INTERNATIONAL ENERGY AGENCY
COAL INDUSTRY ADVISORY BOARD

CIAB

41st PLENARY MEETING

DISCUSSION REPORT

IEA Coal Industry Advisory Board Plenary Meeting
IEA Offices
Paris
7-8 November 2019

CIAB PLENARY DISCUSSION SESSIONS

Thursday, November 7th November 2019

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 two discussion sessions discussed at the CIAB's 40th Plenary meeting.

DISCUSSION SESSION AGENDA

"Discussion Session 1: The Ongoing Need for Coal to Meet Global Energy Demand
Chaired by Mr Glenn Kellow, President and CEO, Peabody

- **Update on US Coal Strategy** – *Mr Lou Hrkman, Deputy Assistant Secretary, US Department of Energy*
- **A Global Update on New Build Coal** – *Mr Toby Lockwood, Senior Consultant, IEA Clean Coal Centre*
- **Current Technology Trends in Coal Power Stations & Electricity Grids, Challenges & Opportunities** – *Mr Alok Jha, Regional Sales Director, Steam Power, GE, South Asia*

Discussion

"Discussion session 2: CCS, It's Role & Value
Chaired by Mr Paul Simons, Deputy Executive Director, IEA

- **The Role & Value of CCS -** *Dr Niall Mac Dowell, Reader, Imperial College, London*
- **CCUS Cost Reduction Opportunities for Coal Power Plants -** *Dr Graham Winkelman, Practice Lead Climate Change, BHP*
- **CCUS, IEA Programme Update –** *Ms Samantha McCulloch, Head of CCUS Unit, IEA*

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 two discussion sessions were focussed on:

1. The ongoing need for coal to meet current and future energy demands
2. The role and value of CCS to address CO_2 emissions and achieving net zero CO_2 targets and associated objectives.

The first discussion session included a review of the US coal strategy with an update on the US CoalFIRST initiatives and was provided by the US Department of Energy. There then followed by an update from the IEA Clean Coal Centre on new build coal across the globe and finally GE provided review of current technology trends associated with coal power stations and electricity grids, outlining challenges and opportunities.

The second discussion session focused on the role and value of CCS, the cornerstone of which was the presentation of the key 2019 CIAB study undertaken with Imperial College London. This made clear it is now a case of fossil AND renewables and not fossil OR renewables if energy demands are to be met and there is to be a reasonable chance of achieving a 'net-zero' position on CO_2 emissions. There followed a presentation associated with another CIAB project carried out over 2018-19, focused on CCUS cost reduction opportunities. This was based on 'learning by doing' at Sask Power's Boundary Dam and Shand Power Stations. The session concluded with an update from the IEA concerning their CCUS programme.

DISCUSSION SESSION 1: The Ongoing Need for Coal to Meet Global Energy Demand

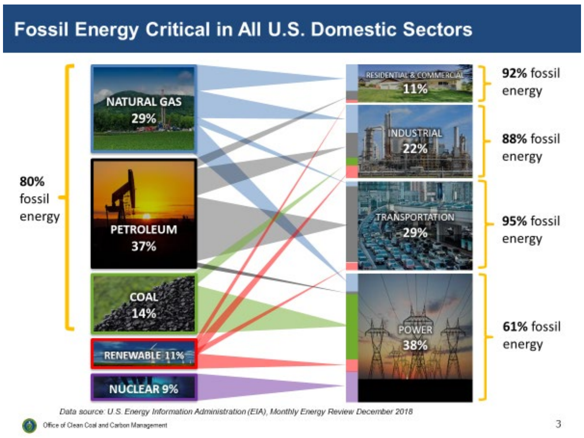
Chair - Mr Glenn Kellow, President and CEO, Peabody

Mr. Kellow opened the first session which focused specifically on the ongoing need for coal to meet global energy demand and welcomed the three speakers. The first presentation delivered by Mr Lou Hrkman from the US Department of Energy provided an overview of the US coal strategy and included an update on key coal usage related activities including the US CoalFIRST programme. The second presentation delivered by Mr Toby Lockwood from the IEA Clean Coal Centre provided an update on new build coal activities, associated technology deployment and funding trends on a global basis. The third presentation delivered by Mr Alok Jha from GE focused on current technology trends in coal power stations and associated electricity grids, outlining key challenges and opportunities.

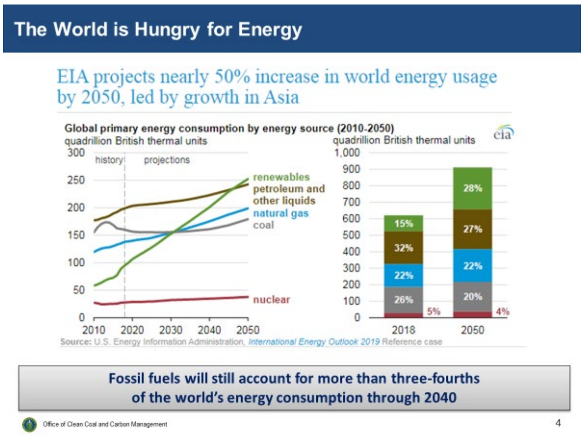
Update on US Coal Strategy

Mr Lou Hrkman, US Department of Energy

Mr. Hrkman provided a brief introduction to the presentation outlining the global challenges and the need for international engagement with technology and innovation key to achieving any element of breakthrough regarding the ongoing use of fossil fuels and reducing CO_2. He summarised the key areas of importance with respect to coal which delivers significant economic advantage in the US, also seeking to position itself as a trusted energy producer globally. Mr Hrkman outlined the criticality of fossil fuels across all US domestic sectors

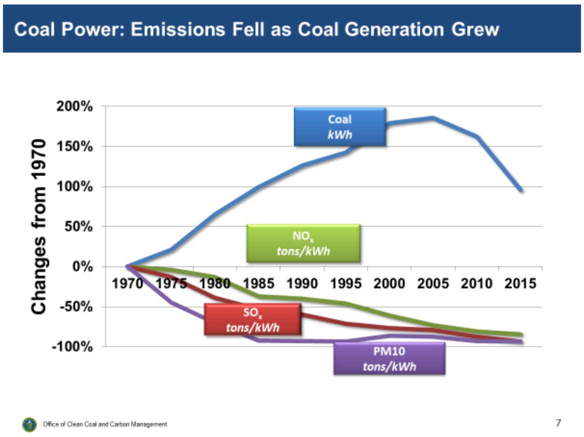


He also commented, in reality, fossil energy is here for the longer term given the global demand for energy. The EIA projects approximately 50% increase in world energy consumption by 2050, led predominantly by growth in Asia.



Living standards will not be sacrificed and the ‘clean’ economy will need coal to be included in the mix when considering reliability, affordability, grid resiliency and maintaining of living standards. Given CO_2 has no borders, technology and innovation are crucial to delivering carbon-free fossil energy consumption.

Mr Hrkman commented on the history of the US DOE in supporting technology and innovation, identifying previous achievements such as low NOx burner and SCR technologies and the approaches adopted by the DOE. A similar approach is being taken regarding the CO_2 emission challenge, Mr Hrkman referenced the reduction in emissions achieved despite significant increases in coal-based electricity consumption between 1970 and 2005



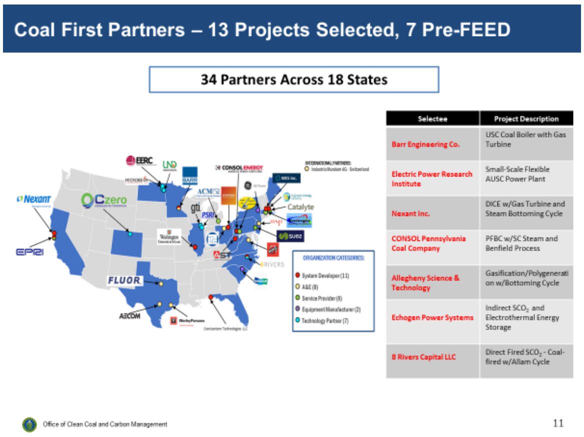
Mr Hrkman talked through the DOE’s clean coal and carbon management priorities touching on the development of coal plants for the future, modernisation of the existing fleet, reducing the cost of CCUS, advancing the role of ‘big data’ and addressing the energy water nexus. He mentioned the number 1 priority is to get the cost of CO_2 capture to around $30/ton.

The focus of the presentation moved to provide an update on the US Coal FIRST initiative with the goal of developing the coal plant of the future with emphasis on zero emissions, a plant design that is small and modular therefore easier and quicker to construct, with a smaller footprint and easier to permit.

