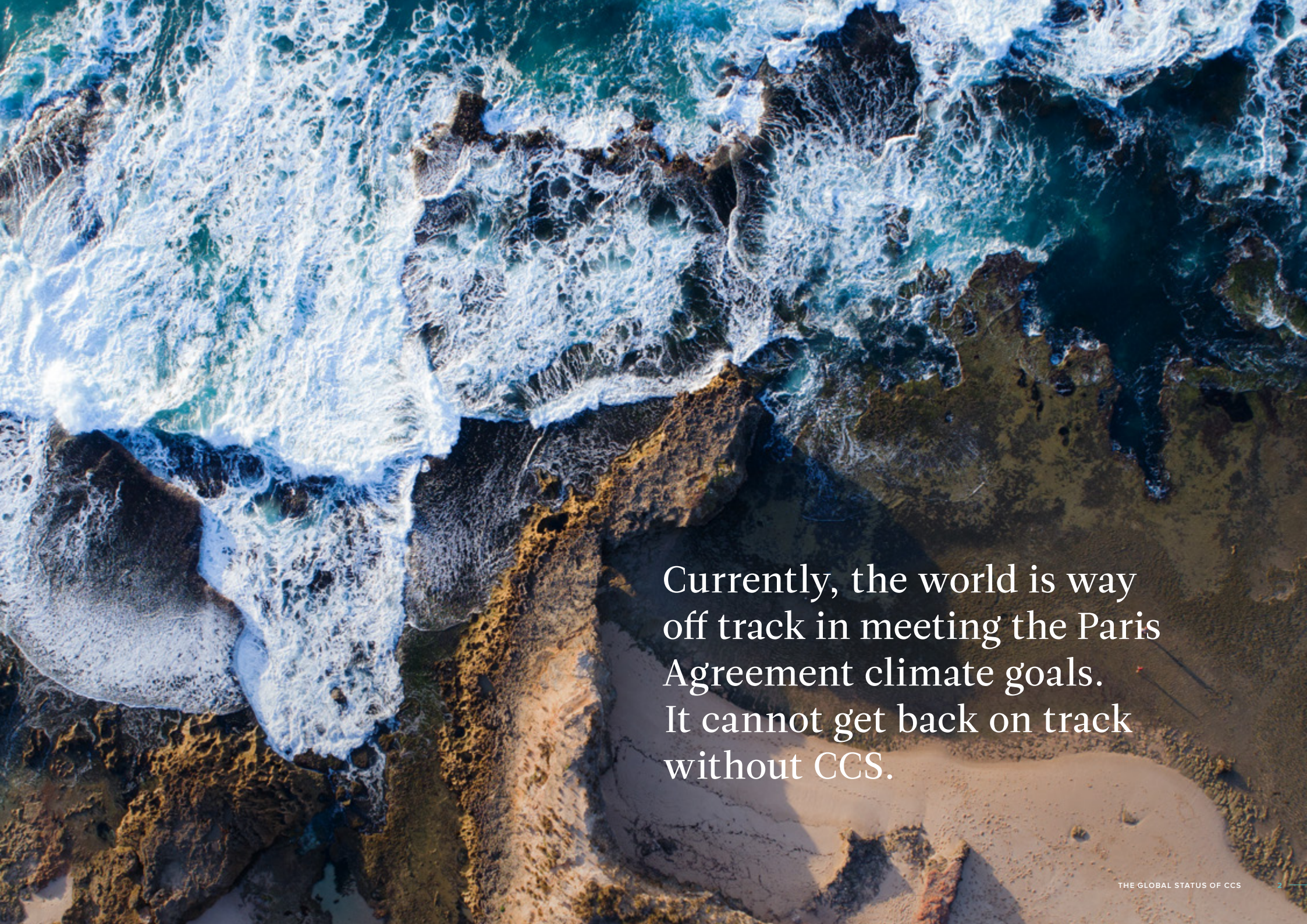


The Global Status of CCS

—— 2018



GLOBAL CCS
INSTITUTE

An aerial photograph showing the ocean's edge where white, frothy waves are crashing against dark, jagged rocks. The water is a deep blue-green, and the rocks are dark brown and black. The scene is dynamic and powerful, capturing the raw energy of the sea.

Currently, the world is way off track in meeting the Paris Agreement climate goals. It cannot get back on track without CCS.

About Us

The Global CCS Institute (the Institute) is the world's leading authority on carbon capture and storage (CCS) – an international climate change organisation whose mission is to accelerate the deployment of CCS as an imperative technology in tackling climate change and providing energy security.

The Institute drives this adoption by sharing expertise, building capacity and providing information, advice and advocacy to ensure this clean technology plays its rightful role in reducing greenhouse gas emissions.

The Institute's large and diverse international membership includes governments, global corporations, private companies, research bodies, academic institutions, and non-government organisations, all of whom are committed to CCS as an integral part of a clean energy future.

About this Report

The Global Status of CCS Report 2018 documents the status of CCS around the world and significant operational milestones over the past 12 months. It demystifies common misunderstandings about the technology and identifies where and how it can, and must, be more widely deployed. It also tracks the worldwide progress of CCS technologies and the key opportunities and challenges CCS faces.

With commentary from leaders and luminaries from across the climate change echelon, this report makes an indelible case for CCS as an indispensable climate change solution. It is an invaluable resource for governments, policymakers, scientists, academics, media commentators and the millions of people who care about our climate and want to take the heat out of our planet.

You can download the full report from the Institute's website at www.globalccsinstitute.com.

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An
IMPACTFUL
YEAR
across all fronts

Brad Page

CHIEF EXECUTIVE OFFICER *Global CCS Institute*

I think it is likely that when we look back in a few years, 2018 may well go down as the year when the stars started to again align for CCS. After the celebration of the Paris Agreement in 2015 turned to the hard work of delivery, it has become increasingly clear that the world will need all the technologies, mechanisms and approaches available to curb ever-increasing emissions. In this past year, and for the first time in quite a long time, we have seen decisive action from a number of governments to include CCS in their armoury.

CCS has proven itself real, happening and here to stay.

Significantly, the policy confidence we have sought for so long has started to materialise.

In the United States a bi-partisan law – the FUTURE Act – was enacted reinvigorating section 45Q tax credits for investment in Carbon Capture Utilisation and Storage (CCUS). This was a significant win for the stimulation of new CCUS projects across the United States and addressed the importance of introducing what is essentially a carbon value to drive investment in energy security and emissions reductions.

In the United Kingdom, Minister of State for Energy and Clean Growth, the Rt Hon Claire Perry, established a dedicated CCUS Council to examine ways of returning the UK to a CCS leadership position as a central plank of the Clean Growth Strategy. I have the honour of sitting on the Council and in a short time the Council and the related Cost Challenge Taskforce have clearly identified the huge clean growth opportunities available to the UK if full-scale industrial hub and cluster projects, which draw on the North Sea's vast storage capacity, are progressed.

In China, where no less than 30 different facilities advanced into various stages of development during the year, commitment to this technology is fast-growing as national, regional and municipal governments embrace CCS and make it part of their long term strategic plans.

Norway and the Netherlands, saw Governments recommit to CCS and project proponents are responding. The Norwegian government has committed to advance its large-scale full chain industry-based CCS development and the Port of Rotterdam CCS Backbone Initiative has embarked on the large-scale decarbonisation of refining, power and petrochemical clusters.

As coal as a fuel source grabs headlines and prompts hot debate, we need to remember that more than 200,000 MW of new coal-fired generation capacity is in construction around the world, none of which will close in a short period and all of which will add very significantly to the climate change challenge. CCS is the only technology that can truly decarbonise these facilities and remains a vital technology for addressing electricity sector emissions.

But the big message now is that CCS is the conduit to a new energy economy.

As a seminal video released this year by the International Brotherhood of Boilermakers powerfully makes the case, CCS is central to delivering well-paying jobs, reinvigorating regional communities and providing low-carbon materials and services. Further evidence of this is in the early development by a Japanese consortium partnering with Australian governments and industry to launch a pilot hydrogen supply chain project gasifying Latrobe Valley lignite. If successful, this is expected to lead to a commercial plant applying CCS to produce clean hydrogen. The benefits to the coal-rich Latrobe Valley region are enormous in terms of jobs, economic and technology development.

In 2018, more and more people started to recognise CCS for its cumulative capacity to mitigate climate change.

Our 2018 Status Report is populated with supporting comments from broad constituency who understand that tackling climate change and meeting Paris targets can only be achieved by embracing a complete cache of clean solutions of which CCS must be one.

For me, one of the most piercing comments comes from 17-year old Australian Polar explorer, Jade Hameister, who has seen the effects of climate change first hand. She says:

“Carbon capture and storage is one of the stand-out technologies that exists today that will form part of the solution, and one that must be pursued as if our lives depend on it – because they do.”

In the past year, countries have been incentivising investment, industry has accelerated deployment, new innovations have been unveiled, and new energy economies have emerged.

CCS has proven itself as real, happening and here to stay.

It has been an impactful year in every sense of the word.

BRAD PAGE

Chief Executive Officer

Polar EXPLORER



JADE, AGED 16, PULLING HER SLED OVER SASTRUGI ON THE WAY TO THE SOUTH POLE (DECEMBER 2017). CREDIT – ERIC PHILIPS/ICETREK.COM

AMBASSADOR ARTICLE

THE GLOBAL STATUS OF CCS



JADE, AGED 14, ON THE WAY TO THE NORTH POLE (MAY 2016). CREDIT – ERIC PHILIPS/ICETREK.COM

We still have a

FIGHTING CHANCE

Jade Hameister

YOUNGEST PERSON TO SKI TO THE NORTH POLE (AGE 14)

YOUNGEST WOMAN TO COMPLETE THE 550KM TRAVERSE OF THE GREENLAND ICECAP (AGE 15)

YOUNGEST PERSON TO SKI FROM COAST OF ANTARCTICA TO SOUTH POLE (AGE 16)

ONE OF ONLY THREE WOMEN IN HISTORY TO SKI A NEW ROUTE TO SOUTH POLE

All expeditions were unsupported and unassisted.

Carbon capture and storage is one of the stand-out technologies that exists today. It will form part of the solution, and must be pursued as if our lives depend on it – because they do.

A stand-out technology that must be pursued.

Having just turned 17, I am no expert on the science of global warming, but I am likely the only person on the planet of my generation to have had the privilege of first-hand experience in Earth's three main polar regions – skiing to the North Pole, the South Pole and crossing Greenland's icecap. Journeys that saw me cover a total of around 1,300 km in 80 days.

I was witness to the tragic damage global warming is doing to these incredibly beautiful and fragile environments.

I now feel a deep emotional connection with our planet Earth and a responsibility to play my part in addressing climate change before it's too late.

For the first time in the history of our species, we have one common threat against which we must all act as one.

My generation will inherit this great threat of global warming and the political decisions of today's leaders. Please give us a platform from which we can still achieve a positive outcome.

I am confident that my generation will have the technology, the passion and the unified movement to make a meaningful difference, but it's up to current world leaders to make sure we still have a fighting chance.

Urgent investment and support for the development of clean technologies is critical.

At a glance: the business case for CCS

1 Paris climate change targets cannot be reached without CCS.

Internationally recognised evidence by specialist climate change bodies concur that international climate change targets cannot be achieved without CCS.

International Energy Agency (IEA) findings maintain that to reach Paris climate targets of 2°C by 2060, 14 per cent of cumulative emission reductions must derive from CCS. In the transition between the 2°C scenario (2DS) to the beyond 2°C scenario (B2DS), this rises to 32 per cent.

Despite this, there are not nearly enough facilities coming onstream. To reach the Paris 2°C target, more than 2,500 facilities need to be operating by 2040 (based on a facility with capture capacity of 1.5 million tonnes per annum (Mtpa) of carbon dioxide (CO₂)).

2 CCS is the only clean technology capable of decarbonising major industry.

International climate change experts such as the Intergovernmental Panel on Climate Change (IPCC) and IEA confirm that CCS is the only mitigation technology able to decarbonise large industrial sectors, particularly the gigantic steel, cement, fertiliser and petrochemical industries.

3 CCS is the conduit to a new energy economy of hydrogen production, bioenergy with CCS (BECCS), direct air capture (DAC) and carbon to value (C2V), representing a raft of CO₂ reuse applications.

Hydrogen: Several CCS clean hydrogen initiatives are at the planning and feasibility stages in Europe – Hydrogen 2 Magnum (H2M) in the Netherlands, H21 North of England, Hynet North West, Ervia Cork CCS, HyDeploy in the UK. In Australia, the Hydrogen Energy Supply Chain is paving the way towards CCS enabled hydrogen production.

BECCS: Bioenergy with carbon capture and storage offers large-scale negative emissions (carbon removal) where CO₂ emissions are removed from the atmosphere through the application of CCS to the transformation of trees and crops into energy fuels. The CO₂ capture at Arkalon and Bonanza ethanol plants in Kansas, and CO₂ storage in enhanced oil recovery, as well as Illinois Industrial CCS are well-known BECCS operations in the US.

DAC: Direct air capture, whereby CO₂ is removed directly from the atmosphere through the use of capture technologies that bind or “stick” to CO₂, is operating successfully at Zurich-based Climeworks, Canada’s Carbon Engineering (CE), and Global Thermostat in the US.

C2V: CO₂ is being innovatively used to manufacture new C2V products, including fertiliser feedstock (SABIC in Saudi Arabia), soda ash (Carbon Clean Solutions in India), foams used in mattresses and upholstered furniture (Cavestro in Germany), bricks and cement (Australia’s Mineral Carbonation International), it is acid gas injection with subsequent CO₂ storage.

4 CCS creates jobs and sustains communities.

The clean energy revolution can create new employment and economic opportunities for entire communities through the provision of services including project management, engineering, finance, legal and environmental roles. It will also add value through the manufacture of CCS componentry (such as boilers and turbines), construction of new CCS facilities, low-carbon fuel supply chain and CO₂ infrastructure development, notably CO₂ pipelines and related transport facilities.

Early deployment of CCS, especially retrofits, avoids early retirement of productive assets, keeping people in employment.

5 There is abundant storage capacity to support widespread CCS development.

With abundant underground storage resources at our disposal, storage remains a practical and logical CO₂ mitigation solution. Most of the world’s key CO₂ storage locations have been well assessed, and almost every high-emitting nation has demonstrated substantial storage potential.

Detailed surveys have been undertaken in many countries, including the US, Canada, Australia, Japan, China, Norway and the UK, where potential storage sites are well defined and well documented.

6 CCS is cost effective and costs continue to decrease as more facilities commercialise.

CCS is often criticised as being high-cost compared to wind or solar because the comparison uses the levelised cost of electricity (LCOE) as its measure. This is an incomplete and inaccurate comparison, however, because it does not measure total cost of generation, which includes transmission, distribution, system reliability and resilience.

Another major influence of cost is the carbon-emitting industry to which it is being applied and where it is located (that is, whether it is near an underground storage site or if it is geographically stranded). Other CCS cost determinants are:

- the concentration of CO₂ in the gas stream from which CO₂ is being captured
- the distance to and quality of the storage reservoir
- the cost of capital and labour in the location where the plant is being constructed.

Importantly, CCS costs are following the simple law of economics and continue to decline.

7 CCS has been working safely and effectively for 45 years. There are now 18 large-scale facilities in commercial operation around the world.

Monitoring undertaken since the Val Verde CCS facility began operating in Texas in 1972 demonstrates that CO₂ can be safely stored deep below ground. Oil, gas and naturally occurring CO₂ reservoirs have proven that fluids can be safely sealed underground for millions of years. CCS projects target the same kinds of geological structures.

The world's 18 large-scale facilities are already capturing almost 40 Mtpa of CO₂, and a total of over 230 Mt of CO₂ has been safely injected underground to date.

In China alone there are more than 20 CCS facilities at different scales in progressive development and myriad others in planning.

In Saudi Arabia and the UAE, CCS's application to industry is being embraced by a number of industrial facilities, and in the Netherlands, Norway and the UK, CCS "hub and cluster" developments are progressing.

8 CCS is the only technology capable of effectively eliminating fossil fuel emissions.

CCS is a pragmatic technology with wide application enabling it to reconcile our current fossil fuel dependence. This is the only technology able to curtail emissions from the more than 500 new coal plants currently being built around the world (and the additional 1,000 in planning).

CCS's ability to retrofit keeps jobs and economies alive as the world transitions to a low-carbon future.

9 CCS complements renewables, striding towards a wholly decarbonised future.

CCS and renewables are partner technologies working towards the same decarbonised objective.

10 Policy confidence is needed to sustain investment in CCS.

CCS requires clear timeframes, and an understanding of how carbon values change over time. It also requires clarity regarding eligibility (who can access it).

Specific policy confidence apparatus/mechanisms are:

- economy-wide market reduction targets, including nationally determined contributions (NDCs)
- CCS-specific legal and regulatory regimes that address all aspects of the project lifecycle
- removal of CCS barriers such as those remaining in the implementation of amendments to the London Protocol
- introduction of a carbon value in countries where none exists (for example, Norway's carbon tax, and the recently enhanced US 45Q legislation)
- policy predictability that ensures large capital investment and long gestation/asset life of CCS facilities are not jeopardised by overt changes in political direction
- transparent public engagement, which continues to build support across all stakeholder echelons
- robust research and development support.

IPCC: 1.5°C – CCS is essential

In October 2018, the Intergovernmental Panel on Climate Change (IPCC) released its highly anticipated Special Report on Global Warming of 1.5 °C (SR15), reinforcing the role carbon capture and storage technology must play in beating climate change.

This report was a response to a request by the UNFCCC at COP21 in Paris (2015) which called for a comprehensive assessment of what was needed to reach a 1.5°C world.

The 195 signatories to Paris agreed to keep global temperatures from rising “well below 2°C and to try and limit increases to less than 1.5°C.”

Compiled by 91 authors and drawing on 6,000 research references including those of the Global CCS Institute, the report found that reaching 1.5 °C would require “rapid and far-reaching” transitions in land, energy, industry, buildings, transport, and cities.

As report author, Professor Jim Skea of Imperial College, London, noted: “Limiting warming to 1.5°C is possible within the laws of chemistry and physics but doing so would require unprecedented changes.”

The report said that global net human-caused emissions of carbon dioxide (CO₂) would need to fall by about 45 percent from 2010 levels by 2030, reaching ‘net zero’ around 2050.

Significantly for CCS, it made the point that any remaining emissions would need to be balanced by removing CO₂ from the air. CCS was acknowledged in three of all four pathways IPCC authors used to reach 1.5°C and was singled out for its ability to: “play a major role in decarbonising the industry sector in the context of 1.5°C and 2°C pathways, especially in industries with higher process emissions, such as cement, iron and steel industries.”

Over the past year, the Institute has been vociferous in underscoring that CCS is the only clean technology that can decarbonise major industry – sectors that cannot be turned off “at the flick of a switch”. For some industries, like cement and steel, there is simply nothing else.

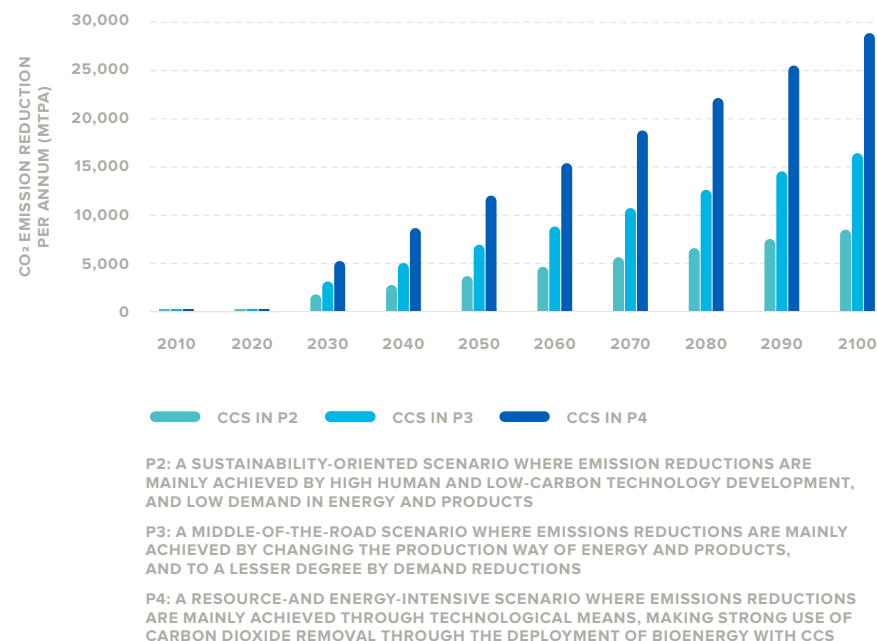
The report also identified the challenges that CCS faces in terms of institutional and economic constraints, particularly the reliance on investment and climate policy incentives.

This will continue to be a major area of focus as the Institute continues to raise awareness and support for CCS as a requisite climate change technology.

As Professor Skea has very sagely said: The linking word in the latest IPCC report is “and” not “or”.

It is time to embrace every option and CCS must be one.

FIGURE 1: CCS contribution in CO₂ emission reduction in IPCC Special Report on Global Warming of 1.5°C. Data analysis based on the Global CCS Institute CO₂RE database¹ and IPCC Special Report on Global Warming of 1.5°C².





A KEY YEAR FOR ACTION AND UNDERSTANDING ON CCS

Lord Nicholas Stern

IG PATEL PROFESSOR OF ECONOMICS & GOVERNMENT *London School of Economics*. CHAIR, *Grantham Research Institute*

The last 12 months have been particularly refreshing in the world of CCS.

There has been a noticeable surge in inclination and activity with policy-friendly CCS legislation introduced in the United States (45Q), China (an ETS) to new levels of political action undertaken in the UK (the Rt Hon Claire Perry's CCUS Cost Challenge Task Force), Norway (ACT – Accelerating CCS Technologies), and the Netherlands (CCS Road-map).

The IPCC 1.5°C report published in October this year was an important advance in our understanding: it showed that the difference in damages from climate change between 1.5°C and 2°C was of real and worrying substance. Thus the importance of going to zero net-emissions within four decades for the Paris target of “well-below 2°C” has been still more strongly underscored (and earlier for 1.5°C).

More and more, people are seeing the practicality and importance in deploying the one technology proven to decarbonise “difficult” sectors such as cement and steel and “locked-in” fossil fuel-based infrastructure.

Another refreshing development has been the capacity for the private sector, mayors, multinationals, even the media, to start putting their weight behind the technology.

The concept of industrial CCS hubs and clusters is taking rapid shape in North Western Europe and this is undoubtedly due to a growing group of leaders who can see the environmental and economic opportunity that CCS brings. Industry is closely situated, storage resources are abundant, employment is assured, the business case is obvious.

In the 2017 Global Status of CCS Report, I said that it was time to coalesce around CCS – governments, policy makers, the private sector. This year, the process has begun and the IPCC 1.5°C report has underscored its importance.

The challenge now is to maintain the momentum, keep the funding pipeline flowing, demonstrate how costs can be reduced and accelerate the train that can deliver on Paris.

Highlights — *for 2018*

New initiatives

New initiatives in CO₂ recycling and major new direct air capture (DAC) projects in the United States, Canada and Iceland.

43

Forty three (43) large-scale facilities – 18 in commercial operation, five under construction and 20 in various stages of development.

Climate ambitions

International recognition that we need CCS to meet the global climate ambitions of the Paris Agreement. The Intergovernmental Panel on Climate Change (IPCC) further reinforced this fact in its 2018 Special Report on Global Warming of 1.5 °C (SR15) by highlighting that we must get to net-zero emissions by 2050 and that it is crucial to deploy all clean technologies including CCS to meet this goal.

Diverse supporters

Endorsement of CCS by a diverse chorus of new supporters including explorers, economists, academics, religious leaders, unions, eNGOs, mayors, the media, movie-makers and the military. One of these is 17 year-old Australian polar explorer, Jade Hameister, a first-hand witness to the ravages of climate change.

Growth in CCS policy

A growth in CCS policy confidence across multiple country jurisdictions:

- the US: enactment of 45Q (tax credit) legislation
- the UK: creation of the UK CCUS Council, and the CCUS Cost Challenge Taskforce
- China: promotion of low-carbon technologies (especially CCUS), grant funding on CCS research, and the indexation of CCUS in amended Environmental Impact Guidance
- Japan: a commitment to establish a hydrogen society by 2030, and to create a Hydrogen Energy Supply Chain (HESC) in Australia.

CCS can...

Confirmation that CCS can generate new employment, new product streams (including BECCS, DAC and CO₂ re-use) and new economic revenues.

Wider appreciation

A wider appreciation that there are significant opportunities to deploy CCS in decarbonising the industrial sector, as well as improving its productivity and competitiveness.

CCS as a “catalyst”

Acknowledgement of CCS as a “catalyst” to new energy economies – particularly CCS with hydrogen. Further advancement of CCS/hydrogen facilities in Australia, the UK, the US, Norway, the Netherlands, Sweden, Canada and Japan.

No technical barriers

Acceptance that “at least a thousand years” of global CO₂ storage resources exist with no technical barriers to secure and permanent storage.

