INTERNATIONAL ENERGY AGENCY
COAL INDUSTRY ADVISORY BOARD

CIAB

40th PLENARY MEETING

DISCUSSION REPORT

IEA Coal Industry Advisory Board Plenary Meeting
OECD Conference Centre
Paris
15-16 November 2018

CIAB PLENARY DISCUSSION SESSIONS

Thursday, November 15th and Friday November 16th, 2018

The *Coal Industry Advisory Board* (CIAB) is a group of high-level executives from coal-related enterprises, established by the International Energy Agency Governing Board in July 1979 to provide advice to the IEA from an industry perspective on matters relating to coal. The CIAB Plenary meeting is held annually and is one of the mechanisms in which CIAB Members provide information and advice to the IEA on relevant energy and coal-related topics. The meeting includes a series of discussion sessions with presentations from external and member speakers on topics of relevance to the industry and a wider audience. This report covers the three discussion sessions discussed at the CIAB's 40th Plenary meeting.

DISCUSSION SESSION AGENDA

"Discussion Session 1: CCUS – Progress & Opportunities
Chaired by Mr Glenn Kellow, President and CEO, Peabody

- **China CCUS Retrofit Study** – Dr Andrew Minchener, General Manager & Mr Toby Lockwood, Senior Consultant, IEA CCC
- **CCUS – IEA Program** – Ms Samantha McCulloch, Head of CCS Unit, IEA
- **CCUS Cost Reduction Opportunities for Coal Power Plants** – Dr Graham Winkelman, Senior Manager BHP Billiton
- **CCS Perspectives Update** – Mr Mike Monea – President & CEO International CCS Knowledge Centre

Discussion

"Discussion session 2: Outlook for Coal & Low Emission Technology - issues, challenges & opportunities – US & Europe
Chaired by Mr Seamus French, CEO, Bulk Commodities & other Minerals, Anglo American

- **US Update & Perspective**
  Mr. Steve Winberg, Assistant Secretary, Fossil Fuels, US DOE
- **Europe Overview & Perspective**
  Dr. Stefan Bockamp, Director Operations, Steam & Biomass - Uniper

Discussion

"Discussion Session 3: Outlook for Coal & Low Emission Technology - issues, challenges & opportunities – Asia and China
Chaired by Mr Colin Marshall, President and CEO, Cloud Peak Energy Resources

- **ASEAN Update & Perspective**
  Dr. Sanjayan Velautham, Executive Director, ASEAN Centre for Energy (ACE)
- **China Update & Perspective**
  Dr. Li Dong, Vice President, China Shenhua Energy

Discussion

Introduction & Overview

The aim of the discussion sessions is to engage the IEA Secretariat, CIAB Members including consumers (particularly the electricity industry), producers and infrastructure/transportation providers, and invited guests, in a discussion concerning major issues affecting the coal industry and its role in effective mitigation of greenhouse gas (GHG) emissions today and in the future. This was especially so following recent IPPC reports concerning the more urgent need to address GHG emissions, especially within the next 10 – 20 years. The three sessions were focussed on CCUS and the outlook for coal and low emission technologies. The first focused specifically on CCUS, associated progress & opportunities during which the level of CCS readiness and the potential impact from a GHG reduction was clear based on existing demonstration projects and lessons learned. Utilisation of CO2 is a major factor hence the greater focus on CCUS and the benefits of CO2 capture **AND** utilisation. With appropriate incentive for technology deployment, development of transport infrastructure and research into CO_2 driven by-products such as hydrogen, CCUS must be taken seriously to address climate change in a 10-20-year timeframe. Discussion Sessions 2 & 3 focused on the outlook for coal and low emission technologies across four key regions. What is clear, is the need for coal-fired power generation to meet demand in developing nations is significant. While there is significant appetite for renewable energy resources the challenge concerns adequate capacity to meet demand. So, coal will continue to play a major role, but the emphasis again must be on clean coal, the adoption of low emission technology including CCUS. In China, the largest emitter of CO_2, there is strong interest and ongoing activity associated with cleaning up its coal-fired power plant, much of which is the most advanced, efficient and cleanest in the world. Older higher polluting plant is being phased out with necessary capacity being taken up by more modern, more efficient cleaner plant. China has some of the most stringent emissions regulation in the world and is investing heavily in cleaner technology including CCUS. However, further incentive is required to give more momentum to CCUS deployment in the short to medium term. Indeed, greater incentive is required to encourage the deployment of CCUS world-wide if there is any chance of addressing the increasingly urgent climate change agenda in the timescales being quoted.

DISCUSSION SESSION 1:
CCUS – Progress & Opportunities

Chair - Mr Glenn Kellow, President and CEO, Peabody

Mr. Kellow opened the first session which focused specifically on CCUS, progress to date and the opportunities that could be realised through effective deployment of CCUS technology. The first presentation, delivered by Dr Andrew Minchener and Mr Toby Lockwood of the IEA Clean Coal Centre provided an overview of a comprehensive piece of work they had undertaken, commissioned by the CIAB concerning a CCUS retrofit case study based on a 1000MWe ultra-supercritical (USC) coal-fired power plant located in China. The second presentation delivered by Ms Samantha McCulloch of the IEA focused on the IEA CCUS program providing the meeting with an update on associated activities, key findings and outcomes. The third presentation delivered by Dr Graham Winkelman of BHP Billiton focused on CCUS cost reduction opportunities with specific reference to learning by doing as gleaned from the Boundary Dam demonstration project. Following on from this, Mr Mike Monea, of the International CCS Knowledge Centre located at Boundary Dam provided greater insight to the project, lessons learned, and opportunities associated with more cost-effective, safe and efficient CCUS technology.

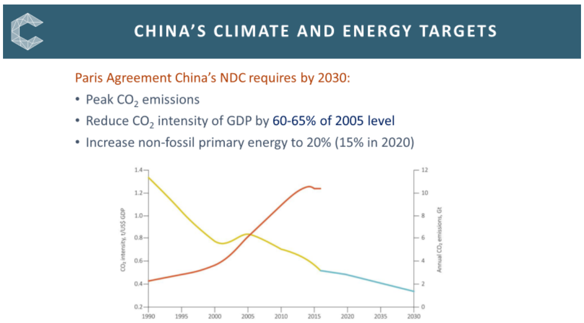
China CCUS Retrofit Study

Dr Andrew Minchener & Mr Toby Lockwood IEACCC

Dr. Minchener provided a brief introduction to the presentation including developments in the Chinese Power Sector, CCUS, the current status of climate and energy policy in China (including drivers & challenges for CCUS), the CCUS retrofit case study and the effect of potential incentives for CCUS retrofit.

In terms of the aim of the study, it was to identify and assess the effect of potential incentives for CCUS retrofit on high efficiency low-emissions coal power plants in China, using NPV and cost of electricity as measures of commercial viability. Dr Minchener summarised the meetings held with various organisations to ensure such a study was undertaken with the necessary rigour and accuracy. Such organisations included China Energy (a CIAB Member), the National Institute of

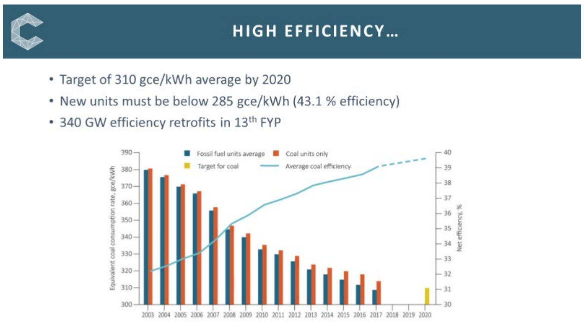
Clean-and-Low-Carbon Energy NICE (part of China Energy), Huaneng Power, the Electric Power Planning & Engineering Institute of China and several others. Reference was also made to China's Climate and Energy Targets in accordance with the Paris Agreement



The current energy mix in China is still heavily dominated by coal with coal making up 55% of installed capacity but 64% of energy generation. There is rapid growth in renewable energy capacity but still a small proportion of generation.

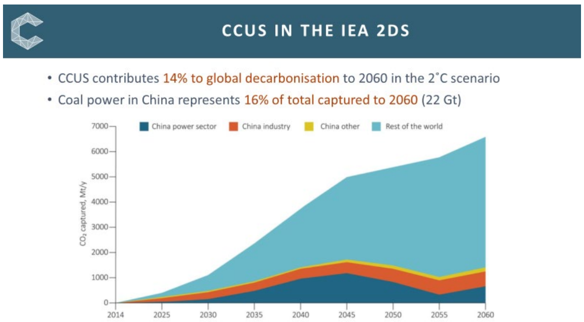
Looking out to 2020 in China's five-year plan, coal is still expected to make up 62% of primary energy consumption and out to 2040 coal generation capacity in terms of TWhs remains constant with other sources of energy set to meet energy demand growth over the next 20 years or so.

Over the past 15 years and again looking out to 2020, China has placed significant focus on increasing the efficiency of its coal-fired power plant with further efficiency retrofits planned



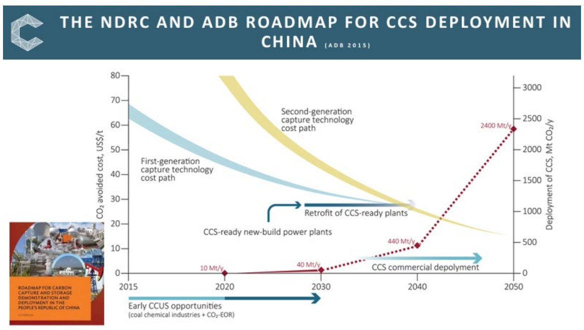
Since 2014, coal units are expected to meet gas plant emissions standards with greater urgency placed on coastal and central regions. Approximately 420GW of retrofit activity is targeted in China's 13th five-year-plan (FYP) and between 2010 and 2016, all coal-fired power plants have been equipped with particulate matter control technology, FGD technology and 92% have SCR technology.

In the context of CCUS, in the 2°C scenario, CCUS, it is projected, contributes 14% to global decarbonisation to 2060 and coal power in China represents 16% of the total CO_2 captured to 2060, representing approximately 22Gt.



CCUS was included in China's National Plan to Address Climate Change (2007) since which there have been various CCUS related activities. This included several bilateral agreements however the financial crisis in 2008 resulted in such agreements collapsing. In 2013 a Notice calling on provinces to develop incentives and regulation which led to a NDRC/ADB roadmap in 2015. Currently there are approximately 7 medium-sized (50-400 ktCO_2/y) EOR related projects operating based on coal-chemicals, natural gas processing and one coal plant-based project. EOR costs associated with chemical plants compared with coal plants are lower hence a stronger focus on chemical plants at present.

China has the largest number of projects under construction or planned according to the GCCSI database. Most are EOR related to help manage project costs with power-sector and saline projects mostly in early development. There is interest in saline acquifer because brime, needed to support this, can be used to produce clean water.



The NDRC and ADB Roadmap previously referenced is a technology roadmap with routes to cost reduction with an aim of commercial deployment from 2030 onwards. If some momentum for commercial deployment can be achieved by 2020 it will best position more intense commercial deployment from 2030. However, CCUS demonstration faces formidable challenges in the absence of targeted support and CCUS demonstration and deployment is essential for cost-effective climate change mitigation.

CCUS needs drivers to incentivise deployment such as revenue streams which will incentivise investment. Others could include a national emissions trading scheme (ETS), a target cap on gCO_2/kWh, higher wholesale tariffs for low carbon plant, similar to those for Wind and Solar. Also, a priority dispatch mechanism therefore, increased load factor on plant equipped with CCUS.

China is currently putting in place a national ETS building on a 7 regional ETS pilot but, applies to the power sector only. The trial period is planned for 2019 with the wider roll-out planned for 2020. No absolute cap on emissions is expected but allowances are likely to be based on energy generation and benchmark emissions. Average CO_2 price is expected to increase to around US$15/t$CO_2$.

