INTERNATIONAL ENERGY AGENCY
COAL INDUSTRY ADVISORY BOARD

CIAB

44th PLENARY MEETING

DISCUSSION SESSION REPORT

IEA Coal Industry Advisory Board Plenary Meeting
IEA Offices
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9th – 10th November 2022

CIAB PLENARY DISCUSSION SESSIONS

Wednesday, November 9th, 2022

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 44th Plenary meeting.

DISCUSSION SESSION AGENDA

"Discussion Session 1: Ensuring a Sustainable & Secure Energy System
Chaired by Mr Keisuke Sadamori, Director Energy Markets & Security, IEA

- **A European Perspective on Energy Security** – *Mr Roger Miesen, CEO/COO RWE Generation SE*
- **Understanding the Cost of Electricity Generation at the System Level** – *Mr Paul Butterworth, Research Manager, Sustainability, CRU*
- **Critical Minerals and the Energy Transition** – *Mr Andrew Fikkers, General Manager, Market Analysis, Glencore*

Discussion

"Discussion session 2: The Importance of Abated Coal in the Global Energy Transition
Chaired by Mr Hitoshi Murayama, Chairman & Representative Director, J-Power and Mr Akira Yabumoto, Director, Energy Resources Strategy, J-Power

- **An Update on CCUS –** *Mr Jarad Daniels, CEO, GCCSI*
- **China Energy Perspectives on CCUS -** *Dr Xu Dong, Director, Carbon Neutralisation Research Centre of the New Energy Institute, China Energy.*
- **Update on China Huaneng CCUS Projects –** *Mr Lianbo Liu, Director, GHG Reduction & Clean Fuel Department, China Huaneng Group Energy Research Institute.*

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 and global Net-Zero objectives.

The two discussion sessions were focussed on:

1. Ensuring a sustainable and secure energy system
2. The importance of abated coal in the global energy transition.

The first discussion session included a European perspective on Energy Security from a major power European power company, RWE. This was followed by a presentation from CRU to help facilitate better understanding concerning the cost of electricity generation at the system level, exposing the limitations of the LCOE approach previously used. The third area of focus concerned critical minerals, in particular critical minerals and the energy transition. As a global leader in minerals mining and supply, Glencore provided some insight into the demand for critical minerals associated with planned further increased rates of renewable energy deployment outlining some of the key challenges and likely supply related constraints. Such challenges could undermine renewable expansion objectives.

The second discussion session focused on the importance of abated coal in the global energy transition. This included an update on CCUS activities based on GCCSI observation which illustrated a significant interest in CCUS and increase in the project pipeline. There followed two China power industry perspectives, one from China Energy concerning their interests in CCUS and associated views on the importance from a decarbonisation perspective. The second from China Huaneng Group provided insight into a tangible example of how abated coal can support renewable energy deployment. This illustrates the importance and value of abated coal in backing up the intermittency and addressing the dispatchable limitations associated with renewable energy deployment and therefore help ensure security of supply.

DISCUSSION SESSION 1: Ensuring a Sustainable & Secure Energy System

Chair - Mr Keisuke Sadamori, Director, Energy Markets & Security, IEA

Mr. Sadamori opened the first session providing an update on IEA perspectives associated with maintaining energy security. He referred to recent steps taken by the IEA to address the Russian invasion of Ukraine including oil stock release to help address supply constraints but the OPEC + cut in supplies stymied this much needed build up. Stock draw downs are likely to continue along with tight market conditions.

The Russian action has caused the EU to turn to the premium LNG market with US LNG helping to reduce reliance on Russian gas. However, the EU demand has driven both LNG growth but also market tightness with associated impact on other regions and countries.

The IEA has supported the EU resilience analysis and associated plan in the event of a complete Russian cut of supply. This has suggested through reduced demand gas storage could still be at 25% capacity in February but with further demand reduction, could be at 30% at the end of the winter period. Whilst the EU should get through this winter, 2023/24 is a concern with a possible shortfall predicted after the storage filling season. So the IEA formed the Natural Gas Task Force to help identify and address what else can be done to manage through the 2023/24 winter.

In terms of the power sector landscape, Mr Sadamori commented on the transition to more renewables and a more distribution-based electricity system with less reliance of large central generation assets.

In concluding his opening remarks, he reaffirmed energy security remained core to the IEA mission. He referred to WEO and the co-existence of abated fossil-based systems to support renewable based power generation. Such co-existence is important to maintain system reliability and resiliency. He referred to Norway where 90% of new cars are EVs yet the consumption of oil and gas remains about the same as 10 years ago with major transport the next area of focus.

With respect to the energy transition there are 5 key areas of focus:

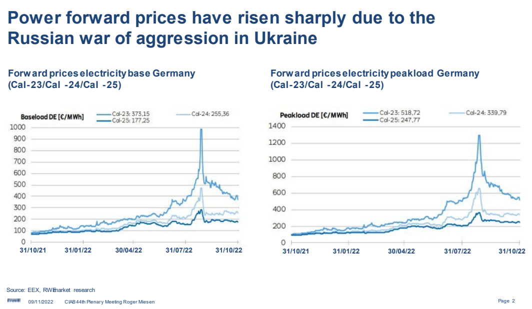
1. Energy Efficiency
2. Renewables and the need to accelerate deployment but also need adequate integration measures in place.
3. Maintain security of traditional fuels
4. Consider wider use of existing assets and the future proofing of assets.
5. Maintaining the resiliency and security of critical minerals supply.

On conclusion of his opening address, Mr Sadamori introduced the three speakers, the first of which being Mr Roger Miesen of RWE.