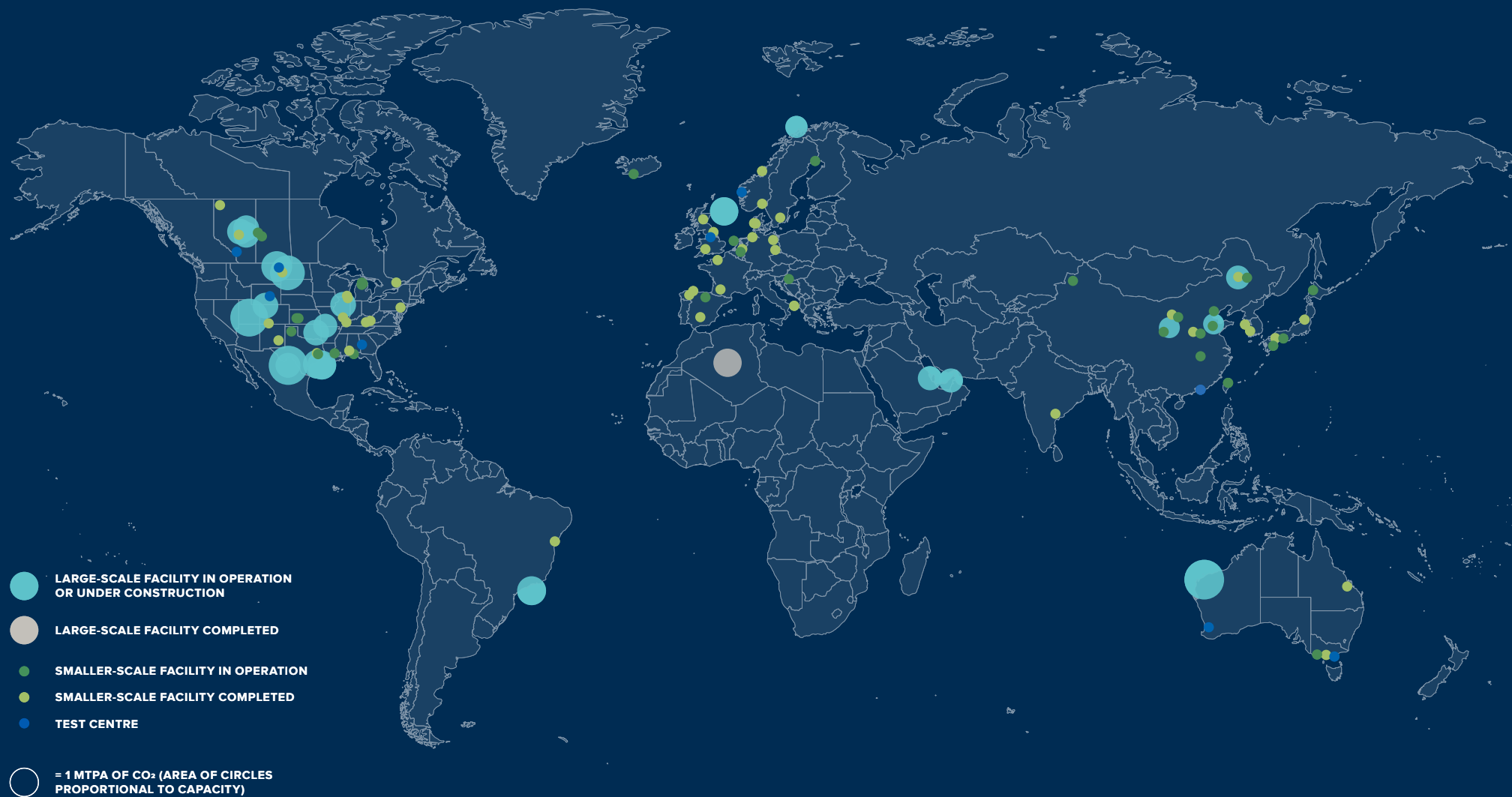
Overview

2018

The history of CCS goes back more than 45 years. Since the first large-scale CCS facility, Val Verde CO₂-EOR, began operating in the Sharon Ridge oilfield in Texas in 1972, 98 CCS facilities and nine test centres have started up or begun construction (see Figure 2).

Today, according to the Global CCS Institute CO₂RE database¹, there are 23 large-scale CCS facilities in operation or under construction, capturing almost 40 Mtpa of CO₂. A further 28 pilot and demonstration-scale facilities are in operation or under construction. Collectively, these capture more than 3 Mtpa of CO₂.

FIGURE 2: Current commercial large-scale CCS facilities, smaller-scale (pilot and demonstration) CCS facilities and CCS test centres around the world. The sizes of light blue and grey circles are proportional to the CO₂ capture capacities of the commercial large-scale facilities in operation or under construction and in completion, respectively. Data is drawn from the Global CCS Institute CO₂RE database as of October 2018¹.



In December 2017, Petrobras reached a milestone of 7 Mt CO₂ captured and re-injected into the subsurface using floating production storage and offloading (FPSO) units since operation in 2013. An annual CO₂ injection of 2.5 Mtpa was achieved in 2017.



Efforts and milestones in developing a portfolio of CCS facilities

1972 to 1990

Early operation of large-scale CCS facilities began in the US during the 1970s and 1980s (summarised in Figures 3 and 4). The driver for this deployment was enhanced oil recovery (EOR), where CO₂ was injected into oil reserves to facilitate increased oil extraction; the CO₂ ultimately being permanently stored in the pore space that previously held the oil. Historically, these CCS facilities used processes in which CO₂ was routinely separated in a high purity form, notably in natural gas processing e.g. Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants) and Shute Creek Gas Processing Plant and fertiliser production (Enid Fertilizer).

1990 to 2009

From 1990, government regulations and incentives provided impetus for large-scale global CCS facilities to emerge. At the same time, wider geological storage solutions were identified.

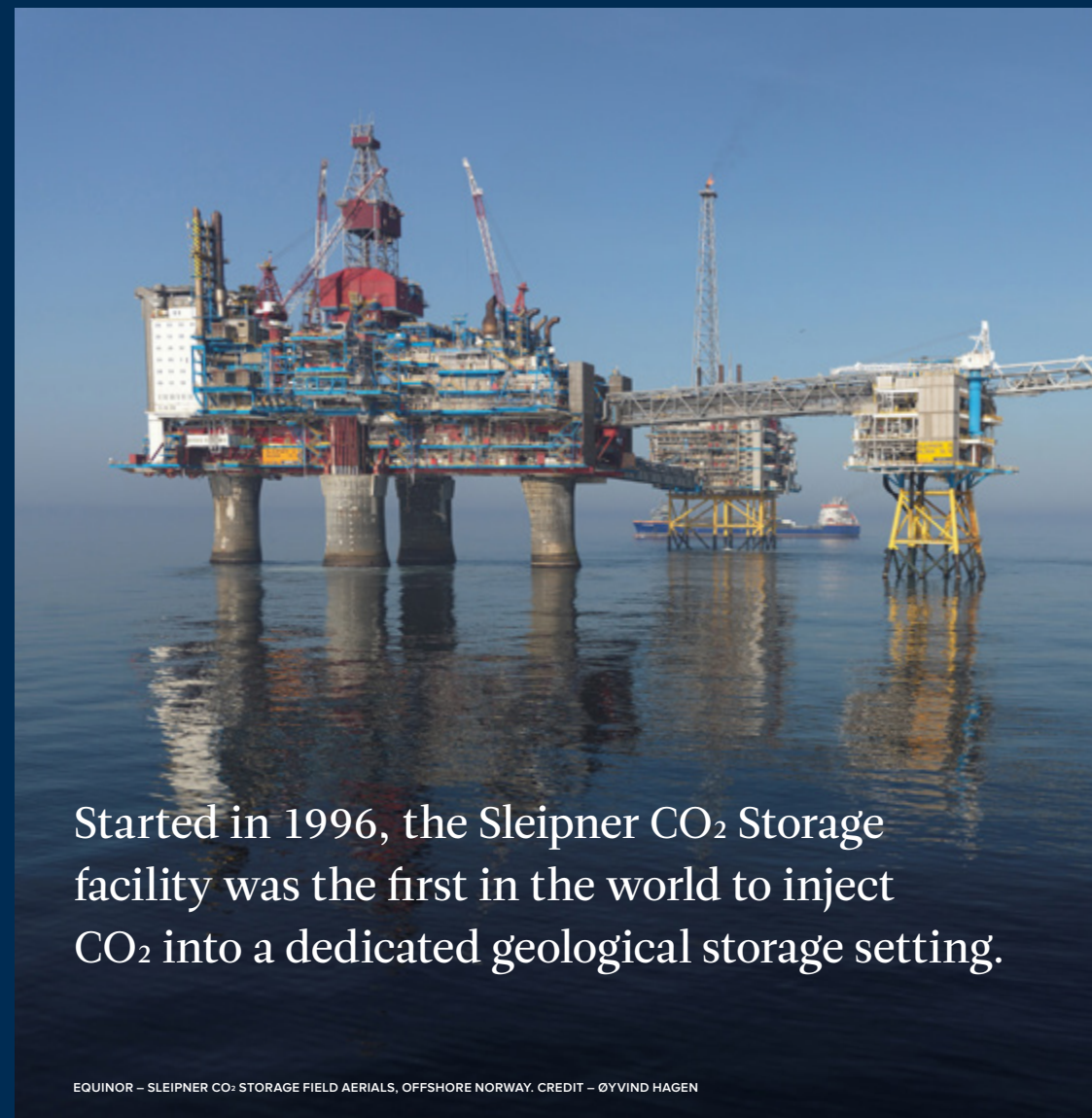
In 1991, the Norwegian Government implemented a CO₂ tax on offshore petroleum production³. This tax incentivised Statoil (now Equinor) to capture and store CO₂ in a deep geological formation at the Sleipner CCS facility, making it the world's first commercial manifestation of CCS technology for dedicated geological storage in a deep saline reservoir.

In 2005, *Norway's Greenhouse Gas Emission Trading Act* came into effect. In 2008, the country joined the European Union Emissions Trading System (ETS), which used a series of regulations and incentives to promote sustainable energy

production. Also in 2008, the Norwegian State mandated CCS as a condition of the license to operate for Snøhvit LNG production. Injection of CO₂ at the Snøhvit gas field development area started in April 2008. To date, Sleipner and Snøhvit have cumulatively stored more than 20 Mt of CO₂⁴. Based on the US EPA calculator, that's the equivalent of taking 4,282,655 cars off the road for one year.

In Canada, the Weyburn and Midale Oil Units in Saskatchewan have been injecting CO₂ for EOR since 2000 and 2005, respectively. Three Mtpa of CO₂ is captured and transported from Great Plains Synfuels plant, the first commercial-scale coal gasification plant (lignite as fuel) in the US.

In Algeria, corporate commitment to minimising environmental impact, manifested itself in measures such as non-atmospheric disposal of CO₂ produced in natural gas processing, fostered the operation of the In Salah CO₂ storage facility between 2004 and 2010. During that time the facility captured and injected almost 4 Mt of CO₂ into the Krechba formation – a depleted gas reservoir. The In Salah CO₂ Assurance Joint Industry Project⁵ was then established for a further five years to monitor the CO₂ storage process using a variety of geochemical, geophysical and production techniques. These techniques are among the world's most pioneering CO₂ storage and monitoring efforts, helping to inform modern monitoring, modelling and verification practices.



Started in 1996, the Sleipner CO₂ Storage facility was the first in the world to inject CO₂ into a dedicated geological storage setting.

EQUINOR – SLEIPNER CO₂ STORAGE FIELD AERIALS, OFFSHORE NORWAY. CREDIT – ØYVIND HAGEN

Efforts and milestones in developing a portfolio of CCS facilities

Post-2009

After 2009, the expectations and ambitions of CCS as a significant climate change mitigation technology advanced significantly and more facilities came onstream. The portfolio of CCS facilities now includes applications in coal-fired power, iron and steel manufacture, chemical and hydrogen production as well as bioenergy with CCS (BECCS).

In 2014, Canada unveiled the first large-scale CCS facility in power generation when Boundary Dam Unit 3 in Saskatchewan began operations. Prompted by federal regulations on CO₂ emissions from coal-fired power stations, this facility exceeded 2 Mt of CO₂ safely and successfully captured in March 2018⁶. Furthermore, SaskPower, the facility operator, claimed a cost reduction of 20–30 per cent for the next facility to be deployed.

In 2015, emission reduction incentives and financial support from the Provincial Government of Alberta and the Canadian Federal Government allowed the Shell-owned Quest facility to begin operations. Since then, Shell has achieved safe and secure storage of 3 Mt of CO₂, ahead of schedule⁷.

Since 2015, one CCS facility has been operating in South America – Brazil's Petrobras Santos Basin CO₂-EOR. In December 2017, Petrobras reached a milestone of 7 Mt of CO₂ captured and reinjected. An annual CO₂ injection of 2.5 Mt was achieved by 10 floating production storage and offloading units – seven at the Lula field, two at the Sapinhoa field and one at the Lapa field.

In July 2015, the commercial-scale Uthmaniyah CO₂-EOR demonstration facility in Saudi Arabia began operating. The CO₂-EOR facility has a

comprehensive monitoring and surveillance plan, including routine and advanced logging and use of new technologies for plume tracking and CO₂ saturation modelling. This facility compresses and dehydrates 0.8 Mtpa of CO₂ produced from a natural gas processing plant, which is then transported for EOR to the Uthmaniyah production unit, part of the giant Ghawar field (the largest oilfield in the world).

Abu Dhabi CCS is the first fully commercial large-scale CCS facility in the iron and steel industry. Commenced in November 2016, the facility processes the high purity CO₂ produced as a by-product of the direct reduced iron-making process at a capture capacity of 0.8 Mtpa at the Emirates Steel Industries factory in Mussafah, United Arab Emirates. The captured CO₂ is transported via pipeline to Abu Dhabi National Oil Company (ADNOC) oil reservoirs for EOR.

In the US, five of the six large-scale facilities commenced operations after 2009, and use EOR as their CO₂ storage mechanism:

- Century Plant (8.4 Mtpa, natural gas processing)
- Air Products Steam Methane Reformer (1.0 Mtpa, hydrogen production)
- Coffeyville Gasification Plant (1.0 Mtpa, fertiliser production)
- Lost Cabin Gas Plant (0.9 Mtpa, natural gas processing)
- Petra Nova Carbon Capture (1.4 Mtpa, power generation).

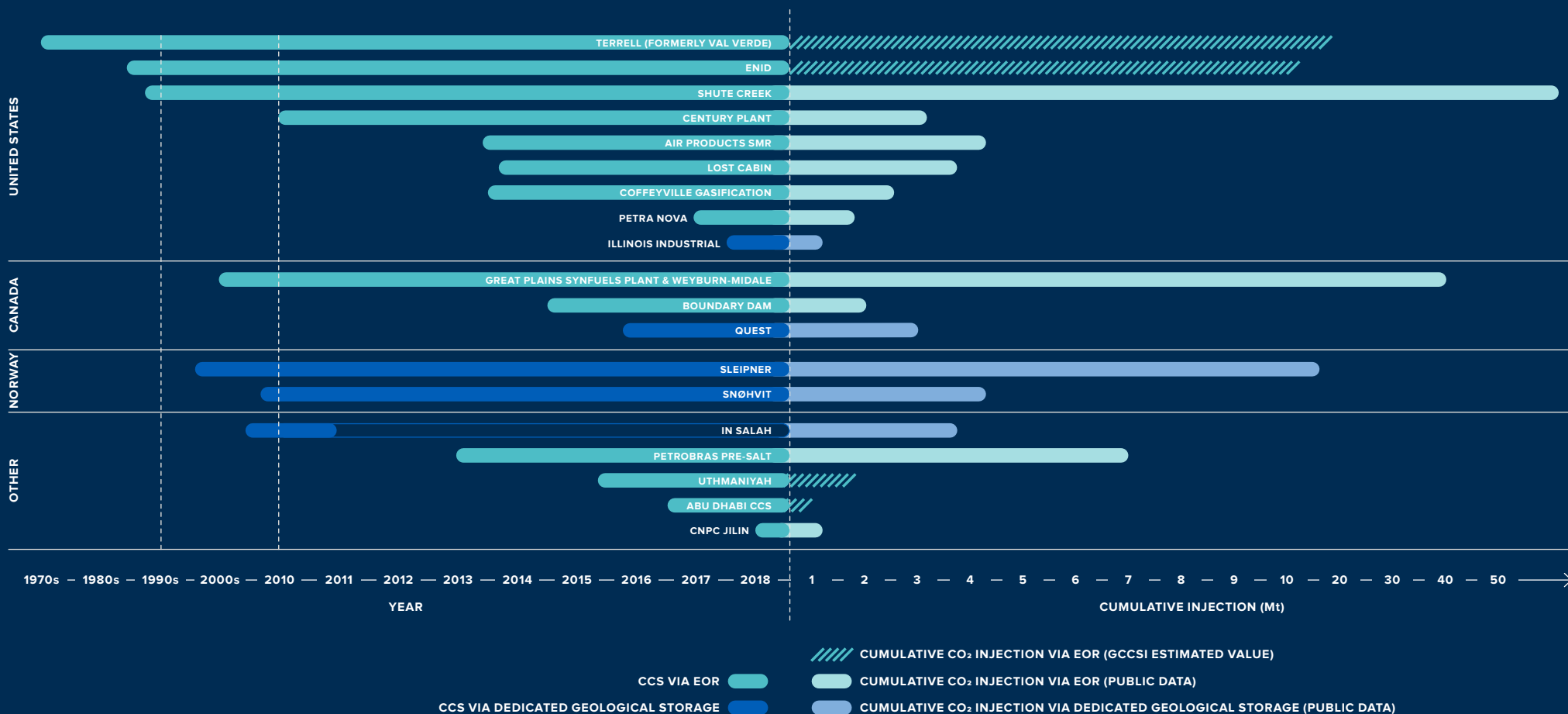
Only Illinois Industrial CCS facility, which commenced in April 2017, captures and stores CO₂ for dedicated storage (1.0 Mtpa, BECCS).

Petra Nova CO₂ Capture Facility recorded a milestone of 2.0 Mt of CO₂ captured in September 2018.



PETRA NOVA CARBON CAPTURE, TEXAS THE UNITED STATES. CREDIT – NRG ENERGY

FIGURE 3: Timelines and projects milestones of commercial large-scale CCS facilities in operation

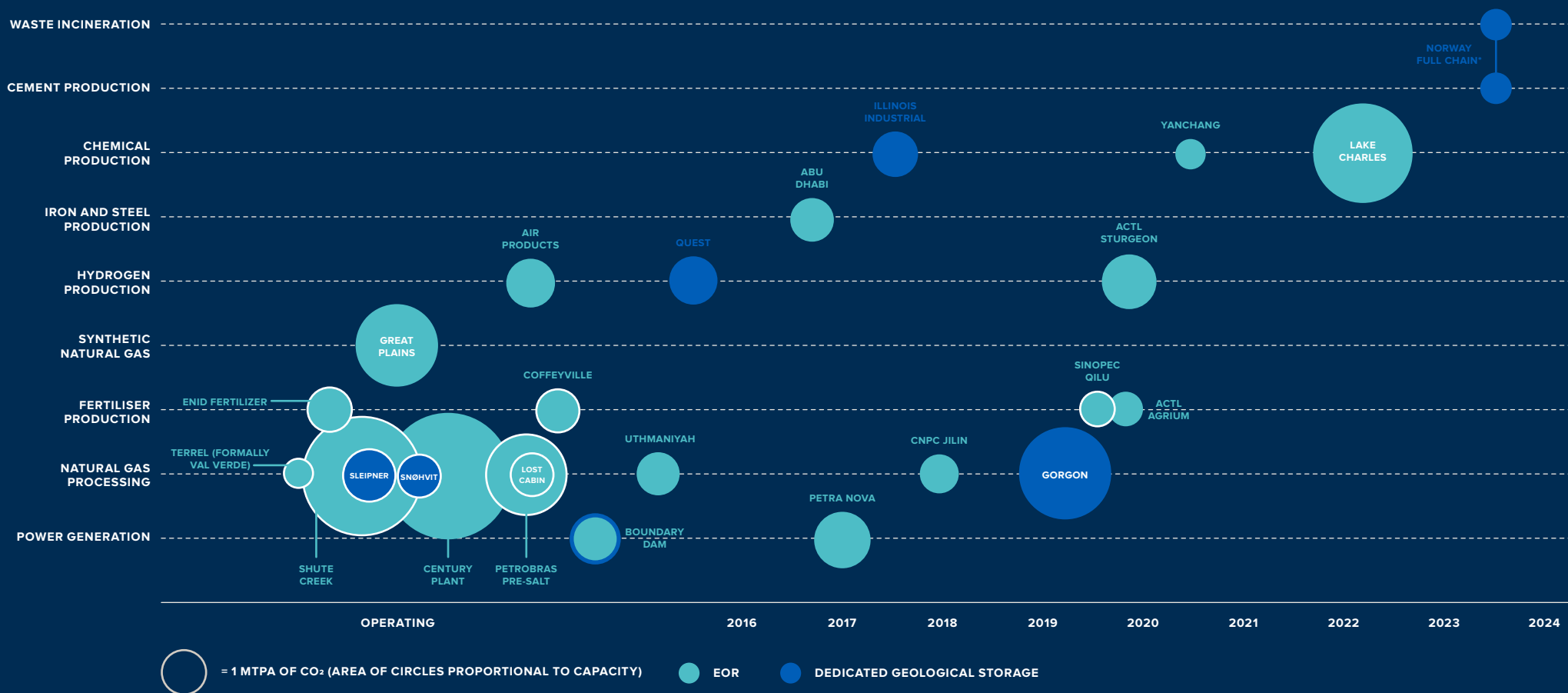


This year, these large-scale CCS facilities publicly announced a number of significant milestones, as seen above.

In 2018, China's CNPC Jilin Oilfield CO₂-EOR facility entered Phase III, reaching an injection capacity of 0.6 Mtpa. Jilin became the first large-scale CCS project operating in China and the world's 18th large-scale global facility.

The project began research and development (Phase I) in 1990 and pilot and demonstration tests (Phase II) in 2008, reaching 1.12 Mt of cumulative injection in 2017¹.

FIGURE 4: Power and industrial applications of commercial large-scale CCS facilities with actual and expected operation dates up to 2024



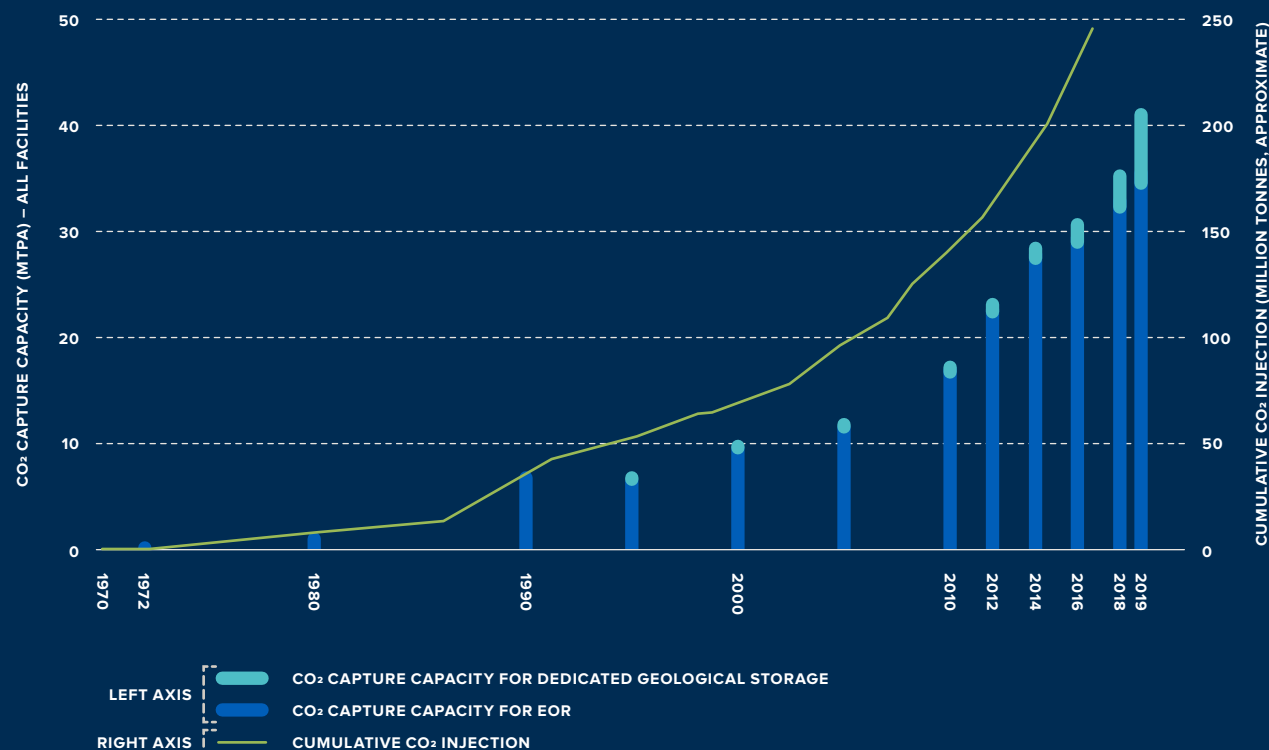
CCS is already in use across a variety of power and industrial applications, and has been for decades.