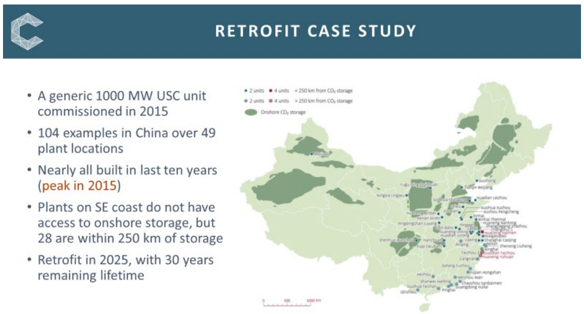
There is potential for cost reduction in China due to lower labour and materials costs although the cost of skilled labour is increasing. There is also considerable potential for mass production when looking at CCUS roll-out across similar unit sizes (600-1000MW) by implementing a centralised modular construction approach.

In terms of barriers to CCUS there are several, such as:

- Limited CO_2 infrastructure (existing projects use tankers or short gas-phase pipelines). Some projects are looking at super-critical phase pipelines.
- Little development of saline aquifer storage
- Stakeholders perceive a lack of high-level political support
- The interaction of CO_2 price with the market can be complex
- Inadequate regulation for storage
- Power companies may not employ CCUS to meet the CO_2 cap

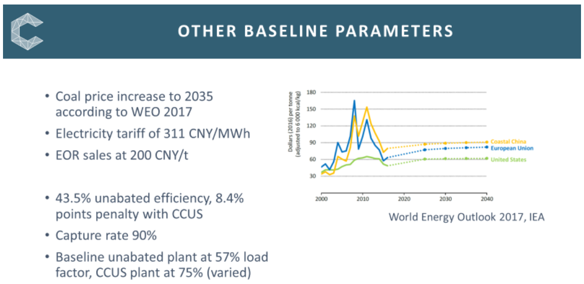
Having set the wider industry, political and regulatory scene in China, Dr Minchener and Mr Lockwood moved the focus of the presentation specifically to the Retrofit Case Study the IEACCC had recently completed for the CIAB.

The Study focused on a generic 1000MW ultra-supercritical (USC) unit commissioned in 2015. This represented a typical unit in China representative of those units which will form the backbone of coal-fired power generation in China for the next 30 years.



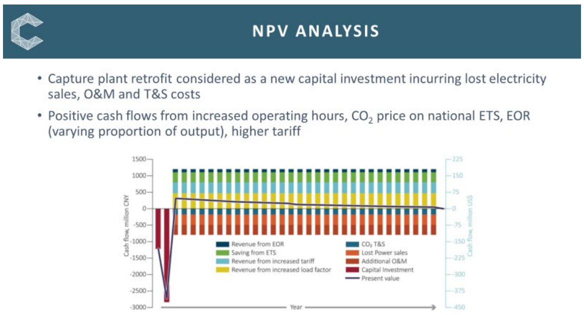
Most power plants equipped with 1000MWe units tend to be two-unit power plants with an overall capacity of 2000MWe. There are more than 49 such plant locations in China with 28 considered to have reasonable access to storage sites.

The baseline parameters for the study were reviewed and included coal price, electricity tariff, potential EOR sales, plant efficiency without CCUS fitted (unabated) and the efficiency penalty with CCUS fitted. Other baseline parameters included capture rate with a rate of 90% used to offer a more realistic condition, and load factor taking into account current load factors and what the load factor might be under preferential dispatch conditions for a plant with CCUS.

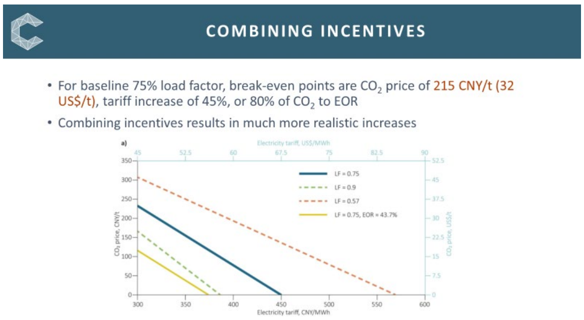


The project focused on an in-land plant location and used cost information associated with capture plant and solvent data obtained from the IEAGHG and Shell Cansolv. The project also assumed two absorber and compressor trains.

In terms of the NPV analysis the capture plant fitted was considered as a new capital investment with associated initial capital costs, lost electricity sales along with associated O & M and T & S costs. Other costs included the energy penalty associated with CCUS retrofit as well as CO_2 transportation costs. With respect to positive cash flow this considered increased revenue due to increased load factor, CO_2 price linked with a national ETS as well as EOR etc.

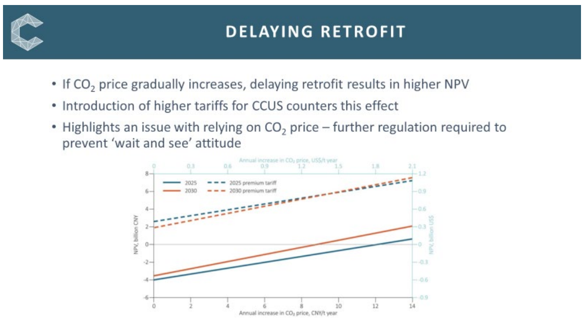


The study considered various incentives, combination of incentives and associated break-even points. It was noted that combining incentives results in much more realistic increases.



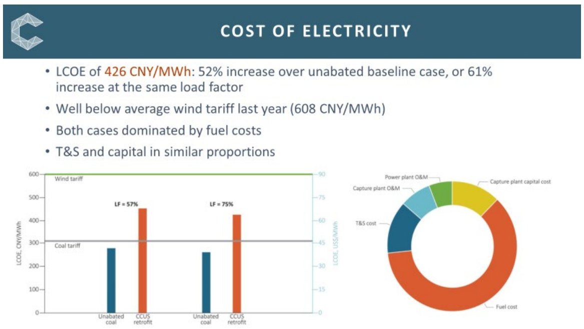
It was also noted that very high volumes of CO_2 to EOR would be required to achieve a break-even in a low CO_2 price situation

The sensitivity analysis considered T & S, capex and the cost of capital. Although impact associated with changes in T & S is not much less than capex there is greater potential for high T & S costs with some uncertainty in China especially with respect to skilled labour. Using commercial power sector cost of capital rates, the baseline assumptions are favourable.

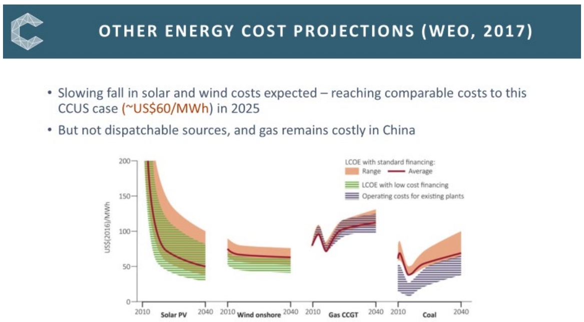


As part of the sensitivity analysis, delaying retrofit was also considered with some interesting points identified in particular with respect to CO_2 price which, if it increased, delaying could result in a higher NPV however, the introduction of higher tariffs for CCUS would counter this. In essence, the analysis highlighted an issue with a 'wait and see' attitude and further regulation may be needed to prevent such an approach to any retrofit decision-making process.

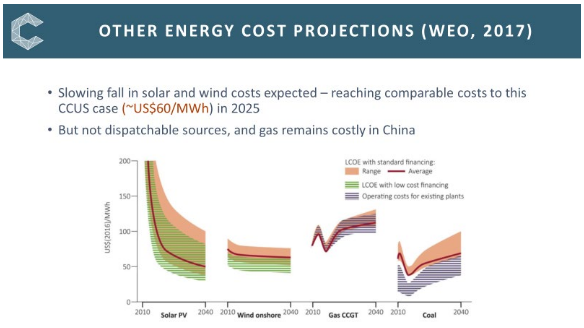
The study investigated cost of electricity related impact with CCUS retrofit. There would be a 52% increase compared with non-retrofit which increases to 61% if considered on a more like-for-like basis in terms of load factor. However, the associated electricity price is still well below the average wind tariff in 2017. Fuel cost remains the dominant factor.



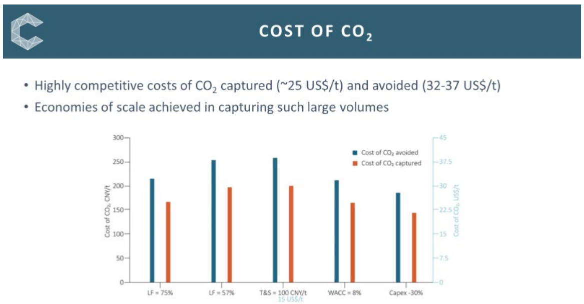
In terms of other energy cost projections (based on the IEA's WEO 2017), the fall in solar and wind technology related costs is expected to slow, reaching comparable costs to the CCUS retrofit case study undertaken. However, the challenge with renewable energy sources such as solar and wind is, they are not a constantly dispatchable source of energy adequate enough to meet ongoing demand. So, given gas remains costly in China, an alternative low carbon dispatchable source is required hence, CCUS.



Revisiting the sensitivity analysis T & S still represents the biggest potential risk however this could be minimised through shared infrastructure. High coal cost could also have a disproportionate impact especially with increased reliance on imported coal as China seeks to develop and improve infrastructure to facilitate greater use of internal coal resource.



With respect to costs of CO_2 captured economies of scale is significant.



In conclusion:

- CCUS on existing large USC power plants could be a highly cost-effective means of CO_2 abatement and power sector decarbonisation along with renewables.
- Retrofit on high efficiency units minimises energy penalty and coal cost
- Capital costs are conservative and not thought to have a major impact on final costs
- Findings of the case study could be applied to a significant proportion of existing fleet in China
- China's high efficiency coal fleet is ideal for facilitating CCS capex and T & S cost reduction through economies of scale with associated knock-on global benefit.

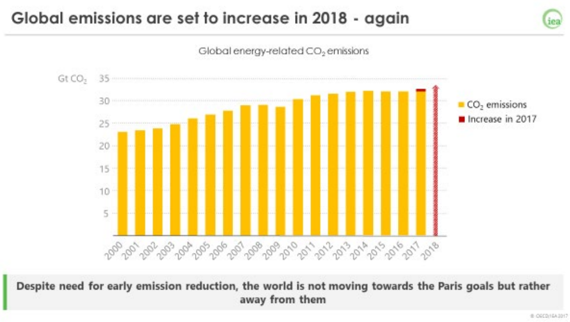
In terms of the outlook for CCUS in China, there are opportunities and challenges:

- China has developed strong R & D capability with focus on EOR & coal-chemicals
- More needs to be done in the power-sector and in saline aquifer characterisation
- There's some political support for large projects but CCUS is not seen as necessary to meet 2030 climate targets so, not a priority.
- Acceleration in policy action and climate targets are needed
- China's ETS is an important signal but not enough on its own to incentivise investment
- Electricity tariffs are believed to be the most promising driver for CCUS deployment, but more is needed.
- Prioritisation is required for storage characterisation through 'capture ready' legislation
- Greater international action on CCUS and continued collaboration with China on large projects is required.