Specific design criteria also included the following:

1.Greater than or equal to 4% ramp rate (with up to 30% natural gas)
2. Cold / warm start < 2hrs
3. A turndown ratio of 5:1 maintaining full environmental compliance
4. Zero liquid discharge
5. Near-zero emissions including CO_2
6. Solids disposal to be predominantly via saleable products
7. Dry bottom and fly-ash discharge
8. Efficiency to be >40% (HHV)

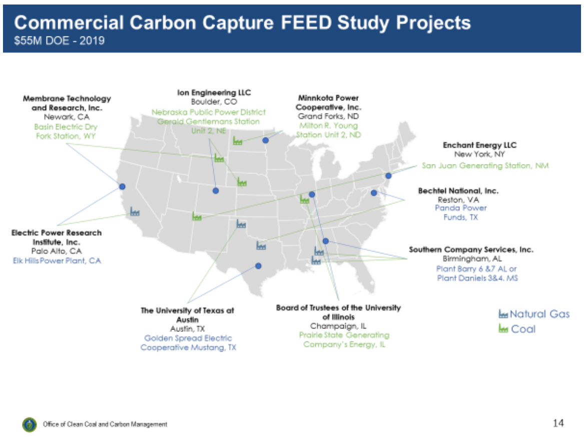
There are currently 34 partners involved in the Coal FIRST programme across 18 States with 13 projects selected of which 7 are Pre-FEED.



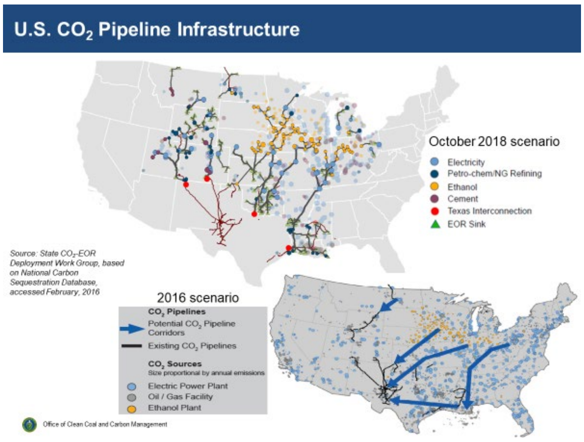
Mr Hrkman talked through the Coal Plants of the Future planning timeline and summarised key milestones to date and those to be achieved in the future with the overall objective of pilot plants to be under construction by 2024 and commissioned by 2026.

Focussing specifically on CCUS, to date, nine FEED studies have been selected with $55.4m in Federal funding awarded. Such projects will support FEED studies for commercial-scale carbon capture systems.

The studies selected are spread around the US and are predominantly focused on EOR.



According to Mr Hrkman, oil companies are starting to see coal fired power plants as a viable CO_2 source option with power plants and CO_2 pipeline routes identified.

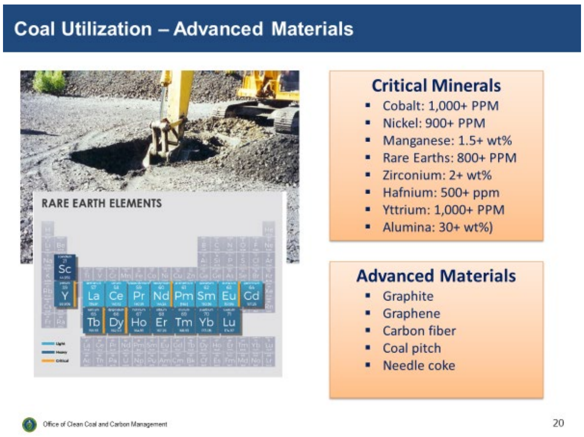


International collaboration is key to advancing and commercialising CCUS on a global scale as well as other clean coal technologies (CCTs) with several examples of multilateral partnerships referenced such as the IEA, the Carbon Sequestration Leadership Forum (CSLF), the Clean Energy Ministerial (CEM) and the Global CCS Institute among others. Funding to support associated R & D is likely to be via bi-lateral agreements with Norway cited as an example of productive collaboration with respect to CCUS.

Also key is public education and wider public acceptance that clean fossil fuel use is not only a reality but essential to balance current and future energy demand with addressing key climate related needs.

The 'technology push' through focused R & D needs to be matched with 'market pull' through financial incentives with 45Q tax credits referenced as a key US policy incentive for CCUS. Many are now recognising 45Q enables CCUS in the power and industrial sectors. Currently the US IRS needs to address key questions to help facilitate investment.

Coal is also being considered for use in the manufacture of products such as roof tiles as well as others such as water filtration, carbon fibres etc. Coal, combustion products such as bottom ash and fly-ash are also being investigated further in the context of critical minerals and rare-earth elements.



The construction industry, both domestically and internationally, is considered to be a significant opportunity for innovative carbon products such as coal-foams, carbon spheres, roof tiles etc.

A techno-economic analysis regarding a wider coal beneficiation program and potential coal industry impacts is being undertaken with carbon products considered to show exceptional promise.

Coal Beneficiation Program Potential Coal Industry Impacts

Carbon Products Show Exceptional Promise

Carbon Product	Potential U.S. Coal Industry Requirements - 2050		U.S. Product Value - 2050 (Million $)
	Coal Production (mmt)	Coal Mining Employment	
Carbon Black	14.1	1,692	5,077
Activated Carbon	22.0	2,641	15,979
Carbon Anodes	25.0	3,005	2,254
Graphite Electrodes/Needle Coke	12.5	1,502	41,315
Carbon Fiber	43.6	5,235	24,538
Carbon Nanomaterials	TBD - EY19/20		
Roofing Tile			
Cement			
Conductive Inks			
Carbon Foam			
Composites			
Total Carbon Products	**117.3**	**14,075**	**89,162**

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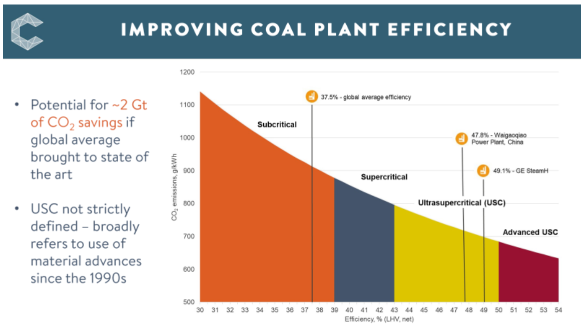
A Global Update on New Build Coal

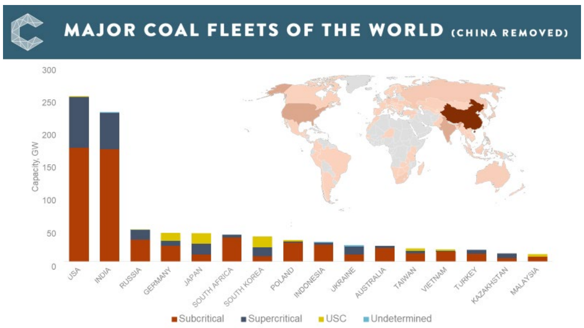
Mr Toby Lockwood, IEA Clean Coal Centre

Mr. Lockwood referenced several recent IEA Clean Coal Centre reports upon which his presentation is based. He talked through the evolution of improved power plant efficiency, the associated reduction in CO_2 and the importance of advanced materials in delivering the performance of ultra-supercritical (USC) and advanced ultra-supercritical (AUSC) power plants of today.



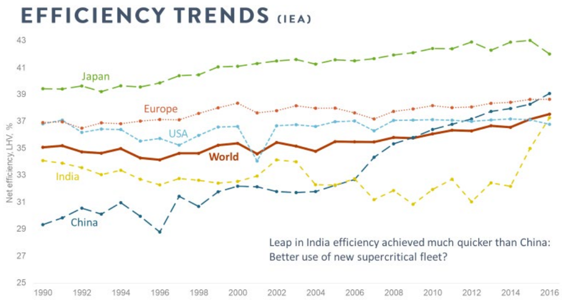
Examples of the most advanced coal-fired power plants currently in operation were referenced with hard coal efficiencies of 47.5 – 47.8% (LHV, net) and lignite fired efficiencies of >43%.

In terms of major coal fleets of the world, the dominance of China is clear to see.