Smaller-scale CCS facilities

There have also been significant advancements in CCS deployment at key smaller-scale CCS facilities:

- **The US:** The Borger (fertiliser) and Arkalon (ethanol) CO₂ Compression facilities (both completed), operated by Chaparral Energy, have supplied more than 4 Mt of CO₂ for EOR during their operational lifetime. In Michigan, Core Energy CO₂-EOR facility (natural gas processing) has been operational since 2003. At the end of 2016, the facility had injected over 2 Mt of CO₂⁴.
 - **Canada:** CO₂ Solution's Valorisation Carbone Quebec (VCQ) is developing and demonstrating commercially viable technologies to capture and utilise CO₂ in various applications while reducing greenhouse gas emissions.
 - **Europe:** A CCS test centre, Technology Centre Mongstad (Norway), has been verifying and demonstrating CO₂ capture technology owned and marketed by vendors. This aims to reduce cost, as well as technical, environmental and financial risks in order to encourage the development of a market for carbon capture technology.
 - **China:** Several smaller-scale facilities are collectively capturing close to 1 Mtpa of CO₂, and have included several path-finding facilities in the power sector and in CO₂ storage applications.
- Among them, Shenhua Group's (now CHN Energy) Ordos CCS Demonstration facility has injected approximately 300,000 tonnes of CO₂ in the period 2011–2014. This was one of the largest demonstration-scale CCS facilities in the world to have injected CO₂ into a dedicated geological storage reservoir. This facility is a pioneer in CO₂ injection evaluation.
- **Japan:** Since 2016, the Tomakomai CCS Demonstration facility has injected more than 200,000 tonnes of CO₂ into offshore storage sites. CO₂ is captured from a hydrogen production unit at Tomakomai's refinery in southern Hokkaido that is demonstrating how a full-cycle CCS system can operate. Japan is also testing advanced capture technologies in the power sector at Toshiba's Mikawa plant and at the new Osaki CoolGen integrated gasification combined cycle (IGCC) system, both near Hiroshima. Additionally, Toshiba has developed a state-of-the-art CO₂ capture plant at Saga City (near Fukuoka), where CO₂ is being used to develop algae for the production of cosmetics.

FIGURE 5: Annual CO₂ capture capacity and cumulative CO₂ injection for all full-chain CCS facilities.
Analysis based on data from Global CCS Institute CO₂RE database.



CO₂ has been injected, mainly for EOR operations (illustrated in Figure 6). Canada has injected over 40 Mt of CO₂, and Norway has injected over 20 Mt, exclusively for offshore-dedicated geological storage. Other countries have a combined contribution of more than 15 Mt of CO₂ injected deep underground for EOR and dedicated geological storage.

Commercial CCS facilities in development

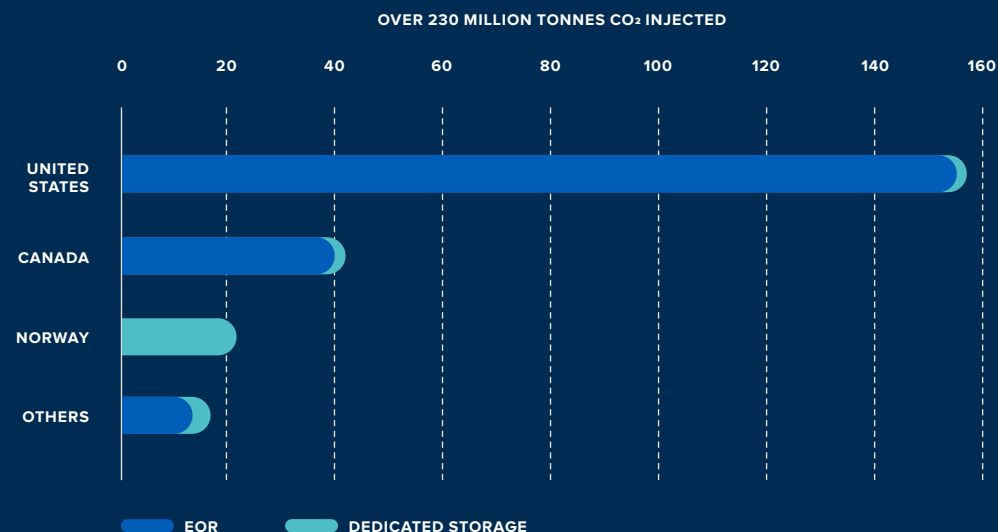
Five commercial large-scale CCS facilities are currently under construction, with four expected to be operational in 2019 and one in 2020:

- **Australia:** Commissioning of the Gorgon CCS facility is underway, with ramp up to full operation expected in 2019. This facility can inject 3.4–4 Mtpa of CO₂ deep in the subsurface beneath Barrow island (offshore Western Australia). Once operational, it will be the largest geological storage facility in the world.
- **Canada:** The 240-kilometre Alberta Carbon Trunk Line (ACTL) is moving into construction phase, with all funding and government approvals in place. ACTL will become the backbone for creating a new decarbonised industry in Alberta. The initial capture facilities near Redwater – the Sturgeon refinery and the Agrium fertiliser plant – will together supply around 1.5 Mtpa of CO₂ for EOR operations.
- **China:** Sinopec Qilu Petrochemical CCS facility started retrofitting a 0.4 Mtpa of CO₂ capture unit to the existing coal/coke water slurry gasification unit at a fertiliser plant. Operational in 2019, captured CO₂ will be transported by pipeline to the Shengli Oilfield for EOR. Additionally, the Yanchang CCS facility in Shaanxi Province has advanced its development of CO₂ capture units at two coal-to-chemicals plants. The 0.05 Mtpa unit has been in operation since 2012, while the larger 0.36 Mtpa capture unit is expected to be operational by 2020. Captured CO₂ would be used for EOR in oilfields in the Ordos Basin in central China. In China, a further 20 CCS facilities are in advanced and early development planning, signalling a new wave of global CCS facilities that will come online through the 2020s.

In China, a further 20 CCS facilities at various scales are in advanced and early development planning, signalling a new wave of global CCS facilities that will come online through the 2020s.

- **Asia Pacific:** The Asia Pacific (APAC) region has become one of the most active CCS regions in the world, with 10 large-scale facilities in development, equally split between power and industrial applications. China accounts for the majority of these, with Japan, South Korea and Australia also moving various CCS developments forward.
- **Europe:** CCS has enjoyed a revival in Europe, where its prowess as an industrial mitigation technology has been widely recognised. Eight large-scale CCS facilities are now in development. This CCS rejuvenation is being largely led by the UK, Norway and the Netherlands, where industrial clusters around North Sea storage options provide an

FIGURE 6: Cumulative CO₂ injection in major countries, approximate. Others include Algeria, Brazil, China, Saudi Arabia, UAE, Australia, Germany, France

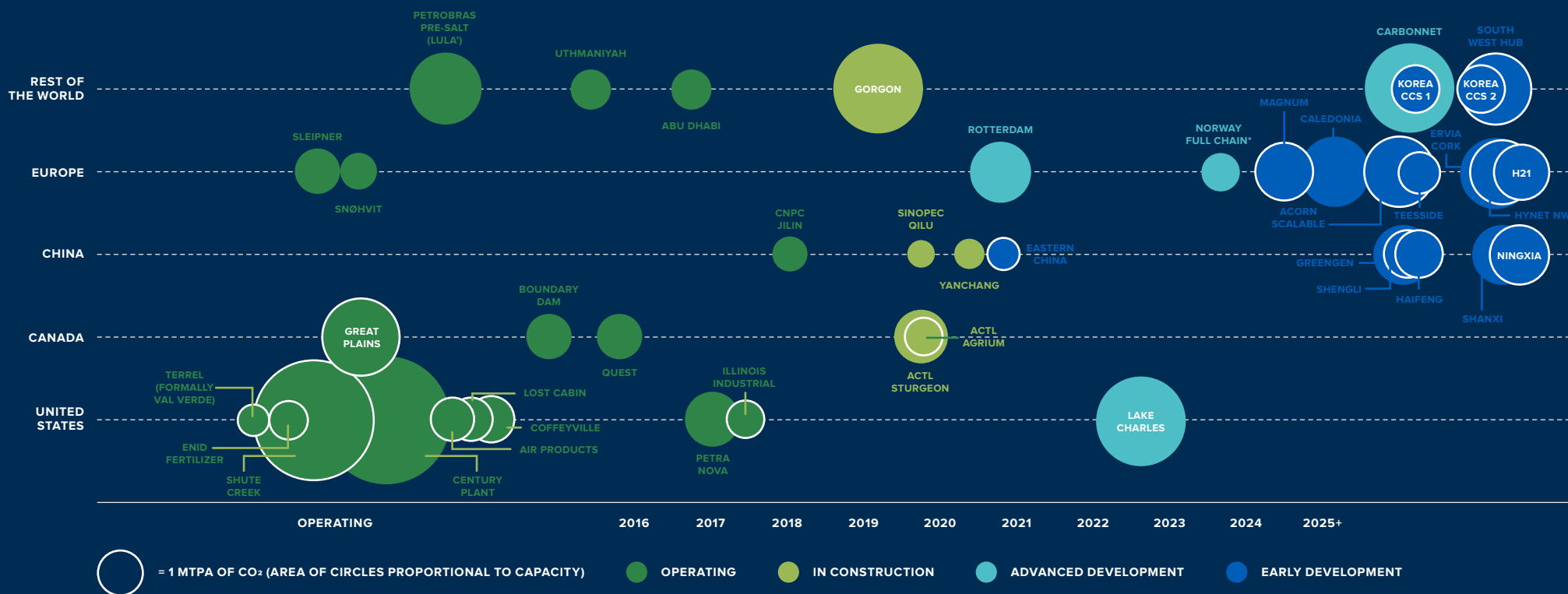


opportunity to significantly reduce the unit cost of CO₂ storage. This move is supported by EU after initiatives, Projects of Common Interests being one of them. Emerging CCS facilities include:

- Port of Rotterdam CCUS Backbone Initiative (a modular CO₂ transport hub)
- Teesside Collective (a CCS industrial hub)
- Caledonia Clean Energy (a pioneer for CO₂ hub)
- Acorn Scalable CCS Development
- HyNet North West Project (decarbonised hydrogen)
- H21 North of England Project (decarbonised hydrogen).

- In **Norway**, feasibility funding budgets have been confirmed for the Norway Full Chain CCS facility, which has identified two capture facilities and will entail transport and storage in the offshore Smeaheia area, with an expected CO₂ storage capacity of up to 100 Mt.
- In the **US**, the stronghold of global CCS deployment to date, development activities have slowed, with one facility (Lake Charles) in advanced development. This slowdown is expected to be temporary, however, with the advent of 45Q legislation (details in Policy section of this report), which has amended the US tax code in favour of CCS investment.

FIGURE 7: Pipeline of commercial large-scale CCS facilities in different countries and regions. At October 2018, there are 43 commercial large-scale global CCS facilities, 18 in operation, five in construction and 20 in various stages of development



There are now 43 commercial large-scale global CCS facilities, 18 in operation, five in construction and 20 in various stages of development.

The next wave

There are now 43 commercial large-scale global CCS facilities, 18 in operation, 5 in construction and 20 in various stages of development.

The current resurgence in CCS deployment will create a new wave of CCS facilities in the 2020s. However, the current pipeline of large-scale CCS deployment does not come close to the CCS component needed to meet Paris Agreement climate goals.

The first-of-a-kind commercial CCS facilities addressed in this report have already been

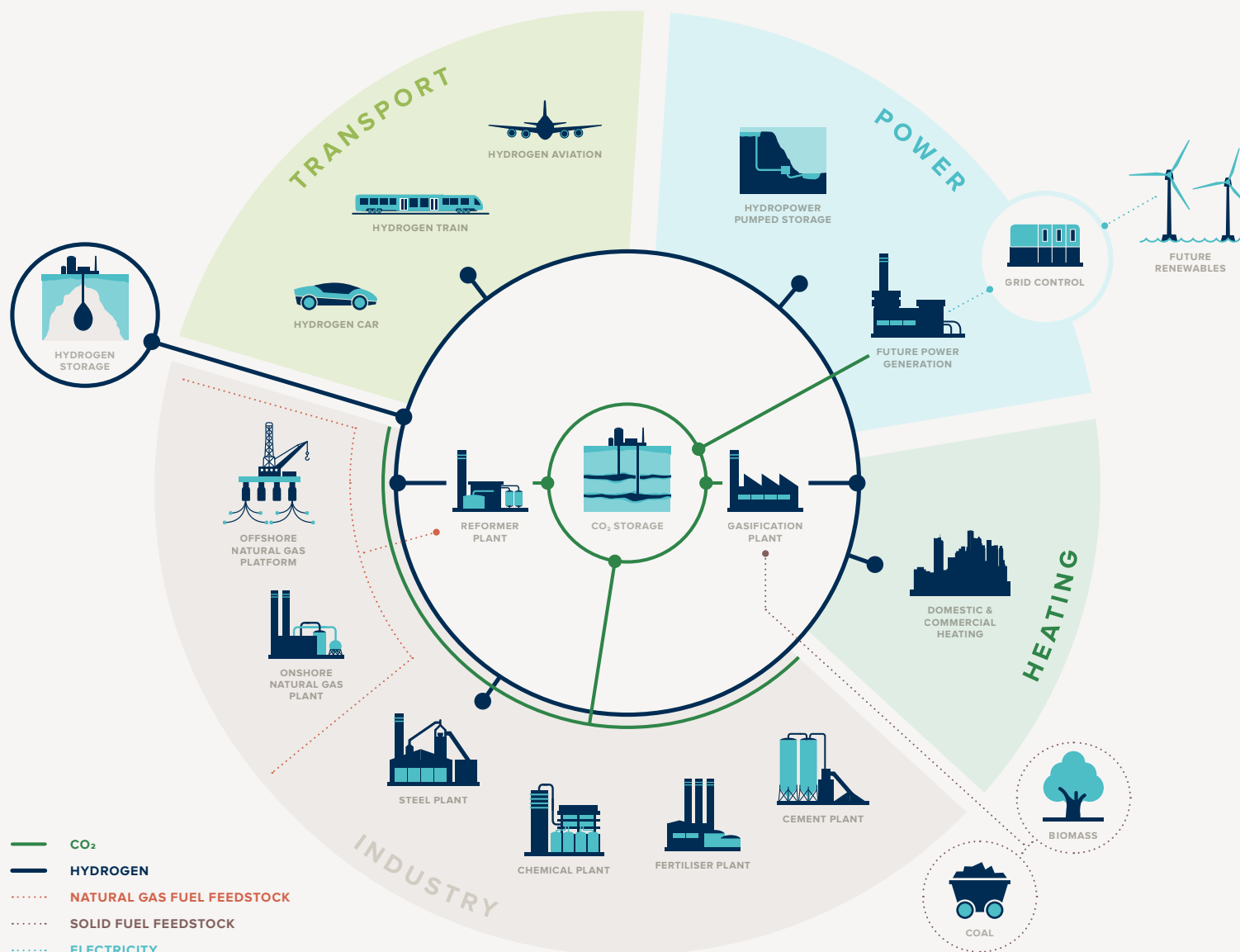
in operation for years, mostly in industrial applications. They are “low hanging fruit” in terms of deployment – natural gas processing, fertiliser, ethanol production where CO₂ capture is an inherent process of productions. There is still a swathe of industrial applications crying out for CCS application. There is also a wave of new innovations such as hydrogen with CCS, direct air capture, CCS hubs and clusters that need to be deployed.

CCS is an effective and far-reaching technology that is now of critical importance.



DR HARRY LIU
Technical Advisor, CCS Projects (Commercial)

Hydrogen with CCS leads the way



If there is one word that has permeated energy and climate change conversations in the past year, it is hydrogen. And right alongside it – CCS.

In 2018, six new large-scale CCS facilities have been added to the Global CCS Institute database. All are in Europe and related to CCS decarbonised hydrogen production:

The UK & Ireland

- H21 North of England
- HyNet North West
- Ervia Cork CCS
- Acorn Scalable CCS Development

The Netherlands

- Port of Rotterdam CCUS Backbone Initiative (porthos)
- Hydrogen 2 Magnum (H2M)

For these eye-catching emerging H₂+CCS developments, there is no barrier for their future deployments. Decarbonised H₂ production by steam methane reforming (SMR)/gasification coupling with CCS has been at scale in commercial practice for decades, with industrial applications in fertiliser production, oil refineries and iron and steel production.

Details of the above new large-scale facilities can be viewed in the Country Case Study section of this report.



UP HERE,
TOO MUCH
CO₂ IS A
PROBLEM

As of June 2018, the Quest
CCS Facility had stored
3 million tonnes of CO₂.



UNTAPPED POTENTIAL

Fatih Birol

EXECUTIVE DIRECTOR *International Energy Agency*

The IEA has highlighted that as much as 450 Mt of CO₂ could be captured, utilised and stored globally with a commercial incentive as low as US\$40 per tonne of CO₂.

The 2017 rise in global energy-related CO₂ emissions underscores the need for stronger and more urgent action across a full range of clean energy solutions, including CCUS. While there have been some recent positive developments, including China's first large-scale CCUS facility, the expanded section 45Q tax credit in the US and the progression of Norway's full-chain industrial project, the potential of CCUS to deliver substantial emission reductions in power and industry remains largely untapped. The IEA has highlighted that as much as 450 Mt of CO₂ could be captured, utilised and stored globally with a commercial incentive as low as US\$40 per tonne of CO₂. Harnessing these low-cost opportunities could provide a solid foundation for scaling up CCUS deployment. The IEA will continue to enhance our efforts on this critical technology.

Storage

The good news is there are no technical barriers to permanently storing CO₂ at the rate and scale needed to meet ambitious climate targets. There is more than enough storage resource available. There is almost absolute confidence among geologists, engineers and CCS experts, based on decades of data, in the safety and permanence of injected, stored CO₂.

Thousands of years of storage available.

One of the earliest storage resource assessments was published in Japan in 1995⁸ by Tanaka and others. Since then, methods for storage resource calculation have continued to be refined, and confidence in the estimates is growing. The quantity and quality of supporting subsurface data is also building.

Today, we have active appraisal programs producing national storage site portfolios. Japan is still refining their storage resources through an ambitious offshore drilling program. Other countries actively maturing their storage resources include Europe, Norway, the US, the UK, Norway, China and Australia, among others.

There is a moderate to high confidence that Europe has over 300 gigatonnes (Gt) of CO₂ of storage – more than double the amount of pore space needed to meet the world's 2°C scenario (2DS) between now and 2050. China's 2016 power generation emissions are over 4 Gt per year⁹. With a storage resource of over 2,400¹⁰ Gt, the deep saline formations and oil and gas fields below China can hold over 600 years of China's power emissions.

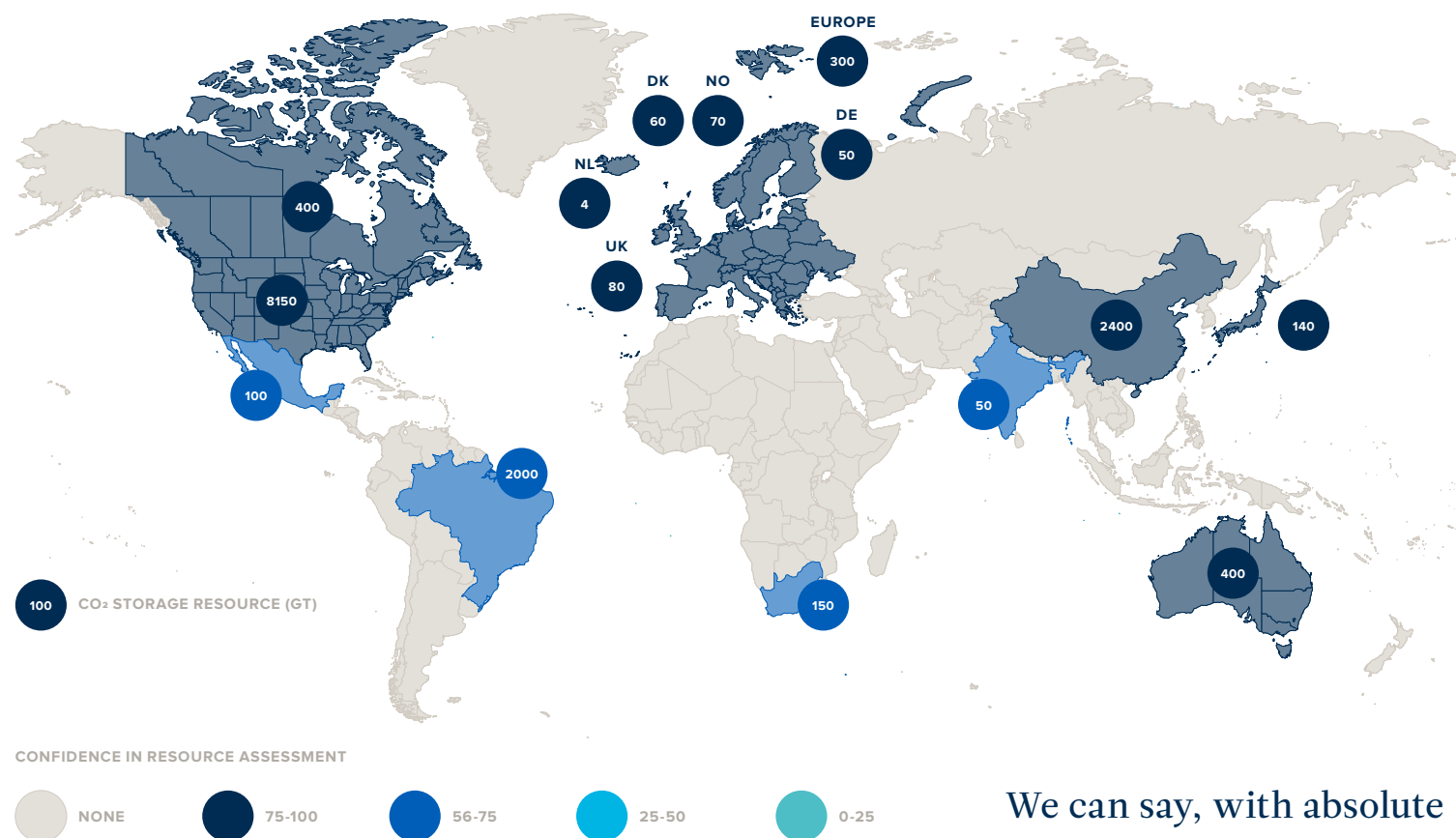
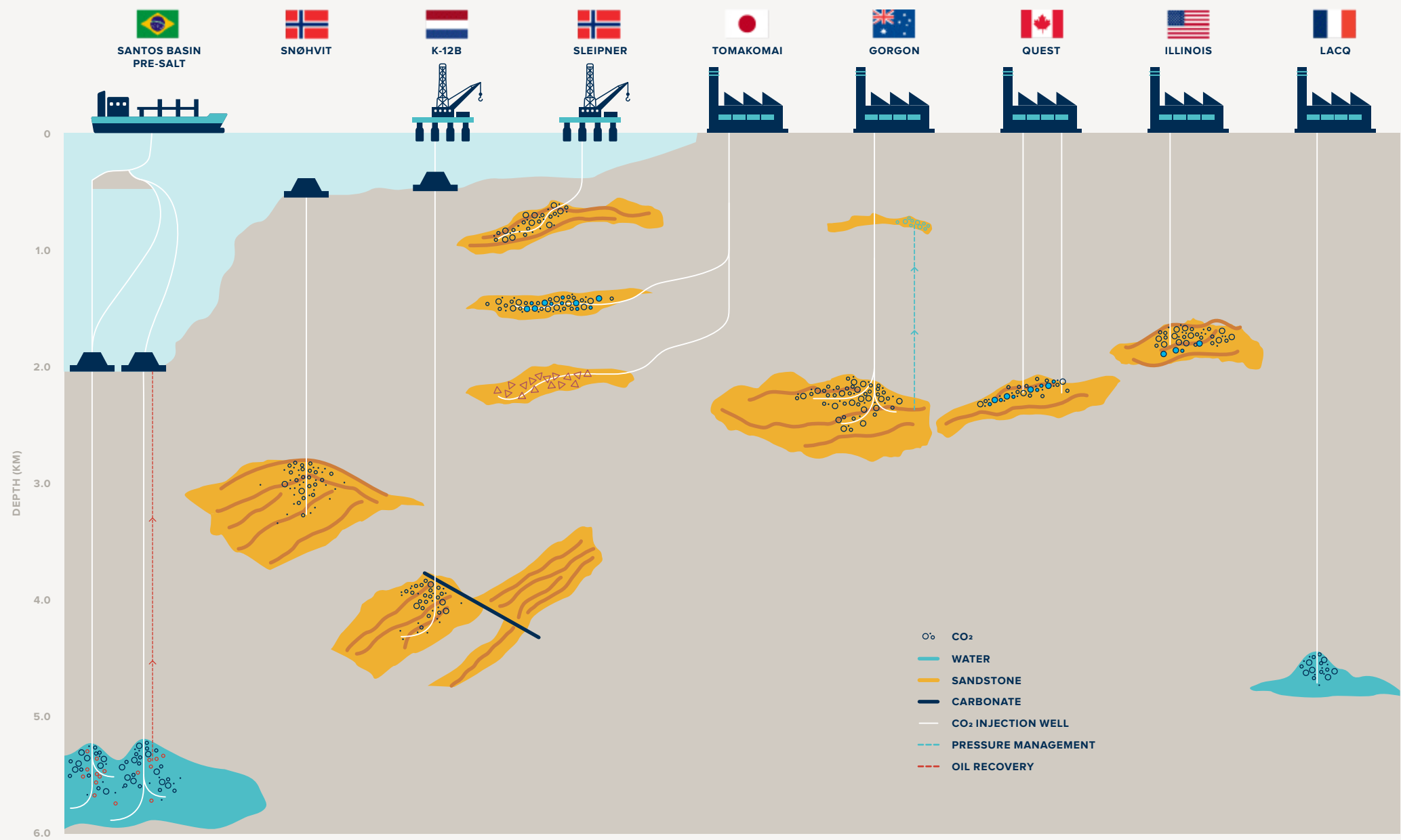


FIGURE 8: Global storage resource potential, based on the latest assessments

We can say, with absolute confidence, that there is more underground storage resource than is needed to meet Paris climate targets.