A European Perspective on Energy Security

Mr Roger Miesen, RWE Generation SE

Mr. Miesen provided a perspective on the forward power prices in Germany which have risen sharply due to the Russian invasion of Ukraine with baseload prices peaking at around 1000 Euros/MWh and peak load prices reaching 1300 Euros/MWh. The situation has been exacerbated due to 50% of the French nuclear fleet being off-line with the UK providing power support to the EU. The UK's reliance on gas has resulted in increased consumption and increased price. Reduced levels of hydro power have had associated impact resulting in little liquidity in the power market.



Whilst gas LNG imports have helped manage gas supply, prices have still soared although fallen back recently but still high influenced by Russian supply restrictions and buyers hedging, waiting to buy in the hope prices would fall further. So, later filling of gas storage has created further price pressures. There are gas tankers waiting offshore to take advantage of further price increases in the event of a cold winter period.

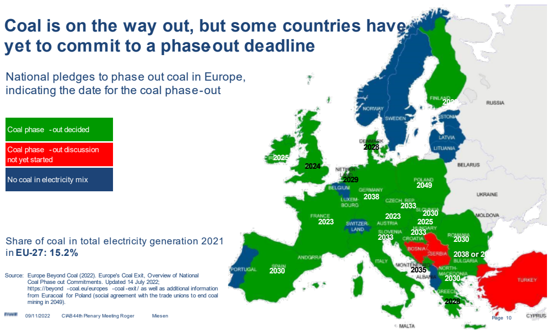
Reductions in gas consumption are helping but for the wrong reasons because industries are closing to reduce consumption with associated economic impact. So, demand destruction is taking place through de-industrialisation within Europe as industries shut down. Furthermore, there are increased tax levies on energy companies.

Mr Miesen talked through some of the EU measures taken in response to the Russian invasion of Ukraine including the REPowerEU Plan focused on further expansion of renewables and the ramp up of hydrogen. He also touched on 2030 and 2050 EU ambitions including the 'Fit for 55' package of objectives but expressed concern that associated policies could be more problematic and extremely challenging.

He then focused on measures being taken by the German Federal Government including the Wind-at-Sea Act, the LNG Acceleration Act, an act to make replacement power plants available (mainly coal and lignite to reduce gas consumption), the Gas Storage Act, additional levies on windfall profits and the transfer of three nuclear power plants to standby operation. However, this involved reversal of a previous German Government decision not to build LNG terminals also having coal and lignite plant on standby and out of the market is extremely costly with associated impact on energy costs.

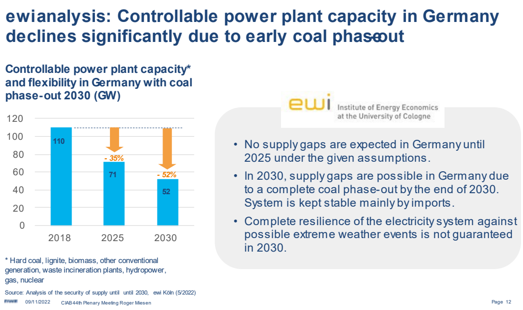
The current energy crisis has had significant impact on some energy companies with Uniper cited as an example along with EDF. In Uniper's case they were forced to buy gas on the open market to meet contractual obligations taking it to the point of collapse. In the case of EDF they were impacted by the French Government policy to keep energy prices low. In both cases associated governments had to step in at significant cost to prevent company collapse.

With Germany and Italy putting coal plants back into service, the UK putting units on standby, what is left of the coal power sector is playing an important role in helping maintain security of supply especially on high demand occasions with little renewable capacity available due to weather patterns yet, the demise of coal in Europe has been decided (now irreversible) and the EU strategy to address current security issues is more renewable deployment.



With respect to coal in Europe Mr Miesen talked through the IEA scenarios showing the strong decline in coal and the dominance of intermittent renewable generation capacity. In effect the developments and discussions associated with CCUS have come too late. Also, the political drive to phase out coal has been too rapid too soon given the limitations of alternative options and associated phase in culminating in some of the challenges now being experienced.

This also impacts on controllable and dispatchable power capacity which in Germany will have reduced by around 50% by 2030 compared with 2018.



The EWI predict in 2030 there could be gaps in supply in Germany and system stability may be reliant on imported energy with complete resilience of the electricity system against possible extreme weather events not guaranteed in 2030.

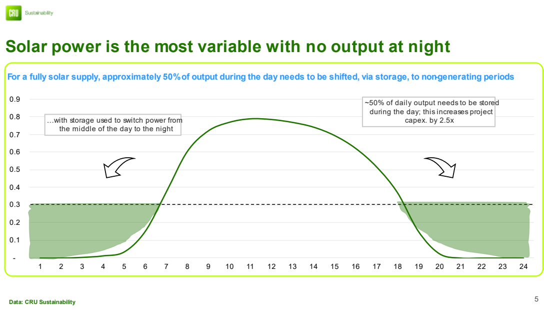
To try and ensure security of supply, RWE plans to invest significantly in wind, solar, storage facilities and gas-fired power plants that can operate with hydrogen. Bioenergy with CCUS is also part of the RWE strategy.

Understanding the Cost of Electricity Generation at the System Level

Mr Paul Butterworth, CRU

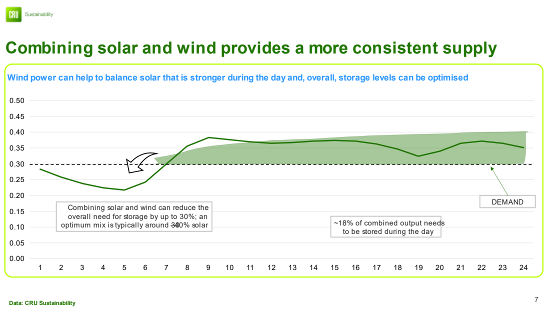
Mr. Butterworth opened by stating he felt the energy cost discussion was a little single faceted and there was need to look at energy cost on a more holistic basis. He spoke initially about some of the renewable energy sources and associated dispatch related challenges.

