An International Commitment to CCS:

Policies and Incentives to Enable a Low-Carbon Energy Future

Coal Industry Advisory Board Submission to the International Energy Agency

21 November 2016

Foreword

Seamus French
Coal Industry Advisory Board (CIAB) Chairman

The Paris Agreement limits the increase in global average temperature increase to well below 2°C above pre-industrial levels. This goal cannot be achieved without a strong, international commitment to the deployment of carbon capture, utilization and storage (CCS) in a diversity of applications, including coal and natural gas-fired power generation, industrial, and bioenergy. The IEA estimates that 12% of cumulative emission reductions to 2050 must come from CCS and the Intergovernmental Panel on Climate Change's Fifth Assessment concludes that achieving a 2°C goal will be 138% more expensive without CCS, equating to 3% of cumulative global GDP through 2100. Therefore, to achieve a goal well below 2°C is unlikely, if not impossible, without CCS.

The use of coal for power generation and steel and cement manufacturing is set to continue, particularly in developing countries, owing to its widespread abundance and affordability. Coal is projected to account for 25% of total primary energy demand by 2040 in the IEA's 2015 World Energy Outlook (WEO) New Policies Scenario. This reflects approximately 700 million tonnes of growth (12%) in thermal and coking coal demand between 2013 and 2040. Almost all the growth comes from developing countries in Asia and Africa. Even in WEO's lowest coal utilisation scenario, the 450 case which meets a 2°C target, coal is 16% of total primary energy demand in 2040. Given that over a third of the global coal-fired power generation fleet is less than 10 years old, it is unrealistic to expect that this fleet will be prematurely shutdown at enormous cost.

If a path toward 2°C is to be met, significant growth in the installation of both CCS and high-efficiency low-emission (HELE) power generation technologies within this fleet will be required. The IEA estimates 12 GW of CCS-enabled HELE plants will be required by 2020, 215 GW by 2030, and 664 GW by 2050. If a path to well below 2°C is to be met, the rate of deployment will need to be further accelerated. Rapid growth in the use of CCS in bioenergy and other applications will also be required. While there is urgency if this high rate of deployment is to be achieved, effective policy measures, which are part of an international commitment to facilitate this rate of deployment do not exist.

Together, industry and government have proven first-generation CCS technology, with 15 large scale projects operating so far and already capable of storing 27 million tonnes of CO_2 per annum. However, this is only a first step. An international commitment to CCS requires that governments have the political will to put in place well-designed CCS policies that: (1) stimulate CCS market uptake, (2) support CCS project development, (3) enable CCS project funding and (4) advance next-generation CCS technologies.

Such policies will create a commercial investment environment in which industry can help bring forward the next wave of CCS projects. It will spur competition and innovation, drive down the cost of CCS, and reduce the commercial risks associated with deployment.

If the goals of the Paris Agreement are to be achieved, an international commitment to CCS, which currently does not exist, is essential. This will require Governments to put well-designed policies in place, public and private banks to finance well-designed projects, and industry to drive project development and technical innovation.

This paper has been written by members of the CIAB, drawing on our experiences in CCS projects around the world, to outline policies and incentives that could provide the underpinning for future successful projects.

An International Commitment to CCS: Policies and Incentives to Enable a Low-Carbon Energy Future

Authors:

Kenneth K. Humphreys, FutureGen Industrial Alliance, Inc.

Maggi Rademacher, Coal Industry Advisory Board

Julian Beere, Anglo American

Mick Buffier, Glencore

Prach Chongkittisakul, Banpu Public Company Ltd.

Nikki Fisher, Anglo American

Patrick Forkin, Peabody Energy

Takashi Irie, J-POWER

Peter Morris, Minerals Council of Australia

Carole Plowfield, FutureGen Industrial Alliance, Inc.

Richard Reavey, Cloud Peak Energy

Shintarou Sawa, J-POWER

Hans-Wilhelm Schiffer, RWE AG

Benjamin Sporton, World Coal Association

Skip Stephens, Joy Global

Coal Industry Advisory Board Submission to the International Energy Agency

21 November 2016

Table of Contents

List of Figures

List of Tables

List of Boxes

Acknowledgements and Disclaimer

This paper was authored by a special working group on carbon capture and storage chartered by the Coal Industry Advisory Board's (CIAB) Chairman and Executive Committee. In addition to the working group authors, this paper reflects input from numerous other contributors, which CIAB greatly appreciates.

Numerous experts, affiliated with CIAB member companies and independent organizations, provided technical input and provided reviews of this paper. The authors greatly appreciate the efforts of contributors: Graham Chapman of the Siberian Coal Energy Company (SUEK); Hwansoo Chong of the Korea Carbon Capture & Sequestration R&D Center; Mücella Ersoy of Turkish Coal Enterprises; Mathias Hartung of RWE AG; Frank Huschka of Uniper; Roland Luebke of Gesamtverband des Deutschen Steinkohlenbergbaus; the staff of the Minerals Council of Australia and Coal 21; Alexandra Neels of Peabody Energy; Andrew Purvis and Alex Zapantis of the Global Carbon Capture and Storage Institute; Brian Ricketts of Euracoal; the staff of the Shenhua Group; Deck Slone of Arch Coal; Yoshihiko Sakanashi and Itaru Nakamura of J-POWER; Graham Winkelman of BHP Billiton; Jeff Philipps of EPRI; and Fernando Luis Zancan of the Brazilian Coal Association.

The project summaries (presented in boxes) substantially benefited from the contributions by: Kerry Bowers of Southern Company; Andy Read of the ROAD project; Leigh Hackett of GE; and Ian Filby of the Government of Victoria, Australia. The authors greatly appreciate this input.

Finally, our appreciation is extended to Antigoni Koufi and the communications team of the World Coal Association that coordinated layout, graphics and printing of this paper.

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 views expressed are those of the CIAB. The sole purpose of this paper is to advise the IEA Secretariat in accordance with the role of CIAB. This paper draws on the experiences of CIAB members based on their involvement in the design, funding, construction, and operation of CCS projects and energy infrastructure projects worldwide. This paper does not necessarily represent the views of IEA or the acknowledged contributors.

Executive Summary

The Paris Agreement on climate change, adopted by 197 governments[1], committed to "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels…" (United Nations 2015). Further, the Paris agreement seeks to balance sources and sinks post-2050, which effectively requires net-zero emissions.

To achieve the goals of the Paris Agreement ("Paris Goals"), an international commitment to carbon capture, utilisation and storage (CCS)[2] is essential. Such a commitment, which must include the necessary policy mechanisms to incentivise CCS deployment, simply does not exist today.

The Paris Agreement Goals and CCS

Achieving the carbon reduction goals of the Paris Agreement must be approached in a manner that provides access to reliable, affordable energy, supports economic development and improves living standards. To achieve this, accelerated efforts to increase energy efficiency and deploy a portfolio of low-carbon energy technologies is required. CCS is an essential component of this portfolio.

The goals of the Paris Agreement are at significant risk without an international commitment to CCS. According to the Intergovernmental Panel on Climate Change (IPCC), achieving a 2°C goal is estimated to be 138% more expensive without CCS (IPCC, 2014). This added expense equates to 3% of cumulative global GDP through 2100 (Krey et al., 2012). Without CCS, reaching a goal that is well below 2°C, would be more expensive, if it is even attainable at all. The 1.5°C aspiration included in the Paris Agreement would almost certainly require negative emissions, which are currently unachievable at a large scale without bio-energy CCS.

These facts point to the need for step-change action on CCS, which despite some important progress has lacked the policy support and political commitment that exists for some other low-carbon technologies. Strong, well-designed policy drives strong action. If governments, coordinating with industry, put well-designed policies in place, public and private banks will finance well-designed CCS projects and industry can drive CCS project deployment.

An International Commitment to CCS

With an international commitment to CCS and the political will to deliver on that commitment, CCS technology can deploy at the rate and scale necessary to help achieve the goals of the Paris Agreement while controlling costs. Such a commitment must be backed by meaningful policies and associated incentives that enable a deployment trajectory consistent with the Paris Goals. These policies must be enacted with urgency or the Paris Goals are at extreme risk.

While all types of fossil fuel-fired generation and carbon-emitting industrial processes will require CCS to achieve a 2°C goal, the global coal-fueled power generation fleet is projected to be the largest user of CCS technology (IEA, 2013). Reliable and low cost energy from coal-fueled power stations will continue to be demanded in developing countries. This will require new construction and, for decades to come, the continued operation of much of the existing generation fleet. Much of this fleet has substantial remaining life and represents locked-in generation capacity for the first half of this century and beyond. Given the scale of financial capital already deployed, it is not realistic to expect that this fleet will be shut down well before the end of its expected life. If a path toward 2°C is to be maintained,

[1]As of 30 October 2016, as tracked on the United Nations website www.unfccc.int/paris-agreement/items/9485.php
[2]For the purposes of this paper, CCS is used to collectively refer to projects that utilise CO_2 as a revenue stream, such as ECR, and also projects that use geologic storage.

exponential growth in the installation of both CCS and high-efficiency low-emission (HELE) power generation technologies within this fleet will be required. The IEA estimates 12 GW of CCS-enabled HELE plants will be required by 2020, 215 GW by 2030, and 664 GW by 2050 (IEA, 2012) to remain on a pathway to 2°C. Achieving the much more aggressive goal of well below 2°C will require even more aggressive deployment. While there is urgency if this high rate of deployment is to be achieved, effective policy measures to facilitate this rate of deployment do not exist. In addition, rapid growth in the use of CCS in bioenergy and other applications will be required.

First-Generation CCS is Technically Proven

Carbon capture technology has been used for decades in natural gas processing and has more recently been deployed in multiple industrial and coal-fueled power plant applications. While the use of CCS outside natural gas processing has generally been in first-of-a-kind (FOAK) or high-value niche applications, the basic technical viability of carbon capture technology has been demonstrated. CO_2 transport is a mature technology. The ability to safely store CO_2 has been proven where suitable geology exists and best operating practices are used. While CCS technology will experience significant technological advancement, cost reduction and broader application as the CCS industry grows over time, first-generation technology is proven.

Policy Drives Innovation, Cost Reduction, and Commercial Risk Reduction

Well-designed CCS policies will become an engine for innovation that accelerates progress.

The required level of CCS deployment will need to be underpinned by trillions in investment, just as renewables will need to be underpinned by investment of this scale. While this represents substantial capital investment, an incentivised market will have sufficient available capital to provide it. Further, this level of investment capital injected into CCS technology will spur competition and innovation. This in turn will drive down the cost of CCS and reduce the commercial risks associated with deployment. This directly parallels the path that renewable energy policies have followed to achieve deployment and efficiency improvements in solar and wind technologies.

CCS Policies Enabling a Low-Carbon Energy Future

If governments that are parties to the Paris Agreement are committed to the goals of the Agreement, these same governments must recognise CCS as part of the solution and should, tailored to their country-specific energy needs, advance policies in four broad categories that:

- **Stimulate CCS Market Uptake.** Achieving a goal of well below 2°C requires substantial CCS deployments and investment capital. For this investment capital to materialise, policies must be put in place that enable investment capital to earn a market-based rate of return. This includes mechanisms that enable CCS to participate in energy and industrial markets while the technology further matures and deploys across global markets. While there is a recognised role for a price on carbon in some markets, a price on carbon is an insufficient policy, and in many cases works against bringing CCS forward to global markets.
- **Support Project Development.** The societal emission and economic benefits of commercial-scale CCS projects are extremely large. To realise these public benefits, CCS projects must navigate a development process that is often complex and typically takes three to seven years. Policies must be in place that financially de-risk and accelerate the project development process so that CCS projects have the maximum opportunity for success. Further, governments have a critical role to play in the development of geologic storage infrastructure and trunk pipelines. The combination of these actions will allow the associated public benefits to be realised as rapidly as possible.

- **Enable Project Funding.** Public policy has the ability to improve project economics and the accessibility to investment capital. Policies must be in place that financially de-risk CCS projects so that they have the maximum opportunity for securing funding from public and private banks and equity investors. Low-carbon renewables have seen a global surge in market penetration due to policies that improve project economics and access to investment capital. A parallel approach should be designed and applied to CCS. If governments are serious about achieving a goal of well below 2°C while also controlling implementation costs, it is essential that governments enact such policies for CCS.

- **Advance Next-Generation CCS Technologies.** The most important innovation engine the government can create is to stimulate CCS market uptake, support CCS project development, and enabling CCS project funding. However, there will continue to be a critical role for governments to play in advancing next-generation technologies and advancing elements of CCS knowledge that are pre-competitive (e.g., storage resource characterisation) or for which there are not identifiable market-based financial returns.

  In particular, the parties to the Paris Agreement who committed to Mission Innovation, which includes a doubling in government clean energy R&D funding, must fulfil that pledge and ensure an adequate amount of that funding is directed to CCS.

  Across these four areas, specific policies have been identified that merit aggressive implementation by governments. Implementation of such policies will enable governments that committed to the Paris Agreement to fulfil both the overarching goals and country-level commitments at lower cost. These policies are listed in Figure 1 and described in detail within the main body of this report.

Futhermore, genuine political commitment to CCS must:

- **Advance a positive CCS narrative.** Many countries depend upon fossil fuels, in both the energy sector and for industrial application, for their economic development and will do so through this century. A narrative that recognises this dependency and emphasises the importance of CCS to achieving the goals of the Paris Agreement is prerequisite.

- **Increase Intra-governmental coordination to substantially improve government CCS programs.** Coordination that builds support for CCS, shares knowledge, and speeds the implementation of government CCS-related policies is essential. Existing government programs that implement CCS policy have made notable progress, but implementing agencies must look ahead toward the Paris Goals and align themselves with the required speed of action and scale of policy incentives needed to achieve that goal. Business-as-usual implementation of government permitting, grants, guarantees, and other approvals will not suffice.

- **Involve Inter-governmental coordination on carbon markets that enable CCS deployment.** Carbon credits generated by CCS projects must be tradeable on an equal basis as carbon credits for other low-carbon technologies. There must be a recognition that while carbon capture is technically feasible for power plants and industrial processes worldwide, there is globally variability in the geologic resources available for storage. Inter-governmental coordination on policy and technology development needs to recognise these differences if CCS is to deploy widely.

Stimulate Market Uptake	**Power Purchase Agreements**
	Product Purchase Agreements
	Policy Parity in Portfolio Standards
	Policy Parity in INDCs
	Technology Transfer Support
	Price on Carbon
Support Project Development	**Project Development Grants**
	Streamlined Permitting
	Land Rights Access
	Long-term CO_2 Liability Transfer
	Hub Transport/Storage Infrastructure
	Transport/Storage Safety Valve
Enable Project Funding	**Improve Project Economics** • CAPEX buy-downs • Accelerated depreciation • Investment & production tax credits • CO_2 price stabilization • CCS emissions trading
	Improve Access to Capital • Loan guarantees • Completion guarantees • Preferred bonds • Development bank financing • Green Climate Fund
Advance Next Generation CCS Technologies	**R&D Tax Credits**
	R&D Grants
	Pilot and Commercial-Scale Projects
	Storage resource characterization

Table 1. CCS Policies to Enable a Low-Carbon Energy Future

The increased ambition adopted with the Paris Agreement requires well-designed policies. The CCS policies and incentives outlined herein meet that test. It is clear from the renewables policy push that has occurred over the past two decades to observe that such a push can be successful at deploying low-carbon technology and reducing emissions. If the goals of the Paris Agreement are to be achieved at the least cost—if at all—an international commitment to CCS, which currently does not exist, is essential.

Introduction

The Paris Agreement on climate change establishes ambitious goals to limit global average temperature increases by substantially reducing greenhouse gas emissions—ultimately to net-zero emissions in the latter half of this century. Achieving the goals of the Paris Agreement will require deployment of a portfolio of low-carbon energy technologies at an unprecedented scale, while simultaneously ensuring implementation costs remain acceptable. This report:

- Emphasises the challenge to achieving the goals of current international climate agreements, while providing access to reliable and affordable energy to support economic development and improved living standards.
- Discusses important implications of the Paris Agreement, including the cost of implementation.
- Concludes that a global commitment to CCS is an imperative if the goals of the Paris Agreement are to be achieved.
- Summarises the current status of CCS and its future potential.
- Identifies CCS development and deployment challenges that can be overcome through a global commitment to CCS.
- Presents policies, and associated incentives, that governments should consider as part of a global commitment to CCS that could be implemented at state, country, and regional levels.

The Paris Agreement: Achieving its Goals and Controlling Costs

The Paris Agreement is an implementing agreement under the United Nations Framework Convention on Climate Change (UNFCCC) treaty. The ultimate objective of the UNFCCC is to "stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system" (UN, 1992). As part of the Paris Agreement, 197 governments committed to "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels..." (UN, 2015). Parties to the Paris Agreement are making specific commitments (i.e., Nationally Determined Commitments) that represent an important step towards achieving the Agreement's goals. The Paris Agreement recognises that these commitments are first steps and parties to the agreement will have to amplify their commitments and actions if the Agreement's goals are to be achieved.

Implications of a "well below 2°C" Goal

Based on the work of the 5th assessment of the IPCC, holding the increase in the global average temperature to 2°C above pre-industrial levels will require stabilisation of greenhouse gas concentrations in the atmosphere at approximately 450 ppm (IPCC, 2014). Global emissions must be slowed, peak well before mid-century, and approach or reach net-zero in the latter half of this century. Achieving a goal of "well below 2°C" would require stabilisation below 450 ppm and likely require negative emissions. It is not likely such a goal can be achieved without CCS.

If governments intend to follow through on the goals of the Paris Agreement, it will require a fundamental transformation of the global energy system. If such a transformation is to take place, it must recognise the character of existing energy system assets, the role for a diversity of energy sources, and the market momentum associated with the energy system. For example, given that more than a third of the global coal power fleet is less than ten years old[3] and represents a significant capital investment, it very unlikely that these more modern plants will be prematurely retired and the associated capital investment stranded. The IEA Clean Coal Centre reports 670 modern high-efficiency low emission (HELE) coal-fueled power units (supercritical and ultra-supercritical) are operating in ten Asian economies (Platts, 2015). These units represent 37% of the electricity capacity in those countries. An additional 672 GW of HELE coal-fueled electricity capacity is currently under construction in those ten Asian economies alone (Barnes, 2015). This "locked-in" generation capacity will shape coal use for the first half of this century. Further, roughly a quarter of global emissions are from industrial processes, such as steelmaking and cement manufacturing, and many of these processes have limited options for carbon abatement beyond efficiency improvements and CCS.

