsen China’s energy security and would directly and negatively impact economic growth. Based on forecasts, the proportion of coal, oil, gas, and other energy sources (e.g., nuclear power and renewables) in China’s primary energy mix are expected to be 55%, 20%, 10%, and 15%, respectively, in 2020.¹ Therefore, low-emissions coal utilization must be developed and deployed in China.

CCUS is also of high interest to China because it can increase domestic production of valuable resources, such as minerals, oil, natural gas, uranium, and water. Thus, CCUS presents a key opportunity to enable cross-industry collaboration to form a framework for an emerging low-emissions industrial structure, thereby balancing China’s development and environmental objectives.

“Today China has developed a pathway for the deployment of CCUS and technologies to use CO₂ to produce various resources.”

THE STATUS OF CCUS IN CHINA

The international community, especially developed countries, has also been increasingly interested in CCUS. In addition to the emissions reduction benefits of CCUS, countries such as the U.S., the UK, Australia, and Canada have set their sights on the considerable market benefits offered by this suite of technologies.

China specifically is actively pursuing research, development, and demonstration of CCUS, which is included in five-year plans and other government documents that cover climate change. For example, the importance of developing CCUS was emphasized in documents and national guidelines such as the Medium- and Long-Term Program for Science and Technology Development (2006–2020), the National Program for Addressing Climate Change in China, the 12th Five-Year Plan for Science and Technology Development, the 12th Five-Year National Plan for Science and Technology Development to Address Climate Change, and the 12th Five-Year Plan for Carbon Capture, Utilization, and Storage Technology Development.

There has been recent progress in advancing CCUS in China. Since the end of the 11th Five-Year Plan, China’s government has supported research and development work carried out by domestic colleges, universities, and research institutes as well as large power, petroleum, and coal companies. This work has laid the foundation for a CCUS industry—and includes launching the country’s largest CCS project in operation to date, Shenhua’s 100,000 tonnes/annum (tpa) full-process demonstration project for CO₂ capture, transportation, and storage in saline aquifers. Other major research, development, and demonstrations related to CO₂ utilization are listed in Table 1.

Today China has developed a pathway for the deployment of CCUS and technologies to use CO₂ to produce various...
resources. However, large-scale full-process demonstration projects over one million tpa in size have yet to be carried out in the country. Thus, to achieve a commercial CCUS industry in the near future the challenges of high costs, lack of maturity of some key technologies, and a lack of complementary facilities and related policies must be addressed. The near-term advancement of the technology is critical.

**CCUS CONTRIBUTIONS TO EMISSIONS REDUCTIONS AND INDUSTRIAL TARGETS**

In 2013, China’s Ministry of Science and Technology’s Administrative Center for China’s Agenda 21 took the lead in conducting a comprehensive scientific assessment of CCUS technologies in China, and published the results in 2014. In this report, the emissions reduction potential and benefits of different CCUS technologies in China were assessed.

Based on the current policies and technology development trends—and as CCUS technology demonstration and industrialization plans are ramping up—enormous potential exists for increased deployment and emissions reductions (see Table 2). If there is expanded policy support and investment for CCUS, greater deployment and the resulting emissions reductions could be achieved sooner, in addition to achieving the broader economic and social benefits.