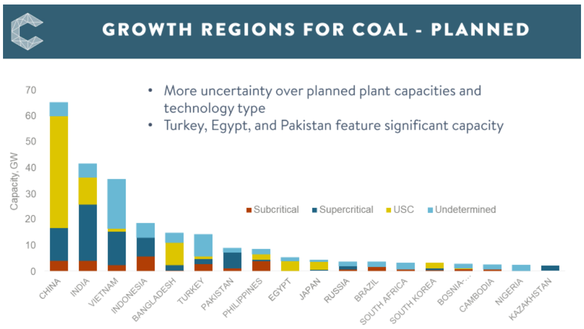
However, China also has by far the largest fleet of USC power plant with approximately 200GW of capacity with South Korea and Japan next with <10% of China's USC capacity.

With respect to efficiency trends, Japan has been the world leader for more than 25 years and still has the most efficient coal-fired power plant. However, China has steadily increased operational efficiency with greatest increases between 2006 and 2016. India, although having some of the worst performing plant, is now achieving major gains in plant efficiency especially in the past two or three years.



Between 2017 and 2018, the greatest increase of any energy source for power generation was associated with coal. Also, coal-fired power plant has the greatest capacity currently under construction with the largest regions being China and India where most of the plant under construction is either supercritical or ultra-supercritical. South East Asia is another region of significant growth with varying commitment to the adoption of high efficiency, low emissions (HELE) technology.

In terms of planned plant construction, again China and India dominate but South East Asia is increasing in importance.



However, there is some uncertainty regarding the data behind the anticipated growth trend. While it is unlikely that all of the plants planned for construction will be built, the predicted trend illustrates the ambition of the more dominant regions.

The drivers behind continued and increased use of coal power include:

- Meeting demand and increasing access to electricity
- Reduced risk through fuel diversity and less reliance on gas
- Increased energy security
- Finance is available from Chinese, Japanese and Korean export banks.

Some of the barriers include:

- Stronger climate policy and focus on renewables
- Reduced financing from development banks and some commercial banks.

There is greater focus on the use of USC technology with key drivers including:

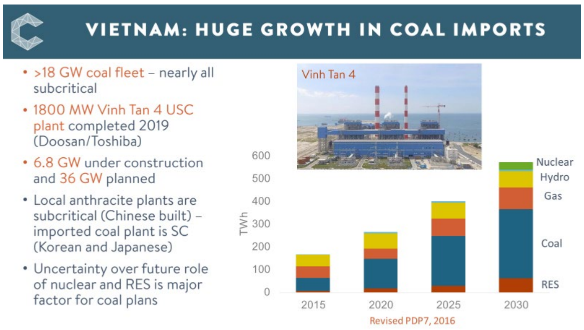
- Reduced lifetime costs especially in regions affected by more costly imported coal.
- Reduced environmental impact
- Technology requirements being linked to the source of finance

There are some barriers which include the following:

- Greater need for capital / financing
- Larger unit size which may be less suitable in areas of grid restriction
- Lack of experience in some developing regions with the technology and a tendency to be more risk averse.

China is leading the deployment of new higher efficiency coal plant although installed capacity of coal-fired power plant is likely to peak around 2020 with a combination of gas and renewables being deployed to meet future growth needs.

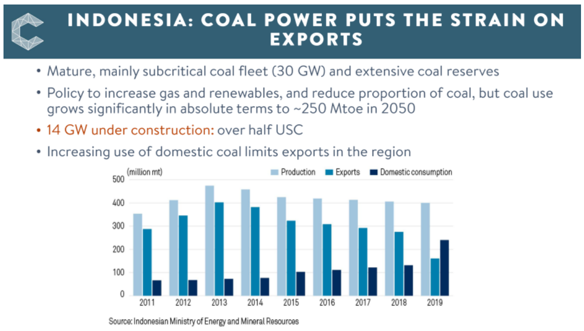
Having provided the wider overview associated with current and predicted future demands for coal power, Mr Lockwood turned to Southeast Asia, in particular Vietnam, Malaysia, Indonesia and the Philippines. Here most countries seek to meet rapid demand growth while seeking to also diversify the energy mix. Electricity access across the region is approximately 80%. In terms of coal there is a mixture of imported and domestic coal burned although domestic coal is often of a poorer quality. There is a regional shift to becoming a net importer of fossil fuel and there are some concerns regarding possible overcapacity due to ambitious build projections.



In Vietnam there is a sizeable but relatively low efficiency coal fleet and a strong commitment to the use of coal in the future energy mix with 6.8GW under construction and a further 36GW planned.

There is some uncertainty regarding the longevity of the coal energy policy with a growing trend to increase the amount of renewables in the energy mix.

In Malaysia, there are some gas constraint related issues therefore there is greater focus on large HELE based coal-fired power plants. Coal is expected to maintain a 50% share of the generation mix out to 2030 but greater consideration is being given to increasing the energy mix diversity in the future to ensure security of supply. However, Malaysia is expected to become a net importer of fuels within the next 10 years.



Indonesia is anticipated to see the most significant expansion of coal usage in the region with 14GW of plant under construction, half of which is of a higher efficiency design. By 2050, renewables are predicted to contribute a greater share of the energy mix than coal however coal is expected to continue to play a significant role.

One of the regions fastest growing economies is the Philippines with coal providing 50% of power supply needs, 75% of which is imported. Under a business as usual scenario, coal power generation could increase 5-fold by 2040.

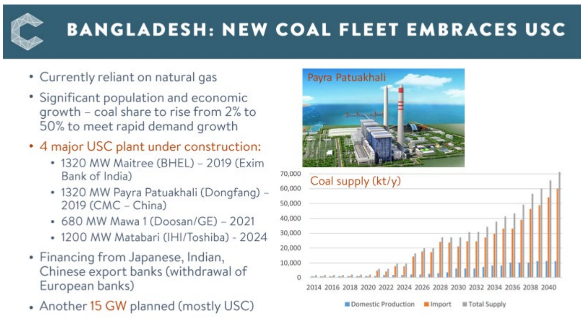
There is growing opposition to large coal-fired power plants in the Southeast Asia region with the Philippines experiencing some of the strongest opposition.

In South Asia, in particular India, Pakistan and Bangladesh, coal will continue to dominate and increase its share. In India which has approximately 200GW of coal, further increase in capacity is projected out to 2022 with 8.7GW of USC under construction. However, looking out to 2027, whilst coal still dominates, its share of the energy mix is predicted to reduce from 48% to 39% with renewables increasing from 33% to 43% between 2022 and 2027.

Of the current installed capacity of circa 200GW only 24% is of a higher efficiency supercritical design therefore the smaller, inefficient subcritical plants need replacing.

In Pakistan there has been negligible use of coal power until recently and by 2030, coal is expected to represent around 20% of the energy mix as Pakistan seeks to exploit the huge Thar lignite resource it has with 660MW of CFB operational and a further 4GW planned. With respect to imported coal, 4GW of supercritical (SC) plant are either operational or under construction.

Bangladesh, until recently has been wholly reliant on natural gas. Over the next 20 years with projected significant growth in population and the economy, the share is set to increase from 2% to 50% to meet anticipated rapid energy demand growth.



Following the withdrawal of European banks, financing of new build coal is expected to come from Japanese, Indian and Chinese export banks.

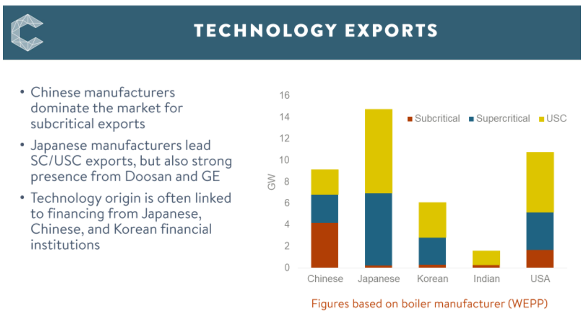
In the Middle East and Africa, Turkey is seeking to exploit its lignite resource given it is currently a net importer of energy with 70% of demand met by imports. There are currently 19GW of coal plant operational, many of which are of a higher efficiency design, with a further 15GW under construction or at various stages of planning. There is some uncertainty as to whether this 15GWs will translate into actual plant.

There is a focus on clean coal in the Gulf region to reduce dependence on natural gas. 2400MW of USC is due to become operational in Dubai in 2023 with another 1200MW USC plant by 2025. The LCOE of HELE coal is competitive with CCGT and solar and is considered a good back up energy option.

In Africa, subcritical plant is planned throughout the continent although two supercritical units are still to be completed in South Africa. Also, a 3960MW USC plant is planned in Egypt with the 1386 USC Safi plant operational in Morocco since 2018. The planned USC plants in Kenya and Ghana have been deferred and two 300MW subcritical plants are under construction in Zimbabwe.