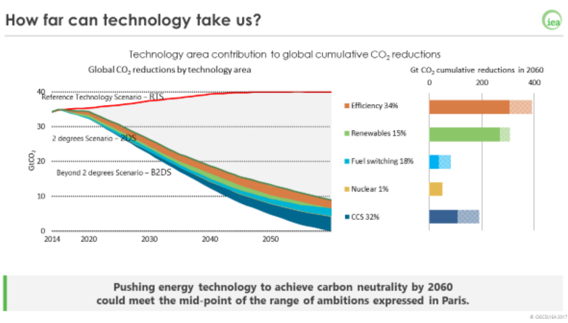
IEA CCUS Update

Ms Samantha McCulloch IEA

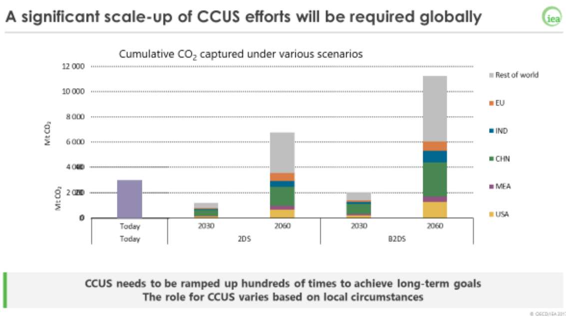
Ms. McCulloch set the context for her CCUS update mentioning the increased focus at the IEA on CCS with energy sector CO_2 emissions increasing and the struggle to break increased development, demand and emissions reduction with a further increase in 2018. Instead of being on a path to achieving the Paris climate change targets, the world is moving away from them.



Technology has a role to play but how far can technology resolve the situation currently being faced? The Reference Technology Scenario (RTS) considers current and announced policy measures including those in National Determined Contributions (NDCs) in the lead up to the Paris climate negotiations. This would see average future temperature increase to around 2.7°C by 2100. While not consistent with climate ambitions, the RTS still represents a significant shift from a historical business as usual approach. However, it's clear a mix of technologies is required, with energy efficiency having greatest impact, followed by renewables then CCS. There is no one-single answer.

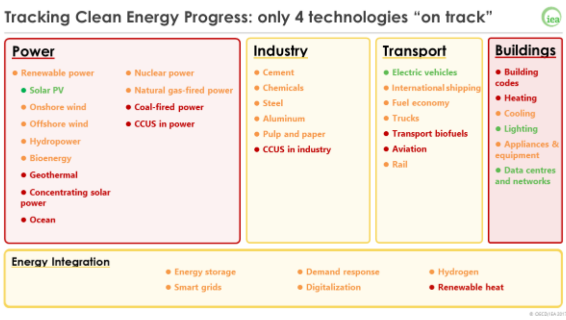


The importance of CCUS should not be underestimated as part of a technology mix. In the scenario presented, energy efficiency remains significant however CCUS becomes more important. That said, a significant scale-up of CCUS efforts is required on a global basis. Getting onto the 2DS pathway would mean reducing cumulative CO_2 emissions by approximately 760Gt.



The Beyond 2 Degree Scenario (B2DS) is still technically feasible but requires a fundamental and immediate shift in global action.

Ms McCulloch mentioned an annual clean energy progress tracking report which she launched recently at the Clean Energy Ministerial meeting. The report tracks progress associated with key technologies against the Strategic Direction Statement (SDS) in 2030. What the report identified is not good.



Of 38 technologies monitored, only 4 are on track, 23 require improvement and 11 are completely off-track. The positive progress in the areas of solar PV, electric vehicles, lighting and data centre energy management cannot make up for the lack of progress across the system, as illustrated by the ongoing rise in emissions. CCUS in the power industry is among those that are well off-track.

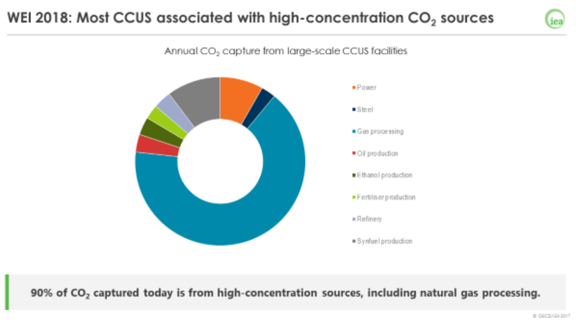
With only two large-scale carbon capture, utilisation and storage (CCUS) power projects in operation at the end of 2017, with a combined capture capacity of 2.4 million tonnes of CO_2 per year, CCUS in power remains well off track to reach the SDS target of 350 million tonnes per year by 2030. CCUS in industry and fuel transformation is also not on track to meet the SDS target. The 15 large industrial projects operational today have a potential annual capture capacity of only around 28 $MtCO_2$.

In terms of CCUS funding, in most regions, the lack of investment reflects the absence of consistent and effective policy to support CCUS. Between 2007 & 2010 governments pledged funding support of the order of US$30bn of which only 15% has been spent, much of which on capital grant programmes. There are several reasons for this:

1. Many large integrated facilities have proved costlier and more complex than first thought. Appropriate allocation of risk across the value chain has been a challenge.
2. Poor programme design. Many programmes not designed with enough flexibility to support large investments in integrated first of a kind facilities and therefore unrealistic funding deadlines.
3. Most programmes offered limited or no operational support to offset the higher operating costs of CCUS facilities

If CCUS is to make the significant contribution it can make, deployment support such as policy, needs to be addressed urgently. **To put into context, the level of funding support for CCUS in the last 10 years is equal to 3% of the support given to renewable energy in 2016 alone.**

Limited policy support means investment has been predominantly focused on industrial applications with high CO_2 concentration schemes. Such facilities account for more than 90% of CO_2 currently being captured, 70% of which is in North America.



Lower capture cost combined with CO_2 related revenue from EOR and the availability of infrastructure has significantly lowered commercial barriers to investment with respect to industry.

Continuing the industry theme, according to WEO 2018 low cost opportunities are available in industry where 450Mt CO_2 could be captured for use or storage with an incentive of less than US$40/t.

Reference was also made to the 45Q tax credit in the US which it is believed, could be a game changer for CCUS and is considered an excellent example of incentivised policy.

There are 5 key activities which could help unlock necessary investment in CCUS:

1. The harvesting of low-hanging fruit, to build CCUS deployment and experience from the ground up
2. Tailored Policies to support CCUS through early deployment phase and to help address integration challenges
3. The targeting of multiple pathways to reduce costs from technology innovation to progressive financial mechanisms
4. Build CO_2 networks to better support transport and storage options
5. Strength partnership, collaboration and cooperation between industry and government.

Ms McCulloch referenced the International CCS Summit to take place in Edinburgh later in November and the COP 24 meetings in Poland. She was encouraged by the level of engagement from industry and government across the globe expected at such meetings as well as a strong delegation from the financial sector.

.

CCUS Cost Reduction Opportunities for Coal Power Plants

Dr. Graham Winkelman, BHP Billiton

Dr. Winkelman opened by referring to the wealth of information gathered and now available suggesting opportunities for significant cost reduction associated with CCUS. Following on from the CCUS study presented earlier, information available suggests a real pathway to CCUS deployment and adoption. Greater cost savings than expected 10 years ago and even 5 years ago are being highlighted.

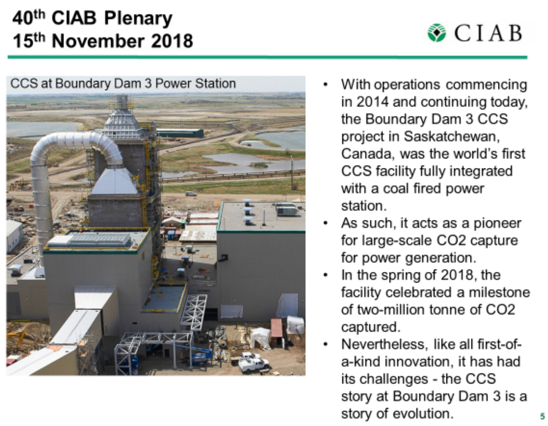
In providing an overview to this part of the CIAB 2018 work programme, Dr Winkelman referred to cost often being one of the major barriers to CCUS deployment. Now there is evidence to back up what was earlier thought in terms of cost reduction opportunities. The study will identify where such cost reduction opportunities reside, and associated analysis will include technology, engineering, project structure, policy, financing and other factors associated with cost reduction.

The report is not yet ready for publication, this will take another 3 months or so to complete but it will feed into the IEA business model / analysis.

Given the recent IPCC report, now is a good time to understand CCUS cost reduction, given the importance of CCUS especially taking into account the more immediate challenges surrounding climate change. To give policy makers and the finance community greater confidence in the potential for CCUS to deliver meaningful emissions reduction, a deeper more rigorous understanding of associated costs and potential for cost reduction, is required.

There has been much work undertaken and reported in the context of cost reduction however, the report associated with this project has one distinctive advantage – it is based on real build and subsequent operational experience, i.e. based on 'learning by doing'.

The Boundary Dam CCS retrofit project has been and is central to data and experience gathering. The world's first CCS facility fully integrated with a coal-fired power station has been operational since 2014. Earlier this year the milestone of 2mtCO_2 captured was passed. However, as a first-of-a-kind project there have been challenges and lessons to learn but, it's a story of evolution.



As is often the case in the next-of-a-kind, lessons learned are applied generating associated efficiencies resulting in updated designs and approaches etc.

Early indications suggest that 30% savings could be realised should a similar project be undertaken today. Further, recent findings from feasibility studies undertaken by the International CCS Knowledge Centre (based at Boundary Dam) indicate the potential for significantly deeper cost reductions. For example:

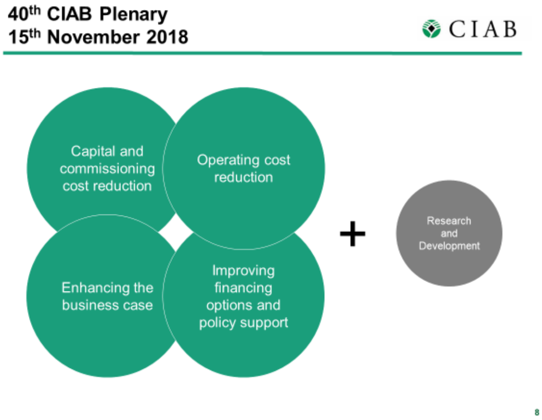
- Capital costs could be reduced by 60%
- Capture rates of 97% have been achieved at various loads, not just full load operation. The ability for a coal power plant to ramp up and down is key and performance experienced at Boundary Dam has been incredible
- The cost of capture is as low as US$45/t

In terms of the report being produced as part of this element of the CIAB 2018 work programme, it is intended to be a summary and not an exhaustive document. The intention is for it to be useful for non-experts including policy-makers.

The report will focus on strategic high-impact information such as:

- Estimate of current costs
- Summary of work to date
- Potential savings now and in future
- A clear link to real lessons learned, not just theory.
- A view on what could be achieved by 2025
- To validation statements and claims made

The report will be structured around four key themes with further research and development adding additional value.



Taking each of these themes in turn:

Capital & Commissioning Cost Reduction

The current Boundary project is based on a 140MWe unit however, increasing scale to say 300MWe as is planned for the next project at Shand delivers significant difference in terms of capital cost and associated cost reduction on a per MW installed capacity basis.

Other areas of improvement include:

- Improved integration between the power plant and the CCS plant
- Modular construction
- Reductions in unit outage time during commissioning
- Improved use of available space

Operating Cost Reduction

- Reduced amine consumption. The Boundary Dam experience highlighted amine maintenance costs but also the ability for amine regeneration
- Reduced water consumption
- Reduced parasitic load
- Reduced maintenance costs
- Reduced labour through improved automation
- Improved isolation control and plant redundancy. Boundary Dam highlighted the importance of building in redundancy and appropriate isolations from the start

Enhancing the Business Case

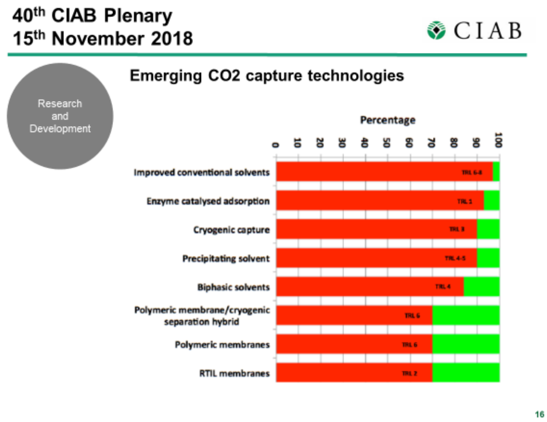
A key lesson learned is the need for consistent CO_2 supply for markets such as EOR. Single source CO_2 does not meet the reliability needs of the oil industry. So, for effective CO_2 utilisation and sustainable markets a CO_2 network needs to be considered with several power plants or industrial sites feeding into that network thereby minimising risk of supply interruption due to plant failure or plant maintenance related issues.