Solar is the most variable of renewable energy sources with no output at night therefore at night other energy sources are needed. Also, capexsolar output varies during the day so peak generation needs to be matched with demand. For a fully solar based supply, approximately 50% of daytime output needs to be shifted such as via storage to address periods of non-generation. This can increase solar related capex by around 250%.



Wind power (above a certain capacity) is more consistent where multiple wind farms are distributed across different geographic areas. However around 15% of daily output would need to be stored during the day resulting in a 30-40% increase in capex.

Combining solar and wind provides a more consistent supply and can reduce the overall need for storage by up to 30%, with an optimum mix considered to include 30-40% solar however approximately 18% of combined output would need to be stored during the day.



Annual variation also needs to be considered, especially with respect to solar which implies 2,500% of daily output needs to be stored.

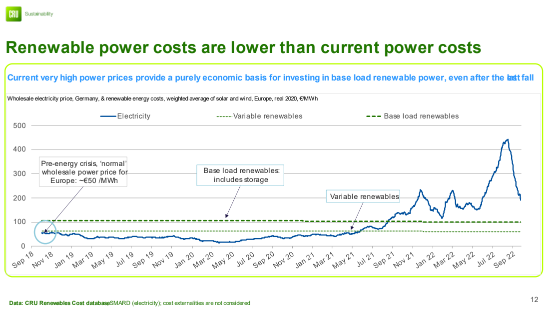
A solution is to ‘over build’ renewables to reduce storage needs, an optimum level is considered to be around 60% but depends on the shape of supply/demand profiles and availability of other generating assets. However:

1. Whilst over building can ensure that demand is always met, there is likely to be excess capacity for much of the time.
2. The optimum configuration will depend on relative capex of renewables and storage and other options
3. Excess power generated through over build of renewables may be curtailed or more likely, used to produce hydrogen.

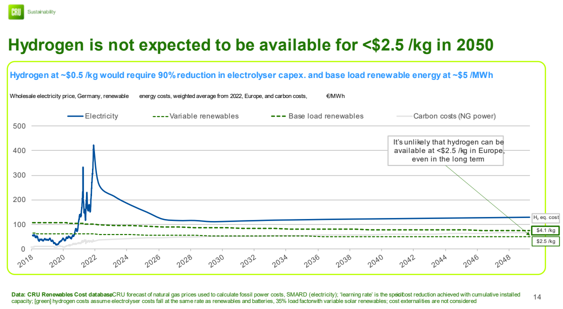
Mr Butterworth put current energy prices into a global carbon price context explaining high energy prices in effect do the same job as high carbon prices, they basically lift the cost of fossil energy making low carbon options more viable.

Electricity prices in Europe are closely aligned with natural gas prices both of which have seen 8-fold increases in 2022. The current high-power prices provide a purely economic basis for investing in base load renewable power, even taken into account recent reductions in price.

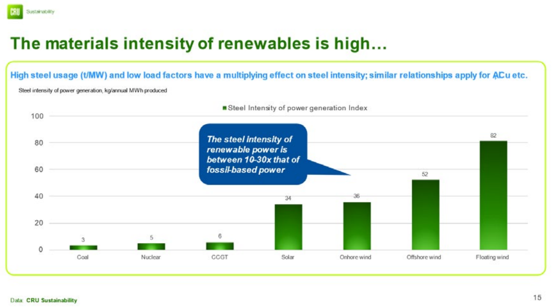
In 2018 the wholesale renewable electricity price looked competitive however if the cost associated with back-up capacity needs (such as fossil or energy storage) is overlayed the renewable price on the face of it looks extremely competitive however this is only because the cost of essential back-up fossil (coal and gas) capacity is very high.



Future power prices will continue to be higher than pre-energy crisis levels. Baseload renewable energy will remain competitive however this does not mean a return to cheap energy. Also there will not be a plentiful supply of low-cost electricity to decarbonise the economy. Even taking into account hydrogen, there would need to be significant capex reduction which is not going to happen even looking into the longer term.



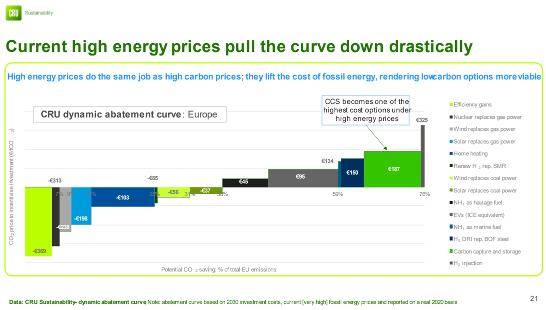
Mr Butterworth then focused on the materials intensity associated with renewable power generation. From a steel intensity vs power generation output on a kg/annual MWh basis renewable power requires between 10 and 30 times the material intensity, depending on associated technology.



Key materials account for 8-12% of renewable energy capex costs with decarbonisation likely to lift metals costs by 30-50% which could add 7% or more to the underlying costs of renewables with greatest impact associated with offshore wind. Furthermore, acceleration of renewables deployment may result in further cost inflation added to which, as commitment to renewables increases so does the cost of associated land. As the competitiveness improves and drive for renewables increases, landowners see greater scope for increased land rental and purchase price.

Could flexible abated coal with CCUS be an option in terms of providing back-up support as well as an alternative to storage? Mr Butterworth reported under ‘optimistic’ assumptions, flexible abated coal power with CCUS could reach a cost level around 10% higher than storage. However this assumes very optimistic parameters associated with the build and operation of such abated coal plant requiring significant technology development with essential scale up needs addressed without further delay.