FIGURE 9: Schematic of CO₂ storage operations around the world. CO₂ has been injected and stored across many different environments, geology, and depths using different injection methods



CO₂ storage experts around the world have concluded that CO₂ can be stored permanently.

CO₂ has been stored for millennia. Natural CO₂ gas fields exist on almost every continent on Earth. They provide strong indicators on the type of reservoir and sealing rocks needed to store CO₂ permanently. They also show that storage sites need to be carefully selected and managed.

For over four decades, research and industrial operations have been storing and monitoring CO₂ at dozens of pilot, demonstration and commercial facilities using monitoring tools to map the movement of the plume and rapidly detect any abnormalities. There has been no incident of significant loss of CO₂ at any of these facilities. Moreover, the facilities have helped accumulate experience and hard data on what happens when CO₂ is injected and stored.

A recently published report in *Nature*¹¹ supported permanence of CO₂ in CCS. Using a near-future scenario of industrial-scale CCS, 98 per cent of the injected CO₂ remains permanently trapped in the subsurface.

The 2 per cent of CO₂ that escapes is mostly attributed to poorly abandoned legacy petroleum wells. Processes are now in place to implement risk management programs and to establish an overarching standard in well-regulated CCS jurisdictions.

The 2018 conclusions mirror the IPCC's conclusions in 2006:

With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO₂ releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas¹².

Decades of operations tell us that we have the technology and experience to deploy.

Over the past four decades, the movement of CO₂ in the subsurface has been predicted, then monitored and measured using standard oil industry technologies. Those same technologies are now being optimised to accurately predict and monitor the movement of CO₂ for storage. As a result, the ability to inject CO₂ has been optimised to achieve the maximum efficiency of injection needed to meet daily and yearly injection targets. Using myriad combinations – horizontal wells, multiple vertical wells, pressure management wells, or co-injection – the injection of CO₂ can be engineered in most formations to meet the needs of the capture rate.

For example, the Tomakomai CCS facility has met its injection targets in relatively low flow sandstones (180 millidarcy rocks). It achieves its targets of 100,000 tonnes per year through wells that extend out to sea for over 3,000 m and 1,000 m below the sea floor to reach an optimal storage site. The CO₂ injection occurs along a 1,000 m section of a perforated well in the storage formation.

The movement of the CO₂ plume in the Sleipner CCS facility has been visualised for more than 20 years. It is now being tracked using 4D seismic as it meanders through the storage formation, 1,000 m below the sea floor in the North Sea off Norway.

Today, CO₂ is being injected and stored in the semi arid climate of Shaanxi Province as part of the Yanchang CCS facility in China. The Santos Pre-Salt CCS facility in Brazil lies in more than 2,000 m of water and uses floating mega-vessels that capture and re-inject CO₂ into oilfields a further 3,000 m below the sea floor.

Massive sandstones, some over 400 m thick, deposited hundreds of millions of years ago in rivers that existed before plants began growing on Earth, are currently storing the CO₂ from, ironically, the world's first large-scale bioenergy CCS project, the Illinois CCS facility in the US.

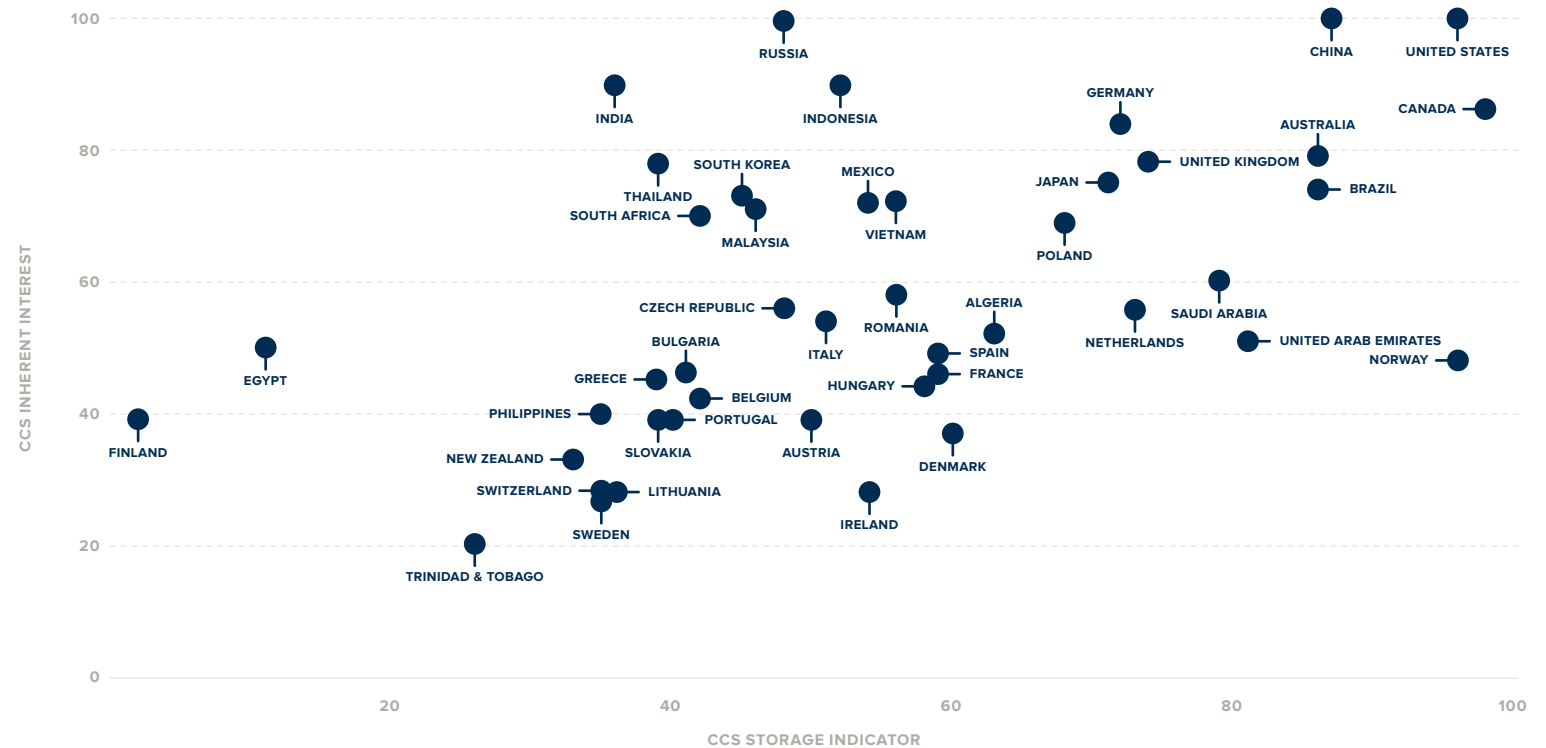
The geology is available. All we need to do is use the resource.



High-emitting nations are ready to store CO₂

It is clear that many nations, particularly those high-emitting, fossil fuel reliant nations such as Australia, Canada, China and the US, have been exploring, appraising and developing their storage resources in order to be CCS-ready. Those countries score high in both the CCS Storage Indicator (CCS-SI) and the Inherent CCS Interest Indicator (CCS-CI). The CCS Storage Indicator (CCS-SI) records an individual nation's development of its storage resources.

FIGURE 10: Comparing 2018 CCS Storage Indicator results and Inherent CCS Interest Scores



The Indicator evaluates a country's geological storage potential, maturity of their storage assessments and progress in the deployment of CO₂ injection sites. The national resource estimates are taken directly from published records. The Inherent CCS Interest indicator (CCS-CI) is a relative index based on global share of fossil fuel production and consumption. The Indicator provides one indication of the potential interest countries may have in implementing policies that locally contribute to CCS deployment and in reducing emissions from fossil fuels.

The above chart shows a general correlation between inherent interest in CCS and development of storage resources. It demonstrates that many countries with the greatest need for CCS to decarbonise their economies have completed the most advanced storage resource assessments. However Russia, Indonesia and India have fallen behind other nations with a high dependence on fossil fuels.

The geology is available.

All we need to do is use the resource.

DR CHRIS CONSOLI
Senior Consultant - Storage (Commercial)



CCS:
the
NO BRAINER

Professor Wallace Smith Broecker

FATHER OF THE PHRASE 'GLOBAL WARMING' *Columbia University Newberry Professor,
Department of Earth and Environmental Sciences*

“It’s getting warmer and warmer but it’s still probably going to be 20 years before global warming is the hot issue it needs to be if people are going to get off their seats and actually do something.

Even birds are changing their migratory patterns. They seem to know what’s going on, but we don’t. How come? They supposedly have small brains. We have big brains but we still can’t figure it out.

The no-brainer is to funnel the CO₂ to a place where the sun doesn’t shine, deep below the ground; the simple, proven process of carbon capture and storage. If we don’t, the ice will melt, and we will follow.”

Policy

Policy must not only support the business case for investment in CCS, it must win the confidence of investors, because once policy confidence is in place, long-term capital investments can be made and the virtuous cycle of investment and cost reduction will accelerate.

People are generally not “wired” to voluntarily make that trade-off, which is why policies are required to alter behaviour.

Policy enacted through legislation is critical to CCS uptake because it provides the tool by which governments can achieve their various objectives. In fact, sufficient investment in CCS simply will not happen without strong and sustained government policy.

Reducing emissions against a backdrop of rising global population and affluence incurs significant costs today and delivers an uncertain long-term benefit. People are generally not “wired” to voluntarily make that trade-off, which is why policies are required to alter behaviour. For example, it will always be easier and less costly to release CO₂ into the atmosphere than to capture and permanently store it. The market, too, does not currently provide sufficient reward for CCS to achieve the required rates of return on investment. That’s why policies to support a business case for investment in CCS are also required.

Even where such a business case exists, the nascent state of the global CCS industry means the well-established and familiar business models, structures and practices that exist in mature industries have generally not yet matured for CCS. Higher perceived risk translates to a higher required rate of return making financing more difficult.

Furthermore, CCS requires investment in long-lived capital-intensive assets. A single CCS facility may deliver millions of tonnes of CO₂ emissions abatement per year, require an initial investment of hundreds of millions (to billions) of dollars, and operate for decades. Investors

must be confident that they have a sufficient understanding of the current and future policy environment to effectively plan to optimise their risk profile before they can reach a positive financial investment decision.

Policy confidence is a prerequisite for investment in long-lived capital-intensive assets

Policy must not only support the business case for investment in CCS, it must win the confidence of investors. Once policy confidence is in place, long-term capital investments can be made and the virtuous cycle of investment and cost reduction will accelerate.

Significant innovations in technology, in business models and in industrial efficiency are generally driven by the competitive powers of the market. Providers of goods or services compete to reduce costs, to improve the utility of their products and, hence, win market share. Innovations can only be protected from competitors for a finite time; knowledge leakage inevitably helps spread developments throughout the entire industry. As a market grows, economies of scale and scope and “learning-by-doing” also deliver cost reductions, which in turn increase demand for the product until market saturation occurs. The net result is the familiar pattern of reducing technology cost over time in real terms.

This is certainly the pattern that has been observed with renewable energy technologies since the turn of this century, driven by very strong and sustained policy support. These cost-reducing processes are only just beginning with respect to the global CCS industry.

To deliver the required policy confidence, the policy environment must achieve four things:

Aligned purpose

There must be a clear stated purpose that sets the context for the policies and is aligned with the purpose of the CCS investment. Investors must be convinced that investment in CCS is an intended consequence of the policies, not an accidental outcome.

Clarity

The policies must be clear and unambiguous so that investors understand and can quantify in commercial terms how such policies create opportunities and risks for CCS investments.

Predictability

Investors must be able to predict with relatively high levels of certainty how their return on investment will be impacted by policies under a range of future scenarios. For example, investors must be able to quantify the impact on costs and revenues of unplanned changes in commercial arrangements and operational status of the CCS facility as part of their risk management process.

Stability

Given the longevity of CCS facilities, investors must be confident that the policies will not be changed in ways that materially reduce their return on investment over the life of the investment. Political risk is a key factor in assessing the stability of policies. For example, how might a new government change policy and what might those changes mean for the profitability of the CCS facility?

By way of example, here are some specific policies/activities that can contribute towards policy confidence for CCS investors:

- economy-wide emission reduction targets
- sector-specific emission reduction targets
- CCS deployment targets and programs
- capital and operational support for CCS deployment (for example, capital grants, contracts for difference, feed in tariffs, CO₂ storage payments – for example, the US’s recently enhanced 45Q tax credits for stored CO₂)
- promulgation of CCS-specific legal and regulatory regimes that address all aspects of the project lifecycle
- removal of legal barriers to CCS, such as the failure to ratify amendments to the London Protocol
- introduction of a robust value on carbon (for example, Norway’s carbon tax)
- sustained research and development support.

The current policy response to climate change generally, and particularly regarding CCS, is inadequate.

Currently, there is a disconnect between the climate targets agreed in Paris in 2015 and the Nationally Determined Contributions (NDCs) to emissions reduction put forth by national governments. The sum of NDCs, if implemented in full, would allow the global climate to warm by approximately 3°C above the pre-industrial baseline.

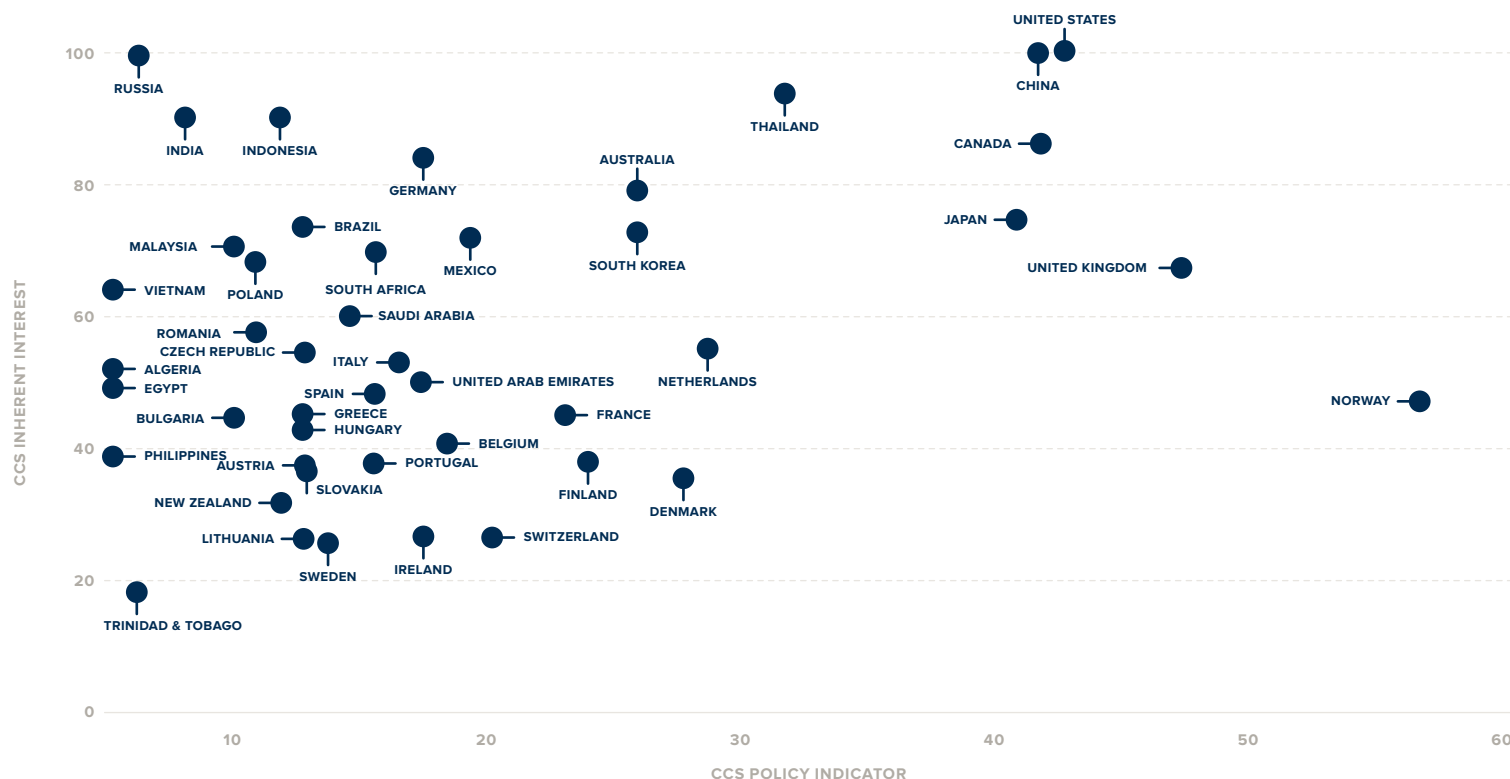
IEA analysis also finds that only four of 37 clean energy technologies are on track to deliver a pathway to the Paris Agreement goal¹³. Clearly, the policy response of governments to the threat of climate change is inadequate.

Although CCS continues to advance, with new facilities commencing operation and others entering the development pipeline, it is one of the 33 clean energy technologies that is not on track. Governments have, overall, failed to implement policies that support a business case for investment and deliver the policy confidence required to mobilise private capital.

The CCS Institute's Policy Indicator¹⁴ assesses nine broad policy measures globally to derive an assessment of each nation's policies with respect to the deployment of CCS. This Policy Indicator is plotted against the Institute's Inherent CCS Interest Indicator on the chart above. The Inherent Interest Indicator uses a range of data on fossil fuel production and demand to determine a relative measure of a nation's economic dependence upon fossil fuels. Logically, economies with the largest exposure to fossil fuels should be most advanced in deploying CCS.

While many governments have recognised the utility of CCS for reducing the tension between economic prosperity and emissions reduction, the Policy Indicator reveals that six – Norway, the UK, the US, China, Canada and Japan – have established themselves as clear leaders through encouraging and progressive policies over the last year.

FIGURE 11: Comparing 2018 CCS Policy Indicator results and the 2018 Inherent CCS Interest Scores for key countries



Policy enacted through legislation is critical to CCS uptake because it provides the tool by which governments can achieve their various objectives.

In US, the 45Q amendments create a good business case for investment in CCS and provide the policy confidence that investors require.

European Commission

As part of the revision of the Emissions Trading Scheme (ETS), the European Commission has established the Innovation Fund, which will set aside 450 million European Union Allowances to support renewable and CCUS energy demonstration projects, energy storage and low-carbon innovation in energy-intensive industry. At least 400 million allowances will be reserved from 2021, with a further 50 million unallocated allowances available from the 2013–2020 New Entrant Reserve Fund (NER300). At the current EUA price of over €20, this fund is worth over €9 billion. The details of the Fund are currently being drafted, with some of the rigidities that caused the NER300 not to drive CCS demonstrations expected to be addressed.

Norway

In 2018, the Norwegian Government allocated NOK280 million to advance CCS deployment, including funding to support Front End Engineering Design (FEED) studies for two full-chain CCS facilities. Each of these facilities will capture 400,000 tonnes per annum of CO₂ for

storage below the North Sea seabed. Norway has a long history of government policies designed to support CCS. In addition to the carbon tax that has been in place since the 1990s, the Norwegian Government has established Gassnova, a state-owned research organisation focused on CCS, and the Technology Centre Mongstad, a CO₂ capture technology testing facility.

United Kingdom

The UK Government's Clean Growth Strategy, released in October 2017, stated that the government's ambition was to have the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently. Subsequently, UK Minister of State for Energy and Clean Growth, the Rt Hon Claire Perry, established the CCUS Cost Challenge Taskforce, which delivered its report *Delivering Clean Growth* in July 2018. Global CCS Institute CEO, Brad Page, was invited to be a member of the UK CCUS Council and a participant on this Taskforce. The Taskforce report acknowledged that CCS/CCUS is pivotal to decarbonising major industry – steel, cement, fertiliser, petrochemicals and flexible natural

gas – and identified the need for stable long-term supportive policy. CCS lays the foundation for the UK to move to a new energy economy with decarbonised heavy industry and hydrogen fuels that complement renewable deployment.

United States

Whilst the rhetoric of the current US administration places no priority on emission reduction, the US has in fact established one of the world's most progressive values on carbon that is captured and geologically stored. In February 2018, the US Congress passed the Bipartisan Budget Act, which extended and increased the tax credits for the geological storage of CO₂ established by section 45Q of the Internal Revenue Code. The CCUS tax credit was originally created in 2008 and was worth US\$10 per tonne of CO₂ used for EOR and US\$20 per tonne of CO₂ stored in saline formations. The original program was capped at 75 Mt of CO₂, after which it would no longer be available. The 2018 amendments will¹⁸:

- increase the current tax credit for CO₂ that is captured and used for EOR or natural gas recovery to US\$35 per tonne in 2026

- increase the current tax credit for CO₂ that is captured and stored in saline formations to US\$50 per tonne in 2026
- ramp up the tax credits from the original values to the new values in 2026, after which they will be indexed by inflation
- remove the 75 Mt cap on the program.

New build and retrofit CCS projects that commence construction before 1 January 2024 are eligible to claim the credits for 12 years, starting from the date the equipment was first placed into service and subject to the following annual CO₂ capture thresholds:

- 500,000 tonnes for power facilities
- 100,000 tonnes for industrial facilities
- 25,000 tonnes for industrial pilot facilities.

The 45Q amendments create a good business case for investment in CCS and provide the policy confidence that investors require. A value of up to US\$50 per tonne of CO₂ is likely to incentivise a new wave of new CCS facilities in the US over the next five years.

China

China's support for CCS has strengthened over the past year as it moves from aspiration to action. The central government has restructured and created a new ministry: the Ministry of Ecology and Environment (MEE). The MEE has been tasked with the "construction of an ecological civilisation". Mitigating climate change is a core component of that concept. China has long recognised the importance of CCS and has recently implemented a suite of measures designed to accelerate CCS deployment. They include:

- creating a national carbon market in the electricity sector
- widely promoting low-carbon technologies, with an emphasis on CCUS

- supporting CCUS pilots and Near Zero Carbon Emissions pilots
- providing grant funding for CCS research projects promoted by the Ministry of Science and Technology
- amending the Environmental Impact Assessment Guidelines to better address CCUS projects
- establishing a CCUS capacity building project for government officials and researchers directly involved in CCUS.

Canada

Under Canada's Clean Growth and Climate Action Plan, each Canadian province and territory must provide the federal government with a description of their first annual plan to price carbon. The price must start at CAN\$10 per tonne of CO₂ (or greater) and rise to CAN\$50 per tonne

by 2022. A federal carbon pricing system will come into effect on 1 January 2019, as a backstop for any jurisdiction that does not put in place a carbon pricing system that meets the federal standard. All direct revenue from carbon pricing will go back to the jurisdiction of origin¹⁶.

A few provinces have already adopted a price on carbon, however a new provincial government in Ontario cancelled its cap and trade program in early 2018 and Saskatchewan has challenged the federal carbon tax. Funding support for CCS projects is available and regulations addressing geological storage of CO₂ have been promulgated in Alberta.

Japan

Japan continues to implement a comprehensive and strategic program to accelerate the deployment of CCS. Led by the Ministry of the Environment and

the Ministry of Economy, Trade and Industry, the Japanese Government supports a wide range of studies on the investigation of potential CO₂ storage sites, CCS feasibility studies, the assessment of legal and regulatory structures necessary for the management of long-term liability for stored CO₂, and the environmental, economic and social impacts of CCS. It also provides funding for pilot CCS demonstration facilities, including the Hydrogen Energy Supply Chain, which was announced in 2018. The Japanese Government is clearly committed through policy to supporting activity designed to systematically identify and defeat barriers to CCS deployment.