Financing Options & Policy Support

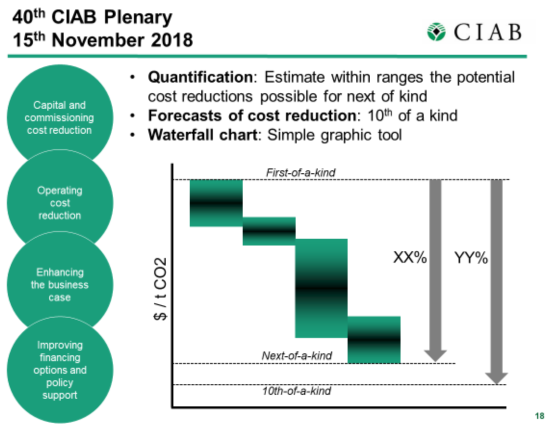
Policy incentive is key. The more projects that get approved the greater the opportunity for cost reduction, reduced risk and a more sustainable financing model. The reformed 45Q policy in the US is seen as an excellent example of policy support and the report will include a case study of similar policy-based incentives.

Research & Development

In addition to learning by doing, ongoing research and development is essential. The IEA is already working on a review of CO_2 capture technologies and associated technology readiness levels (TRLs) etc so, this report will not look to duplicate what is already being done elsewhere.



The report will focus on other innovative technologies such as the Allam Cycle to help illustrate areas for further improvement to help encourage and facilitate the necessary, policy and investment needs etc.



With the necessary policy incentive supported by fact-based research, development, demonstration and operational experience it is possible to drive down the cost of CCUS significant as is already being demonstrated at Boundary Dam and the development of the larger Shand project.

The report, expected to be published early in 2019 will deliver the following:

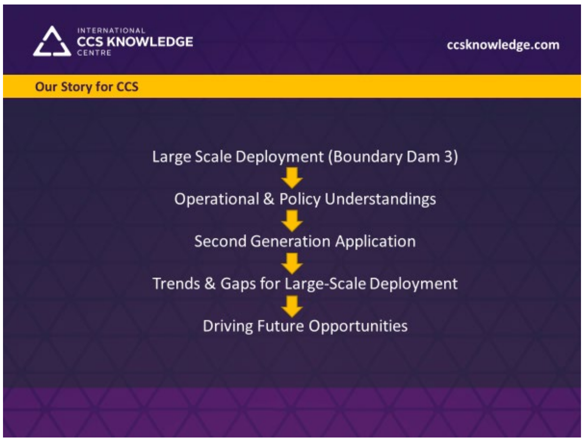
- A positive view of cost reduction potential for CCUS in the power sector.
- Present analysis and conclusions as an evolution of knowledge from theoretical basis to evidence-based.
- Increase confidence in the ability for CCUS to play a significant role in the power sector.
- Contain reference to the applicability of these cost-reduction outcomes to other areas of application of CCUS, including industry

CCS Perspectives Update

Mr. Mike Monea, International CCS Knowledge Centre

Mr Monea provided some overview and background to the International CCS Knowledge Centre located at Boundary Dam. The mandate of the Centre is to advance the understanding and use of CCS as a means of managing greenhouse gas emissions. It is sponsored jointly by BHP and SaskPower. The Centre operates in an advisory role and facilitates and disseminates information based on expertise and lessons learned.

Mr Monea provided a brief resume of the Boundary Dam CCS story to date. The plant was an ideal candidate as a first-of-a-kind trial. Its proximity to a saline aquifer to facilitate the storage element of the trial and access to oil exploration sites to facilitate an EOR trial meant it was possible to gain a holistic overview. This in turn allowed lessons to be learned from a much broader perspective.



The post-combustion technology was chosen from several studies and has been operational since 2014. The technology had a projected capture rate of 90% and a 30-year life with associated life-extension of the power plant. The initial investment was approximately CDN$1.5bn with the captured CO_2 to be used for EOR plus storage or stored in a saline aquifer.

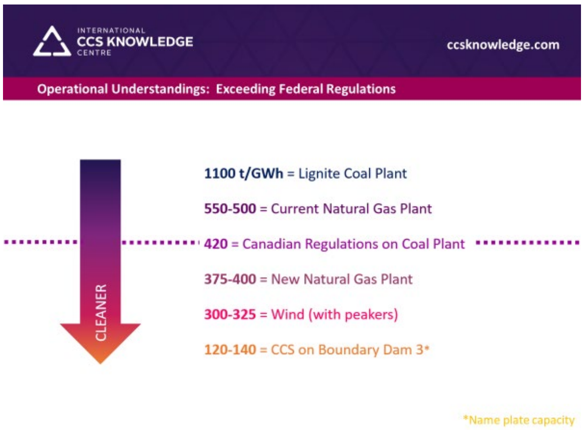
Above anything else a key performance factor associated with the trial was safety of operation and safety associated with CO_2 storage. On both counts, safety has been proven and generated greater confidence in what can be achieved safely.

In terms of project cost having a ‘capture’ island and a power island was the biggest influencing factor. This would not be repeated in any future project and has been a key element of the learning experience. In future, a modular approach to design and construction would be adopted with associated significant cost savings.

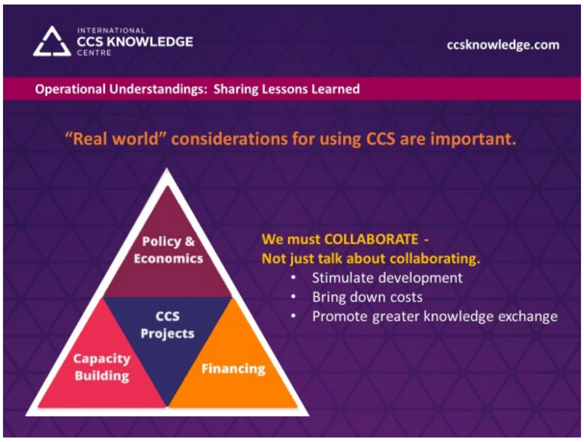
From an operational experience perspective, performance is exceeding expectation and Federal Regulations

For example:

- Actual capture performance can reach 97% compared with the expected 90%
- The power plant has demonstrated the ability to load-follow, which is often necessary to support the intermittency of renewable energy



However, one of the big take-aways is Boundary Dam with CCS is cleaner than wind if the need for peaking plant is taken into account to deal with wind output intermittency, to meet demand. If the fact that fly-ash associated with Boundary Dam is used for cement and concrete production is also taken into account, the CO_2 footprint is even lower because it offsets CO_2 in the cement production process thereby making Boundary Dam almost carbon-neutral.



As referenced by other speakers during the discussion session, collaboration is key to stimulate development, further reduce costs and promote greater knowledge exchange. All of which will help facilitate key drivers of policy, financing, capacity building and greater deployment of CCS/CCUS. Mr Monea pointed out that to date representatives from 50 countries have visited the plant with delegates from China visiting on a regular basis.

Key learnings from the Boundary Dam project are now being applied to the next-of-a-kind project at SaskPower's Shand Power Station, currently going through the feasibility stage.

Based on the Boundary Dam experience it is already anticipated there will be a 90 – 92% reduction in energy penalty. There could be between three and five-times reduction in operating cost through improved management of amines and amine degradation which, based on the Boundary Dam experience, can be corrected. In effect, what has been learned is amine degradation can be managed by tweaking of the solvent as it interacts with the flue gas.

The Shand project is also projected to capture 2Mt/y of CO_2 with a capital cost anticipated to be 67% less than Boundary Dam. It is also expected the cost of capture will be US\$45/tCO_2 with a capture rate up to 97% even at reduced load when combined with renewable energy source also on the grid.

During his presentation Mr Monea referenced the IPCC's 5th Assessment Report where, in the context of CCS the median increase in mitigation cost is referenced as 138% without CCS. Further, almost all IPCC 1.5°C pathway scenarios include CCS.

From an energy security perspective, reliable and affordable energy with reduced emissions are imperative. Implementation of CCS can allow existing generating assets to operate cleanly and aid the decarbonisation of industrial emissions.

Based on the Boundary Dam experience it is believed CCS technology is largely proven in such a way as to significantly de-risk deployment elsewhere.

There is now a real need for multi-lateral bank involvement, less emphasis on test facilities and more focus on full scale build projects. The Asian market is a key area of opportunity there could also be more opportunity in the US based on 45Q related action.

In terms of opportunities and observed trends elsewhere, these were summed up as follows:

China

- Asian Development Bank support
- Various test facilities & pilots in progress
- Opportunities through improved modularisation and lower labour costs
- 2050 INDCs to consider CCS

Canada

- Hubs for infrastructure
- Output based pricing system
- Conversion-type activities gaining momentum

US

- The 45Q based incentive with prices of US$50/t$CO_2$ stored and US$35/t on an EOR basis being quoted.
- Regional agreement opportunities

Industrial based Opportunities

- Fertilisers
- Cement
- Iron & Steel

In terms of driving and incentivising future opportunities four key areas were outlined.

1. Cooperation & Collaboration – multi-stakeholder initiatives, government & private partnerships
2. Improved articulation of the business case, illustrating key areas of value and return
3. Reduced administrative burden such as modification of existing legislation rather than new
4. Incentives & Financing – Supporting early adopters to facilitate fast-track learning, policy-based incentives, creation of financial incentives

The importance of learning by doing has been demonstrated to great effect through Boundary Dam which has opened up opportunity through key lessons learned in a way that no other CCS related project has to date.

Discussion

Following completion of Mr Monea's presentation, Discussion Session Chair, Mr Glenn Kellow briefly summarised what been presented with some key take-aways:

1. The CCUS Retrofit Study undertaken by the IEACCC on behalf of the CIAB illustrated a pathway to CCUS deployment in China and elsewhere
2. The IEA update offered some enlightening insight into current alignment (or lack of) with the Paris climate agreement, the status of clean energy technologies and the significant role for CCUS
3. The CCUS Cost Reduction project outlined significant areas for cost reduction based on learning by doing which should be a further motivating factor for wider CCUS deployment
4. Backing up the opportunities for CCUS cost reduction was an excellent practical and tangible example placing fact-based data much of which exceeded expectation.

Mr Kellow then opened the floor for questions to all presenters.

Some clarification was sought regarding the CO_2 capture cost of US$45/t quoted by Mr Monea based on the Boundary Dam experience. Did this figure consider the complete process through to CO_2 compression? Mr Monea clarified the figure quoted does not include pipeline related costs or revenue from storage or EOR related use. So, it considers all costs (capex & opex) up to compressor outlet and also takes into account lost generation capacity due to capture plant parasitic load.

There was also a comment regarding the emissions/GWh performance associated with Boundary Dam and the suggestion performance exceeded that of wind technology when considering the need for back-up peaking plant. It was suggested a rethink of how dispatch of a CCUS equipped power plant is managed and that it shouldn't just be a back-up for wind. It was also commented that capture performance at Boundary Dam, when operating at base load, can increase from 90% - 97% at no additional cost.

In a broader context considering all four presentations, the point was made regarding the importance of ‘U’ in CCUS because storage alone is not going to be a widely accepted option. However, ‘utilisation’ must go beyond EOR and therefore CO_2 conversion related projects should be another key area of focus when considering utilisation. Scaling however, was recognised as a key challenge when considering wider CO_2 conversion options.