In Japan, there has been renewed interest in coal following the Fukushima disaster, as Japan seeks to reduce dependence on nuclear and the costly import of LNG. Currently 14GW of USC plant are under construction but coal is set to reduce its share of the energy mix slightly, looking out to 2030.

From a technology export perspective, Chinese manufacturers dominate the subcritical market whereas Japanese manufacturers lead in SC & USC technology exports although other manufacturers such as Doosan and GE perform strongly.



With respect to project financing, commercial banks still represent the largest source of identified financing although PFI arrangements are increasing their presence. Other forms of financing might include balance sheets or subsidies etc.

In summing up, Mr Lockwood made the following points:

- Coal is still being deployed worldwide as a means of energy diversification, reducing energy cost and improving energy security.
- SE Asia is a major growth area for coal
- Uptake of state-of-the-art HELE technologies is variable across regions and depends on policy, resources, financing and geography.
- Some new build plans have been deferred due to concerns associated with possible overcapacity and environmental opposition.
- The Middle East, Africa and Central Asia are emerging growth areas for coal power.

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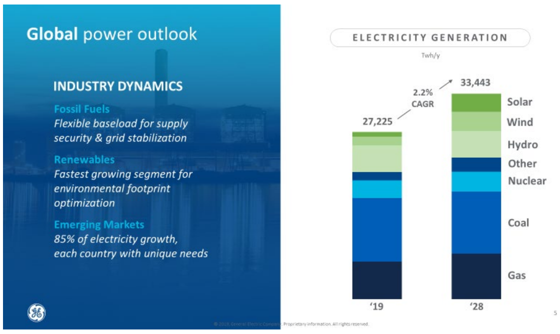
Cleaner Coal Deployment

Mr. Alok Jha, GE Steam Power

Mr. Jha in his opening statement, reinforced the view that there is a role for coal now and out to 2040. He talked through some of the key market drivers such as security of energy supply citing an example of stranded gas assets in India due to fuel access issues. From a LCOE perspective, coal is still the lowest cost option however, coal is also supporting the implementation of renewable energy through grid support and flexible operation capability. So, it is becoming more of a case of coal and renewables and not an either-or situation. The carbon footprint associated with the coal power plant is reducing, a reality not always recognised.

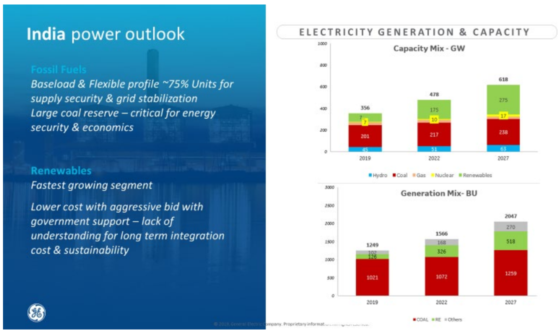
Future challenges are more concerned with thermal power being cleaner and dealing with the intermittency and grid stability issues associated with renewable power.

From a global power outlook perspective, fossil fuels will continue to account for approximately 50% of the energy mix for the next 10 years with emerging markets representing 85% of projected electricity growth.



In terms of India, renewable energy is projected to represent around 50% of the capacity mix looking out to 2027. However, in terms of actual power generation and associated load factors etc, coal will still dominate, taking around 60% of the load.

There are some doubts also as to whether the renewables deployment objectives can be met given the anticipated cost is estimated to be around $200bn to deliver, most of which is solar based.

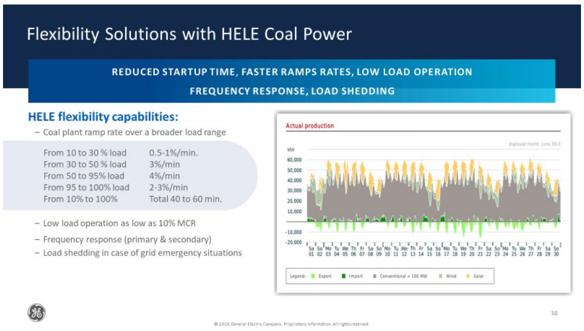


Mr Jha commented, the most advanced coal power plant, the GE SteamH design can deliver 49.1% efficiency with associated benefit in terms or reduced emissions and reduced size of any capture plant to be fitted with associated cost and operational efficiency benefit.

Advances in technology and air quality controls systems (AQCS) can address all sources of non-greenhouse gas emissions such as NOx, SOx and particulate matter to meet and exceed some of the world's strictest regulations.

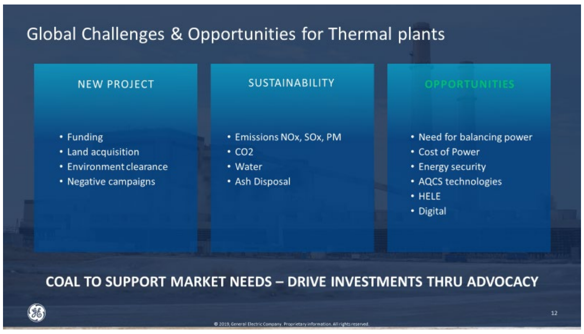
HELE coal power plant with state-of-the-art emissions abatement technology can now compete with a typical combined cycle power plant.

Advances in materials and improved understanding associated with material properties and behaviour has significantly improved the operational flexibility of HELE coal plants, which is key to supporting the deployment of renewable energy technology.



Although significant advances in coal power generation technology have been achieved to improve efficiency, operational flexibility and reduce overall carbon footprint, there remain challenges associated with the future us of coal.

Such challenges include financing with many banks refusing to finance new coal related projects. Land acquisition along with the negative perception associated with coal are further key issues that need to be addressed.



That said, there are also significant opportunities associated with ensuring energy security, maintaining grid stability, ensuring the affordability of electricity etc. Also, when equipped with carbon-capture technology, the coal power plant can become more or less carbon neutral.

Discussion

Following completion of Mr Jha's presentation, Mr Glenn Kellow thanked the three speakers for their presentations and opened discussion with a couple of questions.

He asked Mr Jha what technology could make the greatest impact associated with coal power in the near term, to which Mr Jha responded, temperature. Increasing operational temperature to 700°C will correspondingly increase efficiency. Also, digitisation can have a significant impact especially in the context of reducing operational and maintenance costs

Mr Kellow asked a similar question to Mr Hrkman who commented, for him, the most exciting coal related technology near term was the coal-foam technology development which could offer significant benefit to the construction industry.

Mr Julian Beere asked Mr Lockwood why subcritical coal plant was still being constructed in Africa to which Mr Lockwood replied it was due to limited industrial establishment and financing.

Mr Karl Bindemann asked Mr Jha about the challenges associated with the management of advanced materials especially in a flexible operation environment, given current experience suggests failure rate challenges with associate impact on plant availability. Mr Jha commented this was an area GE was investing resource into research and are developing associated solutions to address.

Mr Seamus French commented on a difference in financing perspectives between Mr Lockwood's presentation and Mr Jha. Mr Lockwood referred to recent reports mentioned limited finance from multi-development banks however, Chinese and Japanese banks have stepped in. Mr Jha reported greater financing challenges citing an example in Bangladesh.

Mr Carlos Fernandez asked Mr Hrkman which technologies will most likely be associated with the Coal FIRST programme. Mr Hrkman was not able to comment given the US DOE is currently I an active procurement phase regarding pre-FEED studies.

Mr Fernandez asked Mr Jha how the CAPEX investment case can be made for new coal given lower load factors and greater emphasis on flexible operation to which Mr Jha responded, in India, coal still remains the cheapest option on a LCOE basis.

Mr Mick Buffier asked Mr Lockwood why the coal power plant projects in Kenya and Ghana are not proceeding to which Mr Lockwood responded in Ghana the project was at a very early stage of proposal however the government is not enthusiastic. In Kenya the project is further developed but stalled due to environmental opposition however the project has not been confirmed as cancelled yet.

Mr Kellow asked all three presenters what their view is from an advocacy perspective with respect to gaining more traction in advancing clean coal technology deployment.

Mr Hrkman's view is reduced grid reliability and resiliency, with associated impact on life-style due to impact of power cuts, could focus the mind more. He mentioned Texas was close to losing the grid in the summer, New England almost ran out of natural gas, so coal becomes more of an insurance policy.

Mr Jha agreed with the points made. Also there seems to be a reluctance to discuss coal so, some plants in India are operating at 25% efficiency because of the reluctance to discuss the need to improve their efficiency performance due to being coal-fired. There needs to be a recognised period of transition from coal to renewables therefore, an acceptance that coal is still needed and efforts to deploy clean coal technologies need to be supported.