**TABLE 1. Select CCUS demonstration projects in China**

<table>
<thead>
<tr>
<th>Name and Project Name</th>
<th>Location</th>
<th>Demonstration features</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNPC Jilin Oilfield CO₂-EOR Research and Demonstration</td>
<td>Jilin Oilfield</td>
<td>CO₂-EOR</td>
<td>Storage capacity: ~100,000 tpa</td>
</tr>
<tr>
<td>Zhongke Jinlong CO₂ Chemical Utilization Project</td>
<td>Taixing, Suzhou</td>
<td>CO₂ chemical utilization in alcohol plant</td>
<td>Utilization capacity: ~8000 tpa</td>
</tr>
<tr>
<td>CNOOC CO₂-based Degradable Plastics Project</td>
<td>Dongfan, Hainan</td>
<td>CO₂ separation from natural gas and utilization for chemicals production</td>
<td>Utilization capacity: 2100 tpa</td>
</tr>
<tr>
<td>Sinopec Shengli Oilfield CO₂ Capture and Flooding Demonstration</td>
<td>Shengli Oilfield</td>
<td>Post-combustion capture + CO₂-EOR</td>
<td>Capture and utilization capacity: 40,000 tpa</td>
</tr>
<tr>
<td>ENN Group Microalgae Carbon Fixation Bioenergy Demonstration Project</td>
<td>Dalad Banner, Inner Mongolia</td>
<td>Bio-utilization of coal chemical flue gas</td>
<td>CO₂ utilization capacity: ~20,000 tpa</td>
</tr>
<tr>
<td>Huaneng Green Coal-Fired Power Tianjin IGCC Power Plant Capture, Utilization and Storage Demonstration</td>
<td>Binhai New Area, Tianjin</td>
<td>Pre-combustion capture + CO₂-EOR</td>
<td>Capture capacity: 60,000 to 100,000 tpa</td>
</tr>
<tr>
<td>Guodian Corporation CO₂ Capture and Utilization Demonstration Project</td>
<td>Tanggu District, Tianjin</td>
<td>Post-combustion capture</td>
<td>Capture capacity: 20,000 tpa</td>
</tr>
<tr>
<td>Sinopec Coal Gas CO₂ Capture, Flooding, and Storage Demonstration Project</td>
<td>Shengli Oilfield</td>
<td>Coal gas capture + CO₂-EOR</td>
<td>Capture and utilization capacity: 70,000 tpa</td>
</tr>
<tr>
<td>Sinopec Shengli Oilfield CO₂ Capture, Flooding, and Storage Demonstration Project</td>
<td>Shengli Oilfield</td>
<td>Post-combustion capture + CO₂-EOR</td>
<td>Capture and utilization capacity: 500,000 to 1,000,000 tpa</td>
</tr>
</tbody>
</table>

**TABLE 2. Forecasted CCUS potential**

<table>
<thead>
<tr>
<th>Year</th>
<th>Development</th>
<th>Emission reduction potential</th>
<th>Expected output, RMB/yr (US$/yr)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>Ten large-scale CCS/CCUS technology demonstration or industrial-scale facilities</td>
<td>50 million tpa</td>
<td>120 billion RMB/yr (US$18.8 billion/yr)</td>
</tr>
<tr>
<td>2030</td>
<td>Commercialization of CCUS</td>
<td>200 million tpa</td>
<td>Over 300 billion RMB/yr (US$46.9 billion/yr)</td>
</tr>
</tbody>
</table>
Considering the large potential revenue and emissions reductions, CCUS should, first and foremost, be applied to reduce emissions from China’s coal-fired power, coal-to-chemicals, and steel and cement production sectors. Integrating CCUS projects could form industrial clusters of emissions reductions across these different industries and reduce net costs.

**PRINCIPAL PATHWAYS FOR PROMOTING CCUS IN CHINA**

China possesses several characteristics that are important for growing a successful CCUS industry, including CO₂ emissions that are largely clustered around industrial centers, diverse geology, proximity of sources and sinks, and commodity prices high enough to help support CCUS projects. Through systematic planning, pathways for CCUS project development in China have been identified.

The first opportunity identified is associated with using CO₂ from coal-fired power plants to enhance oil recovery (CO₂-EOR) and enhance water recovery (EWR). The water produced in EWR could be further processed to extract valuable minerals, such as lithium salts, potash, and bromine, and also simply to produce usable water (treatment would be required) as many coal-fired power plants are located in regions of the country where water scarcity is higher. There may also be opportunities to use CO₂ from some steel and cement production facilities for these purposes.

Another potential CCUS opportunity is to use the relatively pure CO₂ from coal conversion processes in China, such as the production of synthetic natural gas, for enhanced coalbed methane (ECBM) production. In addition, the captured CO₂ and newly produced methane could be combined with coke oven gas (H₂ and CH₄) to generate a feedstock to produce syngas, liquid fuels, methanol, etc.

Yet another CCUS opportunity is related to using the lower concentrations of CO₂ generated during steel and cement production. Such CO₂ could be used for the mineralization of bulk solid wastes (such as slag and phosphogypsum), generating value-added materials. In addition, low-concentration CO₂ can be used directly for the cultivation of microalgae. The cultivated microalgae can be used for fertilizer—particularly suitable for treating the saline-alkali and desert soils in China. This would have a co-benefit of increasing carbon fixation in soil. Oils from the microalgae could also be used in fuel production and in the chemical production industries, although this work is quite preliminary.