In the IEA's World Energy Outlook (WEO) 2015 New Policies Scenario, coal is projected to fuel 30% of the electricity mix and comprise 25% of global primary energy demand in 2040. Total coal demand for all uses increases by approximately 700 million tonnes, or about 12% between 2013 and 2040. Almost all growth comes from developing countries in Asia and Africa. The New Policies Scenario takes into account the policies and implementing measures affecting energy markets

[3]Finkenrath, Smith, and Volk (2012) reported more than a third of the global fleet was less than five years old. The age of the fleet has conservatively been incremented five additional years for use in this paper.

Box 1: High Efficiency Low Emission (HELE) Technology

In addition to the deployment of CCS, HELE technology is a prerequisite for achieving the goals of the Paris Agreement. Roughly half of new coal-fired power plants being built employ HELE technology, such as supercritical (SC), ultra-supercritical (USC) and integrated gasification combined cycle (IGCC) technologies coupled with advanced emission controls.

As reported by the World Coal Association (WCA 2014), the average efficiency of coal-fueled power stations around the world today is 33%.[4] This is well below current 'off-the-shelf' technology efficiency rates of ~40% and state-of-the-art technology efficiency of 45% to 47%. By the end of the decade an efficiency of 50% appears possible. Increasing the efficiency of coal-fueled generation by one percentage point reduces CO_2 emissions by between 2-3%. Moving the current average global efficiency rate of coal-fired power plants from 33 to 40% by deploying more advanced technology could cut CO_2 emissions every year by 2Gt, which is the equivalent of India's annual CO_2 emissions.

For these reasons, expanded adoption of HELE technology is an action that must occur in parallel to a rollout of CCS.

Examples of HELE technology incorporated into operating plants include:

- Japan's Isogo USC Thermal Power Station, which is owned by CIAB member, the Electric Power Development Co., Ltd. (J-POWER). This plant operates at 45% efficiency and its non-CO_2 emission levels are less than that of a natural gas-fired combined-cycle plant.

Figure 1. J-POWER's USC Isogo Plant (photo credit, J-POWER)

- China's Waigaoqiao No 3 USC plant (operated by CIAB member, Shenhua) is setting similar new standards to Isogo for non-greenhouse emissions.
- Germany's Neurath USC lignite power plant (operated by CIAB member, RWE) can cycle up or down by 500 megawatts (MW) in 15 minutes, to manage fluctuations in available renewable power production.

Figure 2. Neurath USC Power Plant (photo credit, RWE)

- Nordjyllandsværket Power Station Unit #3 in Denmark, which is the world's most efficient coal-fueled power plant operating at 47% efficiency.

[4] *Lower Heating Value (LHV) basis.*

that had been adopted as of mid-2015 as well as declared policy intentions, even though specific measures needed to put them into effect may not have been adopted (IEA, 2015). This scenario represents one possible energy future, but certainly not one in which the Paris Goals are achieved.

WEO 2015's 450 scenario depicts one possible pathway to a 2°C goal (but not "well below 2°C"). It results in lower coal utilization, but also reveals a more significant role for CCS in a diversity of applications. In that scenario, coal is projected to fuel 12% of the electricity mix and comprise 16% of global primary energy demand in 2040. In such a scenario, the IEA estimates 12 GW of CCS-enabled HELE plants will be required by 2020, 215 GW by 2030, and 664 GW by 2050 (IEA, 2012).

Taking into account the size and diverse character of the existing energy system and alternative future pathways, the IPCC's 5th assessment examined the cost of transforming the energy system. Their examination is based on economic modelling performed by leading scientific organizations engaged in modelling the intersection between climate, the energy system, and the economy. In support of the 5th assessment, the cost of achieving the 450ppm stabilisation target, which likely achieves a 2°C goal, was explored. From this work some compelling conclusions can be made:

- Unsurprisingly, a 2°C goal cannot be achieved without widespread deployment of low-carbon technology.
- The majority of the energy-economic models employed in the 5th assessment cannot achieve a 2°C goal without the deployment of CCS.
- The cost of achieving a 2°C goal is the least with a diverse portfolio of low-carbon technology, including CCS, wind, solar, biomass, nuclear, and energy efficiency is employed.
- Strikingly, CCS is the single most influential class of technology for reducing the cost of achieving a 2°C goal given its broad applicability to electricity generation, synthetic fuel production, industrial processes, and bioenergy.
- Limiting CCS deployment substantially increases the cost of achieving a 2°C goal.
- Limiting wind, solar, and nuclear has substantially less effect on the total cost of achieving a 2°C goal.

The Paris Agreement is more stringent than a 2°C goal, its goal is "well below 2°C" with a stated aspiration of 1.5°C. Achieving a more stringent 1.5°C goal would almost certainly require net-negative emissions. CCS is the only technology that can deliver net-negative emissions at the necessary scale. This could take the form of CCS-enabled power plants co-fired by coal and biomass, or CCS bioenergy facilities for which first-generation technology exists.

Box 2: Co-Firing Coal-Fueled Power Plants with Biomass as a Pathway to Negative Emissions

The IPCC's Fifth Assessment emphasises the importance of CCS as it applies to bioenergy.

One of the principal challenges to using biomass for power generation is securing an adequate biomass supply year-round to keep a large power plant (e.g., 500-MW) fueled. This drives most biomass power plants to a smaller scale (e.g., 50-MW). Application of CCS to smaller facilities is technically feasible, but costs rise due to a lack of economies-of-scale. Further, the pipeline network for numerous small facilities is expensive.

The existing coal-fired power plant fleet can be an effective springboard for advancing the application of CCS to bioenergy through biomass co-firing. A coal-fired power plant, co-firing with biomass and outfitted with carbon capture technology could generate net-negative carbon emissions.

With limited capital investment, up to 10% biomass co-firing has been proven in coal-fired power plants. Co-firing at much higher rates, while more capital intensive, is not uncommon.

Figure 3. Waycross, Georgia Fuel Pellet Plant (photo credit, RWE)

In 2011, CIAB member RWE opened the world's largest wood fuel pellet facility in Waycross, Georgia, United States. Construction of the USD 200 million dollar facility was completed under budget and ahead of schedule. The facility's capacity is 750,000 metric tons annually. The pellets are principally shipped to Europe for use in coal-fired power plants.

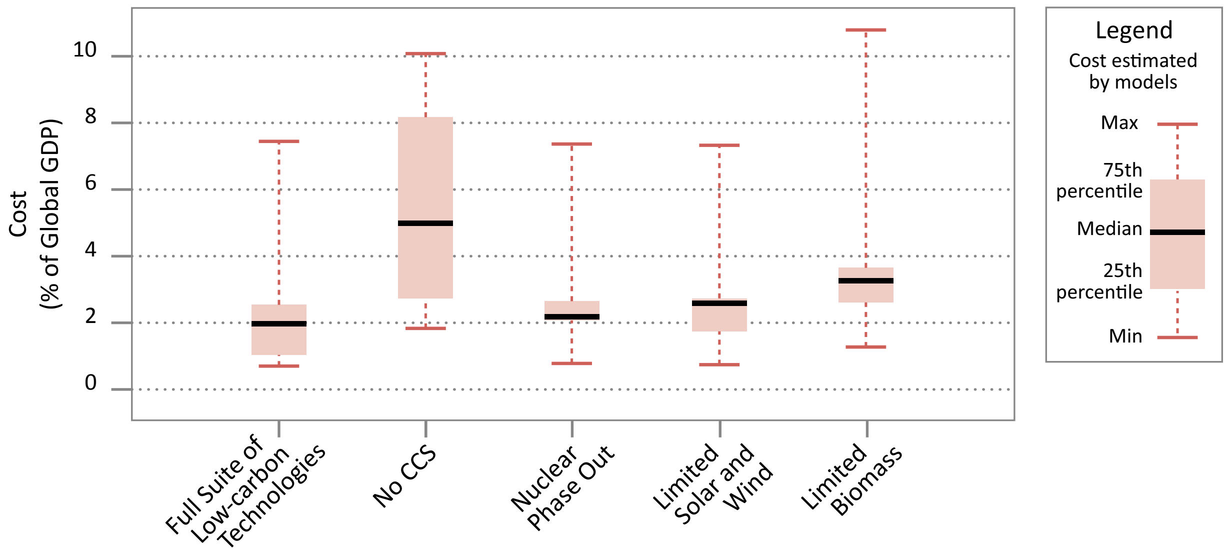

Figure 4. Costs of Achieving a 2°C goal as a fraction of Global GDP (2010-2100) (adapted from Krey et al., 2014)

Advanced Technology Controls Cost

Analysis underlying the IPCC's 5th assessment estimates the cost of achieving the 450ppm target (effectively the 2°C goal) as 2% of global GDP between 2010 and 2100 (Krey et al., 2014). Added cost of this scale would likely be the single largest, globally coordinated discretionary investment in human history.

If any class of low-carbon technology is limited, implementation costs rise. On average, the cost of achieving a 450ppm target is estimated to rise to 5% of cumulative global GDP between 2010 and 2100, if CCS technology is not deployed. Some models employed in the 5th assessment estimated costs could rise to 8% of cumulative global GDP or higher (See Figure 4).

An International Commitment to CCS

In a world with competing demands for investment resources, if the cost of achieving the Paris Goals is not contained, governments will simply not achieve them. Recognizing that CCS is the class of low-carbon technology that has the greatest leverage in controlling cost, an international commitment to CCS backed by the political will to deliver on that commitment is required. Today, such a commitment does not exist.

CCS Technology Readiness

Carbon capture technology has been used for decades in natural gas processing, and more recently has been deployed in multiple industrial and coal-fueled power plant applications. While the use of CCS outside natural gas processing has generally been in FOAK or high-value niche applications, the technical viability of carbon capture technology has been demonstrated. CO_2 transport is a mature technology. The ability to safely store CO_2 has been proven where suitable geology exists and best operating practices are used. Contrasted with two decades ago, a first-generation of CCS technology is now technically proven. Examples of first-generation technology include solvent-based processes used for extracting CO_2 from natural gas or industrial process gas streams and amine-based CO_2 capture from coal-fueled power plants.

Box 3: Boundary Dam Power Plant CCS Project

Project Description

In the fall of 2014, the Boundary Dam project came online as the world's first post-combustion coal-fired CCS project integrated with a power station. The project transformed the aging Unit #3 at Boundary Dam Power Station near Estevan, Saskatchewan into a reliable, long-term producer of up to 115 MW of base-load electricity, capable of capturing up to one million tonnes of CO_2 each year. The source fuel is lignite (brown) coal. Captured CO_2 is principally sold to the Weyburn-Midale EOR project. There is also the option to send CO_2 directly to a saline geologic site.

The project is a CAD 1.24 billion partnership between the Canadian government, the Saskatchewan government, SaskPower, and other private industry partners. SaskPower and CIAB member BHP Billiton have partnered to fund a learning center that will spread learnings from the project globally.

Figure 5. Boundary Dam Power Plant (SaskPower CCS, 2016)

The project was balance sheet financed and, as a regulated provincial utility, SaskPower was able to build the project cost into their rate base. The project benefited from CAD 240 million in grant funding from the Canadian government.

Lessons-Learned

A few of the many lessons-learned from the Boundary Dam project that can inform policy include:

- The ability to secure approval to build the cost of CCS into the rate base was essential to allowing the project to proceed.
- The project was allowed to maintain its prior air permit, and the retrofitted plant remains within the permit envelope. It was not necessary to apply for a new permit or to undergo time-consuming modifications.
- The CAPEX buy-down grant from the Canadian government was essential for this FOAK plant to have acceptable project economics. Given the need for second- and third-generation technology with improved performance, CAPEX buy-down grants will continue to be an important mechanism for advancing CCS projects.

Box 4: Kemper Integrated Gasification Combined Cycle (IGCC) CCS Project

Project Features

Construction has been virtually completed on the 582-MW Kemper integrated gasification combined cycle (IGCC) power plant. The combined-cycle island is currently generating commercial power using natural gas. The coal gasification island, which includes carbon capture equipment, is currently being commissioned. When fully operational, the plant is designed to use lignite (brown coal) and have 65% carbon capture. The captured CO_2 will be sold and subsequently transported sixty miles for use in onshore enhanced oil recovery (EOR).

The project owner is Mississippi Power, a subsidiary of Southern Company, the second-largest utility in the United States. The project has been balance sheet financed.

Solvent-based post-combustion technology is proven first-generation CCS technology. The Kemper project is advancing next generation pre-combustion carbon capture by incorporating Transport Integrated Gasification (TRIG™) IGCC technology, developed by Southern Company and KBR, Inc. Included in the Kemper project is utilization of the CO_2 for EOR to deploy commercial scale CCS.

As a regulated utility, Mississippi Power is entitled to apply for rate recovery for prudently incurred capital and operating costs. Mississippi Power is subject to a cap of USD 2.88 billion of capital cost for plant equipment. Other allowable project-related costs including those for the lignite mine, the CO_2 pipeline and interest bring the current total costs eligible for recovery to approximately USD 4.2 billion. For multiple reasons, costs of this FOAK plant have risen to USD 6.9 billion. Among the reasons were multiple design changes during construction due to CO_2 regulations in flux, an unexpected surge in labor costs, and an extended construction schedule adding interest during construction. Southern Company has borne the cost of FOAK over-runs. Subsequent plants should see substantially lower capital

Figure 6. Kemper IGCC Power Plant (Mississippi Power, 2016)

and construction costs due to the extensive learnings on this FOAK project.

The project also benefited from approximately USD 400 million in grant funding from the United States Department of Energy (DOE). Up to USD 279 million in investment tax credits were anticipated to be applied, but unfortunately, the tax credits legislatively expired prior to the plant achieving online status.

Lessons Learned

The United States DOE and Southern Company had a more-than-decade-long, cost-shared partnership to develop and bring to a pilot-scale the TRIG™ gasifier. DOE's policy of the cost-shared R&D has been essential to bring the TRIG™ technology forward.

Three of the other learnings that can help shape future sound policymaking, include:

- CCS power projects require known targets in CO_2 emissions. Changes in emissions rules impact design and construction schedules, causing delays and cost increases.
- The initial demonstration of FOAK technology brings cost risk, which can be substantial. If government desires step-change CCS technologies to come forward there must be more balanced policies to share cost risk.
- Policies by government to increase the support for tax credits for disposal or sale of CO_2 will also assist the economics of future projects by ensuring CO_2 capture costs are recovered.

There has been very meaningful progress in the development and demonstration of CCS over the last twenty years to build upon, however, the gap that policy and associated incentives must fill remains large. There are fifteen CCS projects in operation today and another seven under construction (GCSSI, 2015). Each one of these projects has added, and will continue to add, to the knowledge base of CCS. Of these twenty-two:

- Ten involve separation of CO_2 from natural gas
- Nine involve CO_2 separation from industrial process streams
- One uses pre-combustion CO_2 separation from an IGCC power plant
- Two involve post-combustion CO_2 capture from power plants

Notably, while coal-fueled power plants are anticipated to be the largest user of CCS if the world is to be on a path to fulfil the Paris Goals, only three of these twenty-two projects involve coal-fueled power plants. Together, the three plants total less than 1 gigawatt (GW) in capacity. While these three plants represent meaningful progress, when contrasted with the 215 GW of CCS-enabled HELE coal power plants the IEA estimates need to be online by 2030 just to maintain a trajectory toward 2°C, let along well below 2°C (IEA, 2012), the size of the gap is significant. Unfortunately, the number of projects in the pre-construction development process has declined in recent years as governmental financial support for such projects has waned. Additional information on the status of CCS by global region is provided in Annex 1. Clearly, if CCS is to be deployed at a rate consistent with achieving the Paris Goals, there must be a step-change rate of deployment which can only be enabled by well-designed policies.

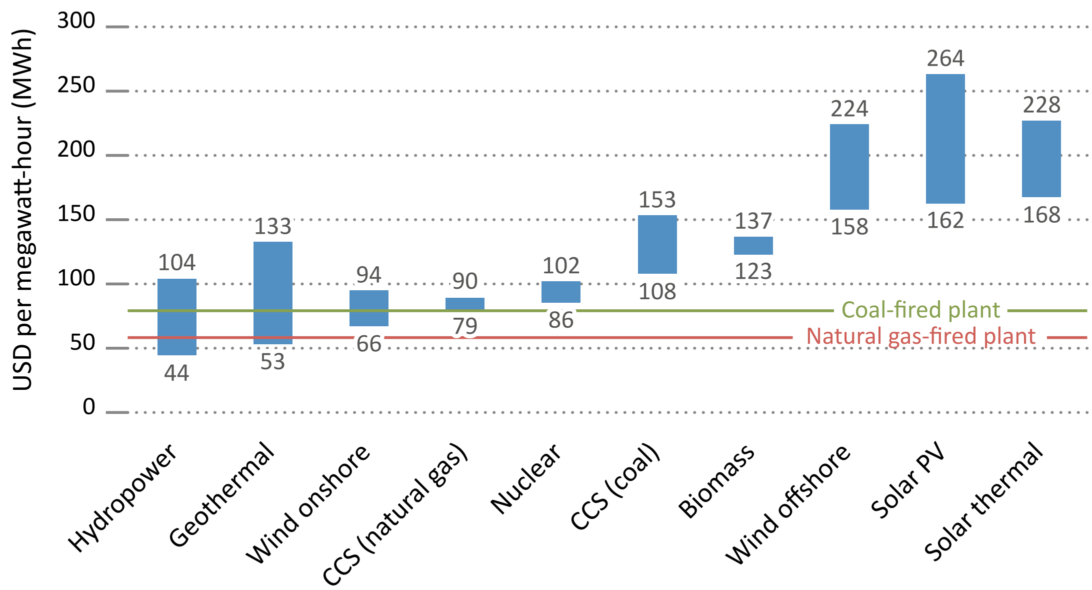

Figure 7. Levelised Cost of Electricity for Low-Carbon Sources (GCCSI, 2015b)

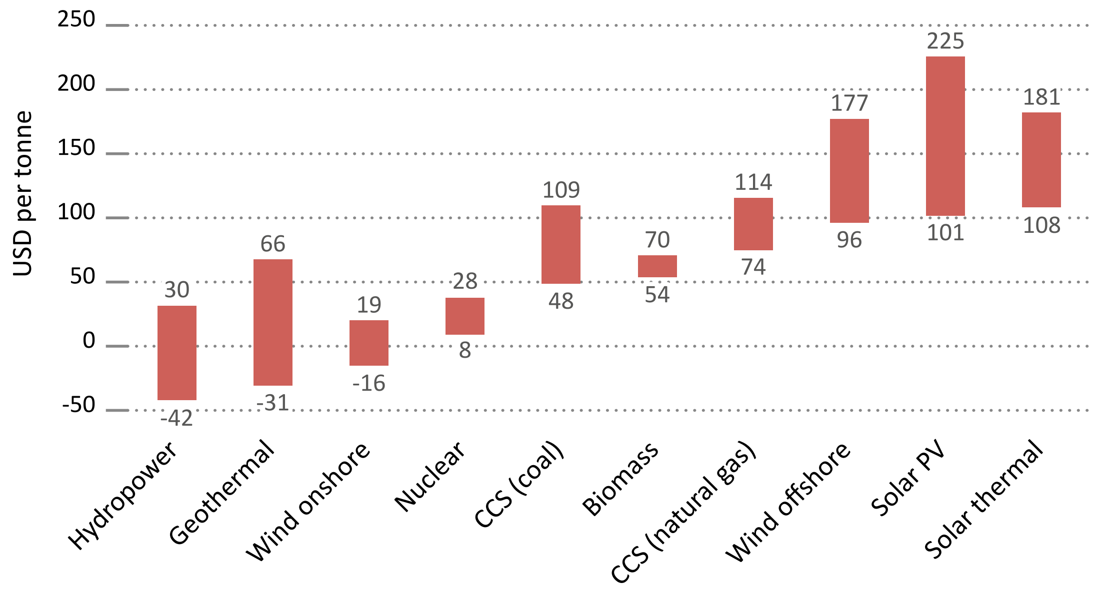

Figure 8. Avoided Cost of CO_2 per tonne (GCCSI, 2015b)

As would be expected, the cost of a power plant or industrial process CCS is greater than the unabated version of that same process. However, based on expected costs for mature CCS technology, it is often a less costly option than some other low-carbon alternatives. The GCCSI has examined the cost of CCS and other low-carbon technologies as it applies to power generation (GCCSI, 2015b). The results for United States power plants based on both levelised cost of electricity as well as the cost per tonne of CO_2 are shown in Figures 7 and 8, respectively. It is not uncommon for short-term market clearing prices for power to be lower or higher, but the costs in the GCCSI study provide a more equitable basis for comparing technologies side-by-side. Further, to keep the comparision equitable, the costs do not reflect policies and incentives (e.g., feed-in tariffs or production tax credits) that preferentially benefit some low-carbon technologies but not others.