Mr Lockwood commented on the lack of public understanding regarding the reality of coal and that greater and more immediate progress concerning CO_2 reduction can be achieved, more than many realise.

Mr Hrkman agreed with the public perception comment and that the reality is the more immediate climate change objectives cannot be achieved without applying technology to coal power, such as CCUS, which is now known to work.

Mr Kellow commented on the compatibility of liberalised markets, coal, grid reliability etc. In countries with liberalised markets, coal seems to be being pushed out however regulated markets may better support coal.

Mr Michael Flanigan referenced the financing challenges highlighted by Mr Jha and suggested Mr Hrkman might take this comment back to Capitol Hill and see whether the World Bank could provide more help in bridging finance gaps.

There being no further discussion, Mr Kellow summed up and thanked the three presenters.
Mr Peter Freyberg offered the comment that consumers can exert more influence if they wish to continue to have affordable, reliable as well as an environmentally responsible energy mix.

DISCUSSION SESSION 2

The Role and Value of CCS

Chair – Mr Paul Simons, Deputy Executive Director, IEA

Mr Simons opened the discussion session by stating that coal remains an important area of focus for the IEA. He referenced several important IEA activities associated with coal in 2019 such as the presentation of the Coal 2019 report in China and the special focus on coal-fired power generation in Asia in WEO 2019.

The Role & Value of CCS in Different National Contexts

Dr Niall Mac Dowell, Imperial College London

Dr Niall Mac Dowell presented the outcome of the major piece of work which had formed the cornerstone of the CIAB 2019 work programme. He provided an overview of the project which focused on several case studies covering the UK, Poland, New South Wales (Australia), Indonesia as well as Texas and Wyoming (USA).

The project was based on four scenarios:

1. Business as Usual
2. All Technologies are available
3. No CCS but all other technologies are available
4. Renewables and Storage where only renewable power and energy storage can be deployed.

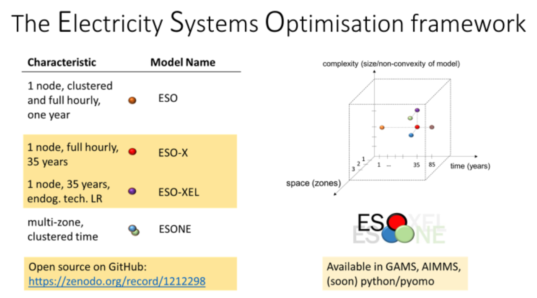
In the context of renewables, bioenergy was omitted due to upstream CO_2 related issues.

For each of the scenarios the cost optimal capacity expansion, unit commitment and economic dispatch profiles were calculated on a technology agnostic basis, for the period 2015 – 2050.

In the US case, three additional scenarios for each case study were also evaluated looking at:

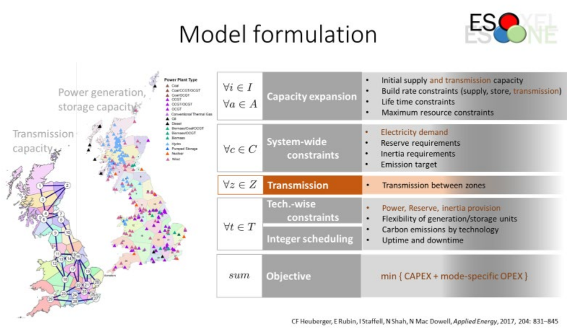
1. 48A + 45Q + EOR – Extending All Technologies scenario to include the use of CO_2 for EOR and accounts for additional revenue
2. 48A-ext + 45Q +EOR – As '1' but with the extension of 48A to apply to all coal-CCS plants built any year within the period
3. EOR Only – Assumes 45Q and 48A are discontinued and that only EOR is available to support CCS.

Modelling was undertaken using the Electricity Systems Optimisation (ESO) Framework.



In effect 1 node is equivalent to one country, ESO-X refers to capacity expansion, ESO-XEL concerns technology learning and ESONE is a case not just of where things happen but also when.

Taking the UK as an example, model formulation covers factors such as capacity expansion, system-wide constraints, transmission, technology related constraints along with integer scheduling.

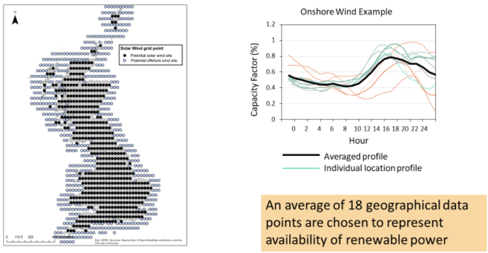


The model leads on transmission capacity looking at inefficiencies associated with 'moving' power around, system inertia and checking system resiliency.

When considering renewable energy resource availability data is taken from a virtual solar and wind farm model, looking at global weather patterns which helps to predict power availability.

For a given case study, when assessing renewable energy capacity factors, an average of 18 geographical data points are chosen to represent the availability of renewable power with the UK aggregation of spatial data used as an example to illustrate cause & effect..

Aggregation of spatial data across zone



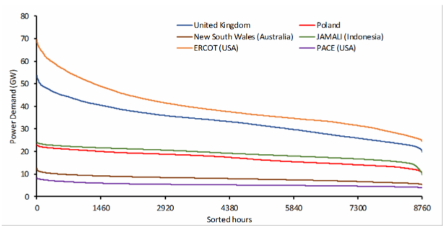
From a power system evolution perspective, the period considered was from 2015 to 2050 with both installed capacity (GW) and power generation (TWh) taken into consideration. The study focused on power evolution across the various regions being considered.

The evolving role of CCS, CO_2 supply and possible volatility, its effect on system design, as well as CCGT-CCS capacity factors were all taken into consideration.

The studies five regions were presented in more detail along with the varying regional characteristics.

Such characteristics included variations in power demand over a typical year as well as gas to coal price ratios over the study time period between 2015 and 2050.

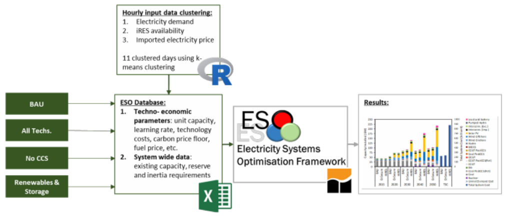
Varying regional characteristics



The spread based on seasonality is interesting to note and illustrates a large seasonal shift for power, greater in some regions than others. Seasonal variation, or lack of, can impact on technology choice and best fit. From the gas/coal price ratio the US is characterised by relatively cheap gas and Poland by relatively cheap coal.

Dr Mac Dowell explained the project workflow and how each scenario was run through the ESO database, with the ESO framework delivering associated results based on data input.

Project workflow

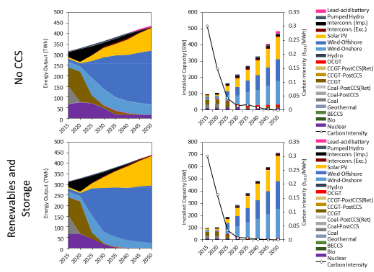


Dr Mac Dowell then talked though each case study in turn starting with the UK. This discussion report will highlight some of the headline findings only. For further detail the associated project report should be consulted.

UK

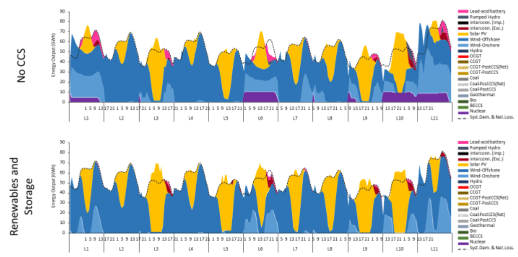
From an installed capacity and power output perspective, post 2025 coal does not feature in any of the scenarios. From a carbon intensity perspective, this drops to zero by 2050 under the No CCS and Renewables & Storage scenarios. However, the challenge then concerns meeting demand.

Capacity installed & power output (2)



Under the same scenarios there are periods of unmet demand, i.e. power shortages.

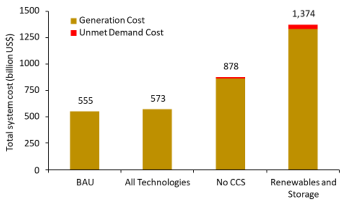
Dispatch patterns (2)



It is interesting to note, in the No CCS scenario, nuclear power plant would need to be used to meet peak demand and therefore be able to operate in a commensurately flexible manner which could present significant operational challenges for such plant.

Also, when it comes to total system cost, under the No CCS and especially the Renewables & Storage scenarios the costs increase significantly which will have associated impact on what the consumer pays.