Although some core CCUS technologies are at an early stage of research and development, these technologies hold value for improving China’s energy security, benefitting the environment, reducing emissions, providing new sources of economic growth, growing emerging strategic industries, and improving national competitiveness.

Based solely on the development status of CCUS today, the potential for emissions reductions and the economic benefits of various CCUS options as forecasted in 2030 are shown in Table 3.1. If there is expanded policy support and constraints in the market are reduced, CCUS technologies that are still being researched, developed, and demonstrated could mature more quickly and enter the market sooner, resulting in even greater benefits.

**CONCLUSIONS AND RECOMMENDATIONS**

The development of a CCUS industry is an important way forward for reducing emissions in China. New industrial clusters could potentially develop into foundations for economic growth, promoting sustainable socioeconomic development. To realize this potential, the Administrative Center for China’s Agenda 21 makes several recommendations:

1. Conduct a systematic assessment of the costs, safety, environmental aspects, and other factors related to CCUS in China, especially in regions with better conditions for early CCUS demonstrations, such as the Ordos Basin, Songliao Basin, Bohai Bay Basin, and Junggar Basin. This will give a more accurate understanding of the potential for CCUS in the country.

2. Due to the lower capture cost, concentrated sources of CO₂, such as from the coal-to-chemicals industry, should be used initially as the source of CO₂ for CCUS demonstrations. When considering technologies, attention should be given to increasing energy efficiency through integration of CCUS with existing processes, and thus decreasing coal consumption. For example, efficiency may be achievable through integration of CCUS with the production of synthetic natural gas. Potential opportunities include achieving breakthroughs in the core technologies, such as gasification.

3. Certainty must be increased around the prospects of the large-scale, commercial application of post-combustion capture, pre-combustion capture, and oxy-fuel combus-
TABLE 3. Potential emission and economic benefits of various CCUS technologies in China (estimated)

<table>
<thead>
<tr>
<th>Category</th>
<th>Product</th>
<th>Combined emission reduction potential (‘0000 tpa)</th>
<th>Combined economic benefits (‘00 m RMB/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2020</td>
<td>2030</td>
</tr>
<tr>
<td>Increased energy output and more efficient utilization</td>
<td>Oil, coalbed methane, natural gas, shale gas, and other such energy products</td>
<td>323–330</td>
<td>2495–2620</td>
</tr>
<tr>
<td></td>
<td>Conversion and production of syngas/liquid fuels</td>
<td>1500</td>
<td>5250</td>
</tr>
<tr>
<td>Increased mining and utilization of mineral resources</td>
<td>Microalgae biofuel</td>
<td>2.6</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Potash, iodides, boric acid, bromine, lithium salts, etc.</td>
<td>10</td>
<td>300–600</td>
</tr>
<tr>
<td></td>
<td>Uranium mining</td>
<td>50–100</td>
<td>5280</td>
</tr>
<tr>
<td></td>
<td>Water for industrial and agricultural use</td>
<td>60</td>
<td>3400–3700</td>
</tr>
<tr>
<td>Conversion, synthesis, and utilization of organic chemicals</td>
<td>Methanol</td>
<td>2000</td>
<td>5000</td>
</tr>
<tr>
<td></td>
<td>Organic carbonates and derived materials</td>
<td>534–546</td>
<td>855</td>
</tr>
<tr>
<td>Increased biological and agricultural output and utilization</td>
<td>Technology for conversion of microalgae-fixed CO₂ into biofertilizers, etc. (food and feed additives)</td>
<td>10.4</td>
<td>132</td>
</tr>
<tr>
<td>Synthesis and utilization of inorganic chemicals and materials</td>
<td>Carbonate products and materials</td>
<td>520</td>
<td>1840</td>
</tr>
<tr>
<td></td>
<td>Potash</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5020–5090</td>
<td>25,060–25,180</td>
</tr>
</tbody>
</table>

In conclusion, CCUS is an important way forward to reduce CO₂ emissions in China. Integration of key technologies can reduce costs and uncertainty, allowing CCUS to play an important first step in reducing the country’s emissions.