ALEX ZAPANTIS

General Manager – Commercial





SOLUTIONS

OFF ALL SIZES

are needed

Barney Swan

INTERNATIONAL DIRECTOR *ClimateForce*

We must incentivise big and small solutions that drive autonomy to clean up our emissions. Connecting both the corporate world and everyday people to projects like CCS, direct air capture, biochar, reforestation, kelp/algae farming, distributed microgrids, and waste-to-fuel facilities will spread awareness to investors, CSR/ESG managers and the public. Once integrated between social class and culture, we can create a global system change that will lead us towards a net positive future. We should focus on the opportunities we have to create change. Whether it be a respectful conversation about conflicting ideas, building on a problem with a sustainable solution, or simply picking up rubbish when no one is around, we can all create a present that brings us closer to the reality of a future we can be proud of.

ClimateForce is a seven-year CO₂ reduction challenge borne out of the 2041 Foundation. Its mission is to provide access to solutions that reduce CO₂ for individuals and organisations – mobilising the reduction of 360 Mt of CO₂ by 2025.

In November 2017, Barney and his father, Robert Swan (OBE, the first person to walk both Poles), attempted to become the first people in history to walk to the South Pole powered entirely by renewable energy. Over the course of the 60-day expedition they encountered an Antarctica that was melting beneath their feet.

Legal ——— *and regulatory*

The results of the Institute's 2018 Legal and Regulatory Indicator (CCS-LRI) assessment shows that CCS-specific legal and regulatory development remains largely unchanged since 2017, a disappointment and a contradiction to the earlier headway made in a number of countries. For some, the absence of further improvements or developments to their national regimes will offer few challenges.

The state of CCS-specific models in many other jurisdictions, however, may prove perilous for those nations with ambitions to deploy the technology in the near term.

Widespread legal and regulatory inertia

The Institute's CCS Legal and Regulatory Indicator (the CCS-LRI) offers a detailed examination and assessment of national legal and regulatory frameworks in 55 countries and examines a range of legal and regulatory factors likely to be critical for the regulation of the technology.

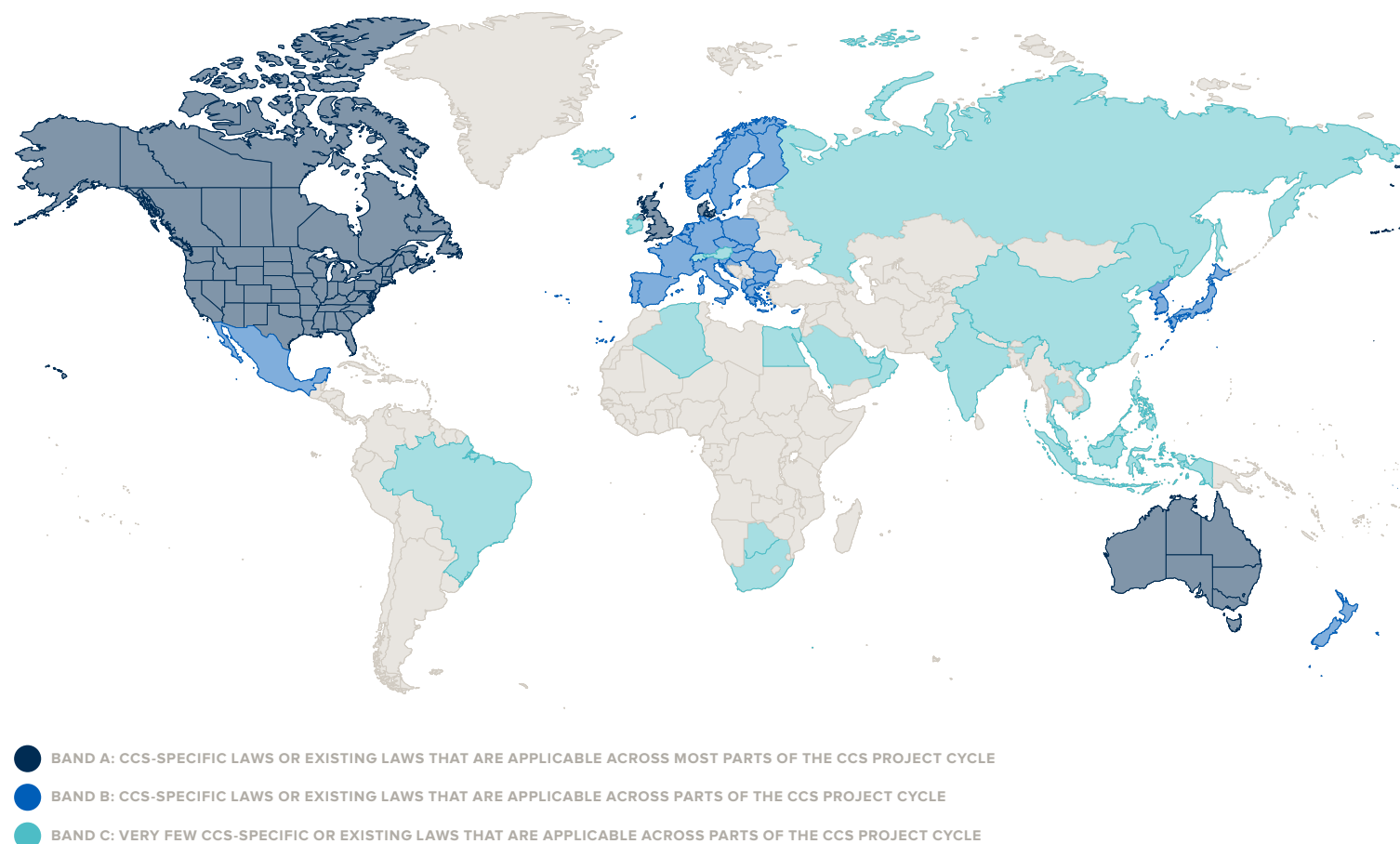
The resulting Indicator offers a comprehensive model to track progress and opportunities to develop CCS-specific legal frameworks worldwide, as well as a perspective of the current status of CCS law and regulation.

Five nations with highly advanced CCS-specific regulatory regimes (Australia, the US, Canada, the UK and Denmark), all of whom have high scores and are identified within Band A of the Institute's CCS-LRI assessment, have seen no significant change to their models in the past year, indicating that further opportunities to improve domestic frameworks could largely have been overlooked and remain low-priority activities.

Critically, the sluggish pace of legal and regulatory development continues among nations included in Bands B and C of the CCS-LRI. For these countries there has again been little or no observed improvement to their regimes in the past 12 months.

While there could be a host of reasons for this global slow-down, in many instances the absence of clear government policy on CCS deployment has resulted in legislation becoming deprioritised, abandoned or simply overlooked.

FIGURE 12: Global perspective of CCS-specific law and regulation 2018



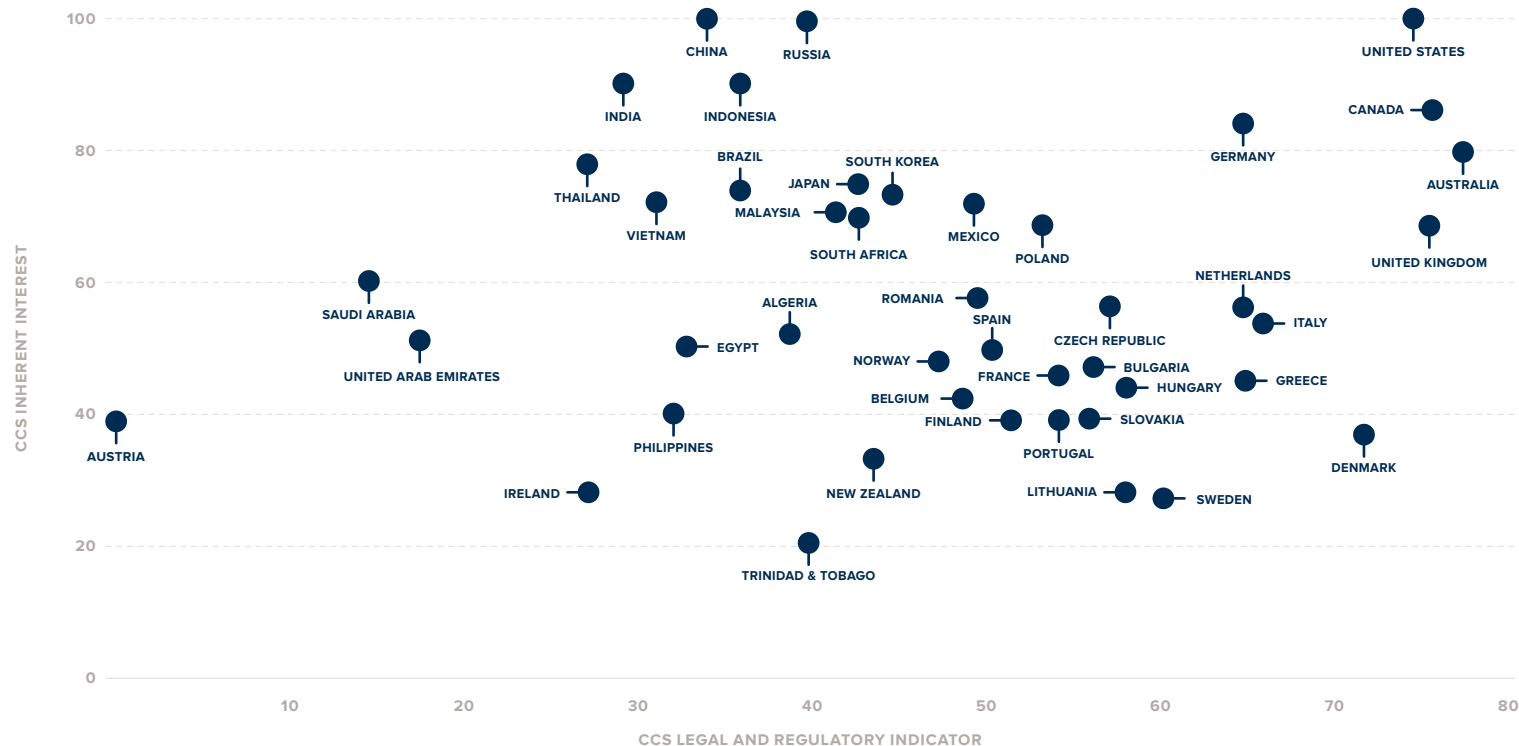
Timely development is imperative for supporting deployment

Proponents continue to highlight the need for improved policy support, but greater emphasis needs also to be placed on the development of facilitative legal and regulatory frameworks. Failure to prioritise this activity will likely result in greater uncertainty for project proponents and regulators, and ultimately delay the deployment of projects globally.

Several uncertainties surrounding the technology remain within international agreements and will require timely resolution. In the case of the London Protocol, for example, which seeks to protect the marine environment and prevent pollution caused by the dumping of waste, a protracted delay by signatory parties to formally implement a 2009 amendment means that a prohibition on the cross-border transportation of CO₂ for CCS remains in effect.

The inclusion of CCS within the architecture of the international climate change agreement has proven an important factor in ensuring national policy support for the technology. While there has been clear recognition within many facets of the UNFCCC, greater clarity is needed around how CCS activities are included in future funding mechanisms, particularly those developed under the Paris Agreement. Such clarifications are critical for ensuring the technology's deployment.

FIGURE 13: Legal and regulatory indicator results 2018



“Despite the inertia of recent years, there are signs of renewed urgency in developing CCS legislation.”

The need to develop facilitative legal and regulatory frameworks will also be critical for those nations that have strong policy commitments to deploying the technology as a part of their climate change mitigation targets. It is apparent that, for some, including those nations in Band C of the Institute's CCS-LRI, the limitations posed by current regulatory frameworks may prove acute when project proponents seek to deploy the technology at scale and within the necessary timeframes.

Several nations with high Inherent Interest scores – China, for example – also have strong policy commitments to the technology. For some of these countries, deployment of CCS comprises a significant aspect of their post-Paris national climate mitigation pledges. If they are to meet their ambitions for timely deployment, it is critical that all remaining barriers to the technology are removed and supportive models of law and regulation are developed.

The experience to date of nations with more advanced models of CCS-specific law and regulation, such as the UK, the US and Canada, suggests the design and development of legislation is complex and time-consuming, and requires engagement across industry and government sectors. Nations with genuine commitments to the technology's deployment will need to take immediate steps to address this critical aspect of their national response. Activities will most likely include: assessments of the capacity of existing national regimes to host CCS projects; decisions around the preferred approach to regulation; and the identification of key regulators and administrative elements.

Among those nations with more advanced models of CCS-specific law and regulation, there are also significant opportunities to further enhance domestic regimes. Regulators and policymakers in these countries will want to look to streamlining domestic regulatory processes,

the provision of further guidance and developing further legislation to address the remaining impediments to deployment.

Early signs of renewed impetus

Despite the inertia of recent years, there are signs of renewed urgency in developing CCS legislation.

Buoyed by successive calls for action from project proponents and the international community alike, attention has again focused on the need to ratify the Article 6 amendment under the London Protocol. Several governments have also made minor improvements to their national regimes in recent years, with others indicating their interest in developing more holistic regulatory models for the technology.

The UK, a country with a highly developed and comprehensive regulatory framework, emphasised the significance of legal regimes in their recent report from the CCUS Cost

Challenge Taskforce¹⁷. In addition to highlighting the significant opportunity for innovation in the UK's regulatory landscape, the report raised the potential for the UK to export this newly developed expertise to other countries. It also recommended that the government further enhance this regime by promoting greater international cooperation around the transboundary shipping of CO₂, as well as pushing for greater regulatory coherence and allocation of risk for CCUS projects.

IAN HAVERCROFT

Senior Consultant, Legal & Regulatory (Commercial)



More than 4 million tonnes of CO₂ has been stored to date since 2008 in Snøhvit CO₂ Storage facility located off shore Norway.





Stop looking for

UNICORNS

Dr Niall Mac Dowell

IMPERIAL COLLEGE *London*. FLCHEME

By now, it should be well accepted that CCS is a key element of any least-cost solution to climate change mitigation¹⁸, and that it will only become more important¹⁹ given the role that greenhouse gas removal technologies will play in meeting the more ambitious Paris 1.5°C target.

Yet, despite an abundance of evidence, there are only 18 large-scale facilities operating around the world – less than 1 per cent of what is likely to be required by 2040 if we're to stay on track to meet the Paris target⁴.

CCS may be a mature and well-understood technology with a demonstrated value to the energy system^{20, 21}, but we are repeatedly told that it is “pre-commercial” and that the “costs must come down”¹⁷.

How do we fix this impasse?

What is needed, I believe, is a better understanding of the ways in which the public and private sectors can, and should, work together to deliver this vital technology. Astute risk allocation and ownership are key to reducing the investment risk associated with CCS projects, improving their

bankability and reducing the level of public support required to bring them from a pre-commercial concept to a viable investment. Here, for the third time, Canada has shown great leadership with the development of the Alberta Carbon Trunk Line, via a combination of public and private funding²². Obviously, the details would vary between regions, but this is a model that could be duplicated in other parts of the world, where CO₂ transport and storage infrastructure does not yet exist.


So why should the public and private sectors take this step? Surely it is easier for both sides to sit on their hands, waiting for a breakthrough “unicorn” technology to be developed and avoiding the need to take on this risk now.

Not so. Unicorns, by definition, are rare. Waiting for one to manifest is a high-risk strategy²³, jeopardising our ability to meet our targets²⁴. Importantly, given its technical maturity²⁵, CCS is a powerful answer that is far from being a unicorn. However, neither is it simply a plug-and-play technology. It requires specific and bespoke infrastructure to be developed for it to work.

Rather than focusing exclusively on costs, we should instead consider the value proposition of CCS. In addition to delivering least-cost power to consumers, and adding flexibility and resilience to energy systems, CCS has the potential to stimulate the economy. Some recent work by Summit Power²⁶ presents the first quantitative social cost-benefit analysis associated with the deployment of CCS. This work indicates that developing CCS in the UK could result in as much as a 5:1 payback to the economy.

That's right. CCS doesn't so much cost money as make money! Delivering CCS at a scale commensurate with the UK Committee on Climate Change's projections could create more than 200,000 jobs across the economy²⁵.

Meeting our climate targets and realising these returns, though, is increasingly endangered by delay. By far the best way to reduce the cost of CCS and profit from its benefits is to stop looking for unicorns and conscientiously progress the options we have in hand today.

A group of five men, likely industrial workers or boilermakers, are posed in a dark, industrial environment. They are wearing various types of caps (flat caps, a bowler hat), overalls, and work shirts. One man in the center wears a black bowler hat and a blue shirt. Another man to his right wears a flat cap and sunglasses. The man on the far right is holding a pair of large pliers. The background is dark and industrial, with some horizontal lines visible.

Of the 18 large-scale CCS facilities in operation, 16 are industrial. As CCS becomes more widely deployed, a whole new CCS industry is being created – CCS-specific componentry, boilers, turbines, pipelines and other CCS specialty products.



CCS drives

JOB CREATION

AND

powers economies

Newton B Jones

PRESIDENT International Brotherhood of Boilermakers

As a labour union that builds, repairs and maintains heavy industrial facilities, the International Brotherhood of Boilermakers trains and dispatches skilled workers across North America. The type of work we perform requires sending thousands of craftsmen and craftswomen – welders, riggers and mechanics – to industrial sites to install major systems, including emission controls and CCS technologies. Boilermakers see first-hand how CCS drives job creation and powers economies.

Take, for example, three Canadian CCS projects in which we have been involved: the Shell Quest Scotsford Upgrader and the North West Redwater Sturgeon Refinery, both in Alberta; and SaskPower's Boundary Dam project in Saskatchewan. Each of these projects is unique. Shell Quest adds CCS capability to an existing upgrader that processes bitumen into a refinery-ready oil. The North West Redwater Sturgeon Refinery is being built from the ground-up to capture CO₂ produced during the refining process. And SaskPower's Boundary Dam is the world's first commercial-

scale post-combustion project to add CCS to an existing coal-fired power plant. (See www.CleanerFutureCCS.org.)

Each project has created well-paying union job opportunities that include healthcare, pensions and other benefits. Thousands of skilled workers travelled to the sites and lived in local communities, where they spent wages on lodging, dining, products and services. Taxes from these projects supported schools and community services, such as police and fire protection. Increased spending in area communities created indirect jobs to support the population of workers building those facilities. And now that the facilities are operational, full-time workers there continue supporting local communities through taxes and personal spending.

In North America and around the world, organisations are just scratching the surface of implementing CCS technologies that can substantially mitigate CO₂ emissions. Consider, for example, the Allam Cycle technology being developed by 8 Rivers portfolio company NET Power near LaPorte, Texas. The

plant produces zero emissions using natural gas as the fuel source. There is also the solvent and absorber approach used by US utility NRG in partnership with JX Nippon that captures 90 per cent of post-combustion CO₂ at the coal-fired Petra Nova plant near Houston, Texas.

The opportunities for CO₂ mitigation, job creation and economic growth surrounding CCS globally are staggering. And while power generation receives most of the attention for CCS, it will be necessary to adapt CCS technologies to every type of heavy industry that emits large volumes of CO₂: oil refining; steel milling; cement making; aluminium smelting; manufacturing and others.

Policies and financial support from governments along with private investment to commercialise CCS not only promote real solutions to climate change, they also drive job opportunities and economic development. Scaling up CCS to the extraordinary level necessary to help meet the Paris Accord global warming targets will profoundly benefit workers and communities alike.

Established in 1880, the International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers & Helpers is a diverse union representing workers throughout the US and Canada who are employed in: industrial construction; maintenance and repair; ship building; manufacturing; railroads; cement; mining and related industries. More information can be found at www.boilermakers.org.



All beliefs are
LEGITIMATE

Archbishop Serafim Kykotis

EMINENCE METROPOLITAN OF THE GREEK ORTHODOX ARCHBISHOPRIC OF ZIMBABWE AND ANGOLA,
SERAFIM KYKOTIS (GREEK ORTHODOX PATRIARCHATE OF ALEXANDRIA AND ALL AFRICA).

Head of the Department of Climate Change Crisis and Sustainable Development Goals of the United Nations.

MEMBER OF THE EXECUTIVE, WORLD COUNCIL OF CHURCHES

“As a theologian who has spent his life striving to make the world a better place, I am deeply committed to do everything I can to stop the crisis that is climate change. COP24 brings us to a crossroads in our confrontation to build a better world for our children and future generations. As Katowice will show, we are failing in our climate change efforts. We are on a bus without brakes, travelling towards a major destination. But we keep arguing about how to get there.

Whilst there is almost unanimous belief that the world is warming, there are different beliefs about how to address it. There is an ongoing presumption that one belief is better than the other? Some of us are very familiar with this debate. The reality is, all beliefs are legitimate.

If we have any hope of saving humankind and the planet, we need to look at every solution. Carbon capture and storage is an obvious one. Proven by science, commercial application and common sense, CCS must form a vital part in our climate change response.

Just as the UN Security Council is working with member states to ensure the survival of humankind, we all need to work together – countries, industry, organisations and individuals – using everything at our disposal to protect our planet.

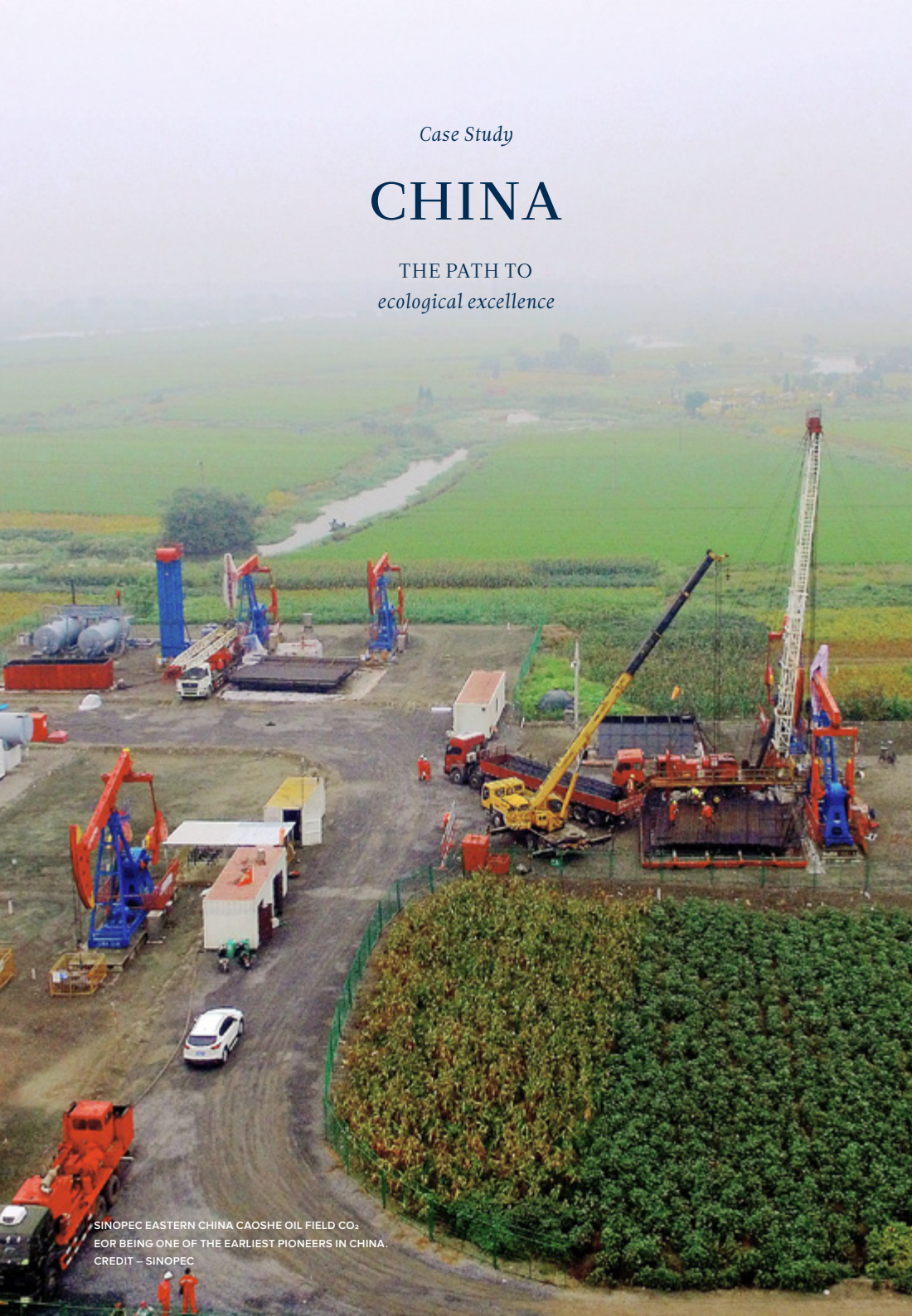
Climate change success will only come when everyone is working together and everything is embraced.”

Case ——— *Studies*

Case Study

CHINA

THE PATH TO
ecological excellence



SINOPEC EASTERN CHINA CAOSHE OIL FIELD CO₂
FOR BEING ONE OF THE EARLIEST PIONEERS IN CHINA.
CREDIT – SINOPEC

A number of significant and far-reaching climate change developments have taken place in China over the past year.

One of the most significant has been the restructuring of government departments – namely, the restructuring of the Ministry of Environmental Protection into a new Ministry – the Ministry of Ecology and Environment (MEE). The Department of Climate Change also transferred from the National Development Reform Commission into MEE.