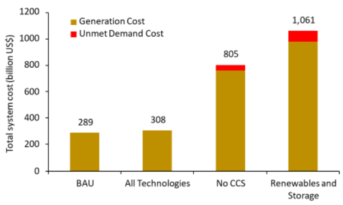
Total system cost



Poland

In Poland, considerable CCS retrofit would be needed in the All Technologies scenario however, as in the UK when considering the No CCS and Renewables & Storage only scenarios there are considerable challenges regarding unmet demand and significant increase in total system cost, greater than that experienced in the UK.

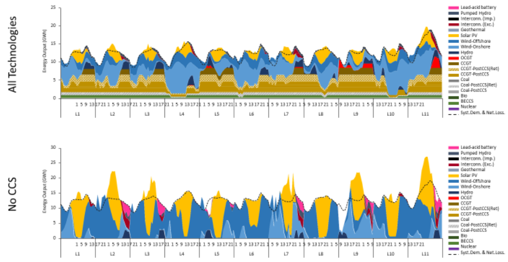
Total system cost



New South Wales

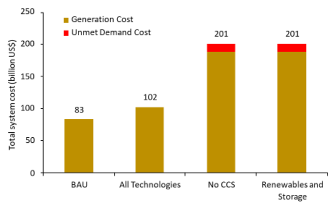
A key factor here is under the All Technologies scenario and especially in the No CCS scenario there would need to be significant investment in offshore wind. Currently no offshore wind is installed so, to meet energy demand, the capacity of wind power required may not be achievable. Therefore, there will be periods of unmet demand.

Dispatch patterns



As has been the case for the UK and Poland, Total System Cost increases significantly under both the No CCS and Renewables & Storage scenarios without giving ant certainty regarding meeting demand therefore presenting security of supply related concerns.

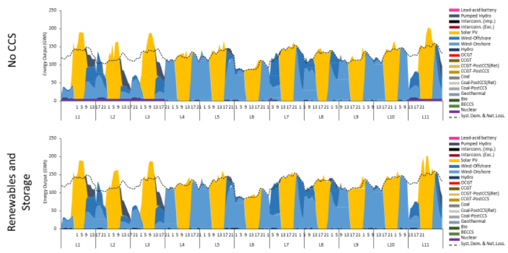
Total system cost



Indonesia (JAMALI)

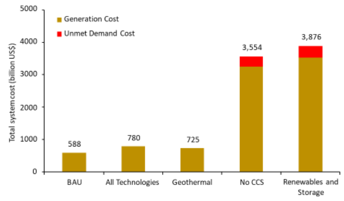
Wind speed in Indonesia is such that wind generated power is unlikely to make a significant contribution in meeting demand. So, in the All Technologies scenario, no renewable energy is deployed due to inadequate levels to meet demand. Furthermore, it is clear, under the No CCS and Renewables & Storage scenarios there will be significant periods of unmet demand.

Dispatch patterns



Also, under the No CCS and Renewables & Storage only scenarios, the total system cost increase is 5x that of the other scenarios, including geothermal, which was included in the Indonesia case study only due to associated resource potential.

Total system cost



Again, such magnitude of total system cost increase does not guarantee security of supply, in fact, as stated, there are notable periods of unmet demand.

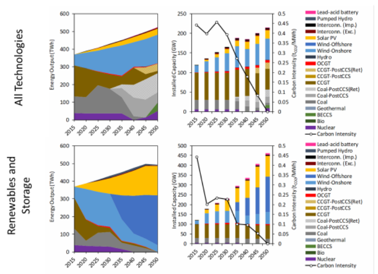
USA (ERCOT & PACE)

In the case of the USA, given the size of the country it was decided to model two States.

Texas – Electric Reliability Council of Texas (ERCOT)

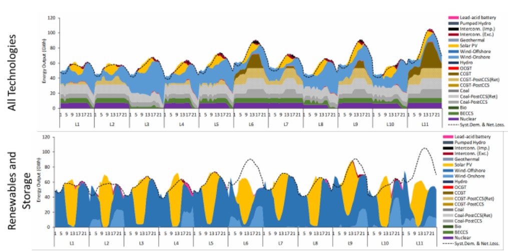
46Q and 48A allows coal to play an important role even with low cost gas on the system.

Capacity installed & power output



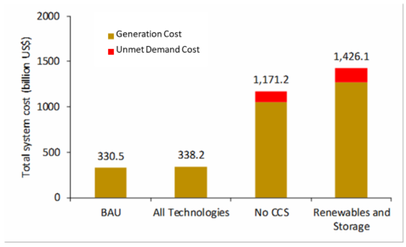
Under the Renewables & Storage scenario, more than double the size of the current system would be required to meet demand. It is interesting to note the challenges Texas had during the summer of 2019 which illustrate the difficulties that can occur with too much renewables on the system.

Dispatch patterns



Similarly, when considering the dispatch patterns, there are significant periods of unmet demand under the Renewables & Storage scenario and the increase in total system cost with CCS removed and emphasis on Renewables and Storage only is considerable.

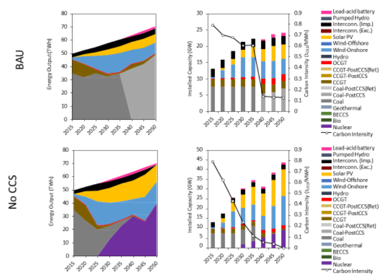
Total system cost



Wyoming – PacificCorp East (PACE)

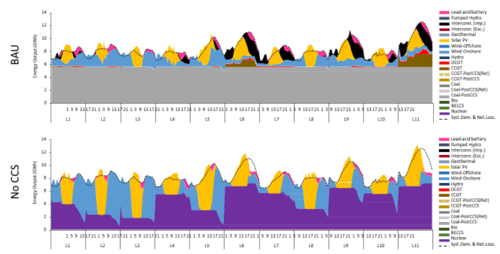
Under Business As Usual it is not possible to achieve net zero CO_2 but, 45Q and 48A plus the need to meet demand means considerably more coal + CCS, not seen in any of the other case studies. Also, a considerable amount of nuclear power is needed if CCS is taken out of the mix.

Capacity installed & power output

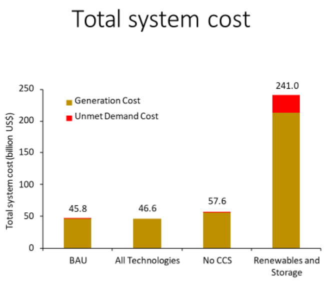


From a dispatch perspective coal with CCS carries the major burden of load to meet demand under the Business As Usual Scenario but problems occur with unmet demand when CCS is removed, with heavy reliance placed on nuclear.

Dispatch patterns

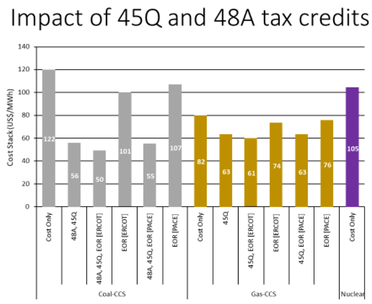


Interestingly there is a modest increase in total system cost under No CCS however total system cost increases significantly under the Renewables & Storage scenario.



As previously mentioned, three additional scenarios for the US case study were included in the overall study given the dynamic nature of US tax credit system which is continuously evolving. The three scenarios are:

1. 48A + 45Q + EOR
2. 48A-ext + 45Q + EOR
3. EOR only



Looking at all three additional scenarios, it is clear to see the benefit of such policy intervention in helping coal with CCS become more competitive compared with gas with CCS and nuclear. EOR helps but it is clear EOR on its own may not be enough to support investment decision making so, policy intervention such as 45Q and 48A is key to help ensure net zero whilst also ensuring he affordability and reliability of electricity supply.

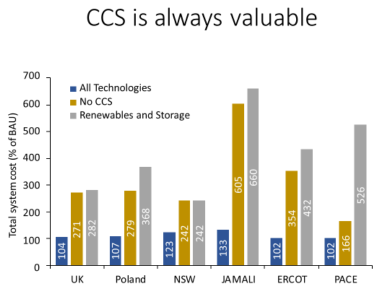
Beyond 90% Capture

The study undertaken by Imperial College also looked the impact of CCS technology capturing greater than 90% CO_2 especially given recent studies which have demonstrated 99% capture rates are achievable with low marginal cost.

Increasing capture rates will increase the capacity factor of plants with CCS. Also, in some cases consideration has been given to the use of bioenergy to 'mop' up remaining CCS if 90% capture rates are implemented. However, increasing the capture rate thereby increasing the load factor of plants with CCS more-or-less eliminates the need for bioenergy and the associated challenges regarding CO_2 impact that bioenergy can present.