Looking at carbon price, Mr Butterworth stated a carbon price of greater than 250 Euros/t would be needed to fully decarbonise the EU economy to incentivise the technology needed to replace fossil energy resource. However, current energy prices and associated carbon price equivalency lift the cost of fossil energy, making low-carbon options more viable as previously stated.



Mr Butterworth suggested if the coal industry is serious about CCS, then it should be advocating a commensurate carbon price.

In conclusion, the key takeaway messages from Mr Butterworth's presentation are as follows:

1. Current high energy prices imply a global carbon price of around £100/tCO_2
2. Base load RE is not cheaper than fossil power in a steady state energy price environment without carbon capture.
3. Inflationary factors (not typically accounted for) partially driven by accelerated RE deployment could increase the cost of renewables by 20-30%.
4. RE technology requires 10-30 times the materials intensity compared to fossil energy.
5. CCS requires a low energy price and high carbon price to incentivise investment & development.

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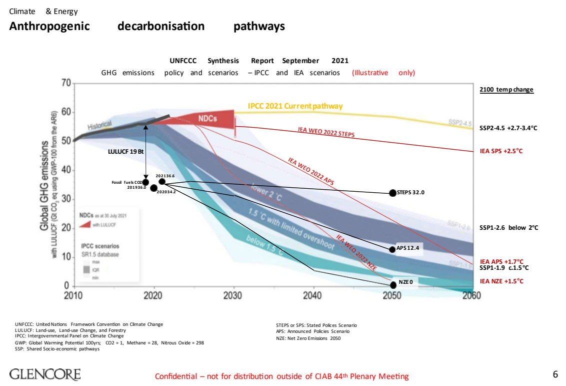
Critical Minerals & the Energy Transition

Mr. Andrew Fikkers, Glencore

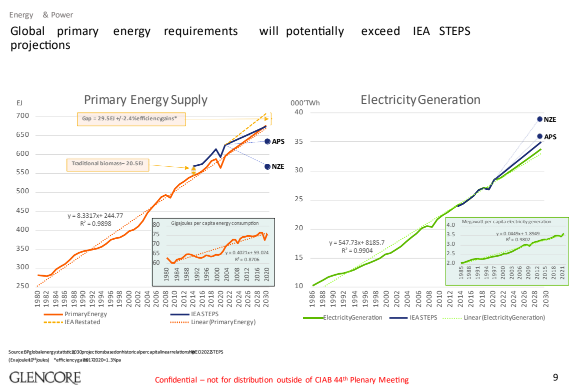
Mr. Fikkers opened by touching on some energy system related misconceptions such as some believing a 1GW coal power plant can be replaced by a 1GW of renewable capacity (capacity for capacity). This somewhat simple view by many is a misconception.

He talked through the various scenarios such as STEPS, APS, NZE etc.



In APS there is an assumption the necessary renewable capacity can be built however in terms of fossil fuels, by 2050 there remains around 19bt CO_2 that still needs to be addressed.

Mr Fikkers referred to a strong correlation between global population and primary energy needs with a view that increased energy demand will exceed any efficiency gains achieved over the next 7-10 years.



With respect to materials supply to meet the needs of projected renewable energy technology deployment he talked through the application of various materials and associated availability both in terms of mined supply and material reserves (tonnes and life). For renewable technologies the main areas of focus in the short to medium term will be Zinc, Nickel and Copper. In 2021 mined supply and global demand were fairly closely aligned. Timing is key so, if demand significantly increases there will likely be challenges associated with ramping up supply to meet associated demand. Taking into account typical project development and approval process can take up to 10 years.

Mr Fikkers talked through the various implications associated with the supply of key materials Zinc, Copper & Nickel. In summary the implications of metals supply in delivering the energy transition are as follows:

1. Up to 2030 the supply of zinc and nickel supports STEPS, however SDS becomes challenging due to shortfalls which increase significantly post 2030.
2. The supply of copper is unlikely to be sufficient to meet STEPS post 2027. Also copper grades are declining.
3. China, EU and USA together could exacerbate shortages of copper supply to developing nations.
4. The base copper cumulative supply shortfall versus STEPS to 2030 equates to the following (assuming there is no change in vehicle and power related demand)
   - 15.8M EVs = > 0.5mbbls/d
   - 350GW wind = 885TWh shortfall
   - 680GW solar = 910TWh shortfall

All of which equates to the following
   - >900TWh increase from coal with associated .380Mtpa CO_2
   - >900TWh gas consuming .266bcm pa (circa 190Mtpa LNG)

Of the three key minerals touched on above, copper is the most influential with respect to shortfall so, coal and gas may need to pick up energy shortfalls associated with lack of copper.

With respect to LNG additional projects need to reach FID to close the pending supply gap. In terms of LNG Mr Fikkers made the following key points:

1. 25Mt of operational supply will deplete by 2030
2. >280Mt or 19 Freeport terminals are required by 2030.
3. The EU's growth of LNG imports is impacting other economies now in energy deficit with coal partially filling the energy shortfall.
4. An extended period of very high gas prices will limit economic growth and support higher near-term coal demand.

With respect to coal, Mr Fikkers reported an immediate change of course from coal and fossil fuels is challenging as reflected by current policies and the most recent NDC's. Global coal demand is potentially 630Mt higher than STEPS with copper supply limitations adding 380Mt and replacement of EU LNG adding 250Mt (totalling the 630Mt figure quoted above). However substantial investment will be required to ensure sufficient coal supply even under APS. Also, operational cost pressures and carbon pricing will result in higher coal prices.

In summing up, Mr Fikkers concluded the following:

1. Global energy demand will likely exceed SPS projections, especially if electrification targets are not met and/or if the developing world transition finance requirements are not met.
2. Copper supply will likely limit installation of wind and solar generation capacity before 2030.
3. The supply of metals post 2030 will continue to be a constraint unless policy support fast-tracks expansions.
4. Gas, in particular LNG could potentially be constrained. Also higher near-term prices will lead to lower economic growth and drive increased demand for coal in China, India and developing nations.
5. Global energy shortages are too large for renewables to resolve in the near term.