In order to realise the economic advantages of CCS, the technology needs the opportunity to fully mature and certain market challenges which CCS faces (e.g., permitting, equal access to investment capital, and access to geologic storage rights) need to be addressed by well-designed policies and associated incentives.

An International Commitment to CCS

The political will to adopt "the well below 2°C" goal clearly existed in 2015 at the Paris Climate Conference. The political will to adopt the necessary policies that allow for achieving that goal while controlling costs has yet to be demonstrated. This creates an opportunity for governments to make an "international commitment to CCS".

That commitment being that all parties to the Paris Agreement acknowledge the critical role that CCS must play in a low-carbon energy future and work to build global acceptance of the technology. Further, each party to the agreement, according to its own needs, must put in place well-designed CCS policies that: (1) stimulate CCS market uptake, (2) support CCS project development, (3) enable CCS project funding and (4) advance next-generation CCS technologies. Such policies will create a commercial investment environment in which industry can help bring forward the next wave of CCS projects. It will spur competition and innovation, drive down the cost of CCS, and reduce the commercial risks associated with deployment. Specifically, the coal-fired power plant fleet can provide a springboard to enable the application of CCS at a large scale to industrial and bioenergy activities.

CCS Deployment Challenges That Effective Policy Can Solve

To design effective policies, it is important to have clarity around the challenges that CCS projects routinely face in the current marketplace. The commercial-scale CCS demonstration projects conducted over the past two decades by industry, usually with substantial government financial support, have helped clarify the challenges and helped identify effective policies that can resolve these challenges.

While every project will have its unique challenges, most will be faced with navigating the majority of those discussed here. The challenges are broadly grouped into three areas: (1) financial challenges, (2) transport and storage challenges, and (3) stakeholder challenges.

Financial Challenges

- **Accessing investment capital.** Individual CCS projects will often have capital investment requirements in the USD 500 million to USD 2+ billion range. Each project represents a large tranche of capital, but each project also creates the capacity to achieve substantial CO_2 reductions. Sufficient financial resources in capital and debt markets exist to provide this capital. However, capital markets remain challenging specifically for CCS. Some investors do not yet view CCS as a clean energy technology, view it as unproven, and/or as unmanageably complex. With each successful project these views can be overcome. The appropriate policies will be essential to the next wave of successful projects. This challenge applies to international bank financing and institutional investment. It also exists within some corporate entities that self-finance.

- **Achieving a risk-based return.** Power plants, whether coal, gas, or bioenergy, will be one of the largest users of CCS. Investment in these facilities typically yields lower rates of return than, for example, oil or specialty chemical projects. In many cases governmental entities regulate the allowable rate of return on power plants and are reluctant to increase it. CCS projects have the potential for added technical and operational complexity. Thus, it becomes extremely important for CCS projects to be de-risked to the point that project investors and regulators will allow capital investment to proceed. Policy mechanisms can assist with this de-risking.

- **Covering first-generation CAPEX and OPEX premiums.** Most CCS projects using first-generation technology will have capital expenses (CAPEX) and operating expenses (OPEX) above those for more mature technology, and above what the current market can bear. Absent a mechanism to cover these price premiums, many CCS projects will not proceed. If first-generation projects do not proceed in mass, lower cost second-generation technology is less likely to materialise, which will ultimately make it very difficult, if not impossible, to achieve the Paris Goals.

- **Managing CO_2 Value.** Clearly, when revenue can be realised from the sale of CO_2, this improves the baseline project economics. While there are other niche markets for CO_2, enhanced oil recovery (EOR) is the largest commercial market. However, this market has significant challenges. First, in many regions of the world EOR opportunities do not exist, or require coordinated EOR project development. Second, the monetary value of CO_2 is tightly coupled to the value of oil, which is volatile in its price. As a result of this coupling, many CCS project investors will view the revenue from CO_2 as an uncertain revenue stream that increases project risk and therefore increases the difficultly of securing the investment capital. There are mechanisms (e.g., a collared tax credit) that could mitigate this risk. In the case of saline storage, which is the most globally available geology for long-term CO_2 sequestration, absent an incentive, it is purely an added cost that impinges on the ability to finance the project.

- **Minimizing project-on-project risk.** Project-on-project (or cross-default) risk refers to the fact that CCS projects effectively involve a supply chain: a capture plant delivers CO_2 to a pipeline, the pipeline transports the CO_2 to a storage site or end-user, and the storage site or end-user injects it. A significant concern of project investors is that one weak link in this supply chain could strand assets in the balance of the chain rendering them unable to deliver a financial return. For example, if an EOR project receiving CO_2 from a power plant incurs performance or compliance issues that force a temporary shut-down (e.g., for three months), the upstream power plant which now has no off-taker for its CO_2 might also need to shut down unless there is a policy "safety value" (e.g., the ability to buy CO_2 credits, receive cost-recovery for that action, and thereby remain in compliance). These types of project-on-project risks, which occur during construction and operations, must be substantially mitigated, to the satisfaction of investors, if CCS projects are to be widely deployed.

- **Covering second-generation technology prove-out costs.** First-generation amine technology for carbon capture is reaching maturity after decades of development. Its performance and cost are reasonably well understood, and bankable EPC contracts can be secured for this technology from equipment providers. The same is not true for second-generation technologies which have yet to be commercially proven. Prove-out budgets of USD 200M to USD 500M for these technologies in small-scale pilot projects will not be uncommon. Unlike wind and solar, where meaningful pilots can be conducted at 1-MWe scale, most CCS technologies will require pilot testing at ten times that scale and thus require significant capital. Ensuring the availability of capital for these second-generation technologies to be tested in the 2020 to 2030 timeframe is essential if the objective is to remain on a CCS deployment trajectory where CCS costs decline with time due to technology innovation and the Paris Goals can be achieved.

Transport & Storage Challenges

- **Securing CCS permits.** There is progress in the development of CCS permitting regimes, but the time required to navigate the complex permitting process and defend appeals remains a challenge. Historically, air permits have often been the long-lead permit in the project development process for large stationary emission sources. However, permits for pipeline siting

Box 5: FutureGen 2.0 CO_2 Transport and Storage Project

Project Description

The FutureGen 2.0 Carbon Transport and Storage Project was to design, permit, and construct a 28-mile pipeline and CO_2 storage reservoir. The reservoir was sized to receive a minimum of 1.1 million tonnes (MMT) per year for twenty years from an upstream carbon capture project (i.e., the FutureGen 2.0 Oxy-Combustion Retrofit Project).

The project was a partnership between the DOE, the State of Illinois, and an alliance of coal industry companies. The transport and storage project benefited from a USD 459 million DOE grant toward the capital cost of the infrastructure. Twenty years of operating costs were to be covered by a cost-of-service, off-take agreement between the upstream carbon capture project and the downstream transport and storage project.

Following an extensive geologic characterization effort, the project was the first commercial-scale CO_2 storage reservoir to secure final permits from the United States Environmental Protection Agency (EPA) under its new CO_2 storage permitting scheme (i.e., Class VI Underground Injection Control regulations).

The engineering design, which included the pipeline storage, storage site design, and integrated control and safety systems, was complete for the purposes of construction. All commercial contracts were negotiated, insurance and long-term stewardship issues were addressed. Stakeholder support was strong, the required property rights were under contract, and 100% of the required funding had been secured. However, out of a concern that the federal government grant funding would expire prior to full spend-out of those federal funds, the project was terminated soon after construction was started.

Figure 9. FutureGen Storage Site (Photo credit, FutureGen Alliance)

While it is most unfortunate that the project did not proceed to completion, it represents a project where all permitting, contracting, design, and liability management issues were overcome, providing one model for future project success.

Lessons-Learned

Among the many lessons-learned that can inform CCS policy, a few include:

- The State of Illinois passed new legislation regarding the siting of CO_2 pipelines, which enabled the project to secure a permitted pipeline route. With the permitted routing, the project received the right of eminent domain, if needed.
- In the host State of Illinois, subsurface rights are held by private landowners. Through intensive stakeholder outreach and fair compensation, the property was able to obtain project rights. However, this achievement will not easily be replicated, and governments should consider policies for acquiring such rights routinely on other projects. Also, the granting of federal land rights will be essential on some projects.
- The State of Illinois passed project-specific legislation that required certain operator responsibility in exchange for taking on the long-term stewardship liability.

and CO_2 storage now rival the duration of the air permitting process. Major CCS projects will likely take two to five years to permit absent streamlined processes. FOAK CCS projects will often face challenges in the permitting process unless there is operational flexibility provided in the permits for the early years of operation when plant performance is being optimised.

- **Securing pipeline property rights.** The widespread deployment of CCS will require the construction of significant pipeline infrastructure. While there is some flexibility when routing a pipeline, adequate flexibility does not always exist to avoid opposing landowners. As there are major capital investments to be made at the upstream capture facility (e.g., power plant or cement plant), and at the downstream storage facility, project investors are reluctant to approve major investment unless all pipeline property rights have been secured. On many projects, this will have the effect of slowing the deployment of CCS without well-designed policy mechanisms to resolve the challenge.

- **Securing storage resource property rights.** In many regions of the world where subsurface property rights are held by private landowners, it will not be uncommon for a CO_2 storage project owner to acquire subsurface rights from 10 to 100 landowners. A few individual landowners, or even only one, will have the ability to halt the entire project absent a policy mechanism to ensure projects can access subsurface resources for the collective benefit of all. In regions of the world where subsurface property rights are held by governments, there must be a mechanism to provide access to these rights for CCS projects to proceed. This applies to dedicated storage (saline reservoir) rights and, in many cases, enhanced oil recovery rights.

- **Managing long-term storage liability.** Commercial insurance markets are increasingly comfortable with CCS and willing to insure the construction and operational risks associated with the storage site's routine operating life. However, insurance markets will not insure the risks, albeit minimal, associated with long-term (e.g., 50 – 100 year) post-operational liability. Debt markets are not overly concerned about long-term liability as debt is repaid during the operating life of the project. Equity markets are extremely concerned about long-term liability as the equity investor is a long-term owner of the asset and any residual liabilities. There are proven mechanisms to address this challenge, such as when a state or national government agrees to take the long-term liability once the storage site is certified as properly closed, but those mechanisms are not yet in place in most jurisdictions.

- **Addressing storage resource proximity and quality.** In some regions of the world, the amount, location, and quality of CO_2 saline storage capacity and potential EOR storage capacity is not well known. While nearly every CCS storage or EOR project will require project-specific geologic characterization, it is imperative that private project developers have sufficient basic geologic data so that they can quickly target potentially viable sites, dramatically reducing the development timeline for new storage projects.

Stakeholder Challenges

- **Gaining CCS acceptance.** While there are political leaders, environmental non-governmental organizations (NGOs), business leaders, and citizenry that understand CCS' essential role in managing climate change concerns, its importance is not widely enough appreciated, and this lack of understanding is inhibiting the deployment of CCS in terms of siting projects, permitting facilities, and raising capital.

- **Having Government Alignment.** Global political leaders and their governments established the well below 2°C goal, which requires the transformation of the global energy system at an unprecedented pace. Renewables, nuclear, efficiency, and CCS will all be essential to achieving

Box 6: CarbonNet CO_2 Storage Project

Project Features

The Australian CarbonNet project is developing a multi-user CO_2 transport network and storage site. Located in the Gippsland Region of Victoria, Australia, the network will ultimately gather CO_2 from multiple carbon capture projects, transport the CO_2 ~100 km via a shared pipeline and inject it into an offshore storage site.

The federal government and Victoria state governments are principally proving the viability of the geologic storage reservoir, permitting the storage site, and providing a legal mechanism for addressing long-term CO_2 liability.

Ultimately, the geologic storage site will be made available to the private sector for final construction and operation. By fully validating and permitting the storage resource, the government is striving to substantially reduce the geologic and commercial risk associated with new storage site development, which will facilitate multiple carbon capture projects in Victoria to proceed on a commercial basis.

Lessons-Learned

Australia and Victoria have legislative and regulatory frameworks for CO_2 storage in place. While they remain untested, CarbonNet has prepared a regulatory approvals strategy deployed by GCCSI as part of their Regulatory Test Toolkit. CarbonNet's experience is that regulatory permitting has been particularly drawn out. This points to the need for capacity building within the regulatory agencies and a more efficient permitting process that aligns with the needs of commercial projects. As the project proceeds, it will be of particular interest whether the established long-term liability regimes, which were developed under Australian and Victorian legislation, facilitate private sector investment in the development of storage sites.

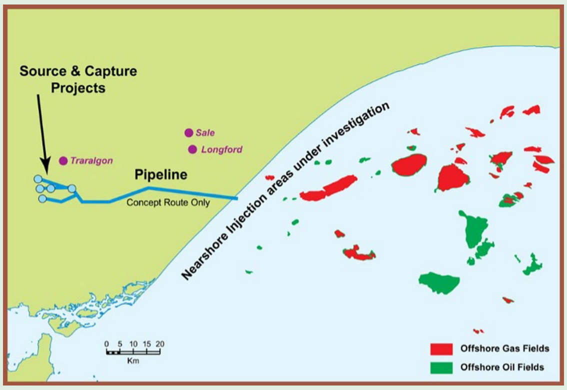

Figure 10. CarbonNet Project (Graphic credit, Carbon Net)

the goal cost-effectively. In some parts of the world, early CCS projects have struggled through oscillating governmental commitment. Having sustained governmental commitment, market-based policies, expedited governmental decision making, and governmental risk-sharing (e.g., assuming long-term storage liability and sharing in the cost or operating risk associated with FOAK projects) will all be essential to staying on track toward the Paris Goals.

Policy Mechanisms That Overcome CCS Deployment Challenges

The challenges that face CCS, with few exceptions, are relatively consistent across regions of the world. However, the specific form of the policy mechanism employed in each region to address these challenges will vary for good reasons. Thus, a variety of proven policy mechanisms are discussed herein for consideration by individual governments. It is absolutely essential that the adopted policies create a long-term stable market where CCS can be sited, permitted, and the associated investment capital can realise an acceptable financial rate of return. Otherwise, it will simply be impossible to sustain a rate of CCS deployment that is consistent with achieving the Paris Goals at the least cost—if at all.

Table 2 presents proven policy mechanisms, which are recommended for consideration by all governments. These mechanisms directly address the major deployment challenges which CCS currently faces around the globe. Different countries will find some mechanisms more well-suited to their own situation than others. Following the table is a discussion of four groups of mechanisms that: (1) stimulate CCS market uptake, (2) support CCS project development, (3) enable CCS project funding and (4) advance next-generation CCS technologies. Within each group are multiple policy mechanisms. Some mechanisms simultaneously address multiple challenges. While twenty mechanisms are identified for consideration, if governments implement even a limited set of well-designed, very strong, and complementary mechanisms, it will be sufficient to spur substantial CCS deployment and drive CCS cost reduction.

Policies to "Stimulate CCS Market Uptake"

- **Power Purchase Mechanisms.** Electricity is sold in a variety of ways: spot-market sales, fixed-price power purchase agreements, cost-of-service power purchase agreements, contracts for differences, feed-in tariff rate recovery, and hybrids. An effectively designed power purchase mechanism is likely the most powerful policy mechanism that would accelerate CCS deployment in the electricity sector.

  As power generation is a capital intensive business that generally yields modest rates of return, long-term predictability in power generation project revenue streams and insulation from financial risks is of paramount importance to securing the investment capital required for CCS projects to proceed.

  Long-term (20- to 30-year) power purchase agreements (PPAs) which allow for coverage of all prudently incurred capital and operating costs with a pre-established rate of return, and signed by creditworthy counterparties can be designed to be investment-grade. Feed-in tariffs, which have been very effective at facilitating renewable energy deployment in Europe, are one example. A second example are PPAs designed to allow the electricity producer to sell power at any time into the spot market, while receiving a subsidy for the difference between the spot market price and the full cost of electricity production. These types of arrangements are often referred to as cost-of-service agreements or contracts for differences.