Continuing the theme of CO_2 conversion, the importance of H_2 as by-product and the associated business case is an area that should be given greater consideration and focus. In response there was general agreement and the IEA commented this was a key area of focus for them as part of their ongoing work programme.

DISCUSSION SESSION 2
Outlook for Coal & Low Emission Technology – Issues, Challenges & Opportunities – US & Europe

Chair – Mr Seamus French, CEO, Bulk Commodities & Other Minerals, Anglo American

Mr French provided an overview to the session commenting, for the first time the industry is getting a sense of change of sentiment toward CCUS, almost a mindset change compared with previous years with greater emphasis on how to make CCUS happen, cost reduction and policy change etc. He then proceeded to introduce the presenters in Discussion Session 2; the first being Steve Winberg, US DOE and Dr Stefan Bockamp, Uniper.

US Update & Perspective

Mr Steve Winberg, US DOE

Mr Winberg set the scene for his presentation outlining the current US administration's energy priorities following the wider US first plan, with focus on:

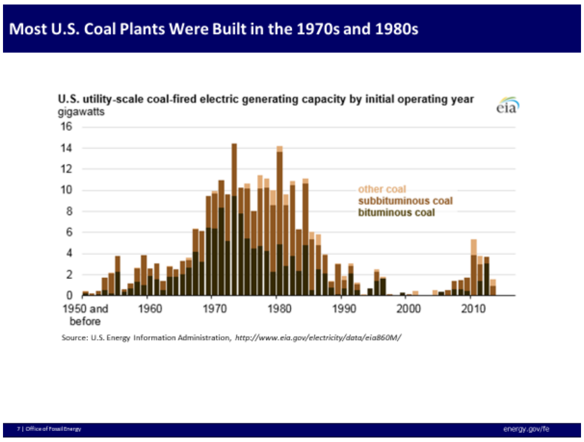
- Boosting domestic energy production
- Grid reliability and resiliency
- Job creation
- Energy security

He made it clear that his presentation and associated comments would be restricted to coal and CCUS.

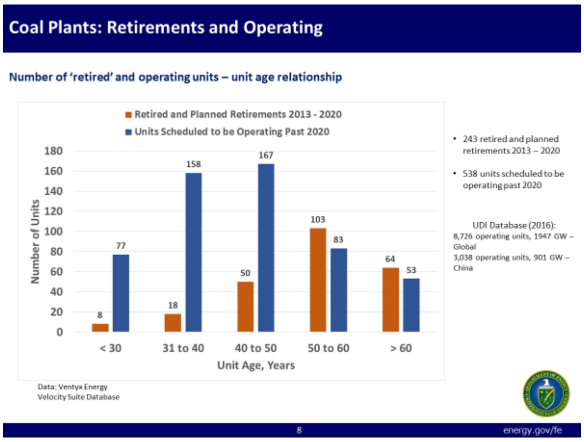
With respect to US energy-related CO_2 emissions, there had been a 14% reduction between 2005 and 2017 with little by way of increase over the next year or so. In terms of the US electricity sector specifically the reduction in CO_2 emissions was even greater at 25% predominantly due to increased use of natural gas. This is set in a context of global energy-related CO_2 emissions increasing by 21% over the same time period.

As per projections offered by others such as the IEA and already referenced during the meeting. The US EIA is in broad agreement that worldwide use of coal will continue but the trend will be flat out to 2040. Thus, reinforcing the point that reducing emissions of CO_2 is a global challenge.

Most coal-fired power plants in the US were built in the 1970s and 80s so, most are 30 – 40 years old.



In recent years there has been a decline in coal consumption in the US and the current administration is looking to slow that rate of decline.

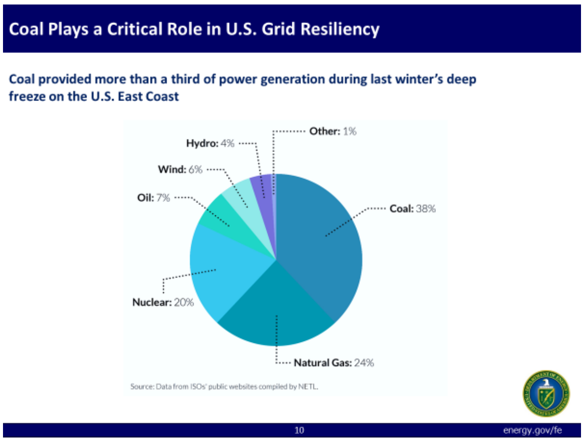


Coal plant closure and the associated decline in coal consumption has not been solely driven by increased uptake of natural gas for power generation but also by environmental regulation impacting on both the mining and combustion of coal.

Higher costs associated with mining and combustion have also accelerated coal-plant retirement and New Source Review in the US is hampering the uptake of new technologies.

Coal-plant capacity factors have also declined due to increased use of natural gas but also due to plant age. Coal-plant is now having to operate in a more flexible manner and cycle to stay in the market as well as support the intermittent nature of renewable energy with associated impact on component life.

Coal continues to play a critical role in US grid resiliency and recently coal plant was called on in a major way during a deep-freeze experienced in particular in the northeast region of the US. As plant retirements continue, problems associated with maintaining grid resiliency will become more acute.



Reserve margins are becoming tighter with associated impact on peak power prices becoming even more acute in winter.

Much of the current power plant operation is based on interruptible natural gas which can be cut to power plants during severe winter periods with associated impact on power generation capacity.

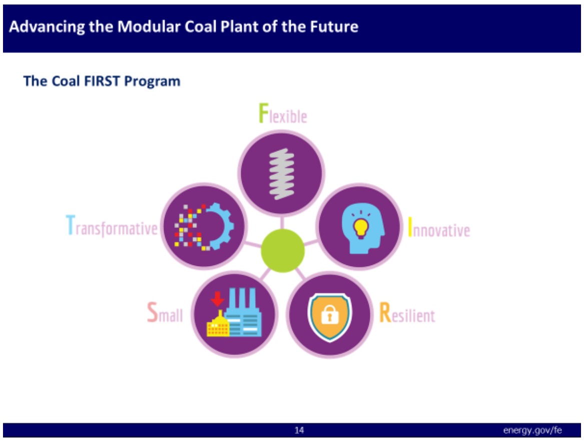
The current US administration has rolled back some of the regulation that was impacting on coal, in particular, the electricity generation sector as well as the mining industry. Key actions include:

- Affordable Clean Energy (ACE) to replace the Clean Power Plan (CPP) which will help facilitate the upgrading of existing plan - In the proposed stage.
- Revoking the Federal Coal Moratorium - In final stage
- Revising the EPA Coal Ash Rule – In final / ongoing stages
- Revising EPA Regional Haze Requirements – Ongoing
- Revising the EPA MATS Rule – Ongoing
- Delaying effects of the EPA Steam Electric Rule – In final stages

With respect to upgrading the existing coal fleet emphasis is being placed on advancing and demonstrating technologies such as topping cycles which can improve efficiencies by 5% and cycling capability to improve the economics of operation. Also, there is focus on advanced materials and processes to improve efficiency and reduce emissions.

From an advanced coal technologies perspective, Mr Winberg outlined the US Coal FIRST Programme to advance what is referred to as the Modular Coal Plant of the future.

The US DOE has issued a request for proposals (RFP) for pre-FEED studies looking at transformational technologies with modular coal units being of 50 – 350MW in scale and >40% efficiency that are also nimble, flexible and with near-zero emissions.



The Coal FIRST Program focuses on five key elements

1. **F**lexible
2. **I**nnovative
3. **R**esilient
4. **S**mall
5. **T**ransformative

The benefits associated with the modular approach were summarised as follows:

- Modular power plants can be created from 'building blocks'
- Pre-constructed systems only need to be connected to other systems
- Smaller component size simplifies transportation
- Modularisation allows any changes and modifications to be made in a fraction of the time.

In terms of the challenges these were summarised as follows:

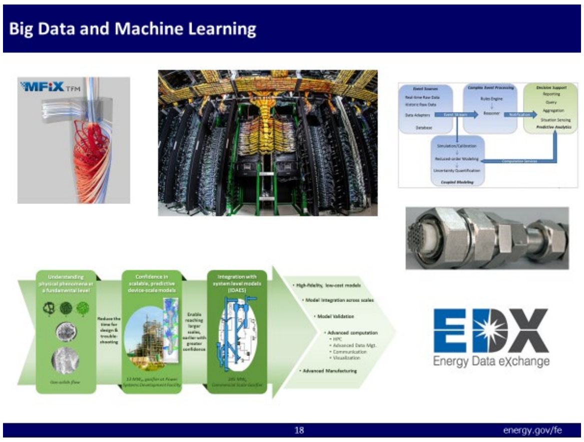
- Limited size and operating conditions of products made via Additive Manufacturing and lack of designs using AM products
- Modelling tools are still in early development
- Advanced technologies require further development

From a manufacturing improvement perspective, an example is the use of 3D printing techniques for key components whilst at the same time building in key sensor technology, e.g. oxy-pressurised combustion.

Various impacts of modularisation from a fleet perspective were reviewed in terms of technology, business and environment touching on key points such as higher availability and lower maintenance costs; lower finance risk, plant footprint reduction and associated GHG emission reduction.

In terms of the pre-FEED studies and associated RFPs recently issued, the key funding opportunity announcements cover plant areas such as steam turbines, critical components for which there are two funding announcements which will involve pilot studies and staging projects. There is also a FEED funding opportunity announcement.

Key to meeting the necessary timelines is 'big data' and 'machine learning'.

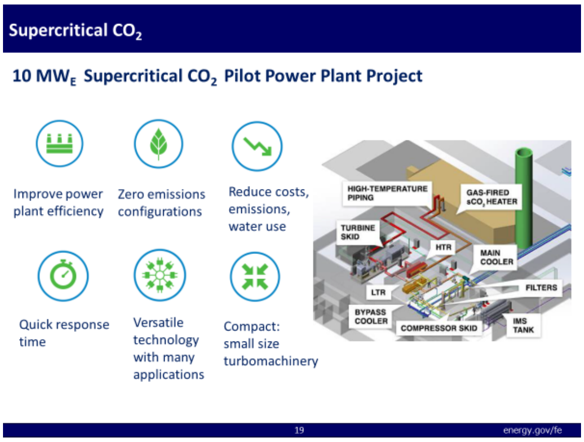


Cyber security is also key as these modular units are constructed with built-in sensor technology and appropriate control system integration.

Another area of development concerns supercritical CO_2 with the Gas Technology Institute (GTI) in the US the main contractor associated with this project.

The current project comprises a 10MWe supercritical CO_2 pilot power plant focusing on 6 key areas:

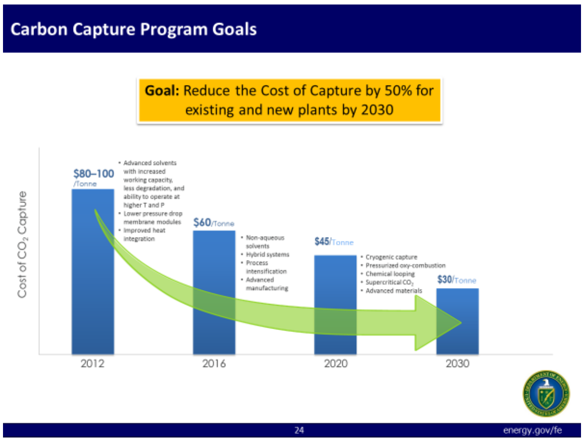
1. Improved efficiency
2. Zero emissions
3. Reduced cost and water use
4. Quick response time
5. Technology versatility
6. Compact



Mr Winberg then shifted focus to CCUS and the US DOE investments in CCUS. Between 2016 and 2019, the annual spend is around US$200m per year and for years 2018 and 2019, associated programmes are fully funded. Focus is on carbon capture, CO_2 utilisation and storage. Mr Winberg made it clear the US is very much in the game of CCUS, referencing three current projects:

- Air Products, Port Arthur, TX, which began operations in 2013
- Petra Nova CCS (Thompsons, TX), which began operations in 2017
- ADM Ethanol Facility (Decatur, IL) which began operations in 2017.