Questions & Discussion

A European Perspective on Energy Security

Ms Nikki Fisher asked whether retrofit of CCUS to existing coal plant had been considered in Europe, to which Mr Miesen confirmed no and there is no interest in Germany.

Mr Paul Baruya asked about BECCS and associated CO_2 to which Mr Miesen commented on the ETS and credits for negative CO_2 emissions and there is a need to recognise there is a need for CO_2 so green CO_2 needs to come from somewhere.

Mr Andrew Minchener in the context of the EU Green Deal asked about the associated hydrogen and whether it was green or blue. Mr Miesen referred to the EU wanting 50% of hydrogen from green sources so there is a need for both green and blue.

Mr Andrew Fikkers commented he understood the 2038 phase out of coal was associated with grid build-out. Mr Miesen commented grid build out should be achieved by 2030 so, the revised phase out of coal should align with this however some significant challenges still need to be overcome.

Understanding the Cost of Generation at the System Level

Mr Mick Buffier asked whether comparing the likes of battery-based power with coal and CCUS was really an apples-for-apples comparison, e.g., if there is 8hrs of solar capacity, what about the remaining 16hrs if no wind. In the case of large consumers (e.g., smelters, metropolitan systems), a lot of batteries would be needed.

Mr Butterworth referred to the polysilicon industry which is very electricity intensive and needs a stable supply. If a battery can last 4hrs, many batteries in series would be needed.

Thomas Spencer (IEA) who had been involved in the coal in net zeros transition study stated the IEA modelling of CCUS included a capacity factor of 70%, which he stated is much higher than if in a back-up role. His view is the short-term variability can be covered by batteries etc. His view is the inter-seasonal variability, from an annual variability perspective he does not see coal and CCUS being cost effective.

Mr Butterworth commented on the need for a higher capacity factor of 90% and large dispatchable power needed to parallel up with other plant.

Mr Roger Miesen stated it was a misconception that base-load capability and large dispatchable power was not needed with more renewables. Technologies that can deliver 6000hrs/yr generation are still needed and it is not true that 100% renewables do not need baseload capability on the system.

Critical Minerals Constraints

Ms Veronika Shime referred to similar challenges in the US with respect to project approval citing a recent project approval after 30 years. She sees less permit approvals as well as less requests for permits therefore less interest from investors who don not want to take the risk.

Mr Fikkers agreed the situation is concerning and commented on statements coming out of COP27 which cannot be resources and delivered.

Mr Tae-Yoon Kim (IEA) suggested several ways to help address the energy gas including reducing demand and reviewing materials intensity. He agreed copper is a major challenge and there will be complexities around what industries are prioritised for limited copper availability. He mentioned the IEA plan to undertake a more granular study concerning critical minerals including steel and rare earth minerals.

In wrapping up the first discussion session Mr Sadamori thanked the three speakers for their excellent presentations and for associated participation in the following discussion,

DISCUSSION SESSION 2
The Importance of Abated Coal in the Global Energy Transition

Chair – Mr Hitoshi Murayama, Chairman & Representative Director, J-Power & Mr Akira Yabumoto, Director Energy Resources Strategy, J-Power.

Mr Murayama opened by commenting on the importance of CCUS. He referred to some who view CCUS as an excuse to continue burning coal which is absolutely not the case. CCUS is a significant CO_2 abatement technology, and the use of abated coal should be taken more seriously along with improved coal power efficiency. In some global regions, continued use of coal is essential so finding a win-win solution is important so there is no compromise associated with CO_2 reduction whilst also realising the benefit of abated coal.

Mr Murayama touched on J-Power's ongoing interest in CCUS and associated transition technology options and referred to several ongoing CCUS related projects. He mentioned the positive trend in the development of CCUS in recent years however the importance of abated coal had not received adequate attention and interest. The sharing of associated experience is important both to the CIAB and the IEA

Mr Murayama then handed over to Mr Akira Yabumoto to introduce the three speakers and to facilitate later discussion.

An Update on CCUS

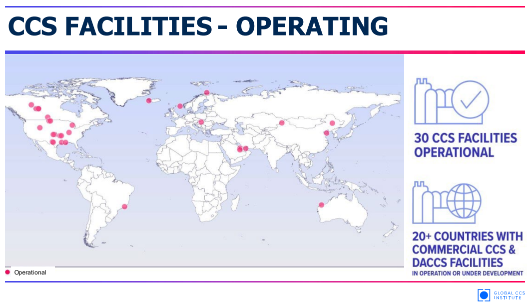
Mr Jarad Daniels, GCCSI

Mr Daniels opened stating high efficiency baseload plant along with CCUS are keys element of delivering on the climate strategy. CCS is an essential tool for reaching net-zero, amongst others.

1. It can help achieve deep decarbonisation of hard to abate heavy industry.
2. It can help enable the production of low carbon hydrogen at scale.
3. It can help facilitate low carbon dispatchable power in support of renewable energy.
4. It can help in the context of delivering negative emissions through BECCS.

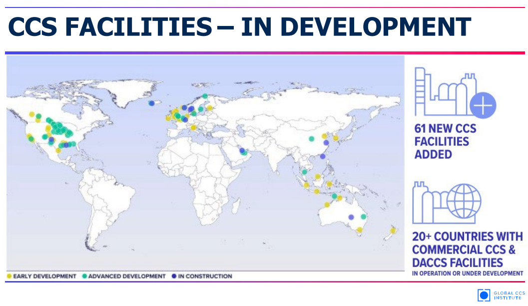
In terms of the demand drivers for CCS, they are centred around net-zero objectives associated with many industries and businesses where CCS is the main option available to decarbonise accordingly. Also managing the balance with economic growth and prosperity, especially in the developing world means responsible use of hydrocarbons with CCS.