In Conclusion

A key finding from the comprehensive study undertaken by Imperial College is that, regardless of national context, CCS is integral to delivering a resilient and cost-effective zero emissions electricity system. Without CCS, the cost increases by a factor of between two and seven..



Other key conclusions include:

1. CCS is uniquely valuable to an affordable transition to 'net-zero' CO_2
2. The role of CCS is a function of fuel prices and power demand seasonality
3. Considering greater than 90% CO2 capture reduces system cost
4. In the case of No CCS and Renewables & Storage, the rate of deployment of new generation capacity was unprecedented, in fact, such scenarios were frequently unable to satisfy demand. So, excluding CCS increases the risk of lost load / unmet demand.
5. The flexibility of fossil with CCS allows it to work with renewable energy, not against it.
6. Demand side response (DSR) does not make a material contribution
7. In the US, EOR alone will not justify CCS, additional support is required.

Possibly one of the most influential conclusions from the study is it is no longer a case of coal with CCS or renewables, it is now a case of coal with CCS AND renewables if a net zero CO_2 position is to be achieved in an affordable, sustainable and environmentally responsible manner.

Discussion

During this discussion session it was decided to take questions and have further discussion after each presentation.

Mr Lockwood asked about the impact of 45Q and 48A in the US.

In response, Mr Hrkman expanded on his comments regarding 45Q and 48A which he did in terms of potential benefits etc. Dr Mac Dowell commented, based on the study undertaken, capturing CO_2 from coal becomes less expensive than capturing from gas under 45Q and 48A. Also, even without 45Q and 48A, the US would still likely proceed with CCS from gas plants to support EOR.

A member of the IEA secretariat asked what was driving an increase in coal when comparing the All Technologies scenario with the Renewables & Storage scenario in the US case study.

In response Dr Mac Dowell stated 45Q and 48A were the driving forces behind coal build based on the modelling undertaken.

There was general discussion regarding the high quality and importance of the study given the key conclusions and messages. The need to ensure the report and associated summary documents are widely disseminated was reinforced by many in the meeting.

CCUS Cost Reduction Opportunities for Coal Power Plants

Dr Graham Winkelman, BHP Biliton

Dr Winkelman outlined the focus of the study and associated presentation which concludes a key element of the 2018-19 CIAB work programme.

The project was undertaken in conjunction with BHP and the International CCS Knowledge Centre based at Boundary Dam power station in Canada. The key focus of the project was assessing the cost reduction potential for CCUS application at coal-fired power plants based on learning by doing at Sask Power's Boundary Dam Station.

Driving down the cost of CCUS focused on:

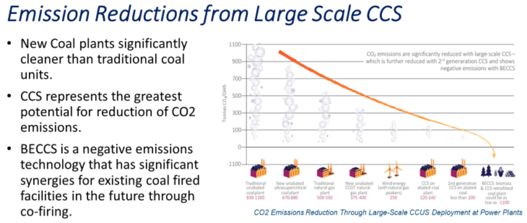
1. Capital cost reduction
2. Commissioning & operating cost reduction
3. CO_2 transport and storage cost reduction

The study was undertaken to better understand where the greatest cost reductions can be leveraged and delivered.

In addition, advancing the business case such as grid support, ancillary services and renewable energy integration was a key area of focus. Also, from a negative emissions perspective, consideration has been given to biomass co-firing within coal fired power plants.

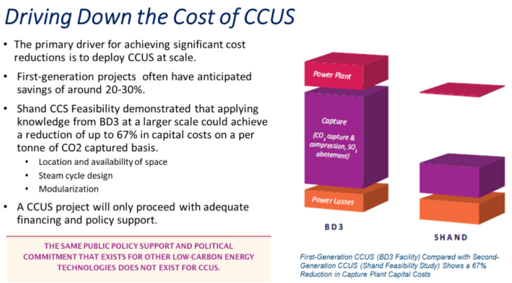
The report contains a considerable amount of information based on the Boundary Dam experience and the FEED study undertaken for Sask Power's Shand Power Station. Some of the key highlights from the report are summarised in this document.

Given global climate objectives there is an imperative need for CCUS however, international commitment as present is disjointed and the pace of development needs to increase significantly. CCS offers the greatest potential for significant CO_2 reduction in the medium to longer term.



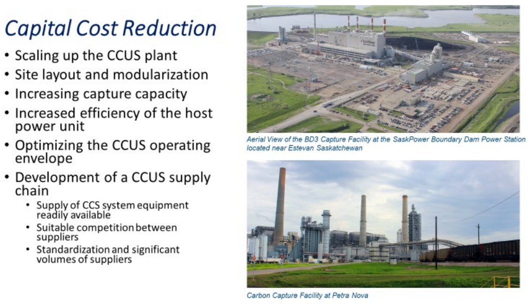
Most CCUS installations to date have been undertaken in other sectors. It is essential to expand on the few already undertaken in the coal-fired power generation sector. These projects provide significant lessons for future CCUS design and development in power generation, in particular, significant cost reductions have already been identified.

The primary driver for cost reduction is technology deployment at scale. The study reveals that CCUS for the coal-fired power sector is becoming cost-competitive with other emission reduction approaches. Technology advancement will lead to further cost improvements and this can be improved further by strengthened policy and financial support.



Key opportunities for cost reduction based on experience at Boundary Dam and at Shand are summarised below:

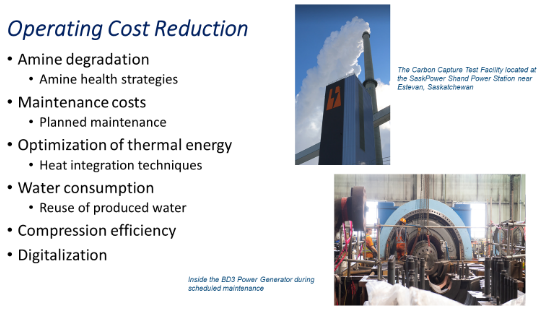
Capital Cost Reduction



Key opportunities for capital cost reduction include:

1. Careful management of site layout to improve integration of power and CCUS plant and equipment.
2. A modularisation approach to construction.
3. Increasing capture rate
4. Increased efficiency of the host power plant
5. Development and availability of a CCUS supply chain

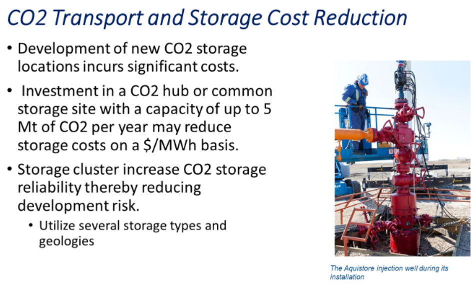
Operating Cost Reduction



Key opportunities for operating cost reduction include:

1. Managing amine degradation – the costs associated with replacing amine are significant so, addressing amine degradation is a key opportunity for cost reduction.
2. Maintenance management and advanced planning (preventative maintenance). Dealing with maintenance issues on an emerging basis can have significant cost impact.
3. Thermal energy optimisation – Using steam from the host power plant rather than having a dedicated steam plant for the CCS unit has significant cost saving implications.
4. Maximising compression efficiency to minimise associated electricity cost.

CO_2 Transport & Storage Cost Reduction



The development and use of a storage hub can significantly reduce costs. A recent UK study suggested costs could be reduced by 80%, from £25/MWh to £5/MWh.

Advancing the business case for CCUS needs to highlight the grid support and ancillary services such as dispatchable backup power which is essential in the context of managing the intermittency of renewable energy.

Similar to points made elsewhere and one of the key outcomes from the study undertaken by Imperial College, CCUS and renewable energy can be complementary in ensuring climate change objectives are met sooner rather than later.

A CCUS equipped coal-fired power plant can increase its CO_2 capture rate when operating at reduced load thereby enhancing the environmental benefit of the renewable energy source by further reducing overall system emissions.

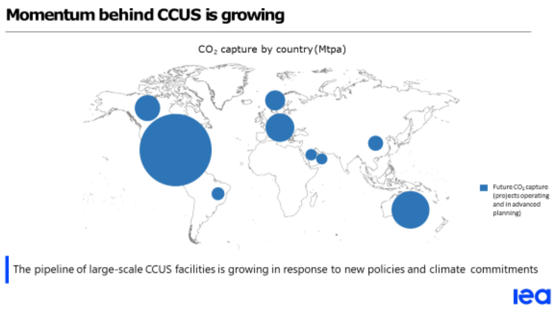
Following conclusion of his brief summary presentation, Mr Roger Miesen asked Dr Winkelman what he thought the estimated future cost of CO_2 on a per ton basis might be. In response Dr Winkelman stated he didn't have such a number at this point.