  For example, in Thailand there is a scheme for supporting wind and solar power through long-term purchase agreements at 150 – 200 USD per MWh. In this instance, CCS projects using mature technology would be able to compete in the same range if given the opportunity for a comparable incentive. Prior to the United Kingdom government reprogramming its funding for other purposes, the United Kingdom had created a long-term power purchase mechanism that would have help and enable CCS projects.

  A financially strong power purchase mechanism can absorb the significant tranche of initial capital required for CCS power projects, as well as the higher operating costs (relative to a conventional carbon-emitting plant).

- **Product Purchase Mechanisms.** Similar to the purchase of electricity, governments could enter into purchase contracts or provide incentives for implementing CCS on processes that produce cement, liquid fuels, or other products.

- **Parity in Portfolio Standards.** Portfolio standards set aside a portion of the electricity market for power generated from certain types of sources. They have been successfully used to aid in the introduction of wind and solar to the marketplace. Portfolio standards can equally be designed to advance the introduction of CCS to the market place.

Table 2. Policy Mechanisms That Enable Achieving a "well below 2°C" Goal

Mechanisms to Solve the Challenges	Accessing capital	Achieving a risk-based return	Covering first-generation CAPEX and OPEX premium	Managing CO_2 value	Minimizing project-on-project risk	Covering second-generation technology prove-out costs	Securing CCS permits	Securing pipeline property rights	Securing storage resource property rights	Managing long-term storage liability	Addressing storage resource proximity and quality	Gaining CCS acceptance	Having government alignment
	CCS Deployment Challenges that Policy Can Solve												
Power Purchase Agreements	✓	✓	✓		✓								✓
Product Purchase Agreements	✓	✓	✓		✓								✓
Policy Parity in Portfolio standards			✓									✓	✓
Policy Parity in NDCs												✓	✓
Technology Transfer												✓	✓
Carbon Price													✓
Project Development Grants	✓						✓	✓	✓			✓	✓
Streamlined Permitting							✓						✓
Land Rights Access								✓	✓				✓
Long-term CO_2 Liability Transfer										✓			✓
Transport and Storage Infrastructure	✓				✓		✓	✓	✓		✓	✓	✓
Transport/Storage Safety Value	✓				✓								✓
CAPEX buy-down grants			✓			✓							✓
Accelerated Depreciation		✓											✓
Investment & Production Tax Credits		✓											✓
CO_2 Price stabilization		✓		✓	✓								✓
CCS Emissions Trading	✓				✓						✓		✓
Loan Guarantees	✓												✓
Completion Guarantees	✓				✓								✓
Preferred Bonds	✓												✓
Development Bank Financing	✓										✓	✓	✓
Green Climate Fund	✓										✓	✓	✓
R&D Tax Credits						✓							✓
R&D Grants						✓							✓
Pilot and Commercial-Scale Demos						✓							✓
Storage Resource Characterization											✓	✓	✓

One portfolio standard approach is to recast existing renewable portfolio standards as low-carbon electricity standards which would include CCS as an eligible technology. This approach has seen early adoption in a number of governmental jurisdictions. A second approach is to create a CCS portfolio standard that has its own market penetration target (e.g., 15% CCS-enabled power by 2025 increasing to 20% by 2030). The CCS portfolio standard would be complementary to the renewable portfolio standard and brings other benefits. This approach: 1) helps ensure CCS enters the marketplace, especially during the initial decade of deployment when the technology is proven, but is not yet fully mature, 2) puts CCS projects in healthy competition with each other, which helps drive down the cost to the electricity consumer, and 3) provides a better opportunity for FOAK CCS projects to have an effective route to the marketplace. This approach has been enacted into law in at least one jurisdiction (Illinois, 2009).

Projects that successfully qualify under a portfolio standard are typically eligible for cost recovery under a power purchase agreement, such as those discussed above.

While historically applied to electricity markets, governments could also consider the merits of portfolio standards that would promote the introduction of low-carbon liquid fuels into the marketplace (e.g., biofuels).

- **Parity in NDCs.** Similarly, governments establish approaches to fulfil their Nationally Determined Commitments (NDCs). The approaches they select should be fuel neutral with CCS treated as an equally legitimate mitigation option as other low carbon options. Given the significant market penetration of CCS required for the world to be on a trajectory that achieves the Paris Goals, governments have an important role to play in facilitating and expediting the pre-construction development of CCS projects.

- **Technology Transfer.** Policies that incentivise technology transfer including capacity building in developing countries are essential. Further, mechanisms such as export-import bank financing that aid countries with technology to develop projects in countries desiring the technology would be highly beneficial.

- **Price on Carbon.** It is recognised that in a mature market with mature CCS technology that a price on carbon in some countries or regions will help drive CCS deployment. The timing of such a policy is of critical importance as a carbon price in the medium-term or one that starts small and builds over time, via a direct carbon tax or indirect price (e.g. through cap and trade), simply does not drive the necessary investment in building out a CCS infrastructure and investing in CCS technology.

Policies to "Support CCS Project Development"

- **Government-and Development Bank-funded Project Development.** Governments and development banks should consider financially supporting project development efforts (i.e., design, permitting, land rights acquisition, and financial structuring) even when there are no plans for ultimate government cost-sharing of construction. Prior to the final investment decision (FID), CCS projects can cost 50 to 250 USD million, which is an impediment to CCS projects proceeding in an immature market. In developing countries there is an additional need for development banks to provide technological and financial support for capacity building and storage site mapping.

- **Timely and Flexible Permitting.** For FOAK applications, the ability to have permitting processes that provide relaxed emission limits during the early years of operation, with final stricter limits taking into account demonstrated plant performance, would increase the number of CCS deployments and likely result in better long-term environmental performance of these CCS

Box 7: FutureGen 2.0 Oxy-Combustion Power Plant Project

Project Description

The FutureGen 2.0 Oxy-Combustion Power Plant Project was to retrofit a subcritical coal-fired power plant with oxy-combustion technology and advanced environmental controls. The plant was to have a minimum steady-state capture rate of 90% resulting in 1.1 MMT per year of CO_2, which was to be transferred to a downstream CO_2 transport and storage project. The plant's design output was to be 168-MWe (gross).

The project was a partnership between the DOE, the State of Illinois, and an alliance of coal industry companies. The power was to be sold to the two major Illinois utilities under an investment-grade twenty-year PPA that guaranteed market access. The power purchase agreement was approved by the regulatory authorities under the Illinois Clean Coal Portfolio Standard law (Illinois, 2009), which is designed to facilitate the deployment of CCS.

The project was to be project financed with a total capital cost of approximately USD 1.3 billion. In addition to the PPA, the project benefited from a USD 590 million DOE grant toward the capital cost. Twenty years of operating costs were to be principally covered by cost-of-service off-take contract between the upstream carbon capture project and the downstream transport and storage project.

The FutureGen 2.0 Oxy-Combustion Power Plant Project achieved all technical objectives inclusive of front-end-engineering and design, and advanced design required to accurately estimate and contract for the construction, commissioning, and start-up of a commercial-scale "ready to build" power plant using oxy-combustion technology, including full integration with the companion CO_2 pipeline and storage site. While light site construction activities were initiated, ultimately the project did not proceed to full construction due to insufficient time to expend federal grant funding prior to its expiration.

Figure 11. FutureGen 2.0 Turbine Rotor (photo credit, FutureGen Alliance)

Lessons-Learned

Among the many lessons-learned that can inform CCS policy, a few among them include:

- CCS projects have inherently long development cycles. Policies which create expiration dates of government co-funding must be aligned with realistic project development schedules.
- The Illinois Clean Coal Portfolio Standard provided a mechanism to secure an investment-grade power purchase agreement, which was extremely well received by the project finance market. The Illinois approach can serve as a legislative model.
- It is common that energy projects are designed as joint ventures, partnerships, or special purpose entities. CCS grants are taxed as income to these entities, diluting the value of the grant, thereby impinging on project economics and financeability. Renewable energy grants are non-taxable. Policy parity for CCS projects would increase the number of successful projects by addressing this taxability issue.

projects. In the case of retrofit CCS projects, the retrofit activity should not require the need to re-permit the entire facility as this will only dis-incentivise facility owners from retrofitting. The Boundary Dam Project in Canada is an excellent example of a project that was able to retrofit under its existing air permit. If the identical plant were located in the United States, the entire plant would need to undergo a multi-year re-permitting process for its air permits—a clear disincentive to retrofitting.

With respect to storage permitting, there are now multiple countries with permitting regimes. There will need to be greater investment in the capacity at the permitting authorities so that permitting can proceed at the pace required to support a CCS deployment trajectory consistent with the Paris Goals. In other parts of the world these regimes do not yet exist. Therefore, part of the permitting effort implemented by governments must include a build-out of well-trained staff with the tools to permit projects efficiently.

- **Land Rights Access.** In geographic areas where geologic rights are owned by private parties, there will often be dozens of individual landowners who must make their geologic rights available to support a single carbon storage project. Unitization and eminent domain policies are common for oil and gas projects to acquire subsurface rights. Similar policies will be a prerequisite to allow the interests of a majority of landowners to prevail and for CCS projects to proceed. Generally, these policies establish a minimum threshold (e.g., 50% or 70%) of subsurface rights holders in a geologically defined area to agree to the use of the subsurface area for an intended purpose (e.g., gas production or gas storage). Dissenting landowners can be compelled to participate on the basis that the opposition of a few should not deny the right of the majority to earn an economic return on their subsurface rights.

  In areas where geologic rights are owned by governments, a mechanism needs to be created for making CO_2 storage formations available in a timely fashion. It is important that it not become a multi-year rights acquisition process. If the process is lengthy and/or uncertain, CCS project developers will wait to conduct major permitting and design efforts, which will further extend the development timeframe for CCS projects and take CCS deployment off the needed trajectory required to achieve the Paris Goals.

  CCS deployment could be further facilitated if governments pre-qualified and pre-permitted storage sites on government-owned lands. Such efforts could begin immediately in preparation for a subsequent wave of CCS deployments. Having a pre-qualified reservoir that is considered a "bankable resource" would make subsequent project investment in carbon capture projects easier. This is pre-competitive work that merits 100% government funding. It should involve industrial consultations, but not industrial cost-sharing at the resource characterization and permitting stage. Ultimately, the qualified storage rights could be sold or novated to an industrial partner.

  Further, land access rights, such as through eminent domain, needs to be available for pipeline siting.

- **Long-term CO_2 Liability Transfer.** While commercial insurance markets have gained comfort with insuring CO_2 storage sites during the operating duration of the project, long-term stewardship and financial responsibility remain an issue that governments can resolve through well-designed policies. On a project-specific basis, the State of Illinois in the United States passed legislation that required the project operator to create a trust fund to hold a payment for each tonne of CO_2 stored. After closure of the storage site, the trust fund and CO_2 stewardship responsibility transferred to the State government (Illinois, 2011). On a state-wide basis, the states of Kansas, Montana and Washington in the United States created a similar policy mechanism through legislation (Ingelson et al., 2010). In Australia, the federal government assumes long-term storage

Box 8: White Rose Oxy-Combustion Power Plant CCS Project

Project Features

The White Rose CCS Project was to be a 448-MWe new-build USC power plant with CCS. It was to be co-fired with coal and biomass. The plant was to capture ~90% of its total CO_2. By virtue of its ability to be 10 to 15 % co-fired with biomass, it had the potential to have net-zero emissions. Further, the CO_2 was to be transported via pipeline to a deep saline storage site under the North Sea.

Delivery of the project was anticipated through a consortium comprised of GE, BOC, Drax, and National Grid Carbon (NGC). The power plant was to be project financed and the transport and storage project balance sheet financed by NGC.

The project was to receive financial support through the CCS Commercialization Programme run by the United Kingdom Department of Energy and Climate Change (DECC). That support was to include a share of GBP 1 billion in grant funding, an electricity sales price support in the form of a contract for differences, and additional government-industry risk sharing arrangements. Further, White Rose stood to benefit from EUR 300 million from the European Union through the NER 300 Programme. In 2015, the United Kingdom government withdrew its financial support leading to the termination of the project.

Lessons-Learned

Much was learned from the project that can inform policies and incentives to move CCS forward. Three of the many learnings include:

- With respect to FOAK technology risk,the risk was to be shared by government and industry. This was a positive policy for the DECC Programme to adopt and facilitated attraction of financial institutions to the project.
- The most significant challenge in the commercial structuring of the project was project-on-project risk. This points to the need for the level of risk-sharing between the government and industrial team to be rebalanced to enable success.
- The transport and storage element is commercially challenging due to the high costs and risks of geologic validation and construction relative to low financial returns. This points to a role for government in funding and facilitating the development of the infrastructure.

Figure 12. Engineering Concept for White Rose Project (photo credit, White Rose Project)

liability for offshore CO_2 storage where the Crown owns geologic rights. State governments in Australia have begun to follow the federal lead enacting legislation to address long-term CO_2 stewardship where Australian States own the geologic rights.

- **CO_2 Transport and Storage Infrastructure.** Except in rare circumstances, there is not a business case for industry to develop CO_2 transport and saline storage infrastructure. Given the cost, permitting, land rights issues, CO_2 pipeline routing issues, CO_2 shipping infrastructure and a need for that infrastructure to be available at a scale and with a timing that is consistent with achieving the goals of the Paris Agreement, governments should consider prequalifying and permitting storage resources, as well as coordinating the development of mainline pipeline infrastructure. This would include port and offshore platform shipping infrastructure in areas of the world where CO_2 storage is offshore and CO_2 would be shipped to a final storage location. Further, it should include international system design or regulation taking into account transportation of CO_2 from one country (likely with limited storage options) to another country for storage.
- **CO_2 Transport/Storage Safety Valve.** Project-on-project (cross-default) risk is a concern for CCS projects. Project investors are particularly concerned that if a carbon capture project is built and financed that there is also a highly reliable sink (e.g., EOR or deep saline storage) which can take the captured CO_2 for the duration of the capture project. If a project's environmental air permits and/or power purchase mechanisms are structured such that the capture project can free-vent (perhaps needing to buy CO_2 offsets) during periods when the downstream taker of CO_2 is offline, it will facilitate project financing. Without such a mechanism, project investors will not accept the project-on-project risk and will not provide investment capital.

Policies to "Enable CCS Project Funding"

All energy infrastructure projects face the challenge of securing adequate equity and debt to allow them to receive a positive final investment decision. Just as governments have created policies to enable project investment for renewable projects, there should be parity for CCS projects. Policy mechanisms have the ability to both improve basic project economics, as well as improve access to investment capital. Policy mechanisms include:

- **CAPEX Buy-down Grants.** Until CCS technology costs reduce, through learning and second-generation, lower-cost technology, grants that buy-down the initial capital costs will be critical to facilitating CCS deployment. These buy-downs are important in at least three major respects: (1) They reduce the capital cost of the project which reduces the net cost of producing the commodity of interest (electricity, cement, chemicals, etc.). (2) They reduce the absolute size of the capital tranche required which opens the project to certain investors (e.g., some private equity funds) that might not otherwise be able to invest due to the required scale of investment. (3) A substantial government financial commitment toward a project is viewed by some investors as positive, so long as the government's role does not add undue risk. Many CCS projects take a significant amount of time to develop (i.e., design, permit, negotiate commercial terms, and construct). Three to ten years will be common, with early projects in the five to ten-year range. Time-limited government grants with no clear possibility of extension, even when progress is positive, is not effective CCS policy. Private investment capital will be less forthcoming if government funds are vulnerable to expiration. Grant funding expiration dates have brought multiple CCS projects to premature termination.
- **Accelerated Depreciation.** In countries that use a depreciation mechanism to allow project investors to expense their capital investment (i.e., claim as an offsetting expense against profits),

Box 9: ROAD USC Power Plant CCS Project

Project Description

The Rotterdam capture and storage demonstration project (ROAD) involves the addition of post-combustion CO_2 capture technology to a new-build USC coal-fired power plant that was designed to be capture-ready. The project site is the 1069-MWe Maasvlakte power plant #3 (MPP3) located in the port and industrial area of Rotterdam, Netherlands. The capture unit is 250-MWe equivalent size and will capture 90% of a flue gas slip-stream from MPP3. The project will capture and store approximately 1.1 Mt of CO_2 per year. The injection location is 6 km from the power plant via pipeline. A long-reach directionally-drilled well will be used to inject the CO_2 into the storage field, Q16-Maas, located 3 km offshore from the injection facility. MPP3 is currently operating, and the construction of the capture installation is planned to be completed in 2019. The overall project cost is estimated to be approximately EUR 500 million for capital and a three-year operating period. Operation of the capture plant beyond a three-year demonstration period will depend on the availability of future grants and the regulatory scheme in place at the end of the demonstration period. The project owners and co-funders are Engie and Uniper (formerly E.ON). The project benefits from EUR 330 million in co-funding from the EU and Dutch governments. As the project is designed with a limited demonstration period, it does not face many of the commercial financing challenges other CCS projects have encountered.

Figure 13. ROAD USC Power Plant (photo credit, Uniper)

Lessons-Learned

Two of the many lessons-learned, which can help inform CCS policy, include:

- The project development cycle, including design, permitting, and funding, for CCS projects can be lengthy and project requirements and economics can change over that development cycle. The Dutch government's willingness to allow modification of the demonstration period and other terms of the grant has been essential to positioning the project for success. Flexibility of grant arrangements is essential for CCS projects.
- The ROAD project required several regulatory changes (most recently a change of law to allow CO_2 storage and hydrocarbon production to occur simultaneously in Q16-Maas geologic reservoir). To the extent governments can anticipate the need for regulatory change to facilitate widespread CCS deployment, proactively making those changes in advance of them becoming hurdles for CCS projects would help speed CCS deployment.

allowing for accelerated depreciation can substantially improve project economics and will allow additional CCS projects to proceed.

- **Investment and Production Tax Credits.** Tax credits, and particularly refundable tax credits, are a well-understood mechanism to accelerate technology deployment, as demonstrated by their successful application to renewable energy.

  Investment tax credits are tied to the level of capital investment in a project. In the U.S., there is a 30% investment tax credit for commercial and utility investors in solar technology. When the credit was recently extended, the Solar Energy Industry Association estimated it would result in a nearly four-fold increase in the installed capacity base over a five-year period. This investment tax credit is on top of other incentives received by renewables, and it is the combination of incentives that is driving the growth of renewables. Investment tax credits could be created for carbon capture projects at industrial or power facilities. They could also separately be created for carbon dioxide storage projects. Such credits would significantly improve the economics of CCS projects and facilitate early and sustained deployments.