This re-organisation has taken climate change beyond strategy and policymaking towards a more vigorous and high-profile program of enforceable action. MEE is tasked with the implementation of “ecological civilization construction”, which provides an even broader dimension to the well-known concept of sustainable development.

This concept is typified by the government’s goal to build a “Beautiful China” by 2035, a nation with innovative companies, a clean environment, an expanding middle class, adequate public transportation and reduced disparities between urban and rural areas.

Addressing climate change is one of the major instruments to enhance the construction of ecological civilisation, and CCS has been embraced as an essential technology to achieve carbon emissions reduction targets. In fact, China has exerted great effort in accelerating CCS deployment from the coasts and the hinterland to the farthest corners of the country.

While other countries are trying to pick technology favourites and debate the rights and wrongs of Paris, China’s CCS policies and strategies have remained stoic and stable.



China has exerted great effort in accelerating CCS deployment from the coasts and the hinterland to the farthest corners of the country.

It is fair to say that there has been no “dithering over Paris” at the Chinese end. On the contrary, China has moved with speed to lay down new laws that will address its ecological challenges and CCS/CCUS has been sitting at the centre of many new initiatives. These include:

- a national carbon market in the electricity sector
- widespread promotion of low-carbon technologies with an emphasis on CCUS, CCUS pilots and Near Zero Carbon Emissions pilots
- grant funding on CCS research projects, included major research and development projects promoted by the Ministry of Science and Technology
- amendment of the Environmental Impact Assessment Guidance to embed relevant indexes on CCUS projects
- the CCUS capacity-building project for government officials and researchers directly involved in CCUS.

Despite this progress, CCS in China is still faced with challenges that are shared globally: a lack of policy operability; not enough commercial investment; and underdeveloped public participation.

The country is also mindful that economic, environmental and social considerations need to work hand in hand. For that reason, EOR is, and continues to be, a major driver of CCS progress and China can now count more than 20 projects at various stages of development:

Jilin CCS

CNPC Jilin Oil Field CO₂ EOR Demonstration Project, located in Jilin Province, Northeast China, reached 1.12 Mt cumulative injection, becoming the first large-scale CCS project operating in China and the world's 18th large-scale global facility.

SINOPEC Zhongyuan Oil Field

SINOPEC Zhongyuan Oilfield in Central China has an injection capacity of 100,000 tonnes per annum and a cumulative injection of 500,000 tonnes since it began operations in 2007. CO₂ is sourced as a waste gas from a nearby chemical plant.

Xinjiang Dunhua

Xinjiang Dunhua Oil Technology Co., LTD (Dunhua Oil) is the only private company in China that focuses on CCS-EOR, capturing 100,000 tonnes per annum from the Dunhua Methanol Plant, which began operations in 2015.

CNPC Changqing Oil Field

CNPC Changqing Oilfield was the leading oil and gas producer in China in 2018. The oilfield is in Dingbian, Shaanxi Province, and is characterised by low pressure, low permeability and low abundance, which makes it ideal for EOR. It began operations in 2017 and now has a capture capacity of 50,000 tonnes per annum.

CHN Energy Jinjie

CHN Energy is developing of a demonstration-scale full-chain CCS facility retrofitting to a subcritical coal-fired power plant unit in Shaanxi Province. At a CO₂ capture capacity of 150,000 tonnes per annum, the captured CO₂ will be injected at the existing CO₂ injection sites previously used by Ordos CCS Demonstration project.

Haifeng Carbon Capture Test Platform

Haifeng Carbon Capture Test Platform is located at Shanwei, Guangdong Province, where abundant offshore storage resources are located. The project is the first of a kind using different capture technologies for supercritical power plant units. The project is in construction and will start testing in 2019. The capture capacity per day is estimated to reach 10–50 tonnes.

Elsewhere, major CCS technical assistance worth US\$5.5 million was implemented through an MOU between the Chinese Government (represented by National Development and Reform Commission), Asia Development Bank, Yanchang Petroleum Group, and Northwest University to develop large-scale CCS pilots.

Against this backdrop of “in-the-ground” activity, the Institute has been advocating widely, working with government, industry, and academia to increase levels of CCS awareness and share information.

In May 2018, the Institute hosted its first APAC CCS Forum in Shanghai, focusing on CCS's ability to decarbonise the industrial sector. It attracted more than 150 attendees including Ministry of Ecology and Environment, Climate Change Deputy Director General, Sun Zheng. The Institute also co-organised a “CCS in steel” forum with China Baowu Steel Group, the world's second largest steel producer, which now operates its own CCS facility.

CCS success in China has been driven by collaboration and commitment between large and divergent stakeholder groups. This approach has ensured that CCS is now an engrained part of the rapidly emerging “Beautiful China” blueprint.

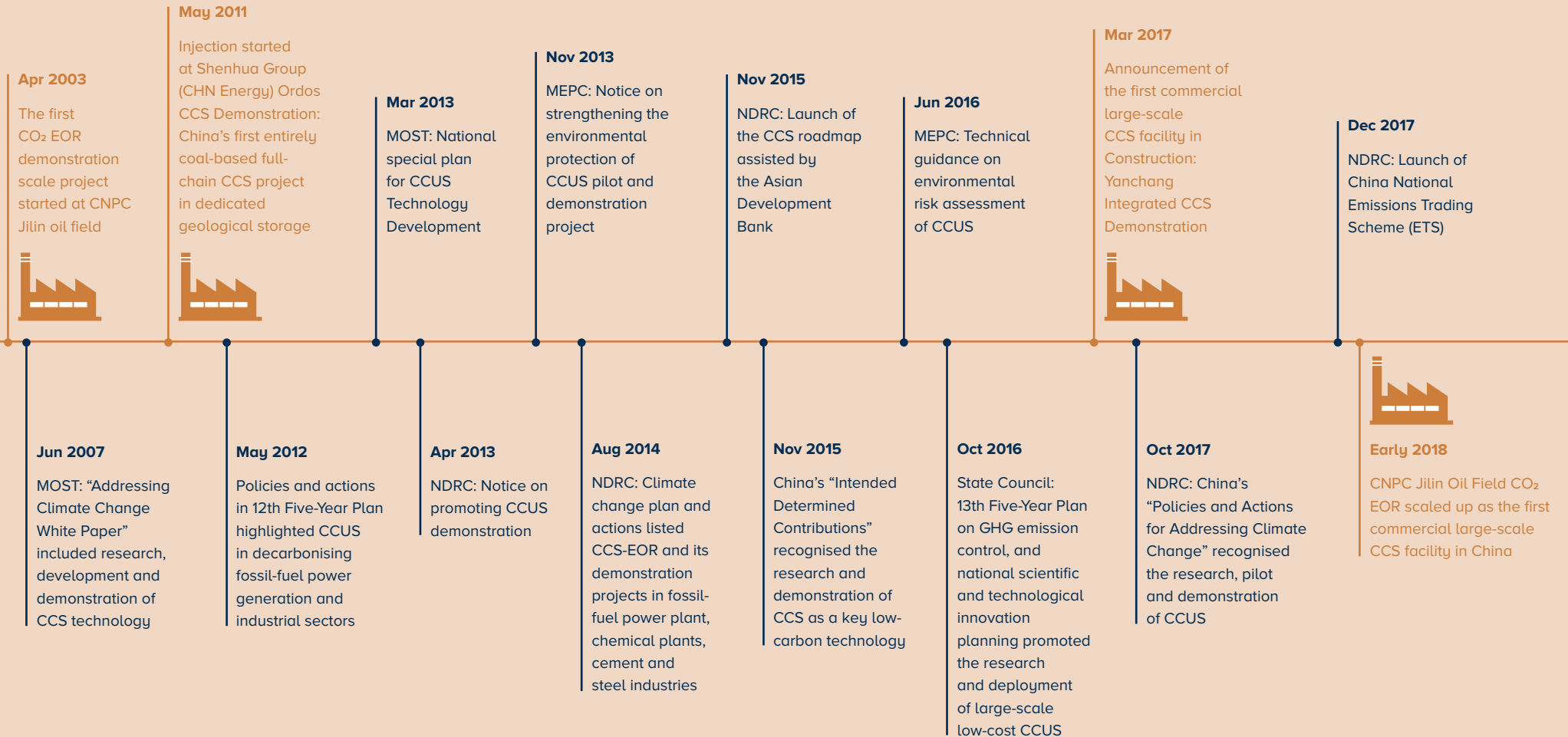
DR XIANGSHAN MA

Country Manager, China – Client Engagement

CNPC Jilin Oil Field CO₂ EOR
joins the ranks as the world's
18th large-scale CCS Facility.



TIMELINE OF CCS IN CHINA



FACILITY POLICY

Abbreviations:

MOST: Ministry of Science and Technology;
NDRC: National Development and Reform Commission;
MEPC: Ministry of Environmental Protection of China.

Sources:

People's Republic of China Information Office of the State Council and Chinese government publications (in Chinese), CO₂RE database Policies Report¹, CCS roadmap in China²⁷, National Centre for Climate Change Strategy and International Cooperation²⁸.



Case Study

UNITED STATES

WORKING AS ADVERTISED
and gathering speed

NET POWER'S 50 MWTH TRANSFORMATIONAL NATURAL GAS OXY-COMBUSTION/ALLAM CYCLE POWER
GENERATION SYSTEM, LA PORTE, TEXAS. CREDIT – NET POWER

It is fair to say that the US continues to dominate the CCS space. And over the past year, deployment and policy have picked up pace.

The United States hosts the largest number of large-scale CCS facilities in the world, which have cumulatively captured and injected more than 150 million tonnes. In the policy domain, the environment continues to improve, paving the way for a further boost in new facilities.

Committed to technology leadership, the US boasts the largest number of large-scale facilities globally. Of the global 18 operating facilities, 10 (including one capture facility with CO₂ injection in Canada) are located in the US. It is proof that, in the US, CCS is “working as advertised”.

Together, US facilities can capture about 25 million tonnes per annum – the equivalent of taking almost 5.4 million cars off the road for one year.

A raft of major facilities

The largest of these, the Century Natural Gas Plant and CCS facility in Texas, alone has a capture capacity of 8.4 million tonnes per annum.

The Shute Creek CCS facility has a further 7.0 million tonnes per annum capture capacity to prevent CO₂ from entering the atmosphere. Petra Nova is the only large-scale CCS power facility in the US, and one of only two globally. Capable of removing 90 per cent of carbon from the generating unit’s flue gas through post-combustion capture, Petra Nova captures up to 1.4 million tonnes per annum. The plant also quietly celebrated storage of two million tonnes milestone, further proof that CCS is firing across all cylinders. The project is a landmark in the CCS landscape, enabling learning and improvement, and paving the way for a more successful future for CCS.

The Illinois Industrial CCS facility – capturing CO₂ from an ethanol plant owned by Archer Daniels Midland and storing it deep in the subsurface adjacent to the plant – also passed its million tonnes milestone.

As these achievements have occurred, the US Department of Energy (DoE) is facilitating further CCS rollout by developing the next set of geological storage complexes (over 50 million tonnes of CO₂) under the Carbon Storage

Assurance Enterprise initiative (CarbonSAFE). Six projects are in feasibility study, advancing towards the large-scale deployment by 2025:

- CarbonSAFE Illinois Christian County
- Carbon Dioxide Storage (ECO₂S) Complex in Kemper County, Mississippi
- North Dakota Integrated Carbon Storage Complex
- Integrated Midcontinent Stacked Storage Hub
- Wabash CarbonSAFE
- Commercial-Scale Carbon Storage Complex at Dry Fork Station, Wyoming.

Ones to watch

But these are only the large-scale plants. Several other facilities are capturing and storing CO₂ at a smaller-scale throughout the country, and many pilot projects are under way.

NET Power’s 50 Megawatts Thermal (MWth) demonstration power plant located near Houston, Texas, has garnered great attention and for good

reason: it seeks to prove that emissions-free electricity from natural gas can be produced at the same price as electricity from a conventional power plant.

CCS advocates, electric utility executives and environmentalists alike have celebrated the facility, which began operations in the first half of 2018. It intends to demonstrate the viability of the Allam Cycle, which includes complete CO₂ capture as inherent in the electricity generation process. Requiring no separate CCS unit and eliminating the energy penalty, the project is a stellar step towards a zero-emission future. It is innovation in the best sense of the word.

In early 2018, the US Department of Energy announced that Regional Carbon Sequestration Partnerships have together injected more than seven million tonnes of anthropogenic CO₂ in different regions and geological formations. A number of these partnerships are studying the possible regulatory and infrastructure requirements that would be needed for commercial deployment of CCS.



The coup of 45Q

The biggest coup, of course, was the bi-partisan approval of the FUTURE Act in February 2018. More colloquially known as enhanced 45Q (in reference to the relevant section of US tax code), this sparked great enthusiasm among the CCS and wider climate change community, as arguably the most significant CCS-related policy development ever enacted.

The legislation provides a tax credit of US\$50/tonne for geological storage of CO₂ and US\$35/tonne for permanently stored CO₂ used in EOR. For the first time, the tax credits are also available for non-EOR utilisation projects and direct air capture, incentivising early-stage investment. Further CCS-relevant federal legislation is pending, signalling strong commitment from lawmakers and the energy policy community to creating the stable policy environment necessary for bolstering CCS deployment.

The caveat that eligible plants have to begin construction soon – by 2024 – has not tempered industry enthusiasm. Two projects have already been announced, with more expected to follow. Occidental Petroleum and White Energy signalled their intention to work together to capture CO₂ from two White Energy ethanol plants. Separately, developers of the Lake Charles Methanol plant presented their plan to invest in a gasification facility expected to capture and store more than four million tonnes per annum of CO₂.

Supportive state-wide environments

At the state level, lawmakers and regulators are creating more CCS-supportive environments. Texas, North Dakota and Montana are taking significant steps to drive CCS investment via policy initiatives.

Committed to technology leadership, the US boasts the largest number of large-scale facilities globally. Of the global 18 operating facilities, 10 (including one capture facility with CO₂ injection in Canada) are located in the US. It is proof that, in the US, CCS is “working as advertised”.

In California, CCS has gained momentum. The state's legislature passed a historic climate law called SB100, requiring the state to move to 100 per cent low-carbon electricity by 2045. Doubling down, Governor Jerry Brown also issued an executive order to achieve total carbon neutrality by 2045. And CCS has to be part of the solution if both of these goals are to be achieved. Furthermore, in an effort to reduce the carbon intensity of fuel sold in California by 20 per cent by 2030, California's Air Resources Board also amended its Low Carbon Fuels Standard (LCFS) in September. The big change: carbon reductions from carbon capture technologies are now allowed to participate in its low-carbon fuels market. At the same time the state also put in place a protocol on CCS, outlining stringent regulation and paving the way for CCS to participate in its cap-and-trade market. While it is yet too early

to predict how the new policy and regulatory framework might impact deployment, commitment from the US's most environmentally friendly state signals a collective understanding that CCS is indeed a vital technology to tackle climate change and is essential for California to meet its climate goals.

The US remains a formative presence in CCS and, despite challenges, it is marrying policy with economically viable projects to keep moving the technology forward. We should continue to expect a further flotilla of facilities to deploy in the coming years.

JEFF ERIKSON

General Manager – Client Engagement



The year of

ACTION ON CCUS

Senator Heidi Heitkamp

UNITED STATES SENATOR *for North Dakota*

When I arrived in the US Senate in 2013 coal-fired power was in a death spiral and Carbon Capture and Sequestration (CCS) projects around the country were struggling. Lignite coal provides thousands of jobs in North Dakota – and at the time near 80 per cent of our energy. This fact had to be balanced though with my belief in climate change and role that people have played in these changes – and therefore a need to greatly reduce emissions from coal and natural-gas energy generating units. The problem in Washington was that both sides of the aisle – and their respective allies – had dug in for years on these issues and very few people saw that there was a path forward where both sides could claim a “win” and would have the added impact of potentially making the US the leader in research, development, and export of these technologies. So I got to work right away and began talking to colleagues on both sides of the aisle, coal companies, utilities, rural electric co-ops, and environmental groups about the possibility of advancing and supporting CCS as key component of our national energy and environmental policies. I told the coal folks that they had to come to grips that they would be operating in carbon constrained world – and I told the environmental community that every major study showed that CCS was going to be necessary to meet any kind of global climate and emissions reduction goals.

Along the way I've introduced several bills; toured facilities in the US, Canada, and Norway; spoken to numerous and varied audiences at conferences; taken hundreds of meetings; and picked up three crucial allies in the Senate – Sens. Sheldon Whitehouse, John Barrasso, and Shelley Moore Capito. During this time the focus also shifted and we began discussing the need for these technologies in reducing emissions in the industrial and manufacturing sectors, incorporating Direct Air Capture (DAC) into our discussions and legislation; and making utilization as major piece of the discussion and re-branding all of our legislation and discussions around Carbon Capture Utilization and Sequestration (CCUS).

I've seen the momentum shift towards CCUS being a viable bi-partisan solution in that time – even more so after the Paris Agreement in 2015 when it became even more clear that in order to meet the stated climate goals – the global community had to invest in CCUS and DAC technologies. While the US and other mature economies have reduced their use of coal-fired power – China, India, many African nations, and other developing countries are

going to continue using coal for electric generation for decades to come. The time to act had arrived.

2018 has become the year of actions on CCUS – it has been a big year for the advancement of CCUS policies and technology. With the FUTURE Act – which I helped write and introduce – now signed into law, the 45Q tax credit has been modernized to give long-term certainty and adequate support to those interested in investing in technology that will be essential in a carbon-constrained world. With cost a prohibitive factor in developing any major industry-changing technology, the 45Q tax credit is poised to jump-start the innovations that will be necessary to ensure existing sources of energy can reliably and cleanly continue to power communities across America. We have also seen successful projects like NET Power's project in Texas and Sask Power's Boundary Dam. We have seen major institutions and think tanks make CCUS a key component of their programs – at Columbia University, the University of Michigan, and Energy Futures Initiative (led by former US Secretary of Energy Ernest Moniz). We have seen private sector investment in CCUS and DAC – with an

investor list that includes the likes of Bill Gates and other Silicon Valley leaders. It truly has been an incredible year for the advancement of CCUS – not only in this country, but globally.

In North Dakota, this is great news for coal, which is in abundant supply and still meets the majority of our energy generation needs. But it's not just coal that stands to benefit – an ethanol plant in Richardton, North Dakota was one of the first companies to express interest in utilizing the expanded 45Q tax credit. By sequestering carbon produced in ethanol production, they'll be able to sell their product in markets that require biofuels to have a lower carbon footprint. North Dakota is also a major producer of natural gas and has built out new natural gas generation to handle the recent population boom and load increase in the state – CCUS could help increase the market for our natural gas and make our current generation even cleaner. The Energy and Environmental Research Centre at the University of North Dakota continues to be a leader in CCUS research – especially as it relates to enhanced oil recovery in the Bakken shale play – and will benefit greatly from the

increased interest and investment from federal, state, and private sources.

In these partisan times, the FUTURE Act was a rare policy win that required a broad coalition of environmentalists, electric utilities, coal companies, industrial manufacturers and many more. We've taken that momentum and have introduced and advanced the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act – a bill that would further engage the US Environmental Protection Agency on CCUS and DAC to ensure a true cross-agency federal commitment to advancing these technologies and the necessary policies. We're looking further into the future of these exciting technologies – and it will require continued cooperation and compromise to continue to build on our progress. The changes and advancement that I have seen in six short years make me confident that I made the right decision to make this a priority as a US Senator – and I am excited to see what the future holds.

Since 2000, Great Plains Synfuel Plant has captured and transported nearly 35 million tonnes of CO₂ for enhanced oil recovery.





Fighting one of the most dangerous

SECURITY THREATS

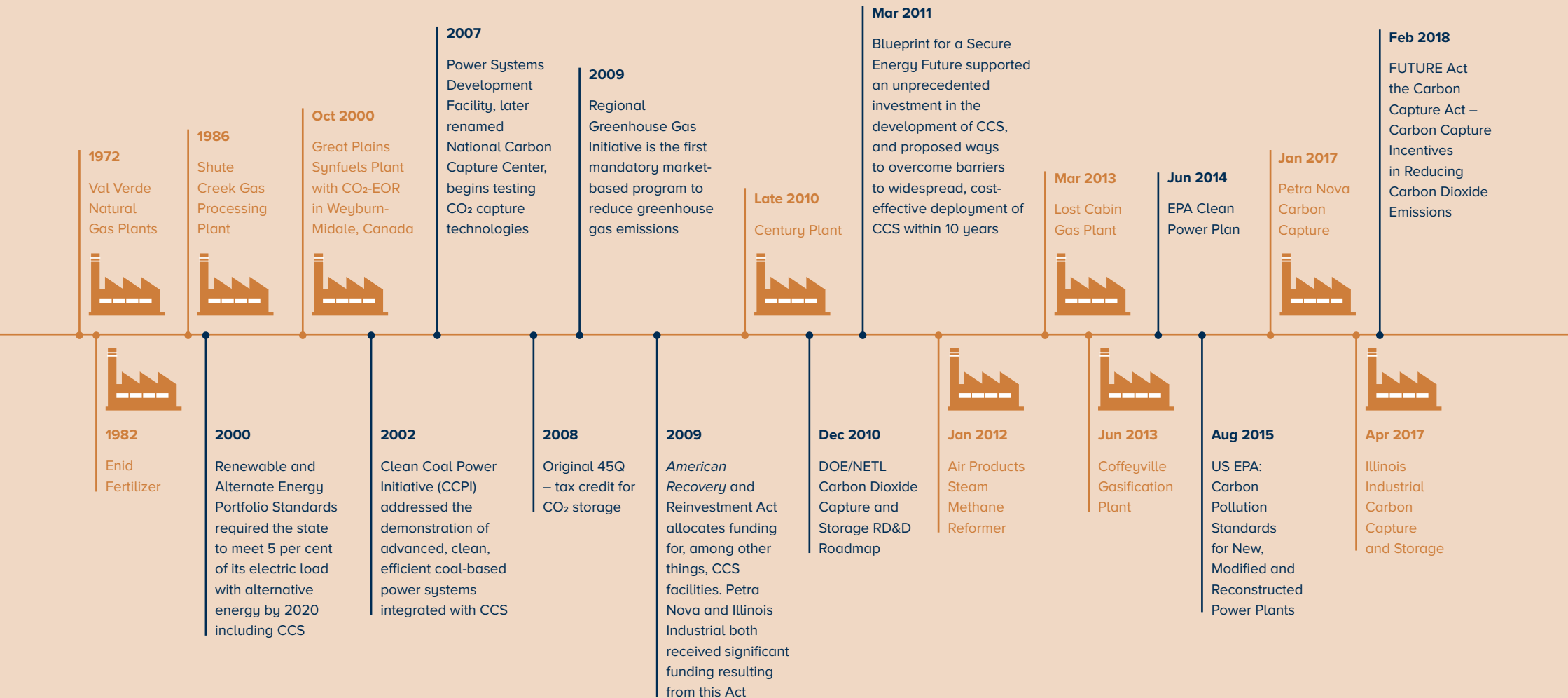
Senator John William Warner

FORMER SENATOR OF VIRGINIA AND SECRETARY OF THE US NAVY FROM 1969-1974

“Climate change is one of the most dangerous security threats of our time and it is important to also view it through the military lense. More frequent events of extreme weather – hurricanes, droughts, floods among others – have shown to lead to political instability, conflict and war. With a changing climate and the US bearing a global responsibility, climate change might lead to increased deployment of our armed troops for humanitarian causes. It is therefore essential to recognize that all available decarbonisation options have to be deployed with urgency and in harmony. Carbon Capture and Storage, as one vital option, certainly plays an important role in delivering deep emissions cuts to prevent global warming”.

Senator John William Warner, former Senator of Virginia and Secretary of the US Navy from 1969 to 1974. John Warner was first elected to the US Senate in 1978 and served five consecutive terms. In 2007, he was the lead sponsor of the Lieberman-Warner climate bill, which would have established a cap-and-trade system to deliver sharp reductions in GHG emissions.

TIMELINE OF CCS IN THE UNITED STATES



FACILITY
POLICY

The way to
CLEAN AIR



Hon Amarjeet Sohi

MINISTER *Canadian Natural Resources*

“As the world makes the transition to a lower-carbon future, CCUS will play a critical role, and the Government of Canada is supporting its development. For example, Canada is working on next-generation carbon capture technologies and has invested in testing new approaches to convert CO₂ captured from various industrial sectors into value-added products. We will also continue to learn from the large CCUS demonstration projects built in Canada. CCUS is one of the technologies that can ultimately give Canadians cleaner air by reducing air pollution and support industries’ transition to a low-carbon economy.”

Case Study

JAPAN

HONING CAPABILITY
and breaking new ground



Over the past year, Japan has continued to hone its CCS capabilities with the country's first CCS hydrogen plant, Tomakomai, pushing past 200,000 tonnes of CO₂ safely captured and stored, ensuring that the technology continues to garner attention and send signals to others of its wider application.

As Tomakomai continues to demonstrate the dexterity of CCS, three other key projects made steady progress – two near Fukuoka on Japan's southernmost Kyushu Island (Saga City Waste Incineration and Toshiba's Mikawa Biomass Power Plant) and another in Hiroshima (Osaki CoolGen).