Addressing the cost of capture forms a major part of the CCUS programme with the goal being to reduce the cost of capture by 50% for existing and new plant by 2030.



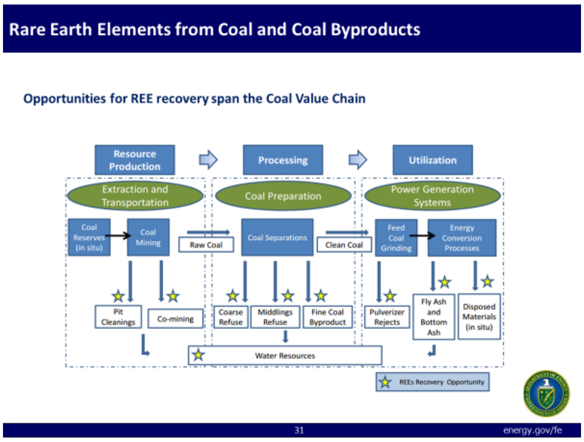
In terms of CO_2 use and re-use the US is looking into several areas to help offset the cost of capture and "fix CO_2 in stable products". Key areas include biological capture and conversion, fuels and chemicals, mineralisation and cements, investing in novel catalysts and advanced catalysts that could commoditise CO_2.

Policy based incentive is another key tool being looked at with the proposed 45Q tax credit mechanism. The US Internal Revenue Service (IRS) needs to write some rules around 45Q but once completed it is believed this will help provide more momentum to real CCUS deployment.

Mr Winberg outlined some excellent outreach related work referring to examples such as the Regional Carbon Sequestration Partnerships (RCSPs) and others such as CarbonSAFE and brine extraction storage tests (BEST)

He also referenced the greater global need for CCUS and the Clean Energy Ministerial Initiative and US involvement in such international collaborations. He commented on the convergence now being witnessed of coal, oil and gas industries regarding CCUS which could be hugely beneficial through cross-industry experience and knowledge sharing. The National Petroleum Council is about to issue a study on CCUS.

Expanding and highlighting the value chain of coal and associated benefit will help bring coal back to the fore in terms of meeting national and global energy needs.



Rare Earth Elements (REE) from coal and coal by-products is a further illustration the value coal can deliver if used responsibly across the three key process areas i.e. resource production (taking account of extraction and transportation); processing (taking account of coal preparation) and utilisation such as power generation systems.

Discussion

A couple of points were raised during discussion:

1. There is significant value to be realised by thinking ahead with the respect to the use and value captured CO_2 can deliver. Based on the Boundary Dam experience, Mr Mike Monea made the point that opportunities had been and will be missed because of learning after the event. Had more been known beforehand much more would have been done during the project-planning phase.
2. If natural gas prices increase to around US$5/MBtu then coal could be back in the mix. History illustrates the volatility of gas prices and therefore the importance of coal in supporting demand management.

Europe Overview & Perspectives

Dr Stefan Bockamp, Uniper

Dr Bockamp outlined the current challenging situation facing the future use of coal in Europe.

In accordance with the Paris agreement, the EU has committed to a 40% reduction in CO_2 emissions by 2030, compared with 1990 levels. The mechanisms to deliver this are targets for renewable energy and energy efficiency plus carbon pricing.

The EU Emissions Trading Scheme (ETS) has been in place since 2005. This has seen a surplus of emissions dampen carbon price. The introduction of the Market Stability Reserve (MSR) allows excess allowances to be removed thereby strengthening the signal. Over the past year a significant increase in carbon price has been witnessed. The absence of a strong signal created space for additional national interventions such as the UK Carbon Price Support.

Several countries across the EU have announced coal closure plans:

- The UK government has set out plans to end electricity generation from coal-fired power plant by 1st October 2025
- In France, the government announced its objective to close such plants by 2022
- In the Netherlands, the government published a legal draft of the “Coal Prohibition” Act with coal phase out via legal prohibition by the end of 2029 at the latest
- In Germany, a commission was launched earlier this year to develop a step-by-step plan to facilitate reduction in coal-fired power generation. The final recommendation of the commission is due by the end of December 2018.

A key challenge for plant owners and operators in countries with declared positions on coal phase-out is getting the necessary work force and technical support for plant with such a relatively short life horizon.

In terms of Uniper’s position on coal plant closure, Dr Bockamp summarised this as follows:

- Uniper is not calling into question the phase out of fossil fuels. Lessons have been drawn from the nuclear power experience and there is no intention of operating in a manner that runs counter to the social consensus.
- Uniper is however, mindful of its responsibility to safeguard the legitimate interests of its employees and shareholders. This involves offering a sense of security and an expectation of future prospects. Avoiding losses in value in any form is key given the risk they can pose to company viability and future opportunities. Also, in addition to power, Uniper power plants provide services relating to grid stability, steam, delivering heat and supplying power to support infrastructure such as railways.

Dr Bockamp then made reference to BREF; the BAT Reference document with BAT being best available technique. Although coal-fired power plant is being phased out in some areas of the EU, such plant still needs to meet the requirements of BREF and be operated and maintained accordingly.

In essence the BREF document specifies the best available techniques for each plant type and each pollutant along with the level of performance that can be delivered by each technology. BAT conclusions specify expected “BAT-Associated Emission Levels”. These are set as ranges so there is a high-end and a low-end. BAT conclusions are subject to political approval. Such approval is published as a Decision of the European Commission, it then starts a four-year clock (maximum) for limits to be adopted and embedded in permits to operate and therefore to make the necessary plant investment to ensure compliance. In the current BREF, new emissions limits must be achieved by August 2021.

Dr Bockamp also explained that BREF is created within a framework of the European Industrial Emissions Directive (IED – 2010). The IED changed the status of the BREF document from advisory to mandatory.

Uniper has undertaken a lot of work and associated investment in the area of coal plant operational flexibility with some plant achieving a minimum load level of 15% operating on one mill. This has presented some challenge but pushing the envelope of minimum load to stay in the market for longer and reduce the need for plant to come off load is key. Another area of significant focus has been two-shift operation at minimum cost, with minimal plant stress and associated investigation into the understanding and reduced failure likelihood of plant damage mechanisms.

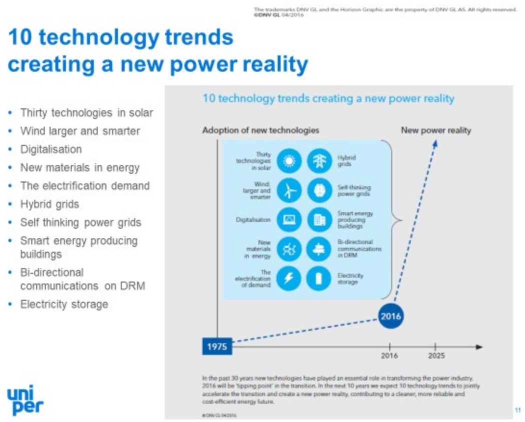
From a national implementation perspective BREF emissions limits are expressed as ranges. These are intended to deal with situations where coal plants are located in close proximity therefore having a cumulative environmental impact. However, national authorities can implement the strictest or least strict set of rules within the legal ranges set by the EU. The difference between the top and the bottom emissions limits could have significant financial consequences for operators.

Changing from annual to daily limits is a challenge for operators especially from a flexible operations perspective and associated plant load changes. How to measure associated emissions accurately especially when trying to collate and align measurements with given loads during load change operation.

With respect to a decision to comply with the IED it is not just a straight choice between invest and comply or don't comply and close. There are two important derogation routes:

1. Plants that operate for a limited number of hours in a year (500 – 1500hrs) under an IED derogation are not expected to achieve the same level of performance as base load plant
2. There is also a process of BAT derogation in the IED which takes account of disproportionately high levels of cost to achieve emission levels associated with BAT compared to the environmental benefits

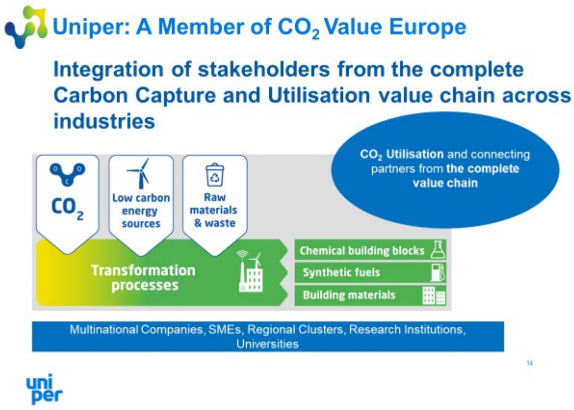
In the context of emerging techniques BREF takes this into account. CCS is recognised as an emerging technique and as an emerging technology, adoption under BREF is not mandatory. That said carbon capture readiness has been adopted in some countries as mandatory for new fossil power plants.



Other technologies are creating additional challenges for coal in Europe. Cheaper solar technology, improved data management for grid control along with better management of power reserve etc is making life more difficult for coal-fired plant. Dr Bockamp stated, by 2025 solar PV will be the cheapest form of electricity generation in many parts of the world. That along with larger and smarter wind plant, digitisation, hybrid grids, smart energy producing buildings etc all add to the question as to whether large scale coal-fired power plant will continue to be necessary.

Uniper believe in the value of CO_2. The company has a proven track record in CCS citing a previous joint venture with Engie at Maasvlakte in the Netherlands. However, sustained low carbon price, political uncertainty in the future of coal plant and a shift in CCS support from power to energy-intensive industry resulted in Uniper and Engie withdrawing.

In addition to CCS, and building on expertise gained, Uniper is looking into innovative uses for CO_2, seeing it as a valuable resource and not just a waste product. It should be possible to build viable and scalable business models in the field of CO_2 utilisation. Whilst technical feasibility is an important issue, Uniper is also committed to helping eliminate legal and regulatory barriers to large scale technology deployment.



Uniper is a member of CO_2 Value Europe focused on CO_2 Utilisation and connecting partners from the complete value chain and involves multinational companies, SMEs, regional clusters, research institutions and universities.

The CCU vision is focus on utilisation and making CCU a key pillar of the transition to a low carbon economy with emphasis on:

- Climate change – Net reduction of CO_2 emissions
- Renewable feedstock – replacing fossil carbon with utilisation of CO_2 as a feedstock for the chemicals, materials and fuels industries.

Dr Bockamp concluded by stating it's not about the if, it's about the how and when coal will be phased out of Europe to deliver the 40% CO_2 reduction target. There are a range of technologies to support the CO_2 reduction path but, from Uniper's perspective, it requires a mindful and responsible approach to safeguard:

- Energy security in Europe during any transition period
- The legitimate interests of employees
- The legitimate interests of shareholders.

Discussion

There were several comments and points raised following Dr Bockamp's presentation. This mainly concerned points regarding the price volatility of fuel, such as natural gas, the intermittency of renewable energy. Therefore, there might be a need to retain coal on a reserve capacity basis until greater confidence has been gained in the context of ongoing energy security. Weather patterns earlier in 2018 such as heavy snow-storms in the UK in April highlighted the need for a mixed portfolio of energy resources to ensure energy security and electricity price stability.

There was further discussion from a 'not-in-my-backyard' perspective. Given several countries are looking to phase out coal in the next 10 years, will these same countries be taking electricity via interconnectors from others that will continue to use coal for electricity generation? Something similar took place in Germany with the phase out of nuclear but there was continued electricity supply from France which continues to use nuclear forms of energy.