NOTES

A. Conversions based on exchange rate of US$1 = 6.4 RMB as of 17 August 2015.

REFERENCES

**Movers & Shakers**

In July, Anglo American announced the appointment of Tony O’Neill to its board as an Executive Director. In addition, there were leadership changes at Anglo American South Africa (AASA). Following the retirement of Chairman of the Board Michael Spicer, Mark Cutifani, Chief Executive of Anglo American, is assuming the role of Chairman of AASA. Anglo American also has appointed Andile Sangqu to the newly established role of Executive Head of AASA.

Aurizon announced that Tim Poole formally became a director of Aurizon on 1 July 2015, and will assume the chairmanship on the retirement of the present chairman, JB Prescott, on 1 September. The company also announced that Jennifer Purdie had been appointed as the new Executive Vice President Enterprise Services.

Orica announced that Craig Elkington is stepping down from Executive Director Finance, effective 30 September 2015, and the appointment of Thomas Schutte as Orica’s new Chief Financial Officer, effective 1 September 2015 or earlier. Mr. Schutte will also be a member of the company’s Executive Committee.

Peabody Energy announced that Amy Schwetz has been named Executive Vice President and Chief Financial Officer. In addition, the company announced that A. Verona Dorch has been named Executive Vice President, Chief Legal Officer, Government Affairs, and Corporate Secretary.

Whitehaven Coal Limited announced changes to its Board of Directors. Rick Gazzard has resigned as a Director of Whitehaven. Joining the board as a new independent non-executive Director is Julie Beeby, most recently CEO of Westside Corporation, a coal seam gas producer in Queensland.

**China**

China’s State Administration of Work Safety announced that the country’s coal mine safety improved significantly in the first half of 2015. Coal mine accidents in China declined 29.8% from a year ago, and fatalities decreased 30.6%, resulting in a fatality rate per million tonnes of 0.179, a decrease of 26.6% from a year ago. These improvements are attributed to the closure of over 500 coal mines nationwide in 2015. Progress will continue this year, through the closing of smaller, higher risk coal mines (e.g., mines with higher coalbed methane concentrations and mines with production rates below 90,000 tonnes per year).

According to the National Bureau of Statistics of China, for the first half of 2015 China’s coal output declined 5.8% year-on-year to 1.789 billion tonnes. Coal sales volume shrank 8.1% to 1.62 billion tonnes. China imported 99.87 million tonnes of coal in the first half of the year, down 37.5% from a year ago, and net coal imports reached 97.53 million tonnes, a decline of 37.7%.

**India**

India’s Coal Minister, Piyush Goyal, recently told the country’s Parliament that Coal India Limited (CIL) would invest about US$9.7 billion over the next five years to increase the company’s production to 908 million tonnes by 2020. The goal of one billion tonnes per year was not mentioned, and the capital investment outlined in August was dramatically lower than the $20–25 billion CIL capital investment announced by the Coal Ministry in May, perhaps suggesting an informal reduction in the country’s 2020 production goal.

**U.S.**

The U.S. administration released the final form of its Clean Power Plan, which aims to reduce carbon emissions from the power sector by 32%, subject to litigation.

**International**

As this issue went to press, 29 Intended Nationally Determined Contributions (INDCs) had been submitted ahead of COP21, representing 57 parties. For details, visit www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx
WEO Special Report on Energy and Climate Change — International Energy Agency — The IEA has released a special report ahead of COP21 focused on the energy sector’s interactions with the climate negotiations process. The report also proposes a bridging strategy to peak global emissions and highlights the need to accelerate the development of emerging technologies. The full report can be downloaded free of charge from www.iea.org/publications/freepublications/publication/weo-2015-special-report-energy-climate-change.html

Operating Experience of Low Grade Fuels in Circulating Fluidised Bed Combustion (CFBC) Boilers — International Energy Agency Clean Coal Centre, Ian Barnes — The IEA Clean Coal Centre has released a report on fluidized bed combustion, which is becoming increasingly prominent for combusting low-rank coal, biomass, wastes, and combinations of such materials. This report sets out examples of the range of low-value fuels, their reserves and properties, with particular emphasis on coal-derived materials, the issues for CFB plants in utilizing these fuels, and selected examples of manufacturer and operator experience with purpose built, or modified, CFB plants. The report also includes a current global inventory of CFB plants using various low-grade fuels.