Like Tomakomai, these facilities are making the case for CCS against a backdrop of extreme weather events and a multifaceted energy program that the government has introduced to keep all energy options in motion.

This includes commitments that, by 2030, 26 per cent of all electricity will be coal-generated, 22–24 per cent of all energy will be renewable, and a hydrogen society will be fully established (following a hydrogen-fuelled Tokyo Olympics in 2020).

That last commitment to hydrogen has been crucial to CCS success.

As stationary hydrogen fuel cells are being installed in households and more than 2,000 hydrogen fuel cell vehicles are put on Japanese

roads, CCS has created another hydrogen highway with the announcement in April 2018 that the Japanese and Australian governments were partnering with industry in both countries to create a Hydrogen Energy Supply Chain in the Australian State of Victoria.

This AU\$500 million project, which involves our member companies Kawasaki Heavy Industries (KHI) and J-Power among its big benefactors, will construct a hydrogen production facility that will use well-tested Japanese technologies to transform Victoria's abundant brown coal reserves into clean hydrogen. This will be shipped to Japan in a tailor-made KHI hydrogen carrier for use in power, heating, transportation and industrial applications.

Pivotal to the project is a CCS plant that will prove that clean coal is only possible through the deployment of CCS.

This kind of unprecedented development would not be possible without a truly collaborative approach between governments, their departments – particularly Japan's Ministry of Economy, Trade and Industry and the Ministry of the Environment – industry, academia and CCS advocates.

In Japan, where industry is the cornerstone of economic success, it is widely acknowledged that CCS is one of the last remaining options to keep the population safe, secure and in work, at the same time as keeping climate change, and its now very visible dangers, at bay.

In the birthplace of the Kyoto Protocol, where the Paris 2°C foundations were laid in 1997, Japan is continuing to chisel out an energy future that is pragmatic, socially conscious, and far-sighted – and where CCS is literally breaking new ground.

HIROSHI NAMBO

Branch Representative, Japan – Client Engagement

Five major milestones in Japan

1. Commencement of CO₂ injection at the Tomakomai CCS facility by Japan CCS with the Ministry of Economy, Trade and Industry's full support – Asia's first full-cycle CCS hydrogen plant, which will capture more than 300,000 tonnes of CO₂ by 2020.
2. Retrofit of Toshiba Corporation 49MW Mikawa power plant in Omuta (Fukuoka Prefecture) to accept biomass (in addition to coal) with a carbon capture facility.
3. Start-up of JPOWER and Chugoku Electric Power Company's Osaki CoolGen facility, a 166 MW oxygen-blown IGCC (integrated gasification combined cycle) plant in Osakikamijima (Hiroshima Prefecture), which will separate and capture CO₂.
4. Completed construction of Toshiba's carbon capture and utilisation (CCU) system at the Saga City Waste Incineration Plant (on Japan's Kyushu Island), using captured CO₂ for algae culture.
5. Announcement by Kawasaki Heavy Industries of a Japanese Hydrogen Energy Supply Chain that plans to gasify Australian brown coal in Victoria's Latrobe Valley and transport it by ship for the future decarbonised hydrogen developments.

Japan is continuing to chisel out an energy future that is pragmatic, socially conscious, and far-sighted – and where CCS is literally breaking new ground.



A ticket to

GREATER ENVIRONMENTAL PROSPERITY

Hirofumi Iwakura

MAYOR Tomakomai. CHAIRMAN Tomakomai CCS Promotion Council

Tomakomai City, Hokkaido, is a large industrial city with a population of 172,000 and a port that is a hub of world trade. The ongoing CCS demonstration project in our city, Tomakomai CCS, is the first of its kind in Japan and a project that has been recognised as essential to the development of Japanese CCS technologies for 2020 and beyond.

Through Tomakomai CCS, more than 200,000 tonnes of CO₂ has been injected offshore since 2017. Such a smooth and faultless operation would not have been possible without extensive cooperation and continuous efforts between stakeholders, such as the Ministry of Economy, Trade and Industry, New Energy and Industrial Technology Development Organization, Japan CCS Co. Ltd and many local industries. As Mayor of Tomakomai, I sincerely respect and admire the persistence and hard work that has made Tomakomai a shining example of industrial, environmental and climate change excellence.

When we were first invited to establish a demonstration test site, the City of Tomakomai established a dedicated

Tomakomai CCS Promotion Council made up of local organisations and corporations to ensure that the facility would enjoy smooth progress. To this day, the city continues to facilitate wide cooperation to ensure Tomakomai's success.

Additionally, Tomakomai's CCS Demonstration Centre has attracted thousands of visitors from Japan and around the world, building on the variety of attractions around Tomakomai, including Lake Utonai, designated as wetlands under the Ramsar Convention, and the area's abundant seafood stocks, including Hokkigai (Surf Clam), which has the highest catch quantities in Japan.

We hope you will come to Tomakomai, not only as an industrial tourist to the CCS facility, but also as a guest of Hokkaido and its many great attractions.

May I extend my best wishes to the Global CCS Institute and all stakeholders involved in CCS as a ticket to our greater environmental prosperity.

Saga City – The world’s best kept secret (*for now*)



CO₂ CAPTURE FACILITY IN SAGA CITY MUNICIPAL WASTE INCINERATION PLANT
CREDIT – SAGA CITY

The Plant is a shining example (literally) of a fully integrated CCU project where trash becomes treasure at the same time as helping meet international climate change targets.

At Saga City, a city of 240,000 people just 38 kilometres from Japan’s ancient city of Fukuoka, on the picturesque southern island of Kyushu, a CCU city of the future is emerging.

Saga is host to a waste incineration plant, which is using captured CO₂ to cultivate crops, create algae cultures and even make the medals for the 2020 Tokyo Olympics from reconstituted metal.

Built by Toshiba and commissioned in 2016, the CCU facility captures up to 10 tonnes of CO₂ per day from the plant’s live flue gas, which is then piped to a glass-covered algae farm only a few hundred metres away. From there, proprietary technology enables the CO₂ to be used to produce exotic, high-end body lotions and anti-aging creams, which are exported to retailers around the world.

It is a world-first application of waste treatment, which has until now been one of the world’s best kept secrets.

Commercial success has burgeoned and now a new wave of agricultural entrepreneurs is acquiring land in the plant’s vicinity to capitalise on the diversity that the CCU/waste incineration “double-act” is delivering.

Multinational Toshiba, a major energy systems and services corporation, has established itself as a world leader in developing carbon capture technologies, particularly the separation of CO₂ emitted from thermal power plants.

Work undertaken by Toshiba’s CCU expert and senior manager, Kensuke Suzuki, at the nearby Mikawa Thermal Power Plant, inspired the development of a CCU unit at Saga City. Representatives from Saga City had been quietly watching the CO₂ capture technology at the Mikawa CCU Plant, which uses chemical absorption in a post-combustion capture process to extract CO₂ at

a very high purity. They were looking for a biomass solution for their city, so officials asked Toshiba if the Mikawa model could be replicated at the Saga site. The answer was yes.

Says Mr Suzuki: “The biggest challenge became the small strip of land that I was allotted to build the plant on. It was very thin. But with knowledge gained at Mikawa, we have managed to build a state-of-the-art CO₂ capture plant, which we believe is the shape of things to come.”

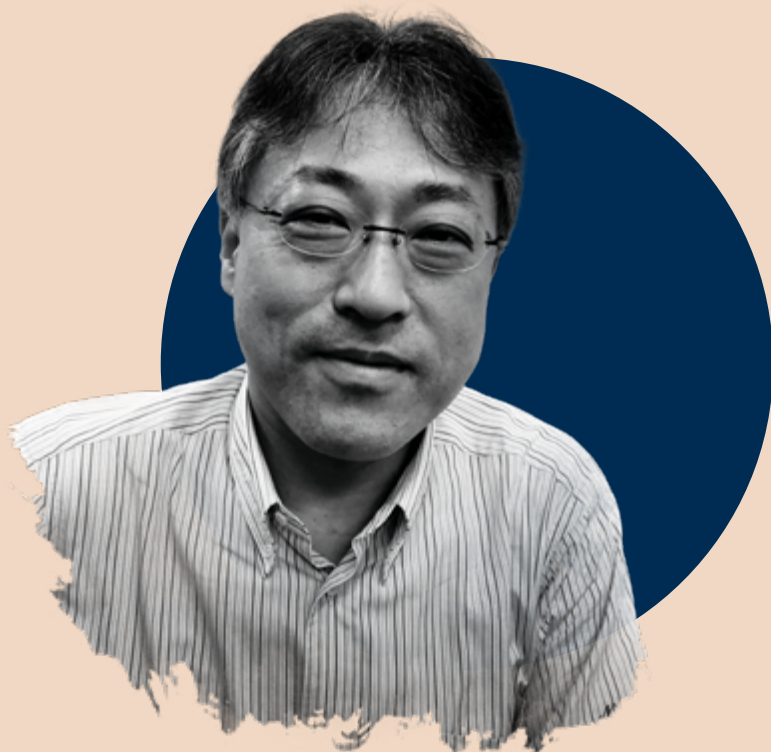
The Plant is a shining example (literally) of a fully integrated CO₂ capture project where trash becomes treasure at the same time as helping meet international climate change targets.

The innovation is also a perfect example of what happens when policy confidence and unwavering passion is applied to CCUS; in this case, when a mayor, Toshiyuki Hideshima, commits his city to become a “living laboratory” to sustainability and climate change mitigation.

As Saga employees will quietly tell you as you tour the plant alongside dozens of local schoolchildren: “This Mayor cares so much he actually goes door-knocking to talk to city residents about the need to recycle everything and mitigate global warming. He truly cares.”

But he is not alone. The national government has designated the Saga municipality as a Special Economic Zone to encourage low-carbon start-ups and create jobs.

Global CCS CEO Brad Page says the Saga City Incineration Plant is one of the best global environmental stories that hasn’t been told. “If the rest of the world followed this model, climate change would quickly become a thing of the past. As such, the Saga City CCU story is unlikely to remain a secret for much longer.”



VITAL FOR JAPAN

AND THE *whole world*

Noriaka Ozawa

DIRECTOR GENERAL FOR ENERGY AND ENVIRONMENTAL POLICY *Ministry of Economy, Trade and Industry*

Following deliberation started in August 2017 by the Japanese Government at the Strategic Policy Committee of the Advisory Committee for Natural Resources and Energy, the Fifth Basic Energy Plan was approved by the Cabinet in July 2018. This Plan includes basic principles and policies towards 2030 and states the willingness of the government to realise energy transition and decarbonisation towards 2050.

Thermal power will still account for more than 50 per cent of the energy mix in 2030. To reduce greenhouse gas emissions, it is vital to promote the development of high-efficiency technologies to mitigate the effects of thermal power generation itself. Both the government and industry in Japan have high expectations for the commercialisation of CCS.

The realisation of a hydrogen economy is also important. Because hydrogen is an energy source that enables total decarbonisation when CCS technology is applied at its production process, much is expected from the wider use of hydrogen in the future.

Also in August 2017, the Round-Table for Studying Energy Situations, hosted by the Japanese Minister of Economy, Trade and Industry, commenced discussion on the long-term energy policy goals for 2050, and in April 2018 developed Initiatives for Energy Transitions.

They discussed the actions that would be needed for energy transition and decarbonisation specific to the realities in Japan, while objectively understanding

both domestic and international situations and learning from various efforts around the world. During the discussion, CCS was considered as one of the main technology options, and together with resource-rich countries and emerging countries, Japan decided to work towards reviving fossil fuels by using CCS. Commercialisation of CCS is not without its challenges of course, including high costs. Providing solutions to such challenges is crucial.

As for the domestic CCS-related technology developments, Japan is implementing a large-scale CCS demonstration pilot project in Tomakomai, Hokkaido. The injection of CO₂ started in 2017 and a total of about 200,000 tonnes has been injected so far. Also, the Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) at the Osaki CoolGen project is being implemented in Osakikamijima, Hiroshima. The construction of the CO₂ separation and capture facility started in 2018, and the full-scale demonstration project will commence in 2019. Through such projects, Japan is looking to establish CCS technologies and reduce their costs so that the country can work steadily towards making CCS commercially viable.

In addressing the global warming issue towards 2050, the practical application and commercialisation of CCS – the technology that enables significant reduction of CO₂ emissions – is vital, not only for Japan, but for the whole world. We would like to express our respect to the Global CCS Institute for promoting the global deployment of CCS.

Case Study

UK & EUROPE

AMBITIOUS POLICIES

and realisable goals



FACILITATING

A *Revolution*

Ben Houchen

MAYOR Tees Valley

The need to reduce our carbon footprint while growing a free and increasingly innovative global economy is one of the most important challenges of our age.

Technological developments mean that we can look forward to a future where we do not have to choose between economic development and environmental protection – but only if we choose to act now. It is vital that we not only decarbonise and offset the environmental impact of traditional industries in the developed world but provide both the method and the motivation for cleaner growth in emerging economies.

The successful deployment of CCUS doesn't just mean we can clean up existing industries and make them more competitive, it also creates opportunities with emerging technologies. Foremost among these is the production and use of hydrogen, which can be carbon neutral at the point of creation and when used. While renewable energy can be used to create zero-carbon hydrogen through electrolysis, CCS can decarbonise more traditional and less clean methods of production.

This means that on top of reducing carbon at the point of energy generation, the delivery of CCS can facilitate a revolution in clean transport and in the way many people heat their homes without significant changes to existing road, rail and gas infrastructure.

I am passionate about placing the Tees Valley at the centre of the UK's new clean growth economy, by developing CCS and

hydrogen technologies that won't just be of benefit to the UK but will have a positive global impact.

We expect low-carbon growth to drive GVA (gross value added) benefits of nearly £40 billion between now and 2050, with emissions savings of 80 megatonnes of CO₂ compared to doing nothing to mitigate industrial impact.

In real terms, this means a much larger economy than today, including advanced industries, with only marginally more CO₂ produced and a CO₂ reduction per dollar made and per head of population.

As the UK moves away from being subject to European Union rules, including on environmental issues and industrial emissions, it has an opportunity to lead the world in carbon reduction, rather than to fall behind as some commentators have suggested.

As a nation, we not only have a responsibility to do this, but also to prove that CCS and hydrogen mean that environmental protection is not antithetical to serious economic growth.

Decarbonisation and the possibilities of clean growth are an opportunity for leaders in regional government throughout the world to place their industrial bases at the heart of a growing industry. This will deliver the dual benefits of prosperity and cutting global carbon emissions. The economic and environmental justifications exist for this. Now the political will must follow.

Reignition and redefinement in the United Kingdom

At the end of 2017, the UK Government launched its Clean Growth Strategy as part of its commitment to reduce emissions and build a low-carbon future. At the heart of this strategy, was the need to deliver clean economic growth and maximise economic and social opportunities for the UK.

In its ambitious industrial policy, the UK Government recognised CCUS as an important technology in its transition to a low-carbon economy. It reaffirmed its commitment to deploy CCUS at scale, subject to costs coming down, and revealed an added “U” in CCS, demonstrating increasing interest in CO₂ utilisation.

As part of the Clean Growth Strategy, the government also pledged to invest £100 million for innovation in CCUS to help lower costs, and reiterated the importance of exploring international collaborative opportunities with countries like Norway and Canada.

The current Minister of State for Energy and Clean Growth, the Rt Hon Claire Perry, demonstrated strong support for the technology and expressed her determination to make the UK an international leader in CCUS, while emphasising the potential for the UK to maximise the economic value associated with the technology.

To realise this goal, Minister Perry established the UK CCUS Council in January 2018, a Ministerially led working group of industry representatives and academia, which includes the Global CCS Institute’s CEO, Brad Page. The Council works to advise on CCUS policy and funding priorities as part of progressing the government’s approach to CCUS.

A CCUS Cost Challenge Taskforce was also established by the Minister to deliver recommendations on how to significantly reduce CCUS costs in the UK. The Taskforce gathered together 40 prominent and reputable industry and academic experts to release its report, *Delivering Clean Growth*, in July 2018. The report generated conclusions, messages and recommendations for the UK Government to achieve the ambitions laid out by the Clean Growth Strategy. Central to these were the creation of:

- a clear cost reduction pathway where government and industry work collaboratively to identify and unlock early investment opportunities
- a new business model for CO₂ transport and storage (which separates transport and storage from CO₂ capture projects)
- CCUS “clusters”, where industrial facilities can share infrastructure and knowledge.

The report also echoed the proposed actions put forward by the UK Committee on Climate Change in its 2018 Progress Report to Parliament to have at least two CCUS clusters operational from the mid-2020s²⁹. Following input from Taskforce’s recommendations, the government will publish its deployment pathway for CCUS by the end of 2018.

On 28–29 November, the UK Government hosted an International CCUS Conference in Edinburgh, in partnership with the Global CCS Institute, the IEA and other leading organisations.

CCUS potential in the UK

The existing industry clusters in the UK will form a key asset for the deployment of CCS. Several industrial initiatives have already built a strong business case for the development of industrial CCS. The Teesside Collective and Caledonia Clean Energy facilities are two ambitious commercial-scale CCS projects that could potentially kick-start the deployment of CCUS in the UK.

The Teesside Collective has made a strong case for the deployment of CCS. Hosting 60 per cent of the UK’s energy-intensive industry, the project would create and maintain almost 6,000 jobs in the region and help decarbonise a unique mix of industries.

Hydrogen is also an important part of the ongoing discussion in building a cost-effective pathway to decarbonisation of energy and gas. Promising developments include HyNet North West led by Cadent, the UK’s largest gas distribution network, and H21 North of England led by Northern Gas Networks. Both will deploy CCS to create low-carbon hydrogen production and distribution networks^{30, 31}.

In 2018, Drax Group announced it would pilot a biomass power generation project with the potential to develop BECCS in the UK. The project aims to capture and store CO₂ from Drax’s power station in North Yorkshire.

JOHN SCOWCROFT

Executive Adviser, *Europe*



In its ambitious industrial policy, the UK Government recognised CCUS as an important technology in its transition to a low-carbon economy.

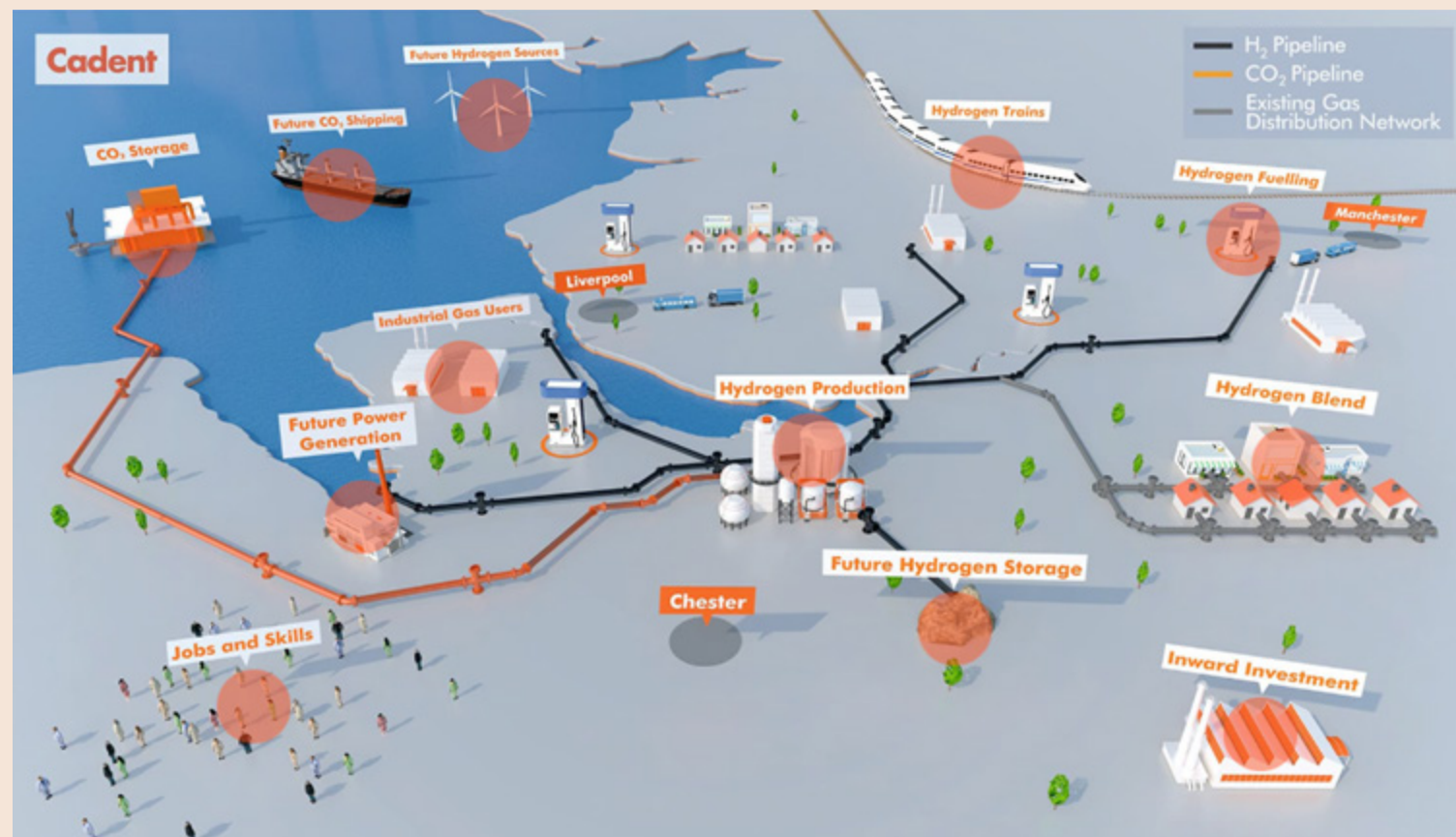
New CCS facilities in development – United Kingdom & Ireland

HyNet North West

- Facility lead: Cadent
- Location: Liverpool, Manchester and parts of Cheshire
- CO₂ capture capacity: Around 1.5 Mtpa
- Anticipated operation date: 2020s
- Storage type: Dedicated geological storage in the decommissioning Hamilton and Lennox gas fields in Liverpool Bay

The HyNet North West is a CCUS-equipped hydrogen production and distribution network developed by the UK gas distribution company Cadent together with Progressive Energy and ENI. The facility will produce hydrogen from natural gas that will then be supplied to industrial sites, to households for heat supply and serve as transport fuel. The project has the potential to serve more than 2 million homes and businesses.

A hydrogen production and carbon capture plant will most likely be located in Cheshire. The facility will convert natural gas into hydrogen gas via auto-thermal reforming to supply a core set of major industrial gas users and industrial sites. With this facility, Cadent is developing CCUS infrastructure that could easily be replicable elsewhere or expanded geographically to include other power generation or industrial sites.



OVERVIEW OF THE HYNET NORTH WEST. CREDIT – CADENT

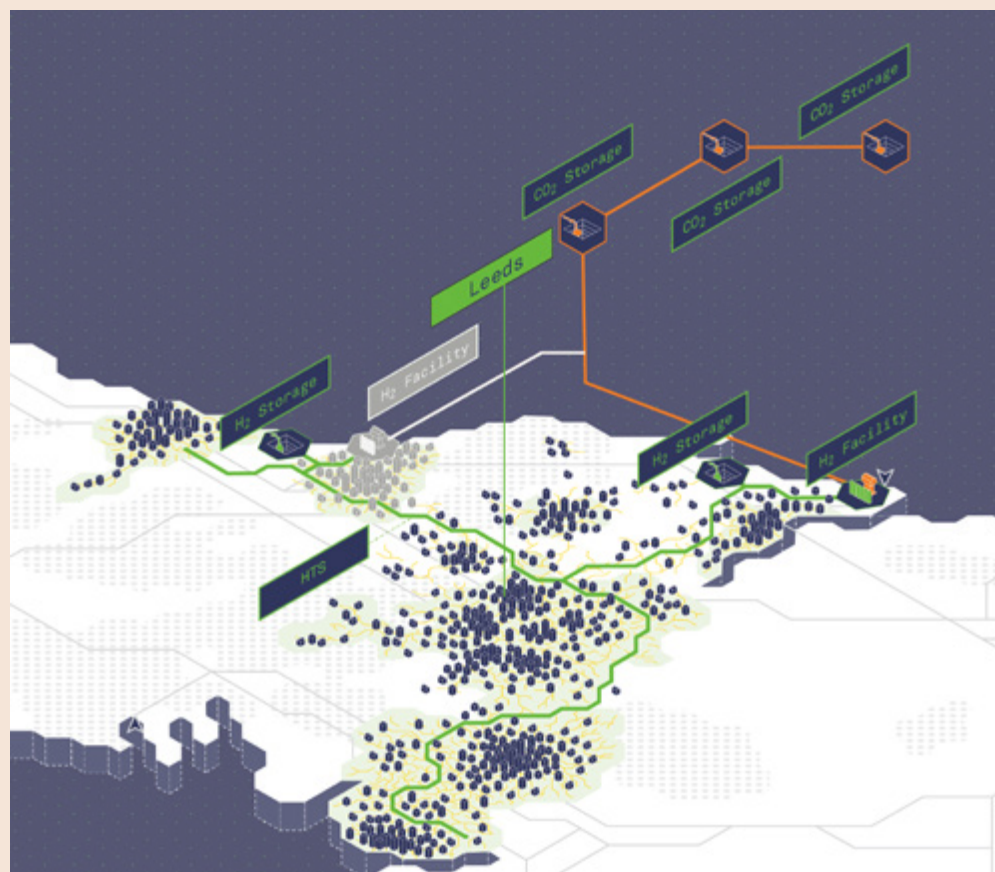
H21 North of England

- Facility lead: Northern Gas Networks
- Location: north of England
- CO₂ capture capacity: scaling up to 20 Mtpa between 2026-2028 and 2034
- Anticipated operation date: 2026-2028
- Storage Type: Dedicated geological storage in saline aquifers and potentially depleted gas fields in the Southern North Sea

The H21 North of England aims to decarbonise power, heat and transport across the North of England. It will convert the UK gas grid from natural gas to CCS

decarbonised hydrogen, converting 3.7 million-meter points across Leeds, Bradford, Manchester, Liverpool, Hull, York, Teesside and Newcastle.