A further point regarding electricity price stability and consumer impact was made in the context that coal is one of the more price stable fuels when compared to others such as natural gas and oil.

There are no answers as such. In the end it is up to regions such as Europe to identify a best approach to CO_2 reduction and for associated governments to address as they consider best. However, whatever decisions are taken, it must be from a best informed and most sustainable perspective.

Mr French closed the discussion session highlighting the significant differences in policy and strategy between the two presentations delivered associated with the US and Europe respectively.

DISCUSSION SESSION 3

Outlook for Coal & Low Emission Technology – Issues, Challenges & Opportunities – Asia and China

Chair – Mr Colin Marshall, President and CEO, Cloud Peak Energy Resources

Mr Freyberg commented on the benefit of the ASEAN and China presentations being the latter presentations because of the more authoritative view that will be provided to compliment the comment and discussion which had taken place during other presentations.

Mr Colin Marshall introduced the discussion session and the two presenters; Dr Sanjayan Velautham, ASEAN Centre for Energy (ACE) and Dr Li Dong, China Shenhua Energy.

ASEAN Update and Perspective

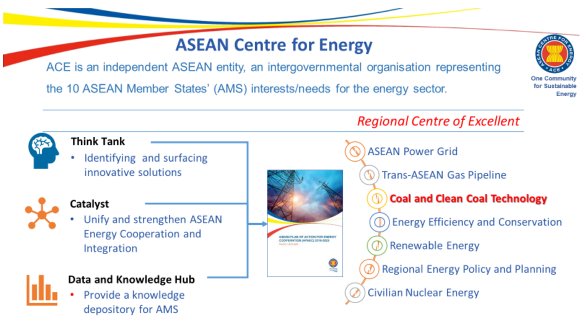
Dr Sanjayan Velautham, ASEAN Centre for Energy (ACE)

Dr Velautham provided an overview to ACE and the region it represents, commenting that ASEAN as a region is the 3rd largest in terms of population behind China and India. It is also the 6th largest economic region with an average annual GDP growth of 5.3%.

The ASEAN Economic Community (AEC) was established in December 2015 and works on the basis of free flow of goods, services, capital, labour etc. It operates on a four-pillar principle:

1. Single market & production base
2. Competitive economic region
3. Equitable economic development
4. Fully integrated region in the global economy

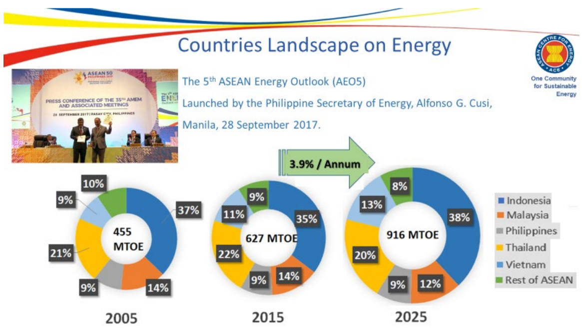
Energy connectivity across the region is facilitated by the ASEAN power grid.



The ASEAN Centre for Energy (ACE) represents 10 ASEAN Member States interests / needs for the energy sector. It is a think tank, a catalyst for energy cooperation and a depository of knowledge and data. There are several areas of focus:

- ASEAN Power Grid
- Trans-ASEAN Gas Pipeline
- Coal & Clean Coal Technology
- Energy Efficiency & Conversion
- Renewable Energy
- Regional Energy Policy & Planning
- Civilian Nuclear Energy

There is an ASEAN plan of action for energy cooperation dealing with the above key areas. In the area of energy efficiency, there are targets to reduce energy intensity by 20% by 2020 compared with 2005 levels. Also, there are renewable energy deployment targets to be achieved by 2025.



Looking at the wider landscape on energy, the 5th ASEAN Energy Outlook (AEO5) was launched in 2017 which considers energy growth between 2005 and 2025 of 3.9%/year. Of all the countries that make up the region, five contribute 90% of the energy supply with Indonesia the largest contributor.

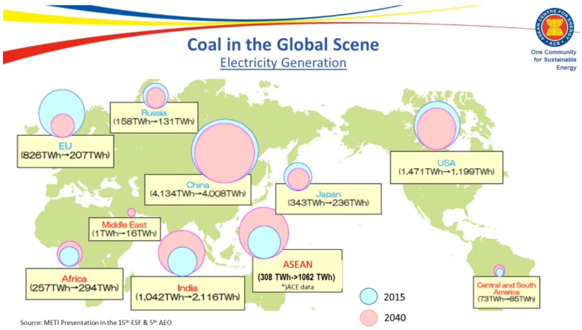
Focusing on coal and the growing role of coal in ASEAN, Indonesia and Vietnam are the largest users of coal in the region. The Joint Ministerial Statement in October 2018 recognised the rising demand for coal use in power generation in the region until 2040. The Ministers acknowledged the need to build and share technical capacity in the context low emission coal technologies, CCUS, best practice in coal handling and cleaner use, technology innovation and corporate social responsibility (CSR) programmes.

Looking out to 2040, on a business as usual (BAU) case, coal is expected to be 40% of power capacity (in GW) with gas at 23% and renewable energy at 30% and renewable energy replacing traditional biomass energy sources. The ASEAN target scenario (ATS) still shows coal with a significant share but lower the BAU with renewable energy taking on a larger share. The

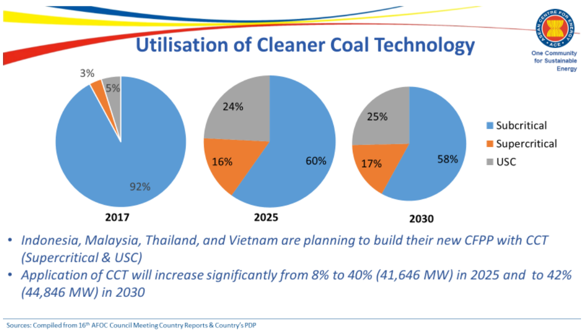
Advanced Policy Scenario (APS) shows a further reduction in coal by 2040 and a more dominant contribution from renewable energy.

Increasing electrification ratio and wealth will lead to capacity growth however, enhanced energy efficiency is expected to lower capacity requirements.

Indonesia produces approximately 90% of the region's coal with Vietnam producing 7%. It is expected ASEAN will see a small increase in coal production between 2016 and 2040 due predominantly to Indonesia's plan limit its coal production from 2019.



Between 2015 and 2040, electricity consumption in the ASEAN region is predicted to increase from 308TWh to 1062TWh. Coal capacity will increase from a little under 60GW in 2015 to in excess of 140GW by 2030. Indonesia and Vietnam will dominate the share of installed capacity with Indonesia looking to increase capacity to just over 50GW by 2027 with Vietnam increasing capacity to just over 55GW by 2030.



During this timeframe, there will be greater use of cleaner coal technologies (CCTs) predominantly via supercritical and ultra-supercritical boiler technologies. Application of CCTs will increase significantly from 8% to 40% in 2025 and 42% in 2030 however, less efficient subcritical boiler technology will still form a large portion of the coal fleet in the region reducing from 92% in 2017 to 58% by 2030.

The amount of investment required to meet demand growth across all technologies will be considerable, estimated at US$200bn, on average up to US$21.4bn/year depending on which scenario is adopted (BAU, ATS or APS).

It is understood there is considerable opposition to the building of coal-fired power plant in the region. Understanding of the issues is key so, associated opinions, perspectives etc are based on verifiable fact. The ASEAN Clean Coal Technology Programme is focused on addressing environmental issues raised from coal production and utilisation, specifically to enhance the image of coal through the promotion of cleaner coal technologies.

Dr Velautham outlined 5 key strategies associated with the CCT programme.

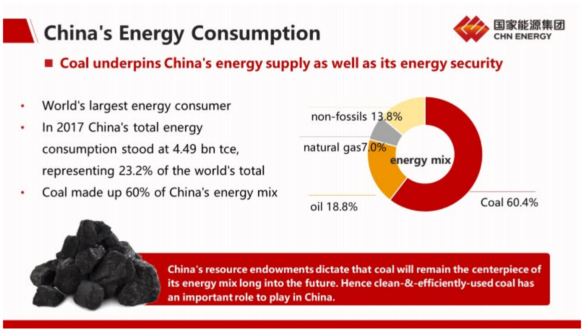
1. Promotion of CCTs for power generation to contribute to clean energy development and economic welfare
2. Increase the level of public awareness regarding the benefits of coal use
3. Promote intra-ASEAN coal trade and increase CCT investment
4. Conduct policy research to enhance coal development and use, and build capacity
5. Establish a fully functional ASEAN Coal Database and Information System (ACDIS)

In conclusion, Dr Velautham outlined ASEAN's strategic direction out to 2025 with three key elements of energy security, affordability, accessibility at the heart of all of which is sustainability. The aim of which is to address how to best optimise resource need and ASEAN's natural resources. To balance the use of coal and renewable energy in a way that ensures energy security, with ongoing electrification a key requirement to facilitate and deliver the energy needs to all. It is a question of how best to achieve affordable electricity across the region.

China Update and Perspective

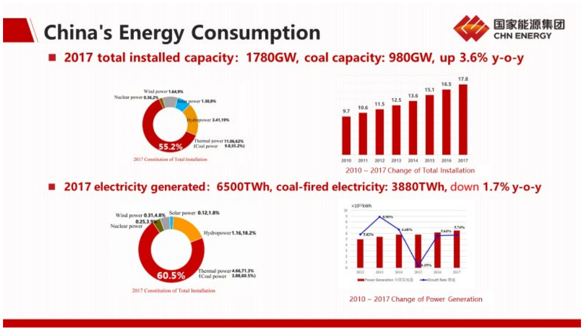
Dr Li Dong, China Shenhua Energy

Dr Li Dong set the scene for his presentation opening with a comment that his presentation would offer a more informed view from China given he and his team live and work there. He outlined the context of his presentation which would focus initially on a country overview followed by a company-based perspective.



Coal underpins China's energy needs with total energy consumption in 2017 equivalent to 4.49 billion tonnes of coal (4.49bntce), of which coal made up 60%.

In China, coal is used to generate power, heat or as a fuel/feedstock in the industrial/chemical sector, with power, the largest single consumer of coal at 51.3% of total coal consumption. Of the 1780GW of total installed power generation capacity in China, coal-fired power generation installed capacity has increased at 3.6% year-on-year (y-o-y) and is currently at 980GW.



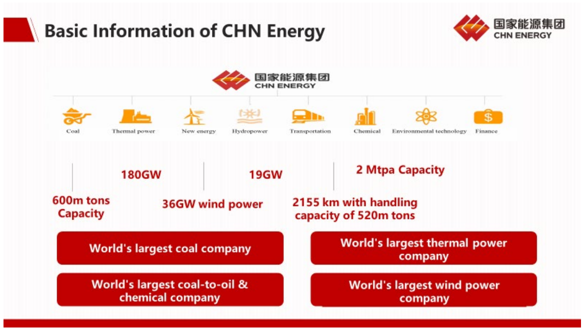
In terms of actual electricity generated, the total generated in 2017 was 6500TWh of which 3880TWh was from coal, a reduction of 1.7% year-on-year.

Between Q1 and Q3 in 2018, there was a small increase in coal consumption (3% y-o-y) with coal production and coal imports up; 5.1% y-o-y and 11.8% y-o-y respectively. During the same period, there has also been increased transition to clean and low-carbon power with a consistent transition to a greener energy mix facilitating an ongoing reduction in the share of coal capacity. Increased hydro generation and high growth in other green energy areas such as solar along with increases in running hours have all helped support a reduced share for coal.

Near-term projections over the next year or so anticipate further growth in coal markets as part of a wider energy growth with total installed power generation capacity reaching 1900GW of which 40% will be non-fossil. That said, the coal from an overall energy mix perspective, in terms of output) is set to reduce from 60.4% in 2017 to 57.5% in 2020 with total power consumption increasing from 6310TWh in 2017 to 7200TWh in 2020.