  Production tax credits are tied to the level of a facility's output. For example, in the U.S., the Wind Production Tax Credit provides a wind power producer with USD 18/MWh in tax credits, which spurred substantial growth in U.S. wind power production. A similar mechanism could be designed by governments to spur CCS deployment. For example, CCS-enabled power plants might receive a tax credit for each MWh of power generated. Alternatively, it could be structured as a tax credit for each tonne of CO_2 captured. The latter approach could apply not only to power facilities, but also industrial applications. It would also be possible to provide a tax credit to a storage site operator for each tonne of CO_2 stored.`

  A limitation of tax credits is that to receive their full benefit, the project investor or operator must owe taxes in an amount at least equal to the tax credit. As some for-profit electricity producers do not have sufficient tax liability and some electricity producers are non-profit (e.g., some municipalities and cooperatives), to them, traditional tax credits have no value or a limited value. However, using refundable tax credits as the policy mechanism resolves this limitation. In the case of refundable tax credits, the tax collecting entity will issue a "refund" to the project investor for the full amount of the tax credit, less any tax liability that project investor may have.

  Further, as with government grants, time-limitations are very problematic in terms of creating project financial certainty and raising capital.

- **CO_2 Price Stabilisation.** In EOR CCS projects, the risk of CO_2 price volatility due to oil price volatility can be mitigated if a tax credit or subsidy were put in place that provided a large tax credit/subsidy when CO_2 prices are low, and a smaller tax credit when the market price of CO_2 is high (i.e., a collared tax credit). This would result in a more stable CO_2 revenue stream to the capture project and make it is easier to finance.

- **CCS Emissions Trading.** Just as renewable energy is not feasible in all locations, likewise, for geographic, geologic, regulatory, economic, and other reasons, CCS will be more feasible in some locations as compared to others. As CCS is a technology that can produce large tranches of real emissions reductions and even negative net emissions (e.g., in the case of a power plant co-fired by coal and biomass), any emission trading schemes or offset programs (including Article 6 carbon markets under the Paris Agreement) should allow CCS-generated carbon reductions to be traded on an equal basis as other carbon credits domestically and internationally.

With respect to improving access to capital, mechanisms include:

- **Loan Guarantees.** This mechanism is well understood by financial markets and many governments. They are quite effective at providing access to investment capital and usually lower the interest rate associated with project debt. The lower interest rate reduces long-term costs. Loan guarantees are a tool available to state, provincial, and federal governments, as well as international development banks.
- **Completion Guarantees.** Particularly for FOAK CCS projects, completion guarantees can facilitate access to capital that would not otherwise materialise. Project investors typically assume construction risk (i.e., getting the project to mechanical completion) and performance risk (i.e., ensuring it performs with an efficiency, environmental performance, and reliability as anticipated). Construction risk is significantly managed through EPC contracts. However, on FOAK CCS projects, performance risk is more difficult to manage due principally to the fact that there is little or no long-term operating history for FOAK technology. Most investors will not invest and no bank will loan on a project that does not have a guaranteed level of operating performance. One approach to structuring a completion guarantee would be for a government to "insure" against performance shortfalls. If a shortfall occurs, the completion guarantee would provide funds to either cover revenue shortfalls or pay for engineering refinements to improve performance. Typically, a completion guarantee would have a hard monetary cap to limit government exposure. Completion guarantees are well understood by the financial sector. If there are no performance shortfalls, the completion guarantee funds are never paid out.
- **Preferred Bonds.** Governments at state, provincial, and federal levels, in many countries, provide low-interest bonds for energy development projects of certain types (e.g., pollution control projects, wastewater management projects, renewable energy projects, and efficiency projects). Extending these bond programs to CCS projects would increase accessibility to investment capital and lower the interest rate on debt, thereby lowering operating costs.
- **Development Bank Financing.** In recent years, some development banks have reduced funding for fossil energy projects, and specifically coal-related projects, in favor of renewable energy projects. At a minimum, CCS-enabled fossil energy projects should have equal access to development bank financing. Further, given the concentration of installed fossil-fueled plants and industrial processes in developing countries, which are candidates for CCS retrofits, there should be equal access to development bank financing. Otherwise, there will not be a sufficient number of CCS projects deployed to stay on a trajectory to the Paris Agreement goals.
- **Green Climate Fund Financing.** Similarly, CCS projects should have equal access to a green climate fund.

Policies to Stimulate Innovation

The largest innovation engine the government can create is to spur more rapid, widespread deployment of CCS by stimulating CCS market uptake, supporting project development, and enabling project finance, as described above. Expanded deployments will create a market-based environment of innovation that productively feeds upon itself. However, there will continue to be a critical role for governments to play in advancing next-generation technologies and advancing elements of CCS knowledge that are pre-competitive (e.g., storage resource characterization) or for which there are not identifiable market-based financial returns. Policies governments should consider to stimulate innovation include:

- **R&D Tax Credits and Grants.** With effective policy, CCS deployments will accelerate immediately using first-generation CCS technology. R&D, particularly as it relates to carbon capture technology, will be essential to the introduction of second-generation CCS technology that is more cost-effective and has a higher level of performance. The eligibility of CCS R&D for R&D tax credits would accelerate the development of lower cost technology, which in turn will increase the CCS deployments. It is also an imperative that all Mission Innovation governments follow through on their commitment to a doubling in government-funded clean energy R&D over the next five years and that a proportionate share of that funding go directly to CCS.
- **Pilot- and Small Commercial-Scale Demonstrations.** Given that large-scale CCS projects can quickly reach project budgets exceeding USD 1 billion, governments should consider supporting numerous smaller projects (e.g., multiple 50-MW demonstrations in lieu of one 500-MW demonstration) to more rapidly advance, at lower risk, second- and third-generation CCS technology (e.g., new industrial processes, improved power technologies, and novel capture solvents still at the development stage). Governments must recognise that such an approach will result in the loss of some economies-of-scale in capital and result in higher operating expenses. Incentives that cover the higher operating expenses, in light of the public benefit of the demonstrations, should be part of the incentive package.

In addition to the above policy mechanisms, there are cross-cutting actions that governments should take, including:

- **Increasing Intra-governmental Coordination.** CCS projects are complex in terms of their engineering, permitting, and financing. Government grants are often issued by one part of an agency, while loan guarantees are issued by another, and tax incentives by still another. The more governments can create one-stop shopping for CCS projects and make decisions on a commercial timeline, the more it will accelerate CCS deployment.
- **Involve Inter-governmental Coordination on Carbon Markets that Enable CCS Deployment.** In addition, carbon credits generated by CCS projects must be tradeable on an equal basis as carbon credits for other low-carbon technologies. There must be a recognition that while carbon capture is technically feasible worldwide to power plants and industrial processes, there is globally variability in the geologic resources available for storage. Inter-governmental coordination on policy and technology development needs to recognise these differences if CCS is to deploy widely.
- **Positive CCS Narrative.** If the Paris Goals are to be achieved, CCS must be viewed as a central part of the solution. The world is not projected to move away from fossil fuels, but the world can move toward a low-carbon energy future where CCS-enabled fossil fuels, renewables, nuclear, and efficiency all play a role. A positive narrative by governments and political leaders will shape the view of financial markets, corporate boards, regulators, and the public and help align them with the need to have widespread, accelerated CCS deployment.

Certainly the list of mechanisms presented here is long, but if the mechanisms are implemented with strength, a limited set of mechanisms could deliver many CCS projects to market.

As an example, governments could provide a package of CCS retrofit incentives to a pre-set percentage of the existing coal-fueled power plant fleet. This could include an investment-grade twenty-year power purchase agreement that allows recoupment of the full cost of capital and provides revenue certainty, permitting flexibility to manage project-on-project risk, and a loan guarantee, and nearly all would likely succeed. Capital cost buy-down grant and completion guarantees would further increase the probability of success, particularly if the projects are FOAK.

Just as public policy and advanced technology spurred the creation and expansion of the renewables industry, public policy will dictate whether CCS remains a niche technology, or grows to be a widespread industrial practice. As concluded by the IPCC, achieving a 2°C goal will be 138% more expensive without CCS. This equates to trillions of dollars in cost savings through the widespread deployment of CCS. With the prospect for this scale of cost savings, investing just a fraction of this amount in policies that enable CCS deployment not only makes economic sense, it is likely the only way to preserve the opportunity that the goals of the Paris Agreement will be achieved.

If governments put well-designed policies in place, public and private banks will finance well-designed projects and industry will drive project development and technical innovation. This is likely the only way the Paris Goals will be achieved.

Annex 1: Regional Profiles

CCS is technically proven with pilot projects and commercial-scale projects underway in many countries. However, the number and type of CCS projects varies widely by country and region. In aggregate around globe the pace of deployment remains inadequate to meet the Paris Goals. Drawing upon the "Global Status of CCS" report (GCCSI 2015) and information gathered from CIAB members, this Annex provides an overview of CCS in six global regions: (1) Asia and Oceania, (2) India, (3) China, (4) Europe, (5) the Americas, and (6) the Rest of the World.

Region: Asia and Oceania

Asia is projected to rely on coal and other fossil fuels for a significant proportion of energy use for the foreseeable future. The IEA energy outlook for Southeast Asia projects that coal use in electricity generation will grow by 5.6% per year, providing 50% of power generation and 29% of total energy demand by 2040 in the New Policies Scenario (IEA, 2015b). The 'energy trilemma' being faced by countries is how to make use of fossil fuels to simultaneously improve the accessibility of energy supplies across the population, achieve energy security, and meet carbon abatement targets. The solution will need to include the deployment of clean coal technologies, HELE technology and CCS, across the electricity and industrial sectors. While demonstration and pilot projects are underway in a few countries, the path forward to foster the commercial deployment is faced with challenges regarding technical, regulatory, legal and financial policies that must be addressed at national, regional and international levels. A synopsis of the current status, challenges and next steps planned for the first-mover countries like Australia, Japan, South Korea and Thailand is found below.

Notable CCS Projects

CCS projects remain limited in number, with only one in the execution stage compared to other regions. However, there are a number of projects in the evaluation stage. These projects will support the next set of critical demonstration projects to test technology and storage options and to build up expertise in the region.

The largest project underway is the Gorgon Carbon Dioxide Injection Project in Western Australia. At an estimated cost of AUD 2 billion, it will be the largest CO_2 geological storage project in the world injecting CO_2 into a deep saline formation. The legal and regulatory framework with the state and national governments is in place and injection is expected to begin in 2017.

The AUD 245 million Callide Oxyfuel Pilot Project was a CCS retrofit to a 30-MWe unit at the Callide power plant in Queensland, Australia. It operated successfully for a two year test period ending in March 2015. During that period it achieved over 10,000 hours of oxyfuel combustion and more than 5,500 hours of carbon capture (Spero, 2014). This oxyfuel plant demonstrated that the technology can be used flexibly with a ramp-up rate similar to those of conventional coal-fired power stations. It was estimated that the next oxyfuel plant could see a reduction in costs of approximately 20%.[5] Storage was not undertaken at this site due to a lack of suitable storage options. The project was a joint cooperation (both technical and commercial) between government and industry in Australia and Japan.

For the mid-term, Australia has two potential hub projects, the CarbonNet Project in Victoria and the South West Hub Project in Western Australia, performing geological testing and drilling at potential storage sites for a multi-user CCS transport and storage network.

[5] *From CIAB consultations.*

Project Name	Status	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Gorgon Carbon Dioxide Injection Project	Execute	2017	Western Australia, Australia	Natural gas processing	Pre-combustion capture (natural gas processing)	3.4-4.0	Pipeline, 7 km	Dedicated geological storage, onshore deep saline formations
Korea-CCS 1	Evaluate	2020	Chungname Province, Korea	Power Generation	Pre-combustion capture	1.00	Shipping, distance being evaluated	Dedicated geological storage, offshore deep saline formations
South West Hub	Evaluate	2025	Western Australia, Australia	Fertilizer Prorduction	Industrial Separation	2.50	Pipeline, 80 - 110 km	Dedicated geological storage, onshore deep saline formations
CarbonNet Project	Evaluate	2020's	Victoria, Australia	Under evaluation	Subject to Industry partner selection	1.0 - 5.0	Pipeline, 130 km	Dedicated geological storage, offshore deep saline formations
Korea-CCS 2	Evaluate	2023	Korea	Power Generation	Pre-combustion or oxy-fuel combustion	1.00	Shipping, distance being evaluated	Dedicated geological storage, offshore deep saline formations

Table 3: Notable Large-scale CCS Projects in Development Within Asia and Oceania (GCCSI, 2015)

Japan's CCS roadmap envisions significant technological improvements stemming from ongoing R&D to help reduce capture costs by 50%. The Japanese government provides funding for 30 - 100% of RD&D project costs related HELE and CCS. The government provides 100% for the Tomakomai CCS demonstration and nationwide storage site investigation.[6] Several notable CCS projects include:

- The Tomakomai Project, commissioned by the Ministry of Economy, Trade and Industry (METI), is the first CCS demonstration project in the country and will run from 2012 to 2021. The project started injecting CO_2 into near shore aquifers in April 2016, with plans to inject 100,000 tonnes at two different depths for each of the next three years, at the same time monitoring it for five years (Healy, 2016).
- The Osaki CoolGen Project is developing an Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) pilot combined with a demonstration of carbon capture.[7]
- The Course 50 R&D Project is capturing CO_2 from a steel furnace. The project involves cooperation between the Japanese government, equipment suppliers, and industry

South Korea does not have a commercial-scale CCS project in operation or under construction. The government is currently revising its CCS Master Plan which will include a large-scale demonstration plant post-2020. The government supports joint efforts to test CCS technologies in the power and steel sectors, including a post-combustion test by Korea Electric Power Corporation (KEPCO) (GCCSI, 2015).

[6, 7] *From CIAB consultations.*

In Indonesia, work surrounding CCS is still in its infancy. A feasibility study for the Gundih CCS Project in Java was completed in 2014. The project would transport CO_2 30 to 40 km via truck to a depleted gas field. It remains in the planning phase (GCCSI, 2015).

Existing Policies and Incentives

In Australia, CCS Flagship Program funding of AUD 1.6 billion has been reduced by successive governments to AUD 300 million. In addition, there is little prospect of utilizing EOR in oil and gas production in the country.[8] This challenges both pilot and demonstration projects under development. There is continuing commitment to laboratory and desktop R&D through programs such, as the Australian National Low-Emission Coal (ANLEC).

In June 2016, the Japanese government established a technology development roadmap for coal-fired power generation authored by a committee of METI. It provides a guide for clean coal technology up to and beyond 2030, including the rollout of next generation HELE and CCS technologies. Due to the reliance on energy imports, the nation will continue to use coal with clean coal technologies in its energy mix to ensure the suitable balance between energy security, economic growth, energy efficiency and the environment. The roadmap sees the acceleration of R&D and commercial applications of IGCC and Advanced USC by around 2020 and establishing IGFC technology by around 2025. The aim is to raise plant efficiencies to as high as 55% (HHV, net) to be used in partnership with CCS as the key technology that can reduce carbon emissions in the mid- and long-term.[9]

In South Korea, the Intended Nationally Determined Contribution (INDC) does not cite CCS as a carbon mitigation technology to cut its greenhouse gas emissions by 37% from the business-as-usual to 850.6 Mt CO_2eq level by 2030 (Republic of Korea, 2015). Still, there is strong interest in CCS in the country led by the Korea CCS Association (KCCSA) which includes members across industry, energy and research institutes and the Korea CCS R&D Center (KCRC) started by the Ministry of Science, ICT and Future Planning (MSIP) to perform CCS policy planning, international cooperation, education & training, as well as develop innovative CCS technology. Between 2011 and 2015, the government provided approximately USD 268.2 million of funding for CCS R&D pilots and projects out of a total budget of USD 333.8 million which includes private investment (CSLF, 2016). The country is currently revising its CCS Master Action Plan to cover R&D activities through 2030 (CSLF, 2016). Various methods of financing are being considered for CCS including: tax credits for the period 2016 to 2025, clean energy credits for power generation (2026 to 2035) and contracts for differences post-2036.[10]

In Thailand, the government has made the commitment to reduce CO_2 emissions by 20 to 25% by 2030 by promoting renewable energy, stopping deforestation, implementing integrated water management and promoting rail over road transportation. To date, CCS has not directly been included as an abatement strategy in the Climate Change Master Plan to cut 100 Mtpa by 2022, and remains a backup strategy. The Department of Mineral and Fuels (DMF) has drafted a CCS roadmap for the country that is not yet approved as policy from the National Environmental Board.[11] Despite the identification by the Asian Development Bank (ADB) of two potential locations as key sites with sufficient storage in Thailand, neither site is yet in a formal planning stage. Thailand has identified 22 potential storage sources, including four oil and gas fields, as suitable for CCS with approximately 70 Mt of capacity.

[8, 9, 10, 11] *Based on CIAB consultations.*

Gaps

There is the need for clear government policy across the complete CCS chain in Asia and Oceania. This involves long-term energy policy statements with clearly defined targets for the demonstration and eventual commercial deployment of CCS technology by 2030. A first step would be the inclusion of CCS as a part of the emission reductions scheme in the INDCs submitted for the Paris Agreement. Because of the 2030 timeline involved, CCS is not yet directly specified as a technology needed to meet carbon abatement targets in the INDCs submitted to UNFCCC for Australia, Japan, South Korea or Thailand.

Clear policy, or a roadmap, defining clear roles and responsibilities, policies to govern transport infrastructure and storage, and clear strategic guidance, will make it possible to undertake plausible new project feasibility studies and coordinate project sites and timelines. The framework must provide clarity on liability requirements, especially those governing long-term monitoring and storage, so risks for project participants are clear and quantifiable. It is critical to identify the main government body or public organization that is responsible for CCS policy and implementation across the value chain (technology, capture, transport and storage).

Despite the creation of a CCS roadmap, the responsibility for the technology is still not clear in Thailand[12], and a new joint CCS roadmap is being developed by industry and government in Australia, with one already existing for Japan.

The international strategy for low-emissions fossil fuel technologies is chiefly focused on the demonstration of CCS technology and HELE fossil fuel utilization technology. Much of the activity for carbon capture technology and HELE research, development and deployment is occurring in North America, Japan, China and Europe where large technology corporations and equipment manufacturers are located (Mineral Councils of Australia, 2016). Japan has the advantage of being home to key OEM operators (e.g., IHI, MHPS, and Toshiba) who are global leaders in providing HELE and carbon capture technologies. This helps in the creation of joint pilot and demonstration projects and creates an incentive for domestic suppliers and technical expertise missing in other nations.