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>
</tr>
</thead>
<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
From the WCA

Welcoming New Leadership

The World Coal Association (WCA) recently announced changes in its leadership with the appointment of Benjamin Sporton as its Chief Executive and Mick Buffier as Chairman. The new leadership marks an important change at the WCA, as it repositions itself to more fully engage on the global challenges facing the coal industry.

The WCA Board confirmed the appointment of Mr. Sporton at its Annual General Meeting in London in early June following an extensive international search. He has been Deputy CEO at the WCA since 2012 and Acting CEO since the end of 2014. He has extensive international experience leading the WCA’s policy and advocacy work, with a particular focus on climate change, energy poverty, and sustainable development. He has also led the WCA’s launch of the international Platform to Accelerate Coal Efficiency (PACE).

Mick Buffier is Group Executive, Coal Assets at Glencore, with 35 years’ experience in the coal mining industry in Australia. He has been a Director of the WCA for over four years. Speaking on his appointment, Mr. Buffier said: “This is an exciting time for the WCA. I am confident that with our new leadership we are well placed to play our role in meeting the global challenges facing the energy sector and making a positive contribution to global efforts to reduce CO₂ emissions.

“For many countries, the reality is that the only way they can meet their growing energy needs is through affordable, readily available coal. According to the International Energy Agency (IEA) global electricity from coal is expected to grow by around 33% to 2040. Given this growth, it is essential that there is greater investment in cleaner coal technologies to widen their deployment—this includes HELE coal technologies and CCUS.”

Mr. Buffier is a Director of ACALET, the Australian coal industry’s $1-billion low-emission coal technology fund. He is a former Chairman and a current Director and Deputy Chairman of the NSW Minerals Council, as well as a Ministerial appointee to the NSW Coal Innovation Council. Mr. Buffier is an Associate of the IEA Coal Industry Advisory Board and a peer reviewer of the IEA World Energy Outlook.

Papal Encyclical Demonstrates Need to Address Climate and Energy as Integrated Priorities

In mid-June, Pope Francis released an encyclical outlining his suggestions to address the environmental impact of humans, including climate change. That document made reference to everything from increasing subsidies for low-emission technologies, specifically renewables, to greatly improved energy efficiency. Speaking in response to the publication, Benjamin Sporton, WCA Chief Executive stated: “Pope Francis has highlighted the huge challenge we face in reducing global CO₂ emissions. If we are to significantly cut CO₂ emissions, it is essential that we recognize the vital role of coal in many countries and look at ways to reduce emissions from coal use.”

According to the International Energy Agency (IEA), global electricity from coal is expected to grow by around 33% to 2040. Demand for coal in Southeast Asia alone is expected to increase 4.8% per year to 2035. Global growth will be largely focused in the developing world to meet the needs of the 1.3 billion people who live in energy poverty and 2.7 billion people that do not have access to clean cooking facilities. Coal plays a critical role in bringing affordable, reliable electricity to hundreds of millions of people in developing and emerging economies, particularly across Asia. For this reason, the WCA has repeatedly called on governments worldwide to recognize the essential role played by all low-emission technologies in global efforts to cut CO₂ emissions, including cleaner coal technologies.

All low-emission technologies are needed, including 21st century coal technology, such as high-efficiency, low-emissions (HELE) power generation and carbon capture, utilization, and storage. The WCA believes that the world must focus on practical solutions to meeting global energy needs and cut global CO₂ emissions—they are integrated priorities.

HELE coal technologies are important to deploy as coal usage continues to grow because such technologies provide significant immediate CO₂ reductions and are a key step on the pathway to carbon capture, use, and storage. According to Mr. Sporton, “Pope Francis has highlighted the scale of the challenge we face. It is only by treating climate and development objectives as integrated priorities that we will successfully overcome these global challenges.”

For more information, please visit the WCA blog: www.worldcoal.org/extract/
The World Coal Association has published a concept paper on establishing a global Platform for Accelerating Coal Efficiency (PACE).

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

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

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

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