There has been exponential growth in CCUS related activities in recent years with the associated capacity of all current projects estimated at 244Mt CO_2 per annum which equates to a 44% year-on-year increase driven by policy and funding support. However, a 100-fold increase is needed to get to the necessary gigaton scale of CO_2 capture by 2050.



Mr Daniels talked through the CCS facilities currently in operation, most of which are located in North America. He also reviewed those in development including the addition of 61 new CCS facilities with now more than 20 countries having commercial CCS and DACCS facilities.

Again, much of the associated development activity is in North America as well as in China, Europe, SE Asia and Australia with a broad diversity of CCS application.



In the past CCS has predominantly been EOR related however >70% of new projects are climate change related, focused on storage and the average project size is increasing to >1Mt CO_2 capture per annum. In addition, dedicated

CO_2 transport ships are being constructed along with subsea pipelines.

Mr Daniels reported an exponential growth of interest in CO_2 removal from the atmosphere. He commented net-zero objectives cannot be achieved without gigaton scale of CO_2 removal. However the associated costs remain high and the rates of reduction will be key. Learning by doing will be essential to reduce capture costs.

Private sector finance with appropriate government policy support is key achieving necessary deployment levels. There is much focus on how to better engage the finance community and demonstrate value.

The tax credit approach (such as in the US) is a game changer, incentivising increased activity. Canada is looking to deploy similar tax credit support with associated policy support. Efforts to adopt common taxonomy principle are key to facilitating a consistent approach. Carbon markets are also becoming increasingly important along with ESG reporting which remains important to commercial activity.

In Europe, Mr Daniels cited the example of Denmark where previously there was pressure against CCS, the public support position has changed due to a better understanding of the industry impact if CCS is not considered. There is a recognition, abatement will not be achieved without CCS. Other countries such as the Netherlands and the UK have announced CCS related funding for projects and the EU, through its Innovation Fund is to invest in 11 CCS and CCU projects supplemented by individual member state policies.

CCUS in the MENA region is being driven by high-level policy and international market expectations and have three facilities in operation representing approximately 10% of the global capture capacity.

In the Asia Pacific region China, Japan, Indonesia, Malaysia and Australia all have CCS related initiatives in place with CCS now part of the national policy discussion in China.

From an international policy and regulation perspective, CCS development has to be driven by policy and regulation with CCS now explicitly stated in IPCC statements alongside renewable technologies such as wind and solar. More than 80% of countries that submitted Long-Term Low-Emission Development Strategies (LT-LEDS) included CCS and 21 countries have included CCS in their Nationally Determined Contributions (NDs) with more expected.

Mr Daniels list 6 areas that need to be addressed to realise CCS at scale:

1. Define the role of CCS and CDR in meeting national climate strategies and plans as well as set and communicate targets.
2. Create a long term, high value case for the storage of CO_2
3. Support the identification and appraisal of geological storage resources.
4. Develop specific CCS laws and regulations.
5. Identify opportunities for CCS networks and facilitate the establishment of transport and storage infrastructure.
6. Enable investment in CCS through appropriate policy and market mechanisms.

In concluding, Mr Daniels stated net-zero by 2050 requires strong action by 2030.

1. CCS deployment is way short of the scale needed to achieve net-zero.
2. The currently installed CCS capacity needs to increase at least 100-fold by 2050.
3. Governments need to put in place supportive policy, incentivise private sector to build, own and operate with commensurate capital investment support.

China Energy Perspectives on CCUS

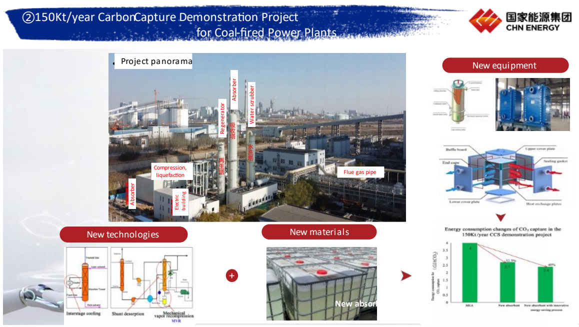
Dr Xu Dong, China Energy

Dr Dong stated thermal power generation accounts for 86.5% of China Energy related CO_2 emissions so, China Energy's business segments that involve CO_2 are mainly thermal power generation, chemical industry activities, coal production and associated transportation including ports.

He spoke of China Energy's storage demonstration project, China's first with a capacity of 100Kt CO_2/yr which started in 2011. To date a total of 302.6Kt CO_2 has been injected and stored. The next project is China's largest at 150Kt/y post-combustion capture demonstration project associated with coal-fired power plant based on a 600MW unit with a capture rate of

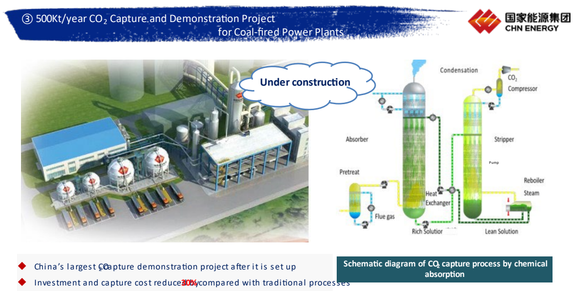
90% and CO_2 concentration of >99% with heat consumption for absorbent regeneration of <2.4GJ/t CO_2. Use of the associated captured CO_2 is divided three-ways – EOR for nearby oil fields, industrial production (baking soda) and production of high value chemicals.

The reduced heat consumption is based on the use of new technologies and new absorbent materials. Compared with other similar projects across the globe, operating costs are 40% lower and energy consumption is the lowest.