The financing of pilot projects remains a challenge for CCS in many Southeast Asian countries, as in other regions. Without a commercial business case, first-generation success stories from abroad and financial support the project pipeline in the region will not grow. For integrated CCS projects, government will need to play a critical role, offering not only policy support but also long-term financial assistance for R&D and storage exploration, since industry alone is unable to cover the high investment costs and associated risks. For example, in Thailand, there is little to no financial incentives provided from public sources for clean coal technologies, so projects would need to seek funding from sources like multinational development banks, alternative funding sources like the Green Climate Fund, go through another interface like the Thailand Greenhouse Gas Mitigation Organization or the government must implement far stricter emissions policies in the next INDC.[13]

Geology is quite variable, and conditions differ widely between specific locations. Consequently, prospective geological storage sites need to be individually characterised. Still, there are general learnings and tendencies that can be applied across a range of sites in different countries (Mineral Councils of Australia, 2016). Finding adequate prospective storage sites remains a challenge for many countries in the region. A joint study released by the Asian Development Bank and GCCSI identified up to 50 potential sources to capture as much as 120 Mtpa of CO_2 emissions from across power, natural gas and other industries. In the same study, as much of 10 Gt of theoretical

[12, 13] *Based on CIAB consultations.*

CO_2 storage capacity exists in saline aquifers and oil and gas fields, but this is difficult to estimate accurately due to data limitations (ADB, 2013). This demonstrates the need in much of Southeast Asia for accurate geological mapping of potential CO_2 sites with field mapping across much of the region.

Given the lack of OEM suppliers, Australia is focusing on storage exploration, geological R&D and appraisal. Due to the timelines required to undertake detailed storage site assessment, this work needs to begin several years before associated feasibility studies for carbon capture plants are planned. With this uncertainty, the selection of appropriate integrated demonstration projects and plants and permitting applications could be delayed. In Japan, an intensive nationwide geological survey is underway by the government to identify at least three adequate offshore carbon storage sites in the country by 2021.[14] In South Korea, a planned demonstration project for around 100 Mt CO_2 was delayed to 2020 until an adequate storage site had been identified and will now proceed.[15] A potential solution in some countries would be to coordinate the planning and construction of CCS projects to match the first-generation CCS EOR projects by 2020 with source and sink storage sites.[16]

Industrial partnership demonstration projects are still limited in many countries and provide a route to reduce emissions in the industrial sector. In Australia, the creation of a Leadership Roundtable for the development of Low Emissions Technologies for Fossil Fuels provides a mechanism to share knowledge and increase collaboration across industry and with government.[17] This industry group, along with government, has also initiated the development of the CCS Roadmap which is still underway to guide Australia's future investment in CCS to meet emission reduction targets in 2030 and beyond.[18] In Japan, the Course 50 project demonstrates the interest from industrial players in the steel market to seek options to limit carbon emissions in the long-term.

Due to the widespread planned use of fossil fuels for the next generation in the region, improved communication and ongoing collaboration are needed to build community support, locally, regionally and internationally with the public and environmental NGOs. One element is building increased education and confidence around clean coal technologies like CCS, as well as working with governments to promote sound regulatory systems and confidence in the sustainability of regulatory and 'patient funding' approaches.[19] CCS is not in competition with renewables, but is a partner that will be needed to meet emission targets at the least cost in a carbon constrained world. This could be done successfully using collaborative research activities directly with the environmental NGOs as a basis to expand knowledge across industrial fields. A key issue is the development of policies and collaboration across industries, since CCS needs to be deployed not only in the power industry but also across oil, gas and other energy-intensive industrial processes.

[14, 15, 16, 17, 18, 19] *From CIAB consultations.*

CCS in India

The IEA predicts that India will utilise coal, a fuel source with reserves in abundance in the country, to meet power and energy demand through 2040. The nation is expected to continue to construct new fossil-fuelled plants, largely coal, while in parallel significantly expanding the solar, wind and nuclear power base to meet growing demand. Policymakers face a multifaceted challenge to tackle energy policy: meeting growing energy demand, offering it at an affordable price, building access to electricity for all citizens, while reducing carbon emissions. The country already has approximately 205 gigawatts (GW) of coal-fired electricity generation capacity with an additional 113 GW of new coal-fired capacity under construction (WCA, 2015b). In India's INDC, it targets "to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030" relying upon on international assistance via "transfer of technology and low-cost international financing including the Green Climate Fund (GCF) (India, 2015). The Platform for Accelerating Coal Efficiency (PACE) recommends the development of clean coal technologies with the construction of new coal-fired HELE units to increase plant efficiency and lower emission levels compared to the subcritical efficiencies (of under 50%) in the coal plants currently under construction or in the planning stage (WCA, 2014).

The development of CCS in the country is a cornerstone of its carbon mitigation strategy, but it remains in its infancy without any substantial concrete demonstration or pilot plants under construction. The GCCSI provides a list of the smaller ongoing R&D activities in the country, mostly organised under the Department of Science and Technology (DST) of the Indian Ministry of Science and Technology (GCCSI and TERI, 2013). In addition to securing international financing for projects, several conditions must be addressed by policymakers and the international community including: the determination of reliable storage capacity sites and volumes, a stronger commitment in terms of CCS technology demonstration by policymakers, and the cooperation and transfer of technology and knowledge (Viebahn, 2014).

CCS in China

In Asia, China is one of the champions for clean coal generation now, implementing HELE, and will remain so by rolling out and deploying CCS in the future. This commitment is demonstrated by government policy commitment, at the international and national levels, and by industry in the planning and construction of HELE plants in the power sector and CCS demonstration and pilots across the power, gas and chemical industries. Like other countries, technical, legal, and regulatory issues for CCS remain, and the economic slowdown adds additional market challenges to the project pipeline. Still, the commitment to provide energy security, economic growth and alleviate environmental problems of the country remains strong, as outlined in a roadmap for CCS demonstration and deployment (ADB, 2015).

Noteable CCS Projects

There are currently four large-scale projects in advanced planning stages in China with a total combined storage capacity of 2.44 Mtpa with the planned operation as early as 2017/2018. All four projects rely on EOR as a storage option.

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Sinopec Qilu Petrochemical CCS Project	2017	Shandong Provice, China	Chemical Production	Industrial Separation	0.50	Pipeline, 75 km	Enhanced Oil Recovery
Yanchang Integrated Carbon Capute and Storage Demonstration Project	2017	Shaanxi Province, China	Chemical Production	Pre-combustion capture (gasification)	0.44	Pipeline, 150 km	Enhanced Oil Recovery
PetroChina Jilin Oil Ffield EOR Project (Phase 2)	2017	Jilin Province, China	Natural gas processing	Pre-combustion capture (natural gas processing)	0.50	Pipeline, 35 km	Enhanced Oil Recovery
Sinopec Shengli Power Plant CCS Project	2018	Shandong Provice, China	Power Generation	Post-combustion capture	1.00	Pipeline, 80 km	Enhanced Oil Recovery

Table 4: Notable Large-scale CCS Projects in Development Within China (GCCSI, 2015)

The strength of CCS is further illustrated in the nine smaller demonstration and pilot projects already in operation during the past decade, and those under construction across the country which provide technological and valuable operational experience. These provide the impetus to speed up the deployment for the larger projects planned shortly. Three of these pilot plants are operating on or near the sites of the larger-scale projects named above including (GCCSI, 2015):

- Shaanxi Yanchang Yulin coal chemical plant operating since 2012 using gasification to capture 50,000 to 80,000 tpa for EOR
- Dongying power station operating since 2010 near the Shengli oil field capturing 30,000 to 40,000 tpa using EOR
- A natural gas processing pilot at Jilin operating since 2009 with the potential to inject up to 200,000 tpa for EOR purposes

Existing pilots also capture CO_2 in the coal to liquids sector (CTL). The Shenhua Group, a CIAB member, has operated the Ordos Pilot Project since 2011, the first comprehensive CCS project in the nation which has captured and stored more than 300,000 tonnes of CO_2 from a coal liquefication plant in Ordos City, Inner Mongolia, China. (MIT 2016; Xivzhang 2014). The GCCSI also noted three additional projects under construction with operations starting as early as 2016 in the power sector which can test different capture technologies. These include: the HUST Oxyfuel Project (35 MW with capacity for 100,000 tpa), the Huaneng GreenGen Project a post-combustion project (60,000 to 100,000 tpa) and the Haifeng CCS Project.

Existing Policies and Incentives

China has relied on coal to electrify the country over the past generation, but has announced plans to reduce reliance on fossil fuels in the future to reduce greenhouse gas levels and improve air quality. That said, the coal-fired fleet is expected to remain the backbone for electricity generation in the future. Installed capacity is projected to increase from approximately 800 GW to about 1,250 GW and contribute to more than two-thirds of its energy needs in 2030, far higher than the global average of 24% (ADB, 2015). To achieve cost-effective climate change measures, the government has implemented clean coal directives, including a commitment to CCS that balances environmental concerns with energy consumption, pollutants, and water consumption, and economic growth as demonstrated in the INDCs submitted to the UNFCCC. The INDC includes targets where greenhouse gas emissions peak in 2030 and source at least 20% of primary energy from non-fossil fuel sources. One theoretical solution to achieve these goals is the potential case to retrofit up to 300 GW of existing coal-fired stations with CCS, which could reduce each unit's carbon emissions by approximately 85% (IEA, 2016).

The commitment of the Chinese government and industry is not limited to CCS, but to minimise the environmental footprint of coal by either closing or raising efficiency levels at older coal-fired plants, the construction of ultra-supercritical units (USC) and reducing other emissions (PM, SO_2, NOx, and mercury) from all thermal plants. The emission standards issued in 2011 by China's Ministry of Environmental Protection and the State Administration for Quality Supervision and Inspection and Quarantine are shown below in Table 5 for gas and coal-fired plants (Shumin, 2015).

	PM (mg/Nm³)	SO_2 (mg/Nm³)	NO_x (mg/Nm³)
Limits for coal-fired power units (0_2 = 6%)	**20**	**50**	**100**
Limits for gas turbine units (0_2 = 15%)	**5**	**35**	**50**
Shenhua Guohua targets for coal-fired units (0_2 = 6%)	**5**	**35**	**50**

Table 5. Key Area Emission Limits and Shenhua Guohua Targets

Many Chinese firms, like the Shenhua Group, have established a path to ultra-low emissions for coal-fired plants by developing a roadmap for efficiency and emission control technologies and increasing investment in environmental technology from domestic sources and abroad. New coal-fired stations with over 600 MW of installed capacity are being constructed with HELE technology. Shenhua targets the integration of advanced pollutant scrubbing technology to provide for the efficient removal of pollutants and are in the process of upgrading existing capacity to achieve defined ultra-low emission targets. In addition, new ultra-supercritical conditions have the potential to limit coal consumption for electricity to ~300 gce/kWh (net) by 2025.[20]

As CCS is deployed over the next decade, Southeast Asia could act as a direct beneficiary from China, who could provide technology, suppliers, and expertise to coal-reliant developing nations in the region and abroad.

Gaps

As in many countries, support for CCS in China would be strengthened by a clear national plan or policy and a complementary regulatory framework to govern CCS pilots and projects. While various governmental ministries and agencies have promoted CCS, the first challenge is the creation of a formal framework to govern regulatory issues, permitting and liabilities, the lack of which is hindering some first-mover projects (ADB, 2015). A clear long-term policy is needed to gain the support of private investors and industry to lower notable technological, financial and legal risks.

Second, the high capital and operational costs faced by large-scale CCS projects is a challenge in China and abroad until a greater number of first-generation CCS projects are launched. The slowdown in the Chinese economy and softer global oil and gas prices complicates this for the country and has created a new barrier to project development. The business case for the four most advanced large-scale projects has deteriorated since all use CO_2-EOR as an additional revenue source for financing.

A third challenge is the high level of energy and water demand needed to implement CO_2 capture technology. CCS projects would require higher water demand at a time when the country faces water scarcity and pollution issues in some regions (ADB, 2015). An upside of CCS is the reduction it could have on local air pollution where high-efficiency coal stations with CCS could reduce particulate matter by approximately 50%, as well as NO_x and SO_2 emissions.

[20] *From CIAB consultations.*

Lastly, the potential for CO_2 storage capacity needs to be geologically mapped and assessed using consistent evaluation models, standardised methodology, and comprehensive data across regions and projects. While academic research suggests that the country has sufficient levels to store projected CO_2 levels, many studies conducted to date estimate a wide range of total storage capacity dependent on the inputs (ADB, 2015) where more accurate, consistent estimates are needed.

Over the next five years, the ADB roadmap makes specific recommendations for the technology to advance including (ADB, 2015):

- Setting CCS-specific targets for the country and integrating the technology into the portfolio of low-carbon solutions
- Prioritizing the next demonstration units that use low-cost[21] CO_2 -EOR
- Establishing a plan for large-scale deployment targeting high priority regions
- Developing policies for CO_2 -EOR and defining CCS-ready
- Providing fiscal and financial support for first-mover projects which could consist of grants, loan guarantees, tax credits and fixed priced program

The ADB roadmap suggests a two-track approach to CCS demonstration and deployment in the mid-term to prove the feasibility of the technology and increased confidence in the government and with the public. One track would continue to target the construction of low-cost coal-chemical pilots with EOR storage and a second track would increase research and development in coal-fired plants to bring down capture costs and build up operational experience (ADB, 2015).

Future CCS projects, in particular those involving industrial partners, would benefit from the creation of a cluster and hub approach, clustering projects of several large emitters to save on transport and storage costs. The Ordos Basin, where the Shenhua Group has a pilot, provides a region where a cluster approach for CCS demonstration with many coal-chemical plants and large storage potential in oil and gas fields in the vicinity (ADB, 2015).

[21] *From CIAB consultations.*

CCS in Europe

In the past two years, European CCS projects across the continent faced significant hurdles in response to negative public sentiment toward coal generation, debates over the early closure of power plants and loss of key governmental funding. With the exception of Poland and Greece, the outlook for new projects is precarious on the continent after a wave of new lignite and coal-fired plants opened in the Netherlands, Germany, the Czech Republic, Slovenia, Bulgaria and Bosnia in the past five years and the retrofitting of units in Italy. The negative public sentiment, unstable political landscape, and weak energy markets have brought many clean coal projects to a standstill in much of the region. Europe still lacks a CCS champion that would raise the profile of CCS, build support and improve public sentiment for the technology.

Noteable CCS Projects

Currently, there are two large projects operating in Norway and outside the European Union with a proven long-term operational track record. The Sleipner and Snovit projects have a combined storage capacity of 1.55 Mtpa that are used for the processing of gas and injection of CO_2 into deep saline formations off-shore, but there hasn't been a new project operational on the continent in eight years.

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Sleipner CO_2 Storage Project	1996	North Sea, Norway	Natural gas processing	Pre-combustion capture (natural gas processing)	0.85	Direct Injection	Dedicated geological storage offshore deep saline formation
Snohvit CO_2 Storage Project	2008	Barents Sea, Norway	Natural gas processing	Pre-combustion capture (natural gas processing)	0.7	Pipeline, 153 km	Dedicated geological storage offshore deep saline formation

Table 6: Operating Large-scale CCS Projects within Europe (GCCSI, 2015)

The Le Havre CCS Demonstration Pilot at Unit 4 tested amine-based post-combustion capture technology and was successful capturing up to 90% of CO_2 and 25 tonnes per day for a total of 1,900 tonnes between July 2013 and March 2014 (GCCSI, 2015).

In the GCCSI report, eleven projects globally were listed in the advanced-planning phase. The two UK projects (Petershead and White Rose) are postponed indefinitely after the cancellation of the UK CCS competition in November 2015, where up to GBP 1 billion was earmarked for project financing. Only the ROAD project (Rotterdam Opslag en Afvang Demonstratieproject) at the Maasvlakte unit in the Netherlands remains in the planning stage, but is also facing delays with operations and is now expected to start by the end of 2019.

All of these projects have strategic significance for the continent and the power sector there and abroad to improve public perception and address perceived risks, prove different capture and storage technologies and share lessons-learned with successor projects to reduce risks and costs across industries and countries (GCCSI, 2015).

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Rotterdam Opslag en Afvang Deomonstratie project (ROAD)	2019-2020	Zuid-Holland, Netherlands	Power Generation	Post-combustion capture	1.1	Pipeline, 25 km	Dedicated geological storage, offshore depleted oil and/or gas reserve
Peterhead CCS Project (cancelled)	2019-2020	Aberdeenshire, UK	Power Generation	Post-combustion capture	1.0	Pipeline, 100 km	Dedicated geological storage, offshore depleted oil and/or gas
White Rose CCS Project (cancelled)	2020-2021	North Yorkshire UK	Power Generation	Oxy-fuel combustion capture	2.0	Pipeline, 165 km	Dedicated geological storage, offshore depleted oil and/or gas

Table 7: Large-scale CCS Projects in Advanced Planning within Europe (GCCSI, 2015)

Smaller CCS pilots and research and development projects are still underway. Examples include the Ketzin Storage Pilot, now closed but with ongoing measuring and monitoring until 2018, and the ongoing CO_2 capture pilot at Niederaussem, which has tallied over 40,000 operational hours at 97% availability. In addition, there are numerous collaborative multinational R&D projects like Hipercap, Octavius, Lisa and Scarlet[22], the Lünen CCU Pilot, a 1 MW at the STEAG GmbH owned plant, undertaken by an international consortium with Mitsubishi Hitachi Power Systems Europe (MHPSE) acting as system integrator which will convert 1.4 tonnes of CO_2, into 1 tonne of methanol daily when operational (PEI, 2015).

Recently, the Norwegian Ministry of Petroleum and Energy presented feasibility studies for three industrial sites looking at establishing a full-scale CCS operation in the country by 2022. The studies establish a case for a full-scale flexible CCS chain where transport is done by ship to a connection point at a storage site instead of by pipeline. The next step will be to create a combined concept and FEED that will be a key input for an investment decision planned for Spring 2019 (IEAGHG, 2016).