Having said the scene from a country perspective Dr Li shifted focus to China Energy, providing a company overview in terms of its formation, asset base and overall size. It is the,

- World's largest coal company
- World's largest coal-to-oil & chemical company
- World's largest thermal power company
- World's largest wind power company



Investment and operational interests extend to Indonesia, Australia, the US, Greece, Russia and others.

Having provide an brief introduction to CHN Energy, Dr Li focused on three key areas for the remainder of his presentation:

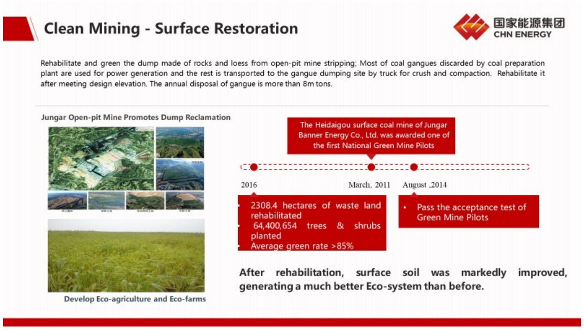
1. Clean mining of coal
2. Clean conversion of coal
3. Interests & activities in CCUS

Clean Mining of Coal

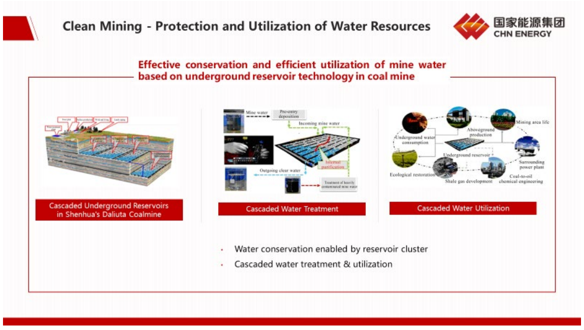
China Energy has 13 coal companies with 74 underground mines and 23 open-pit mines across 8 provinces & autonomous regions representing a total capacity of 680m tons per with 508m tons produced in 2017.

Focus is on clean, safe and efficient mining resulting in world-leading safety records. China Energy is pioneering unmanned underground face working with highly integrate control systems facilitating 24/7 real time monitoring and control of more than 2000 plant items and 57,000 monitoring points.

In terms of clean mining the focus is on surface disturbance reduction and improved resource recovery. Hydraulic props are to be lubricated with water with ongoing R & D in this area to replace emulsified oil with water. Not only is the use of water more environmentally friendly, pure water is also more conducive to reducing hydraulic component failure delivering increased production efficiency, life extension of hydraulic components and reduced maintenance costs.



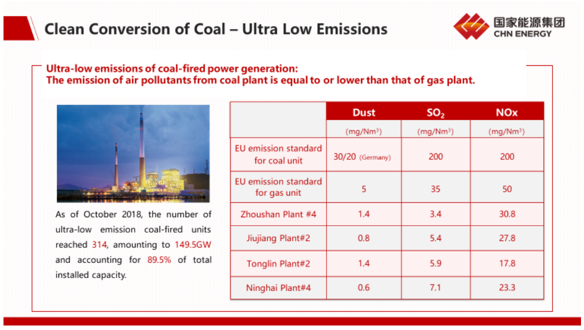
Significant effort is being placed on surface restoration and land rehabilitation, improving surface soil to facilitate improve use from an eco-system perspective. In 2016 rehabilitation of waste lend through improved surface management, soil, planting of trees and shrubs etc resulted in an average green rate of >85%.



Protection and better utilisation of water resources has been based on underground reservoir technology employing cascade systems both in terms of conservation management and treatment.

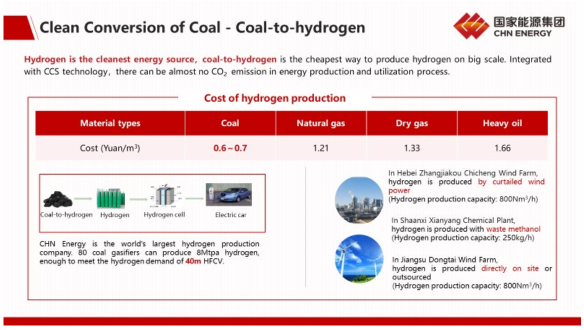
Clean Conversion of Coal

Of China Energy's coal-fired power generation capacity, higher efficiency supercritical (SC) and ultra-supercritical (USC) designs make up 53.4% of the fleet. There has been significant focus and investment on ultra-low emission (ULE) technology with 89.5% (as of October 2018) of the coal fleet equipped with ULE technology delivering performance in terms of particulate, SO_2 and NOx emissions significantly lower the EU emission standards for gas plant (let alone coal).



China Energy installed the world's first 1GW USC double-reheat unit (two installed at Taizhou) which compared with current USC 1000MW units reduces coal consumption by 18.7g/kWh which on an annual utilisation of 5,500hrs basis, represents a saving of 206,000tce across two units and similarly 576,000 tons CO_2.

Significant investment (180 billion yuan) has been put into coal-to-liquids and coal-chemicals including a 5.24Mtpa coal-oil process, a 3.93Mtpa polyolefin process, a 3.57Mtpa methanol process and a 5.74Mtpa coke process all of which are in place.



Coal-to-hydrogen is the cheapest way to produce hydrogen, (one of the cleanest energy resources), on a large scale. When integrated with CCS technology there is virtually no emission of CO_2 in the energy production and utilisation processes. Dr Dong reported China Energy is the world's largest hydrogen production company.

Interests & Activities in CCUS

China Energy believes there are 5 key areas of benefit associated with CCUS:

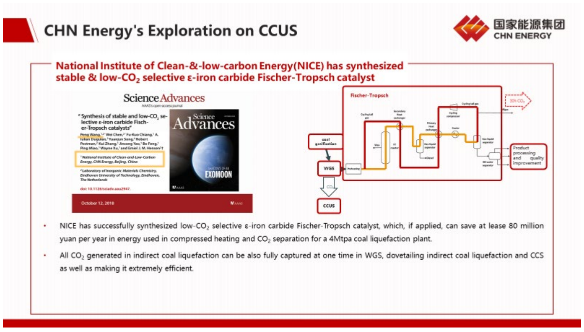
1. Climate Change – Reducing CO_2 emissions from fossil energy
2. Energy Security – Facilitating sustainable use of fossil energy resource
3. Cooperative Environment Improvement – CCUS can reduce other pollutant emissions synergistically
4. Promotion of Economic Development – The extension of CO_2 utilisation technology to the traditional coal-based energy industry chain
5. Social Benefits – Balanced development of energy production and consumption regions

Dr Dong outlined several areas of research and development focus for CCUS.

China Energy is now operating the first coal-to-liquids full CCS process demonstration from capture through transport and storage. Storage is via saline aquifer with >300,000t capacity. Technical feasibility has been tested and demonstrated and, if scaled up to 1Mtpa, it is believed the full cost of CCS can be reduced to <US$30/t$CO_2$.

There is R & D into oxy-combustion capture technology with several pilot studies in operation with the aim of becoming a world leader in reducing capture cost and energy consumption.

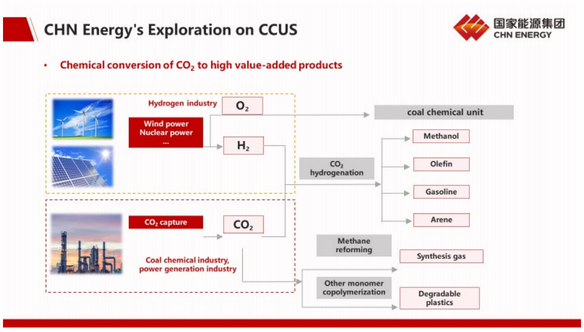
A full-process post-combustion capture CCS project is planned to come on stream during the 13th five-year-plan period (13FYP) with similar aims and objectives to the oxy-combustion project.



The National Institute of Clean-&-low-carbon Energy (NICE) has synthesised stable and low CO_2 selective ε-iron carbide Fischer-Tropsch catalyst.

Other uses of CO_2 are being investigate such as underground and surface fire prevention as well as others in the areas of:

1. Industrial Utilisation – e.g. EOR, EGR, EWR, enhanced geothermal heat recovery
2. Mineralisation – Use in building materials such as blocks, generating power during the mineralisation process
3. Bioenergy – Production of biodiesel, ethanol, hydrogen, feed, degradable plastics



Then there is chemical conversion of CO_2 to other high value-added products.

Dr Dong ended his presentation outlining the maturity status of carbon dioxide chemical conversion technology. The CO_s -methanol industrial process is in operation and most of the other CO_2 conversion technologies are in the pilot or industry demonstration phases. He stated that China is among the world leaders in the development of CO_2 conversion technology.

DISCUSSION

With respect to the ASEAN presentation, a question was raised regarding where growth in hydro might be focused. In answer, the main concentration is likely to be in the Myanmar. In addition to the 8 interconnectors already in operation the plan is to increase to 16 but most of which will be bi-lateral arrangements. More needs to be done to facilitate more by way of multi-lateral arrangements.

The question was raised regarding whether the growth predictions included country specific NDCs and what impact would the World Bank policy associated with new build coal have. In answer, growth considers NDCs and other regional institutions are being looked at for funding. Some areas such as Thailand may have self-funding capability, but other international banks and private funding routes are being looked at. Also, whilst the regional ATS are focused on greener technologies, it is a matter of affordability of electricity and from a LCOE perspective, coal still offers the best solution, but it must be clean coal.

In Thailand, public resistance to the use of coal was mentioned and the country's Energy Minister is looking at a new power development plan out to 2036. Thailand is also looking at electricity import options which may also help anticipated energy demand growth.

In answer to a question regarding the inclusion of the steel and cement industries from a cleaner coal perspective, these will be looked at but the lower hanging fruit related areas associated with electricity generation are being looked at first.

Turning to China, there was a question regarding when Chinese coal-fired power generation is expected to be a non-emitter of CO_2 to which it was stated that China believes this is achievable and is committed to the Paris Agreement with 80% of CO_2 expected to be captured by 2040.

In answer to a coal-liquids related question and associated technology focus, China's heavy reliance on oil was made clear hence the focus on coal to oil technology

The question was asked regarding China's view of the accuracy of IEA forecasts in terms of the amount of coal which will be used to convert to oil, or synthetic natural gas or other materials. China is not in a position to confirm current statistics because their coal conversion technology is still very much at pilot scale and it is difficult to say how such initiatives will be supported by national policy, but the situation may be clearer when the 14th five-year-plan (14FYP) is announced.

There being no further questions, Mr Colin Marshall wrapped up the final discussion session commenting on the quality of the two presentations, the perspectives provided, and the value provided in terms of the insight into ongoing and future energy needs but also the emphasis and priority being placed on the need to implement clean extraction and use of coal.

Mr Freyberg echoed Mr Marshall's comments and expressed his thanks for three excellent and highly informative discussion sessions which he hoped will help drive the need to continue using coal to meet global energy demands but in a clean and sustainable manner. The discussion sessions have demonstrated the readiness and viability of technology which could play a significant role in addressing the global challenges being faced, especially given the need for immediate action.

CIAB

Coal Industry Advisory Board

For more information about the IEA Coal Industry Advisory Board, please refer to www.iea.org/ciab, or contact Carlos Fernández Alvarez at the IEA (Carlos.Fernández@iea.org) or Karl Bindemann, CIAB Executive Coordinator (kbindemann@ciabcoordinator.com)

IEA – International Energy Agency

9, rue de la Fédération
75739 Paris Cedex 15
FRANCE
tel: +33 (0)1 40 57 65 00/01

info@iea.org www.iea.org