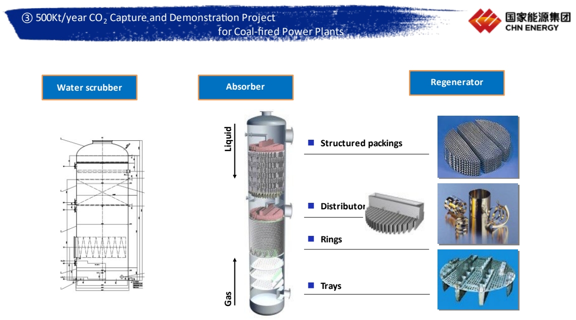


The next project referenced is the 500Kt/yr CO_2 capture and demonstration project also associated with coal-fired power plants. This is associated with the world's first GW capacity USC double reheat generation unit with an average efficiency of 47.83%.

It has a designed CO_2 capture heat consumption of <2.4GJ/tCO_2, associated power consumption less than or equal to 90kWh/tCO_2 with a capture rate of >90% a purity of >99% on a dry basis at a total cost of <$35/ton. It includes a new 3-way composite absorbent system featuring low heat consumption with high capacity and stability. In addition, it features a new structured packing reducing pressure drop by 15-30% and increasing mass transfer efficiency by 10-15%. An amine recovery unit is added at the top of the absorber tower delivering an associated amine loss reduction of around 30%.



Dr Dong talked through the project structure and the three key elements associated with it.



In terms of project timeline, mobilisation of major equipment and completion of tower hoisting has been completed with completion of the main building and associated installations by 31 December 2022. Completion of subsystem commissioning is expected by mid-March 2023 with completion of a 168-hour trial operation period completed by end of April 2023.

From a CCUS R & D and demonstration outlook perspective:

1. China Energy is making breakthroughs in developing key low-cost post combustion capture technologies and performing full system integration research which is helping to facilitate large-scale capture demonstration projects.
2. China Energy is tapping into R & D and demonstration of multi-type, multi-approach and large-scale CO_2 utilisation technologies for commensurate resource and energy applications.
3. China Energy is developing industrially scalable CO_2-based coalbed methane displacement and storage technologies as well as building large-scale demonstration projects in multiple locations.

In summing up, Dr Dong stated China Energy is helping to build a national CCUS full-process industrial innovation platform.

Update on China Huaneng CCUS Projects – An Example of Decarbonising Coal

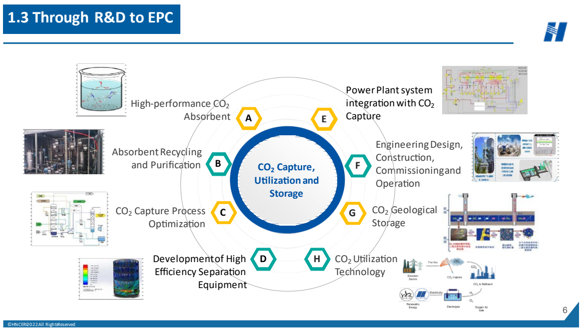
Mr Lianbo Liu, China Huaneng Group

Mr Liu provided some background to the China Huaneng Group and their Clean Energy Research Institute (CERI) which is one of the leading research institutes in China and one of the CCUS technology leaders globally. It is also a project leader in developing the international standard for carbon capture, ISO 27927 and playing a lead role in the world's largest post-combustion CO_2 capture plant associated with the Hauneng Longdong Energy Base at 1.5Mt CO_2 per annum.

CERI has established a international cooperation agreements with well know R & D institutions and large energy enterprises located in Australia, Canada, Germany, Italy, Korea, UK, US and others. Intergovernmental cooperation includes:

1. The US-China Clean Energy Research Centre (CERC).
2. The Australia, China Joint Coordination Group on Clean Coal Technology (JCG).
3. Cooperation Action within CCS China-EU (COACH).
4. Near-Zero Emissions Coal plant China-UK (NZEC).

Mr Liu talked through the process from R & D to EPC involving the development of high efficiency separation technology.

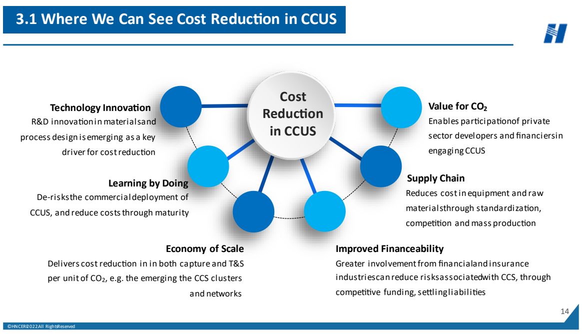


He also talked through the history of CERI and CCUS deployment from 2006 through 2023, the Longdong Energy Base to 2023/24, China's first carbon capture technology output project at the Milmerran Power Plant in Australia. Mr Liu also talked through some of the CERI CCUS milestone projects which included the following:

1. Shidongkou post-combustion carbon capture project started in 2009 with capture capacity of 120Kt CO_2 per annum, the largest PCC facility at the time with a capture ration of 90%. This has had process updates and equipment improvement work in recent years and accumulated 22,000 operating hours demonstrating associated capex & opex.
2. A 1Mt capture feasibility study between China and Australia under the JCG framework. The feasibility study was completed and officially released in 2018 and explained the technological and economic aspects associated with building such a plant.
3. The Longdong 1.5Mt/yr CCUS project. The feasibility studies were completed in September 2021, FEED in mid-2022, construction started at end of 2022 with construction due to be completed by the end of 2023. CO_2 will be transported via pipeline to a dedicated geological storage site and include EOR. It will be integrated with a 2GW peak-load regulating coal-fired powerplant, installed to back up renewables. The key scope is to achieve <$35/t CO_2 captured with reboiler duty of <2.3GJ/ton CO_2 with solvent consumption <1kg/t CO_2

A further key element of scope is to be the first commercial CCS project to demonstrate flexible coal-fired power with CCS, providing peak-load regulation to back up regional renewable power generation.