In addition, there is still interest from European industry to develop CCU to reduce emissions, especially from the chemical, steel and cement industries or within energy-to-waste plants such as in Norway or the Netherlands. A main focus for industrial applications is the development of CCU for polymer production, alternative fuels, and long-term electricity storage. A key project for the cement industry is the Aker Clean Carbon Project at the Norcem cement plant in Brevik, Norway, the first demonstration project for the cement industry. The project, conducted in partnership with Norcem, Heidelberg Cement and European Cement Research Academy (ECRA) kicked off in May 2013 and will test four different types of post-combustion CO_2 technologies over a three and a half year period (Bjerge, 2015).

[22] *From CIAB consultations.*

Existing Policies and Incentives

The European Union implemented the Emissions Trading Scheme as a means to secure long-term emission reductions at the lowest price. The market in this trading scheme is in oversupply, and the prices have fallen far from over EUR 30/tonne-CO_2e in 2008 to under EUR 5/tonne-CO_2e in 2016.

Central coordination of policy and financing for CCS deployment is not governed at the European Union level. Unlike other low-carbon strategies, CCS lacks an EU-wide binding target, criteria and budget for financial support (GCCSI, 2015). At the country level, the United Kingdom went the furthest in establishing a policy framework to govern the CCS supply chain, as well as providing financial support attracting private investment until November 2015, and this gap remains for other member countries and for the region as a whole.

Despite the recent setbacks, there is ongoing fruitful cooperation and knowledge transfer between many organizations including the Zero Emissions Platform (ZEP), Global CCS Institute (GCCSI), Carbon Capture and Storage Association (CSSA), European Climate Foundation (ECF), Third Generation Environmentalism (E3G) and the Bellona Foundation.[23]

On a positive note, studies show that availability of adequate storage for carbon capture within the continent would exist with studies completed for the United Kingdom, Netherlands and Germany. As seen in the project lists above, the off-shore sites in the North or Barent Seas are preferred for the first generation of projects. In Germany, onshore CCS storage is not possible due to public sentiment and regulations, so the construction of offshore CO_2 transportation would be necessary, which is difficult in planning, construction, and financing. The IZ Klima published a study entitled "CO_2 Transport Infrastructure in Germany – Necessity and Boundary Conditions up to 2050," that shows that sufficient levels of storage would be available using saline aquifers in the North Sea out to 2050 (Buit et al., 2014).

Gaps

The path ahead for coal, and with it CCS, in Europe is an uphill battle that would require a change in sentiment and support from the political and public arenas to succeed.

The United Kingdom was originally the frontrunner for CCS deployment, drafting a policy, legal and regulatory framework that the European Union as a whole and most member nations still need to put in place (GCCSI, 2015). A recent report by the Carbon Capture and Storage Association (CCSA) in June 2016 shares thirty-six lessons learned from large scale United Kingdom and European CCS projects in the past decade to assist ongoing regional and global CCS projects (Carbon Capture and Storage Association, 2016).

A few recommendations derived from the United Kingdom report that could ensure CCS projects are able to move from the planning to operating stage include (CCSA, 2016)[24]:

- Cooperation between projects and policymakers is needed to quickly clarify the terms, structure and risk allocation as defined in financing or competition guidelines (ex. CCS ITPD Full Chain Structure)
- Adoption of market mechanisms is needed, such as contracts for differences (CFD) to provide projects a clear way to measure future revenue streams and a route to the market for electricity sales

[23] *From CIAB consultations.*
[24] *The complete report can be found under: http://www.ccsassociation.org/index.php/download_file/view/1023/1/*

- A secure long-term source of public funding and state aid to assist with project development and construction costs, which acts as a safety net to secure additional funding from the private sector. This could be done by inclusion of CCS in the Innovation Fund (GCCSI, 2015).
- Acceptance that initial large-scale projects, especially those covering the full chain of infrastructure, will unlikely be an "attractive investment proposition for the private sector".
- Establish clear legislation and policies on the long-term risks and liabilities of storage so developers can assess the costs and consequences.
- Avoid "additional and onerous financial obligations for storage operators" for first-of-a-kind projects.
- Creation of a long-term vision for CCS deployment and creation of hubs and clusters in the planning stage for storage and transport can lead to significant cost savings for second-generation projects.[25]

The lessons-learned from the UK also show the importance of having a long-term vision for CCS deployment and coordination of projects that could contribute significantly to overall cost reductions and lower risk and contingency requirements.

According to some CIAB European Members, support for using CCS technology to curb emissions in industry still exists, particularly the chemical and steel industries on the continent. As with large-scale projects, industry will need clear policies and incentives from government leaders to pursue projects. Project management and planning that coordinate and use clusters would be a strategy to reduce costs to the private sector.

[25] The White Rose and Peterhead projects confirmed that bids submitted, based on CfD strike prices, would likely be in the range 150-200 GBP/MWh to fully-fund the chain of the complete chain of the project and full costs of storage and transport. The National Grid Carbon (NGC) believes that the transport and storage costs for Phase 2 projects sharing the White Rose infrastructure could have fallen by 60-80% (CCSA, 2016).

CCS in the Americas

North America has been a frontrunner in global CCS technological developments and is home to many of the key projects referenced across the globe for technological knowledge transfer and sharing lessons-learned across governmental organizations and with industrial partners. Despite the strong start, the future of CCS for the next generation of projects in the region has weakened with the loss of project financing, policy support from governments and agencies, and weaker global and energy market conditions, all contributing to a reduction in the number of projects across these countries in the next decade and through 2040 where commercial deployment is critical to reach the goals outlined in the Paris Agreement.

Noteable CCS Projects

Historically, North America, but also South America, has been a forerunner for CCS exploration and development, providing a home to eleven of the fifteen operating projects globally, with seven in the United States, three in Canada and one in Brazil, offering a total of 25.9 Mtpa of storage capacity in place (GCCSI, 2015). The natural gas industry, with six projects utilizing CO_2 for EOR, has the longest track record dating back to the Val Verde Natural Gas Plants (Texas, USA) launched in 1972 and extending through the Century Plant (Texas, USA), Lost Cabin Gas Plant (Wyoming, USA) and Petrobras Lula Oil Field (Santos Basin, Brazil) all launched in 2013. Using EOR as the storage option provides a revenue stream that helps finance ongoing operational costs as defined in long-term contracts. Other industries, such as fertiliser and hydrogen production, have also used EOR as a primary storage option.

Amid CCS projects, the successful launch of the Boundary Dam CCS Project with 115 MW of installed capacity in 2014 in Saskatchewan, Canada was the first commercial-scale power plant globally after retrofitting an existing unit. It utilises post-combustion capture and EOR for storage, and is a case study for utility-owned CCS projects under construction and in the planning stage across the globe and acts as a beacon for sharing technology and lessons-learned from other project planning and operations. The Quest Project, launched in November 2015, is the first large North American project that stores up to 1 Mtpa of captured CO_2 in a deep saline formation. Carbon is captured during the hydrogen manufacturing process, and bitumen is changed into synthetic oil (GCCSI, 2015).

In 2016/2017, the GCCSI reports that five large-scale projects, including two power plants and three projects in the oil, chemical and fertiliser industries, are expected to be launched to ultimately capture up to 6.9 to 7.4 Mtpa of CO_2 in the near future (GCCSI, 2015).

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Coffeyville Gasification Plant	2013	Kansas, USA	Fertiliser production	Industrial Separation	1.0	Pipeline, 112 km	EOR
Air Products Steam Methane Reformer EOR Project	2012	Texas, USA	Hydrogen production	Industrial Separation	1.0	Pipeline, 158 km	EOR
Quest	2015	Alberta, Canada	Hydrogen production	Industrial Separation	0.9	Pipeline, 64 km	EOR
Val Verde Natural Gas Plants	1972	Texas, USA	Natural gas processing	Pre-combustion capture (natural gas processing)	1.3	Pipeline, 365 km	EOR
Enid Fertilizer CO2-EOR Project	1982	Oklahoma, USA	Natural gas processing	Industrial Separation	0.7	Pipeline, 225 km	EOR
Shute Creek Gas Processing Facility	1986	Wyoming, USA	Natural gas processing	Pre-combustion capture (natural gas processing)	7.0	Multiple Pipelines, max 460 km	EOR
Century Plant	2010	Texas, USA	Natural gas processing	Pre-combustion capture (natural gas processing)	8.4	Pipeline, > 225 km	EOR
Lost Cabin Gas Plant	2013	Wyoming, USA	Natural gas processing	Industrial Separation	0.9	Pipeline, 374 km	EOR
Petrobras Lula Oil Field	2013	Santos Basin, Brazil	Natural gas processing	Industrial Separation	0.7	No transport/ direct injection	EOR
Boundary Dam Carbon Capture and Storage Project	2014	Saskatchewan, Canada	Power Generation	Post-combustion capture	1.0	Pipeline, 66 km	EOR
Great Plains Synfuel Plant and Weyburn-Midale Project	2000	Saskatchewan, Canada	Synthetic natural gas	Pre-combustion capture (gasification)	3.0	Pipeline, 329 km	EOR

Table 8: Operating Large-scale CCS Projects in the Americas (GCCSI, 2015)

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Illinois Industrial CCS Project	2016	Illinois, USA	Chemical Production	Industrial Separation	1.0	Pipeline, 1.6km	Dedicated geological storage, onshore deep saline formations
Alberta Carbon Trunk Line (ACTL) with Agrium CO2 Stream	2016	Alberta, Canada	Fertiliser Production	Industrial Separation	0.3 - 0.6	Pipeline, 240 km	EOR
Alberta Carbon Trunk Line (ACTL) with Agrium CO2 Stream	2016	Alberta, Canada	Oil refining	Industrial Separation	1.2 - 1.4	Pipeline, 240 km	EOR
Kemper County Energy Facility	2016-2017	Mississippi, USA	Power Generation	Pre-combustion capture (gasification)	3	Pipeline, 98km	EOR
Petra Nova Carbon Capture Project	2017	Texas, USA	Power Generation	Pre-combustion capture	1.4	Pipeline, 132km	EOR

Table 9: CCS Projects to be launched in 2016/2017 within the Americas (GCCSI, 2015)

In addition, there are some smaller CCS projects devoted to research and development which will be used as a basis for knowledge-sharing and cross-border collaboration. An example is the Brazilian R&D project underway via a partnership between the DOE's National Energy Technology Laboratory (NETL), SATC Clean Coal Center, and the Brazilian Coal Association, in cooperation with the DOE, to construct a research laboratory in December 2016 to study the synthesis of sorbents for CO_2 capture to create zeolites from coal ashes and solid amine sorbents.[26]

While it does not directly involve CCS, there has been a significant fourteen-year R&D project completed by a U.S. consortium, principally funded by the U.S. DOE and the Ohio Coal Development Office (OCDO), to develop, test and certify new materials capable of allowing steam power cycles at temperature 760°C. This would increase the thermal efficiency of coal power plants and reduce the cost of implementing CCS since less CO_2 would need to be captured and stored (Purget et al., 2015). The project's final report is available at: http://www.osti.gov/scitech/biblio/1243058. The follow-up, with funding by the DOE and OCDO, will be the design, construction and operation of the ComTest facility to be completed in 2020, which includes a fired superheater and a 7 MW steam turbine in Youngstown, Ohio.[27]

[26, 27] *Based on CIAB consultations.*

Existing Policies and Incentives

One key reason for the construction of the CCS projects to date are the financial incentives and grants offered by governmental sources like DOE, the Canadian Federal Government and the provincial government of Alberta (GCCSI, 2015). Since 2014, seven large-scale projects have been postponed or cancelled for several reasons. First, the loss of government funding from the DOE led to the suspension or cancellation of five out of six carbon capture storage projects including the FutureGen Project in January 2016 and the Texas Clean Energy Project in May 2016. The loss of public funding (direct funding, tax incentives, and loan guarantees) and perceived political support has a secondary effect and endangers private sector financing.

Second, many projects rely on EOR as a revenue stream over the life of a project and gas and oil prices remain weak. The lower domestic and export gas and oil prices as a result of the ramp-up in shale oil and gas production in the United States over the last decade are correlated with a drop in coal generation in many regions due to fuel switching[28]. Figure 13 demonstrates the difference between the benchmark Henry Hub gas price relative to coal price (on a USD/MWh basis) for the past 16 months. As illustrated, some coal supply regions remain competitive with natural gas at recent gas prices, but others have struggled to compete. With higher plant efficiencies in CCGT units, gas plants are more likely to run before coal in the merit order in some regions of the USA – particularly those heavily dependent on higher cost coal supply regions such as Central Appalachia.

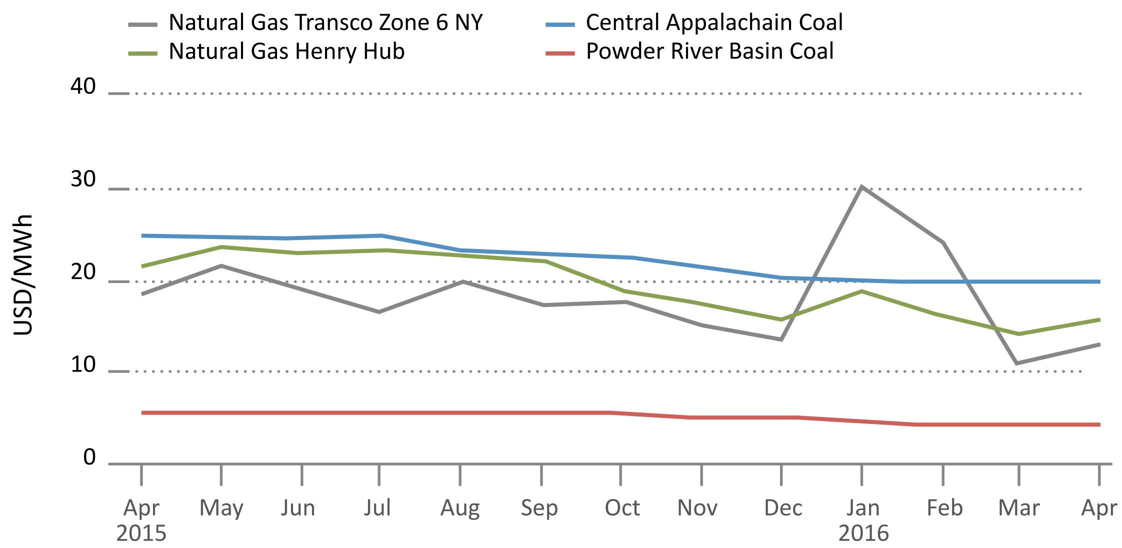

Figure 14. United States Natural Gas vs. Coal Prices (USD/MWh) (EIA, 2016))

[28] *Based on CIAB consultations.*

The third reason is that uncertainties in regulatory, permitting and long-term liability management impair project planning, as well as public and private support. The revocation of the air quality permit for the Indiana Gasification plant led to the cancellation of the project's planned capture capacity of 5.5 Mtpa early in 2015. Lastly, the cost of constructing a new USC coal-fired plant with or without CCS storage capacity is capital intensive and higher than a comparable gas unit, as measured in total costs per MWh and in construction time. Despite these hurdles, earlier projects have improved the framework for project permitting and EOR applications and created standards for the geological mapping of storage in the country.

Gaps

The road for CCS deployment in the Americas remains bumpy, with projects facing numerous technological, regulatory and financing challenges all acting as roadblocks. Additional policy clarity and incentives will be needed to create a sustainable stream of projects to meet global 2040 carbon abatement goals.

In the United States, the EPA is being scrutinised on whether the agency has the authority to adopt long-term emissions standards for power plants and other industries. The EPA's "Clean Power Plan," which calls for a 32% reduction from 2005 levels in CO_2 emissions from existing power plants by 2030, is still being disputed by some states and has a judicial stay issued by the U.S. Supreme Court. The Electric Power Research Institute (EPRI) explored the limits of future coal technologies to meet emissions standards without CCS, finding standards as low as 430 kg CO_2/MWh could be possible (EPRI, 2015).

Currently, CCS and clean coal technology do not share equal footing with other energy sources like renewables. Allowing CCS to be on an equal footing with other clean energy sources includes clear policy directives, permitting and legislation and provides the necessary government financial incentives that would help foster investor confidence in large scale projects. The National Coal Council Report from November 2015 reviews financial incentives that would encourage CCS deployment. They include: contract for differences (CfD); limited guaranteed purchase agreements; market set asides; clean energy credits; tax credits and price interventions; tax-preferred bonds and load guarantees (NCC, 2015). These would generally come from the federal level and would have to be in place before projects could start any significant development. A long-term energy strategy that extends beyond 2030 with clear objectives for emission reduction targets that are included in country-level INDCs and defines support at the regional, national and international level is needed to ensure the willingness of parties to fund low-carbon options like CCS.

This strategy could:

- Provide a clear policy framework governing permitting, insurance and storage that covers eminent domain for property rights to make storage sites available for neighbouring suitable capture projects
- Provide direct financial incentives that provide fixed revenue over the course of a project like tax credits or rebates for non-EOR storage and that minimise long-term project risks
- Provide a market mechanism to recoup CCS costs via electricity market prices and that lowers volatility from the power and oil markets
- Create dedicated funding throughout the life of the project and addresses performance guarantees for first-generation projects, like Kemper and Petra Nova, to encourage private financing

In non-OECD countries like Brazil, the focus is first on modernizing the existing fleet despite the ongoing economic downturn to boost coal plant portfolio efficiencies and reduce greenhouse gas emissions[29]. In a second step, countries can then partner with other governments, development banks, and industry to develop complementary policies that boost confidence to build up capacity, knowledge transfer and insight, establish funding and benefit from lower CCS construction and operational costs of earlier CCS plants.

[29] *Based on CIAB consultations.*

CCS in the Rest of the World

The status of clean coal technology and CCS is mixed across the remainder of the world. One of the first carbon storage projects in the world kicked off in 2004 in Algeria, but the development of further projects have been slow in launching. Two exceptions are one project in Saudi Arabia in 2015 and a second in Abu Dhabi in 2016. Without international support to assist with technical expertise, collaboration and access to global finance sources from both private and public sectors, further deployment may be in jeopardy even in countries heavily reliant on coal like South Africa.

Noteable CCS Projects

Currently, there are two large-scale CCS plants already in operation in Africa and the Middle East, both in the natural gas industry.