CCUS Developments and IEA Activity

Ms Samantha McCulloch, IEA

Ms McCulloch opened her presentation commenting on what seems to be growing momentum behind CCUS and the need to move more urgently to full scale implementation. There are currently 19 demonstration projects across the globe with the pipeline of large-scale CCUS facilities growing in response to new policies and climate commitments.

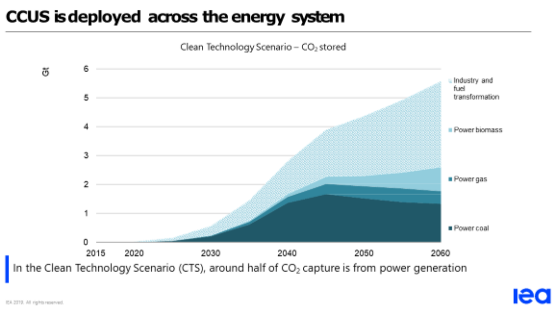
New plants are either at advanced planning stage or in early operation with 45Q driving new projects in the US. In Europe there is increased attention to CCS with a growing recognition that CCS is no longer an option but an essential technology.



Of the current 19 projects, only 2 are associated with the power generation sector, both of which are in North America.

In terms of a shift from the reference technology scenario (RTS) to the clean technology scenario (CTS), CCUS makes the third largest contribution in delivering CO2 reductions behind energy efficiency and renewables respectively.

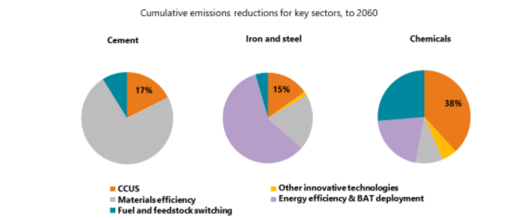
In the CTS, CCUS is deployed across the energy system with around 50% of CO_2 capture from power generation sources and the remainder from industry and fuel transformation sectors.



Under the CTS, 40% of gas generation is equipped with CCS in 2060 and whilst there is a significant reduction in global coal power, almost all remaining coal plants are equipped with CCS in 2060. New studies have highlighted that itis technically feasible to increase capture rates to up to 99% with low marginal cost implications.

In the industrial sector such as iron & steel, cement and chemicals, fossil fuels (predominantly coal) have met 70% of the energy needs over the past 30 years, due high temperature heat requirements in the associated manufacturing processes.

Emissions reductions for cement, iron and steel, and chemicals



CCUS is the most important lever in chemical production and third-largest in the cement and iron and steel subsectors in the IEA Clean Technology Scenario

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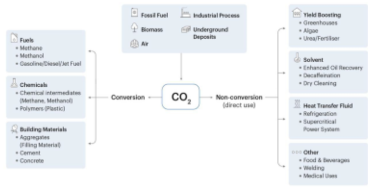
In the IEA Clean Technology Scenario (CTS), CCUS is the most important contributing technology for emissions reductions in the chemical production industry and third largest in the iron & steel and cement industries. The adoption of CCUS will allow continued use of fossil fuels to deliver the high temperature heat source required but with substantially reduced emissions. CCUS can also address the potential lock-in of emissions from long-lived industrial assets.

In the industrial sector, process emissions account for approximately two-thirds of cement and on-quarter of total emissions with the remainder associated with energy. These emissions cannot be avoided through fuel-switching and CCUS is one of few technology options for abatement.

IEA scenario analysis with limited availability of CO2 storage found that investment needs increase by 40% relative to the additional investments in the CTS. Also, an additional 3.3TW of low carbon power capacity will be required which is 50% of current global capacity.

From a utilisation perspective, CO_2 can be transformed into valuable products.

CO_2 can be transformed into valuable products



CO_2 can be used in a broad range of applications involving direct use of CO_2 or use through conversion into other products

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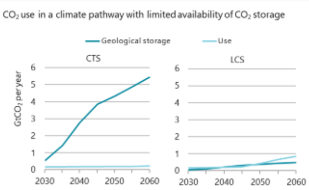
This can be through the direct use of CO_2 or, it can be used through conversion into other products such as fuels, chemicals or building materials.

Currently CO_2 is being used in the fertiliser industry as well as to support enhanced oil recovery and in the food and beverage industry.

There are however some challenges associated with expanding CO_2 utilisation predominantly associated with the increased energy need and associated cost.

That all said, CO_2 use has to be seen as complementary to storage not as an alternative.

CO_2 use is a complement, not an alternative, to CO_2 storage



Limiting the availability of CO_2 storage in the Clean Technology Scenario results in a 77% increase in CO_2 used in the period to 2060

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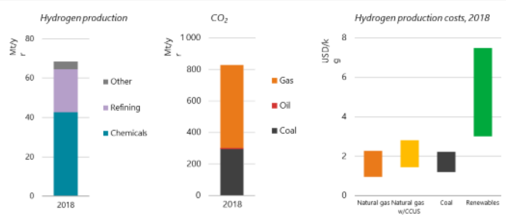
Hydrogen provides a flexible clean energy solution. Currently around 70m tonnes of hydrogen is produced and hydrogen use today is 4 x greater than in the mid-1970s.

Hydrogen provides a flexible clean energy solution



Dedicated hydrogen production is concentrated in very few sectors today, and virtually all of it is produced using fossil fuels. CCUS is an important option for low-carbon hydrogen alongside renewables.

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At present dedicated hydrogen production is concentrated in only a few sectors, virtually all of which is produced using fossil fuels due to the lower cost of electricity. CCUS is considered an important option for low-carbon hydrogen alongside renewables.

In conclusion Ms McCulloch summarised some of the key IEA CCUS related activities including:

1. Recently published CCUS reports
2. Reports to be published in 2020
3. Forthcoming events.

DISCUSSION

There was a considerable amount of discussion based around the following questions and answers:

Mr Kellow asked about the regulatory and risk environment and associated impact on cost and financing regarding the transportation and storage of CO_2.

In response Ms McCulloch commented that risk management had evolved through the use of shared infrastructure and new business models which separate transport and storage elements of the CCUS supply chain. For long-term liability and related risks, different regions have different legislative approaches; for example, in Australia storage management responsibility will pass to the government after a defined period of time. Also, these risks are becoming less of a deal breaker for investment as experience grows.

Mr Schiffer asked about the contribution of different technologies in the context of the CTS and what the main drivers are for the numbers quoted during the presentation.

In response Ms McCulloch talked about the use of cost optimised models which are technology cost driven which have highlighted the role of energy efficiency, CCS and renewables to achieve CO_2 reduction objectives under the CTS.

Ms Constable mentioned the momentum in the gas industry regarding CCS and asked if there were any insights in technology perspectives regarding the role of coal.

Ms McCulloch referenced the higher cost of CCS associated with coal-fired power generation and the need for learning by doing to identify key opportunities for cost reduction and that more needs to be done. There are advantages for the oil and gas industry because of inherent options for by-product through CCS. Involving the oil and gas industry and taking advantage of associated learnings will further help reduce the CCS cost associated with coal.

Mr Beere commented on the contribution of CCUS in reducing CO_2 emissions being the third best contributor at 13%, behind energy efficiency and renewables and asked how tough this was going to be to achieve across the board.

Ms McCulloch made it clear it will be extremely challenging across all technology contributions. In energy efficiency for example, considerably more effort is required to address the insulation and energy consumption of current and future building stock. With respect to renewables there are considerable scale up challenges to be addressed so, the need for a portfolio approach to CO2 reduction and associated technology development cannot be understated.

To reinforce the comments made by Ms McCulloch, Mr Simons stated the technology exists to achieve 39% reduction in CO2 through energy efficiency but there, at present, does not appear to be the political will to implement such technology options

Mr Lockwood asked why there seemed to be some differences in the potential contribution of CCUS in CO_2 reduction depending on which report or which scenario in references, e.g. WEO and projections to 2040 or the ETP cost optimised view to 2040.

In response Ms McCulloch explained that the IEA scenarios were the result of different models and different scenario timeframes. Some say the role of CCUS is overplayed and associated CO2 reduction projections are too high while others say it is underplayed and too low.

There being no further discussion this ended the discussion session of the meeting.

Mr Peter Freyberg thanked all the associated speakers for their input, thanked attendees for their questions and associated discussion and thanked both discussion session chairs for their help and support.

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)

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