Huaneng Group are also investigating phase change CO_2 capture technology which has been demonstrated via a pilot to achieve regeneration energy consumption below 2.3GJ/tCO_2. This has helped verify phase separation performance and associated energy saving capability. It will now be scaled up to being the first 120Kt/yr phase change CO_2 capture demonstration plant in the world which will be operational between 2022/23. Through learning by doing, Huaneng Group can see several opportunities for CCUS cost reduction.



Mr Liu provided an update on Glencore's CTSCo Surat Basin CCS project in which China Huaneng Group is engaged. This will be based at the Milmerran coal-fired power plant located in southern Queensland. It will have a 110Kt/yr CO_2 capture rate with dedicated geological storage and will be the first commercial post-combustion CO_2 capture project in Australia. A key objective is to build a scalable demonstration project with application for coal-fired power plant.

The project started with a pre-feasibility study between 2010 and 2012 and will culminate in plant operation and CO_2 injection around 2023-

25. It will be a 3-year demonstration project with a 20-year plant lifespan and adopts a modular approach to construction to demonstrate associated benefits and balancing manufacturing efficiency with transport (sea and land) and on-site construction logistics.

In concluding, Mr Liu summed up the future role of CCUS and associated value:

1. CCUS in the power industry helps ensure energy security.
2. With respect to heavy industry, it can be a solution to decarbonising hard to abate sectors.
3. Bioenergy with CCS (BECCS) can transition the energy system towards a position of carbon neutrality.

Questions & Discussion

An Update on CCUS

Mr Peter Morris asked if Mr Daniels could provide any update concerning 5 US coal-fired power plants Mr Morris understood are to be fitted with CCS. In response Mr Daniels commented it would be interesting to see what appetite there is to apply to coal given many are aging and may not be considered of value to retrofit. However, he was unaware of US power plants to be retrofitted or of any US policy tools associated with coal-fired power generation.

Mr Mick Buffier asked whether CCUS was being discussed at COP27 or just in side events. He felt there was inconsistency globally concerning support with Australia, he felt, going backwards. In response Mr Daniels confirmed there had been some discussion with formal CCS dialogue being arranged by the IEAGHG. He stated part of the US government approach included an 'all-of-the-above' element. CCS is still part of the discussion but still not in the context of the CO_2 reduction capability it can offer. Mr Daniels also mentioned some ant-CCS discussions which he looked to better understand.

Mr Peter Morris asked where capture efficiency is heading commenting 95% is considered to be cost-effective but there is some focus on 98%. Mr Daniels agreed >95% is a correct assumption to make and is technically achievable. If the purity of CO_2 is likely to increase, then there is incentive to invest. However, he stated it depends on how plant is operated so, peaking plant will have less capture opportunity so, it is important to understand operational and capture objectives and what is techno-economically feasible.

Mr Akira Yabumoto asked what policy could be most effective to further accelerate deployment. In response Mr Daniels stated there is no one-size-fits-all approach. It depends on regional factors, objectives, government think and attitude etc. So different approaches may be needed such as carbon taxes, CO_2 pools, hubs, etc. In addition, market design and payment for ancillary services will be key. Another could be greater involvement of government such as in the procurement of low-carbon products, incentivising CCS in cement/concrete production.

China Energy Perspectives on CCUS

Mr Earl Melamed asked whether to CO_2 capture costs could be reduced to around \$24/t. In response Dr Dong commented in the context of the \$40/t figure quoted this concerns steam used for regeneration with associated heat being around 50% of the capture cost. It also included whole system electricity costs as well as absorbent and labour costs which are lower than in the West and given everything is purchased and built in China, the avoidance of shipping costs helps reduce cost. Given the engineering experience being developed and gained opportunities for further cost reduction should be identifiable.

Mr Hasan Erdogan asked about the coal power plant efficiency, the technology as well as CV of coal used. In response Dr Dong stated his focus is on the CO_2 capture part of the plant so, is less familiar with the power plant. He was not sure whether brown or black coal was being combusted but understood the coal is sourced from a domestic China Energy mine. The power plant is a USC double reheat design.

Update on China Huaneng CCUS Projects

Mr Akira Yabumoto asked about the role of renewable energy in the context of the Longdong project. Mr Liu in response, confirmed the overall capacity of the Longdong Energy Base is 10GW which included 8GW of renewable energy comprising wind and solar, as well as the 2GW coal-fired power plant. The 2GW coal plant is to provide flexible dispatchable power with CCUS to support the whole energy base and the intermittency of renewable energy.

Mr Peter Morris asked about the capture efficiency and associated parasitic load. Mr Liu confirmed a 95% capture efficiency which in itself is not a major challenge for PCC technology. The main challenge is balancing efficiency with cost which depends on the process employed. So, it is a question of balancing capture rate and the associated energy penalty.

Mr Julian Beere asked whether, in the context of Longdong, there was a commercial framework and associated incentive from a carbon perspective. Mr Liu confirmed there is support from the government but also China Huaneng Group have an ambition to be carbon-neutral and in that respect are focusing on the decarbonisation of coal.

Following some healthy discussion, Mr Murayama, provided some closing comments. He highlighted the excellent presentations and informative content and was encouraged by the increased momentum in CCS and hoped tere would be more projects in the future. He felt a significant development were the Chinese projects and associated objectives of demonstrating CCUS as a good and highly effective techno-economically feasible decarbonisation option. He hoped the IEA staff present had also benefited from the presentations and the discussion session and once again expressed his sincere thanks to the three speakers.

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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)

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