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
In Salah CO_2 Storage	2004	Wilaja de Ouargla, Algeria	Natural gas processing	Pre-combustion capture (natural gas processing)	0 (injection suspended)	Pipeline, 14 km	Dedicated geological storage, onshore deep saline formations
Uthmanijah CO_2-EOR Demonstration Project	2015	Eastern Province, Kingdom of Saudi Arabia	Natural gas processing	Pre-combustion capture (natural gas processing)	0.3 - 0.6	Pipeline, 85 km	Enhanced Oil Recovery

Table 10: Notable Large-scale CCS Projects in Operation within the Rest of the World (GCCSI, 2015)

The inaugural InSalah CCS Storage Project in central Algeria started operations in 2004, and was a pioneer in sharing a wealth of technical information, expertise and lessons-learned for future CCS projects around the globe. In the project, CO_2 from several neighbouring gas fields was removed from the gas production stream so the gas would meet export specifications. After treatment in a central gas processing facility, relying on the MEA Amine process, CO_2 was then condensed, transported and stored in a neighbouring onshore sandstone storage formation. Since the start of operations over 3.8 Mt of CO_2 was stored from the project (Ringrose et al., 2013)

The project in Saudi Arabia launched in the summer of 2015 and is expected to be in operation for three to five years, including an extensive monitoring and surveillance plan that will increase technical experience, R&D activities and demonstration of CCS in the country (GCCSI, 2015).

Project Name	Year of Operation	Location	Industry	Capture Type	Capacity (Mtpa)	Transport Type	Primary Storage Option
Abu Dhabi CCS Project (Phase 1 being Emirates Steel Industries (ESI) CCS Project)	2016	Abu Dhabi, UEA	Iron and steel production	Industrial separation	0.80	Pipeline, 43 km	Enhanced Oil Recovery

Table 11: Notable Large-scale CCS Projects under Construction within the Rest of the World (GCCSI, 2015)

A second project in the region in Abu Dhabi is under construction and is expected to launch this year, which will capture up to 0.8 Mtpa from a steel plant and transport it to the Rumaitha oil field. In Qatar, CCS initiatives are also underway as shown in the establishment of the Qatar Carbonates and Carbon Storage Research Centre (QCCSRC) through a partnership between government branches, Shell and academic research groups (GCCSI, 2015). In Turkey, small pilot-scale CCS projects are underway building upon the three decades of EOR experience from domestic gas and oil companies[30].

Existing Policies and Incentives

The South African Center for Carbon Capture and Storage (SACCCS), established in 2009, is the organization responsible for CCS research and development in the country and a division of the South African National Energy Development Institute. SACCCS created a CCS roadmap that was ratified by Parliament that is to be rolled out in five phases and is currently in the third phase of planning a pilot storage site in a location still under determination (SACCCS, 2016). The pilot has been delayed and will likely first begin operations in 2019/2020. CCS is included in the South African National Development Plan (NDP) which provides a vision to guide the country's sustainable development plan to 2030 encompassing climate change, industrial growth, and energy. The South African INDC includes CCS, but only specifically for coal-to-liquid plants where a reduction of 23 Mt CO_2 would be required to meet the country's mitigation target.[31]

The GCCSI reports that while Middle East projects are using CO_2 to improve the recovery from oil and gas fields, unlike North American projects, the focus is not yet on full-scale implementation to create a project business case, but instead on using this knowledge to create long-term carbon management strategies both domestically and internationally (GCCSI, 2015).

In Russia, CCS is still in its infancy with no planned CCS projects on the horizon. In 2015, the government announced a revised Energy Strategy to 2035 with the key message that the energy sector provides the engine to develop the country's economy. Currently, coal is a more expensive fuel option than domestic gas in the power sector, measured by both capital and operational costs, which limits public and private interest in coal-fired generation and clean coal technology at this time. The country is still in the process of identifying and developing potential CCS projects, but

[30, 31] *Based on CIAB consultations.*

incentives and economic challenges limit the priority. For the Paris Agreement, Russia agreed to limiting GHG emissions to 70 to 75% of 1990 levels by 2030, but did not include a passage on using CCS to achieve these targets.[32]

Gaps

Like other regions, financing of pilot and successor projects remains a challenge. The reduced funding for fossil energy projects by some banks and pension funds in favour of renewable energy projects introduces a large challenge, especially for developing countries faced with project costs of USD 500 million for large-scale commercial development. To overcome this, CCS projects must have access to developmental bank and government financing as well as international Climate Funds to move forward. In South Africa, government funding is provided on the basis that it must be used within a defined timeframe, so that any project delays that are likely with new technologies result in the potential loss of governmental funding, furthering difficulties in obtaining matching private contributions and endangering project completion.[33] Existing funding levels, even when accounting for external sources like the World Bank and Norway, are insufficient for establishing a pilot. The government has proposed a carbon tax in the future to promote CCS technologies, but direct government funding, tax incentives and rebates for R&D projects would likely be more successful strategies and more attractive to private investment.[34]

In Russia, the current differentials in domestic fuel prices due to weak gas prices is limiting both the use of coal for generation and interest in pursuing CCS at this moment until market fundamentals change.[35]

A second challenge is attracting or developing technical expertise for CCS projects in these countries and regions. CCS is coordinated through the South African Energy Ministry, and the intention of the pilot is to develop the technical expertise domestically, by using advisory committees comprised of international experts to provide guidance rather than 'importing' the technical know-how.[36] In the Middle East, the large-scale pilots are being used to build up domestic technical expertise to be used in long-term operations including EOR, and can in some countries rely on international collaboration and support from international gas and oil companies.

Storage issues face several challenges that must be solved to create an integrated CCS large-scale project. South Africa has limited potential for onshore storage and is reviewing two sites with the target basins in Zululand and the Algoa Basin. As in Southeast Asia, a substantial amount of work needs to be undertaken to collect, analyze and characterise missing geographical data and assess the potential for on- and off-shore sites.[37] Also, the large distances between coal-fired units like Kusile and the proximity to potential storage sites of a distance of more than 600 km make CCS logistics difficult and potentially cost prohibitive in South Africa.

[32, 33, 34, 35, 36, 37] *Based on CIAB consultations.*

References

ADB (Asian Development Bank) (September 2013), Prospects for Carbon Capture and Storage in Southeast Asia, Manila, Phillipines, ISBN 978-92-9254-290-0, e-ISBN 978-92-9254-291-7, www.adb.org/publications/prospects-carbon-capture-and-storage-southeast-asia.

ADB (Asian Development Bank) (November 2015), Asian Development Bank's Roadmap for Carbon Capture and Storage: Demonstration and Deployment in the People's Republic of China, Manila, Phillipines, ISBN 978-92-9257-042-2, e-ISBN 978-92-9257-043-9, www.adb.org/publications/roadmap-carbon-capture-and-storage-demonstration-and-deployment-prc.

Barnes, I. (2015). HELE Perspectives for Selected Countries, www.minerals.org.au/file_upload/files/publications/HELE_perspectives_for_selected_countries.pdf, The IEA Clean Coal Centre. London.

Bjerge, L. (20-21 May 2015), "Norcem CO2 Capture Project", Presentation at Norcem/ European Cement Research Academy CCS Conference, Langesund, Norway, www.norcem.no/no/CCS-conference.

Buit, L., W. Mallon, P.Schulze, S. Solomon, and F. G. Stienstra (July 2014), Transport Infrastructure in Germany-Necessity and Boundary Conditions up to 2050, www.iz-klima.de/w/files/veroeffentlichungen/141106-final-report-co2-infrastructure-study-iz-klima_english_with-annex_print-version.pdf.

CCSA (Carbon Capture and Storage Association) (29 June 2016), Lessons Learned: Lessons and Evidence Derived from UK CCS Programmes, 2008 – 2015, www.ccsassociation.org/index.php/download_file/view/1023/1.

CSLF (Carbon Sequestration Leadership Forum) (2016), www.cslforum.org/sites/cslf/technologyroadmap/korea.html.

EIA (United States Energy Information Administration) (24 June 2016), Electricity Monthly Update. Retrieved www.eia.gov/electricity/monthly/update/resource_use.cfm#tabs_spot-2.

EPRI (Electric Power Research Institute) (19 October 2015), Can Future Coal Power Plants Meet CO2 Emission Standards Without Carbon Capture and Storage?, Palo Alto, California, www.epri.com/abstracts/pages/productabstract.aspx?ProductId=000000003002006770.

Finkenrath, Smith, and Volk (2012), Analysis of the Globally Installed Coal-fired Power Plant Fleet, www.iea.org/publications/freepublications/publication/CCS_Retrofit.pdf, OECD/IEA, Paris.

GCCSI (Global Carbon Capture and Storage Institute) and TERI (The Energy and Resources Institute of India) (01 January 2013), India CCS scoping study: final report, www.globalccsinstitute.com/publications/india-ccs-scoping-study-final-report.

GCCSI (Global Carbon Capture and Storage Institute) (2015), The Global Status of CCS 2015, Melbourne, Australia, ISBN 978-0-9871863-7-9.

GCCSI (Global Carbon Capture and Storage Institute) (2015b), The Costs of CCS and other Low-carbon Technologies in the United States - 2015 Update, Melbourne, Australia, ISBN 978-0-9871863-7-9.

Healy, R. (11 August 2016), "First CCS demonstration project in Japan starts up, over 100,000 tonnes of CO2 to be stored per year". The Gas Review (422). www.gasworld.com/first-ccs-demonstration-project-in-japan-starts-up/2010858.article.

IEA (International Energy Agency) (2012), Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation, OECD/IEA, Paris.

IEA (International Energy Agency) (2013), Technology Roadmap: Carbon capture and storage, OECD/IEA, Paris.

IEA (International Energy Agency) (2015), World Energy Outlook 2015, www.worldenergyoutlook.org/weo2015, OECD/IEA, Paris.

IEA (International Energy Agency) (2015b), Southeast Asia World Energy Outlook 2015:World Energy Outlook Special Report, OECD/IEA, Paris.

IEA (International Energy Agency) (2016), Ready for CCS Retrofit: The Potential for Equipping China's Existing Coal Fleet with Carbon Capture and Storage, OECD/IEA, Paris, www.iea.org/publications/insights/insightpublications/ThePotentialforEquippingChinasExistingCoalFleetwithCarbonCaptureandStorage.pdf.

IEA GHG (IEA Greenhouse Gas Programme) (05 Jul 2016), Study Report on CCS Options in Norway, IEA GHG Information Paper 2016-IP19, London.

Illinois (2009), Clean Coal Portfolio Standard of the Illinois Power Agency Act, State of Illinois Public Law, 20 ILCS 3855/1-75(d)(1).

Illinois (2011), Clean Coal FutureGen for Illinois Act of 2011, State of Illinois Public Law, 20 ILCS 1108/1.

India (01 October 2015), Intended Nationally Determined Contribution, http://www4.unfccc.int/Submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf.

Ingelson, A., A. Kleffner, and N. Nielson (2010), "Long-term liability for carbon capture and storage in Depleted North American Oil and Gas Reservoirs – A Comparative Analysis", Energy Law Journal, vol. 31, www.felj.org/sites/default/files/docs/elj312/20_431_ccs_liability.pdf.

IPCC (Intergovernmental Panel on Climate Change) (2014), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Edenhofer, O., R. PBichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K., Seyboth, A. Adler, I. aum, S. Brunner, P. Eickemeier, *B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

Krey, V., G. Luderer, L. Clarke, and E. Kriegler (2014), "Getting from here to there – energy technology transformation pathways in the EMF27 scenarios", Climatic Change, 123:369-382. doi: 10.1007/s10584-013-0947-5.

MCA (Minerals Council Australia) (2016), Coal21 website, www.minerals.org.au/resources/coal21/low_emissions_projects/strategic_overview (accessed 30 0ctober 2016).

Mississippi Power (September 2016), website, www.flickr.com/photos/mississippipower/30299590575/in/album-72157673976709900.

MIT (February 2016), Carbon Capture and Sequestration Technologies Program website, www.sequestration.mit.edu/tools/projects/ordos.html (accessed 30 0ctober 2016).

MPS (Modern Power Systems) (2016), "RWE International – Power Plant Engineering and Consulting", www.modernpowersystems.com/contractors/consultants-and-engineers/rwe-power-international/rwe-power-international3.html (accessed 30 October 2016).

NCC (National Coal Council) (November 2015), Leveling the Playing Field: Policy Parity for Carbon Capture and Storage Technologies, www.nationalcoalcouncil.org/studies/2015/Leveling-the-Playing-Field-for-Low-Carbon-Coal-Fall-2015.pdf.

PEI (Power Engineering International) (June 2015) "Coal Plant Provides CO2 for Methanol Production", http://www.powerengineeringint.com/articles/2015/06/coal-plant-provides-co2-for-methanol-production.html.

Platts (2015), Platts UDI World Electric Power Plants Database. www.platts.com/products/world-electric-power-plants-database.

Purget, R., J. Shingledecker, D. Saha, M. Thangirala, G. Booras, J. Powers, C. Riley, and H. Hendrix (01 December 2015), Materials for Advanced Ultrasupercritical Steam Turbines, United States Office of Science and Technical Information, www.osti.gov/scitech/biblio/1243058.

Republic of Korea (30 June2015), Intended Nationally Determined Contribution, http://www4.unfccc.int/submissions/INDC/Published%20Documents/Republic%20of%20Korea/1/INDC%20Submission%20by%20the%20Republic%20of%20Korea%20on%20June%2030.pdf.

Ringrose, P.S., A..S. Mathieson, I.W. Wright, F. Selema, O. Hansen, R. Bissell, N. Saoula, and J. Midgley (2013), The In Salah CO2 storage project: lessons learned and knowledge transfer. Proceedings of the 11th International Conference on Greenhouse Gas Control Technologies, Elsevier Ltd., http://www.sciencedirect.com/science/article/pii/S1876610213007947.

SaskPower CCS (2016), website, www.saskpowerccs.com/ccs-projects/boundary-dam-carbon-capture-project (accessed 30 October 2016).

SACCS (South African Centre for Carbon Capture and Storage) (2016), SACCS website, www.sacccs.org.za/roadmap, (accessed 30 October 2016).

Shumin, M. W., (16 June 2015), "Shenhua Guohua's Application of Near-Zero Emissions Technologies for Coal-Fired Power Plants". Cornerstone, Wiley Periodicals Inc., Hoboken, New Jersey, www.cornerstonemag.net/shenhua-guohuas-application-of-near-zero-emissions-technologies-for-coal-fired-power-plants.

Spero, C., F. Montagner, L. Chapman, D. Ranie, and T. Yamada, (2014). Callide Oxyfuel Project – Lessons Learned, Queensland, Australia, https://hub.globalccsinstitute.com/sites/default/files/publications/157873/callide-oxyfuel-project-lessons-learned.pdf.

UN (United Nations) (1992), United Nations Framework Convention on Climate Change. United Nations, www.unfccc.int/essential_background/convention/items/6036.php.

UN (United Nations) (2015), The Paris Agreement. http://unfccc.int/paris_agreement/items/9485.php.

Viebahn, P. V. (15 March 2014), "Prospects of carbon capture and storage (CCS) in India's power sector – An integrated assessment", Applied Energy Volume 117, Pages 62

WCA (World Coal Association) (December 2014), A Global Platform for Accelerating Coal Efficiency, www.worldcoal.org/pace-concept-paper.

WCA (World Coal Association) (15 April 2015), Setting the Benchmark: The World's Most Efficieet Coal-Fired Power Plants, www.worldcoal.org/setting-benchmark-worlds-most-efficient-coal-fired-power-plants.

WCA (World Coal Association) (November 2015b). The Case for Coal: India's Energy Trilemma, www.worldcoal.org/file_validate.php?file=WCA%20report%20-%20India%27s%20Energy%20Trilemma.pdf.

Xiuzhang, W. (07 January 2014), "Shenhua Group's Carbon Capture and Storage Demonstration", Cornerstone, Wiley Periodicals Inc., Hoboken, New Jersey, www.cornerstonemag.net/shenhua-groups-carbon-capture-and-storage-demonstration.

Abbreviations, Acronyms, and Units of Measure

Abbreviations and acronyms

ADB	Asian Development Bank
ANLEC	Australian National Low-Emission Coal program
CAPEX	capital expenses
CCGT	combined cycle gas turbine
CCS	carbon capture (utilization) and storage
CCSA	Carbon Capture and Storage Association
CfD	contract for differences
CO_2	carbon dioxide
CSLF	Carbon Sequestration Leadership Forum
CTL	coal to liquids
DECC	(United Kingdom) Department of Energy and Climate Change
DOE	(United States) Department of Energy
DMF	(Thailand) Department of Minerals and Fuels
DST	(Indian) Department of Science and Technology
E3G	Third Generation Environmentalism
ECF	European Climate Foundation
ECRA	European Cement Research Academy
EOR	enhanced oil recovery
EPA	(United States) Environmental Protection Agency
EPC	engineering, procurement, and construction
EPRI	Electric Power Research Institute
FEED	front-end engineering and design
FID	final investment decision
FOAK	first-of-a-kind
GCCSI	Global Carbon Capture and Storage Institute
HELE	high efficiency, low-emission
HHV	higher heating value
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IGFC	integrated coal gasification fuel cell combined cycle
INDC	Independent Nationally Determined Commitment
IPCC	Intergovernmental Panel on Climate Change
KCCSA	Korean Carbon Capture and Storage Association
KCRC	Korea CCS R&D Center
KEPCO	Korea Electric Power Corporation
LHV	lower heating value
METI	(Japan) Ministry of Economy, Trade and Industry
MHPSE	Mitsubishi Power Systems Europe
MPP3	Maasvlakte power plant #3
MSIP	(Korea) Ministry of Science, ICT, and Future Planning
NDC	Nationally Determined Commitment
NDP	(South African) National Development Plan

NGC	National Grid Carbon
NGO	non-governmental organization
OCDO	(U.S. State of) Ohio Coal Development Office
OECD	Organization for Economic Cooperation and Development
OPEX	operating expense
PACE	Platform for Accelerating Coal Efficiency
PPA	power purchase agreement
QCCSRC	Qatar Carbonates and Carbon Storage Research Centre
R&D	research and development
ROAD	Rotterdam Opslag en Afvang Demonstratieproject
SACCCS	South African Center for CCS
UNFCC	United Nations Framework Convention on Climate Change
USC	ultra-supercritical
WEO	World Energy Outlook
ZEP	Zero-Emissions Platform

Units of measure

AUD	Australian Dollar
CDN	Canadian Dollar
EUR	Euro
GBP	British Pound
GW	gigawatt
HHV	higher heating value
kW	kilowatt
MMT	million tonnes
MWe	megawatt electric
MWh	megawatt hour
Mt	million tonnes
Mtpa	million tonnes per annum
USD	United States Dollar