The clean hydrogen will be produced from large-scale production plants with 12.15 GW capacity, with integrated CO₂ capture processes to capture up to 20 Mtpa CO₂ by 2035 in several phases. CO₂ storage is planned to be in saline aquifers and depleted gas fields in the Southern North Sea, which can potentially facilitate the advantages of the UK's growing CCS capacity and a CCS trade with Europe. The facility will also include 8 terawatt hours (TWh) inter-seasonal hydrogen storage of that enables flexible supply of clean energy.



OVERVIEW OF THE H21 NORTH OF ENGLAND. CREDIT – NORTHERN GAS NETWORKS

Ervia Cork CCS

- Facility lead: Ervia
- Location: Cork, Ireland
- CO₂ capture capacity: Around 2.5 Mtpa
- Anticipated operation date: 2028
- Storage type: Dedicated geological storage in offshore low-pressure Kinsale Gas Field

The Ervia Cork CCS Facility would involve capturing CO₂ from a number of emission-intensive companies located in Cork, with initial consideration being given to the two modern gas-fired, combined-cycle gas turbine (CCGT) power stations Whitegate and Aghada and Ireland's only oil refining business: Irving Oil Refinery (75,000 barrels per day).

The captured CO₂ is planned to be transported via an existing pipe network, which includes 54 kilometres offshore pipeline, to the potential CO₂ storage sites in the Kinsale Gas Field.

The Irish Government's National Mitigation Plan, published in 2017, recognised that CCS at gas-fired power stations "could facilitate decarbonisation of our electricity sector"³².

By 2050, the Ervia CCS Cork facility is expected to have cumulatively captured and stored 146 Mt of CO₂. Over this time, it is hoped that a CCS industry cluster can be formed around this infrastructure, to allow more industrial emission sources in Cork to make use of the storage facility.

Acorn Scalable CCS Development

- Facility lead: Pale Blue Dot Energy
- Location: Aberdeenshire, Scotland
- CO₂ capture capacity: 3.0 – 4.0 Mtpa, a scale up from an initial pilot development of around 0.2 Mtpa
- Anticipated operation date: 2020s
- Storage type: Injection from a new subsea well into Captain Sandstone Formation in the vicinity of a depleted gas field, at the depth approximately 1,900m below sea level

The Phase II, Acorn Scalable CCS Development, is a full-chain CCS facility that would use the existing CO₂ capture and pipeline infrastructure. Acorn Scalable is a scale up of the pilot project Acorn (Minimum Viable CCS Development), which is in development to operate CCS infrastructure at minimum capital cost for capture, transport and storage of CO₂.

The primary objective of the Acorn facilities is to initiate a low cost full chain CCS project in the North East of Scotland. This would act as a seed [Acorn] from which to grow a network of capture, transport and storage infrastructure³³.

The facility secured funding from the Advancing CCS Technologies (ACT) initiative, part of the European Research Area Networks (ERA-NETs) program. The infrastructure project, CO₂ SAPLING, is qualified as a European Project of Common Interest, making its infrastructure elements eligible for funding under the Connecting Europe Fund (CEF).

Netherlands – Pushing the boat out

With its large, natural industrial port clusters, especially in Rotterdam, it is no surprise that the Dutch have seen a very natural opportunity to “push the CCS boat out”. Government commitment and confidence have also sparked renewed interest in what CCS can do.

CCS was one of the proposed carbon reduction measures introduced to successfully achieve these climate targets. In its coalition agreement, the government outlined that CCS would help deliver 20 Mt reduction of CO₂ by 2030, which included 18 Mt captured from the industrial sector and 2 Mt reduction from waste incineration. Negotiations are currently underway to agree on the key points of the Dutch Climate Agreement. A fact-finding mission and a consultation process were set-up to determine the contribution of CCS to the country’s emission reductions targets (it is likely to be less than the original proposed figure of 20Mt). A final agreement is expected in late 2018.

During the year, the Port of Rotterdam Authority continued to pave the way for the development of CCUS infrastructure that could potentially establish an industrial CCUS hub in the Netherlands. The project aims to develop basic infrastructure to capture CO₂ in the port area from various industrial facilities and store the CO₂ in depleted gas fields in the North Sea.

In April 2018, a feasibility study on the large-scale deployment of CCS in the Port of Rotterdam found that CO₂ capture, transport and storage under the North Sea is technically feasible and a cost-effective measure to reduce carbon emissions and tackle climate change³⁴. In the next months, the three project leads will be consolidating the business case for the project, furthering research on its technical and financial elements. An investment decision is expected in 2019.

The Hydrogen 2 Magnum (H2M) will include a natural gas to hydrogen production plant with CO₂ capture and export facilities. The hydrogen will fuel the Magnum gas power plant, which will be converted into a hydrogen-fueled power plant designed to lower the plant’s carbon emissions at a large-scale. In July 2018, Equinor Energy contracted Jacob Engineering Group Inc. to undertake the feasibility study of a hydrogen production plant with a suitable CO₂ capture technology at Vattenfall.

Natural gas power plants play an important role in the Dutch energy power supply due to their reliability and flexibility. The Hydrogen 2 Magnum (H2M) will help maintain energy security, while significantly reducing CO₂ emissions for climate change mitigation.

Last year, the European Commission adopted four Projects of Common Interest in cross-border CO₂ transport, and Dutch stakeholders are involved in all four projects.

There are also several existing industrial facilities in the Netherlands that capture CO₂ as part of their production process. This year, the Dutch waste-to-energy and recycling company AVR announced it would be the first company in the country to begin the construction of a CO₂ capture plant to capture 60,000 tonnes of CO₂ annually. The captured CO₂ will be transported by the company Air Liquide and used in greenhouses. AVR’s other ambition is to find other applications for the captured CO₂, particularly in concrete and biofuels. AVR hopes to capture 800,000 tonnes of CO₂ annually in future³⁵.

With its large, natural industrial port clusters, especially in Rotterdam, it is no surprise that the Dutch have seen a very natural opportunity to “push the CCS boat out”.

Port of Rotterdam CCUS Backbone Initiative (Porthos)

- Facility proponents: Port of Rotterdam Authority, Nederlandse Gasunie (Gasunie) and Energie Beheer Nederland (EBN)
- Location: Port of Rotterdam area with potential connections to other European industrial areas (North West Rhine-Westphalia and Antwerp)
- CO₂ capture capacity: Initial phase of up to 2 Mtpa from 2021 onwards, with a longer-term target to increase to 5 Mtpa by 2030
- Anticipated operation date: 2021
- Storage type: Dedicated geological storage – offshore deep saline formations at the North Sea (disused gas reservoirs).

Hydrogen 2 Magnum (H2M)

- Facility proponents: Equinor, Vattenfall and Gasunie
- Location: Eemshaven, outside of Groningen
- CO₂ capture capacity: 2 Mtpa
- Anticipated operation date: 2024 (first unit)
- Storage type: Dedicated geological storage in an offshore reservoir in Norway.



“Port of Rotterdam is paving the way for the development of CCUS infrastructure that could potentially establish an industrial CCUS hub in the Netherlands.”

Norway – Forging new pathways

In May 2018, the Norwegian Government presented its revised national budget to Parliament and published its long-awaited assessment of the full-scale Norwegian CCS facility. In total, the Norwegian Government pledged to allocate NOK280 million in 2018 to the advancement and deployment of CCS in the country. This funding includes an additional NOK80 million as well as the unspent funds transferred from the previous year. The allocated budget will fund FEED studies for the capture, transport and storage of CO₂, and up to two new CCS facilities. The funding will also support Gassnova's budget of NOK100 million. The state enterprise will continue to deliver the CLIMIT research program (NOK180 million) and the implementation of concept and pre-design studies for the full-scale CCS project³⁶. The Technology Centre Mongstad will also receive NOK195 million to continue to test CO₂ capture technologies to help reduce costs and potential risks associated with CCS projects.

With their revised national budget, the Norwegian Government provided further clarity on the status of the Norwegian full-scale CCS facility. Following a review of concept studies and assessments completed in the fall of 2017, the government announced the next steps for each of the three industrial sites involved.

The Norcem facility was selected to receive state funding to proceed with further study of CO₂ capture at its cement plant in Brevik. This will be the last advanced planning study phase before a final investment decision. The government has been clear that the Norcem facility has the most favourable conditions for a successful implementation. This follows the advice from external quality assessors³⁶. The facility has demonstrated the lowest cost of CO₂ capture and

good implementation capacity. The facility will capture CO₂ from the flue gas of the cement plant, estimated at 400,000 tonnes of CO₂ per year.

The Fortum Oslo Varme facility was later confirmed to continue FEED studies for CO₂ capture at its waste-to-energy plant in Klemetsrud, following the findings of the concept study and external quality assurance. The facility will capture an estimated 400,000 tonnes of CO₂ per year. Gassnova deemed the learning potential from the world's first large-scale CCS facility in the waste-to-energy industry will be significant.

The aim of the Norwegian CCS full-scale facility is to capture CO₂ from different capture facilities and store them in a geological formation below the seabed in the North Sea. The FEED studies are expected to be completed by 2019. A final investment decision regarding any CCS facility is expected to be taken in 2020-21. If this goes ahead, it will take no more than four years to build the CCS infrastructure. It is estimated that the Norwegian full-chain CCS facility could be in operation at the earliest in 2023-24¹.

Like any CCS facility, success will be dependent on international collaboration and policy confidence – in this case, from the European Union. In fact, the Norway full-chain facility will be an important step forward in consolidating CCS infrastructure that will benefit both Norway and the rest of Europe.

The Norwegian facility can easily collect emissions from other point sources across Europe. According to Gassnova, the facility can secure storage for 4 Mtpa of CO₂, the equivalent of 10 times the amount of CO₂ captured from one of the Norwegian capture plants³⁶. The CO₂ can then be easily transported by ship to a temporary storage site on the Norwegian

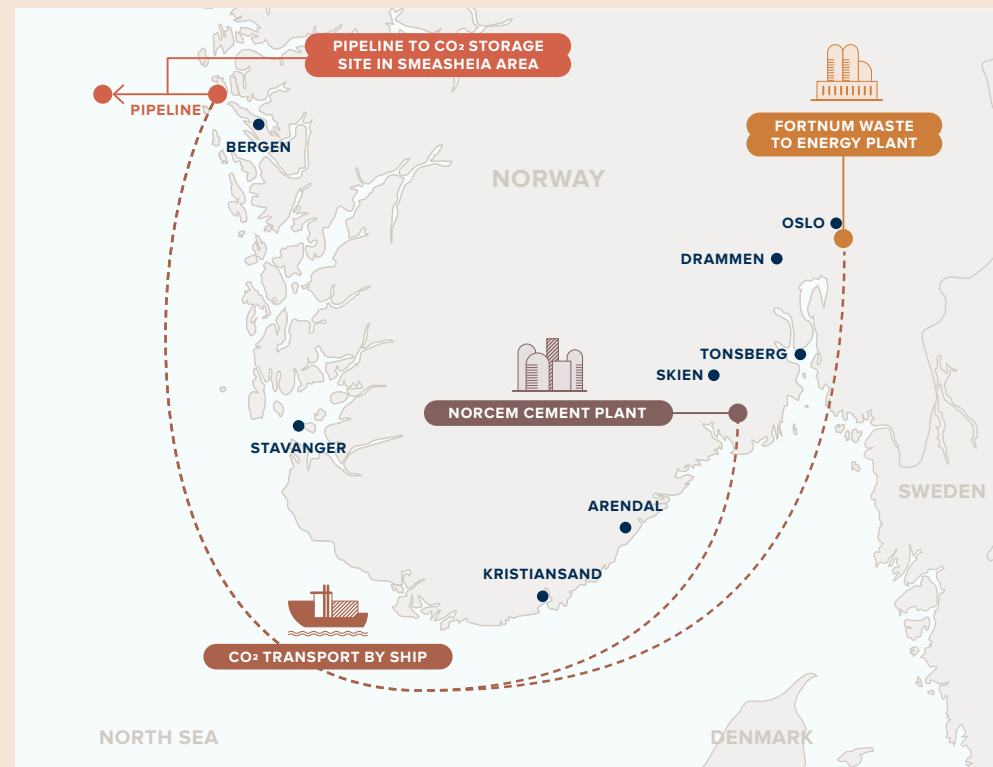


FIGURE 14: CO₂ capture, transport and storage scheme for Norway Full-Chain CCS Facility. Image information supplied by Gassnova

west coast and stored under the North Sea. The regional dimension of the Norwegian CCS facilities is also becoming apparent. The Swedish refinery Preem AB is currently studying how to collaborate with Norway for CO₂ storage.

In July 2018, the Norwegian Ministry of Petroleum and Energy invited companies to bid for exploitation

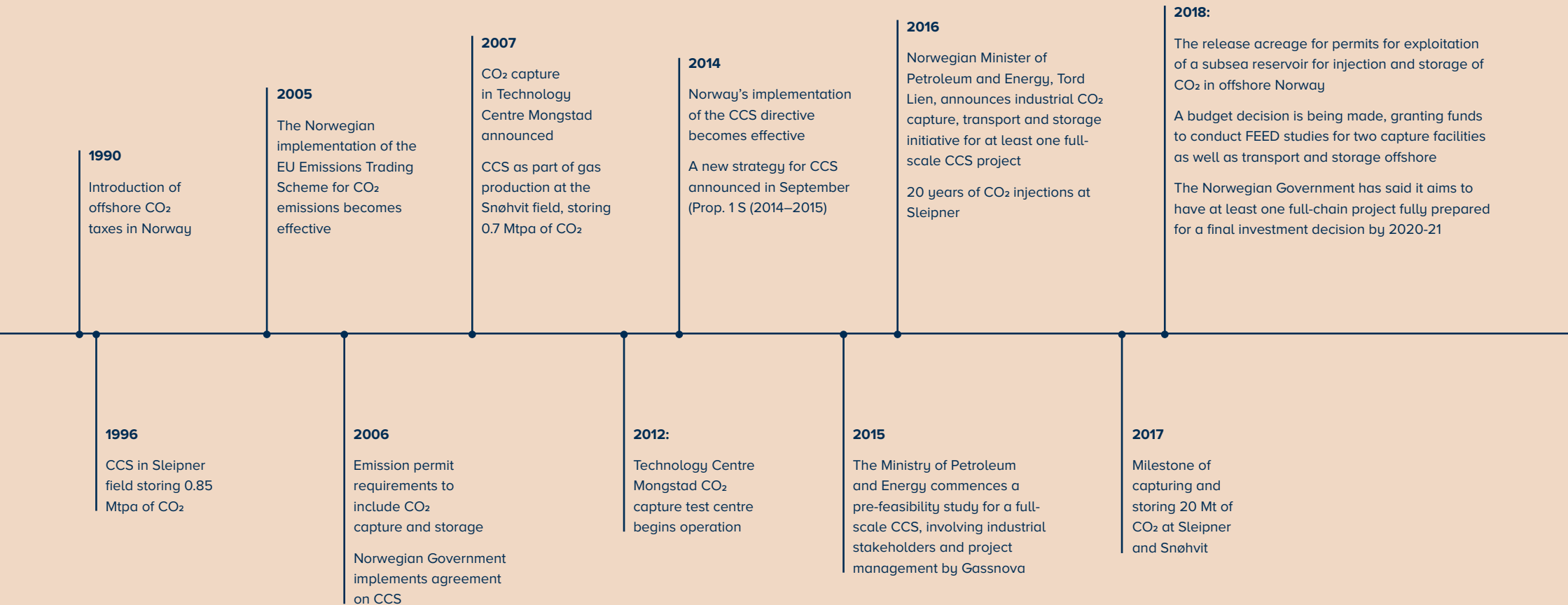
permits for the injection and storage of CO₂ in the Norway's subsea reservoirs, near the Troll field. The exploitation licenses will be allocated during fall this year.

It is evidence that Norway continues to not only pave the way, but forge new pathways, for CCS success.



The facility is part of the Norway Full-Chain CCS, an important step forward in consolidating CCS infrastructure that will benefit both Norway and the rest of Europe.

TIMELINE OF CCS IN NORWAY





Realising
COST-EFFECTIVE
CCS SOLUTIONS

Phil MacDonald

HEAD OF COMMUNICATIONS, *Sandbag*

“Emissions reductions in the power sector are accelerating, but industrial emissions are staying stubbornly high. We see CCS as essential for building low-carbon manufacturing and industry.”

Sandbag is a climate change think tank based in Brussels and London.

GORGON CARBON DIOXIDE INJECTION.
CREDIT – CHEVRON AUSTRALIA

Case Study

AUSTRALIA

TOWARDS THE
hydrogen highway



Over the past year, Australia became an epicentre for vigorous energy discussion, with often furious political debate raging across a swathe of issues including electricity reliability, power pricing, renewables energy targets, coal-fired power and climate change commitments.

Such was the intensity, an outsider looking in could be forgiven for thinking that little or nothing was happening in the CCS space.

The reality, however, couldn't be further from the truth. Australia continued to advance the CCS cause through policy refinement and a major decision to build an international hydrogen hub.

Levelling the playing field

In May 2018, the Australian Federal Parliament introduced a key piece of legislation that stimulated discussion about CCS receiving investment funding through the Clean Energy Finance Corporation (CEFC), the government agency responsible for administering AU\$10 billion in clean energy projects aimed at lowering Australia's carbon emissions.

The *Clean Energy Finance Corporation Amendment (Carbon Capture and Storage) Bill 2017*, could remove the prohibition on the CEFC investing in CCS technologies and allow it to enjoy the same investment opportunities as renewable energy and other low-emission technologies.

The birth of "Blue Hydrogen"

In early 2018, the governments of Australia, Japan and the State of Victoria, along with Institute members, Kawasaki Heavy Industries, J-Power and other industry partners, announced the launch of a Hydrogen Energy Supply Chain (HESC) in the Latrobe Valley, west of Melbourne.

This AU\$500 million initiative is the first step for the future CCS enabled low-emission hydrogen – or Blue Hydrogen – from the Latrobe Valley's abundant brown coal reserves. This hydrogen will be exported to Japan for use in heating and transportation.

Success of the pilot phase will culminate in a commercial-sized plant, which will include a CCS facility that will store CO₂ at multiple storage options in the well-characterised Gippsland Basin.

The HESC project heralds the birth of a hydrogen industry in Australia that will ultimately put CCS at the centre of a new energy economy – securing jobs, sustaining communities, and paving the way for a global hydrogen economy that combats climate change.

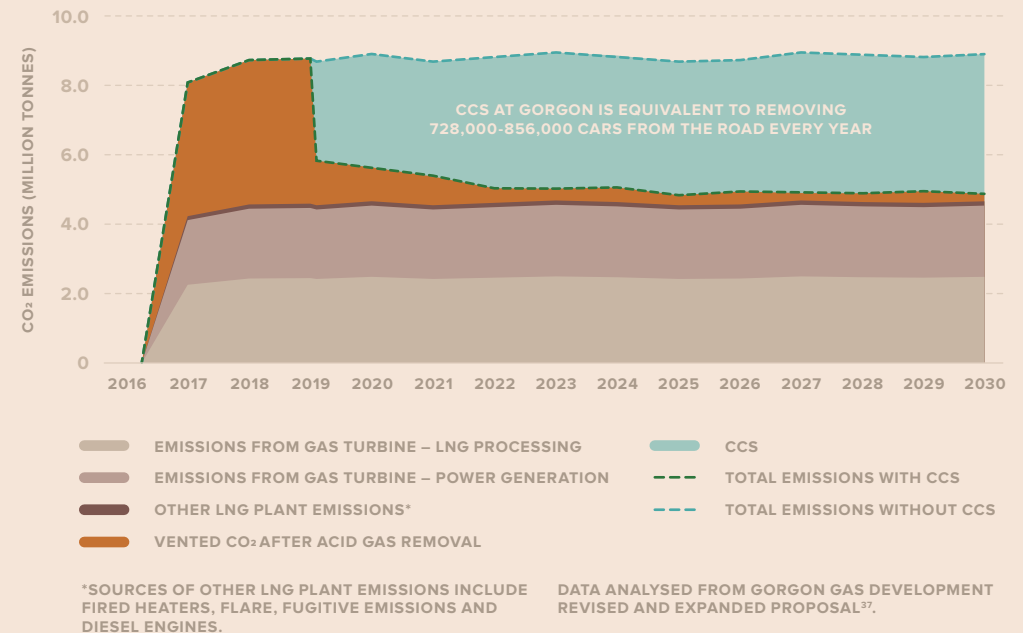
CCS enables hydrogen to be produced from coal or gas with near-zero emissions and at low commercial cost. Multiple studies have found that converting coal and gas to hydrogen and using CCS is the cheapest way to produce low-emission hydrogen.

CarbonNet

As the hydrogen development moves forward, the CarbonNet CCS facility continues to undertake all necessary due diligence to ensure that the CCS network is successful.

Currently, the facility is in the development and commercial establishment phase. Over the past year, this has focused on seismic studies and the drilling of an appraisal well at the Pelican site (see diagram) in the Bass Strait. This will verify the

FIGURE 15: CO₂ equivalent emission abatement from CCS at Gorgon LNG project



properties of porous rock below the seabed where CO₂ will be injected and permanently stored, and investigate the potential for establishing a commercial-scale CCS network.

The network would bring together captured CO₂ at multiple CO₂ emission point sources in Victoria's Latrobe Valley, transporting CO₂ via a shared pipeline and injecting it into deep offshore storage sites in Bass Strait.

CarbonNet is managed by the Victorian Department of Economic Development, Jobs, Transport and Resources, with funding from the Australian and Victorian governments.

Gorgon

Gorgon, which will be the world's largest CCS facility in dedicated geological storage, continues to move towards start-up, scheduled for early 2019. Once in operation, this facility is anticipated to capture and inject between 3.4–4 Mtpa of CO₂, slashing greenhouse gas emissions from Gorgon by about 40 per cent. Emissions will be injected into a storage resource more than 2 kilometres underneath Barrow Island, which lies 100 kilometres off the Australian west coast.

ANTONIOS PAPASPIROPOULOS

Global Lead – Advocacy and Communications



VITAL
and
VIABLE

Akshat Rathi

REPORTER AT QUARTZ, a global business publication

“After a year of reporting, visits to large and small carbon capture plants around the world and conversations with more than 100 academics, entrepreneurs, policy experts, and government officials, I’ve come to the conclusion that carbon capture and storage is both vital and viable. Its mass deployment remains a challenge, but not for the reasons many environmentalists commonly cite.”



RE-IMAGINING

Carbon

Paul Atkins

DIRECTOR, *The Carbon Paradox* (in development)

BAFTA AWARD WINNER, *The Trials of Life* (1990)

EMMY AWARD WINNER, *The Great White Shark* (1995)

SECOND UNIT DIRECTOR OF PHOTOGRAPHY, *Master and Commander* (2003)

SECOND UNIT DIRECTOR OF PHOTOGRAPHY, *The Tree of Life* (2011)

“Carbon can be re-imagined as resource, mined from the sky or industrial sources and sequestered or turned into carbon products.

Carbon is not our enemy. Without it as a greenhouse gas, the Earth would be a freezing wasteland. But too much of it in the atmosphere, and the planet becomes intolerably hot. Global warming is really a carbon balance problem.

Most scientists believe carbon capture and sequestration will be essential to avoid the worst impacts of rising global temperatures. Carbon can be re-imagined as resource, mined from the sky or industrial sources and sequestered or turned into carbon products. This is not only a transformative and profitable idea but a necessary one.

And yet, the world seems unaware that the technology to do this even exists. That needs to change, and I support the Global CCS Institute’s goal of promoting awareness and helping move us toward a clean and prosperous future.”

Dr Julio Friedmann

CEO, *Carbon Wrangler*. DISTINGUISHED ASSOCIATE, *Energy Future Initiative*.
SENIOR RESEARCH SCHOLAR, *Centre for Global Energy Policy*, Columbia University.



A sneak peak into the

FUTURE

BETTER LIVING THROUGH

carbon management

“The future might
carry some big
surprises in carbon
management.”

The stars have begun to align for carbon management, including CCS, carbon-to-value (CO₂ recycling) and carbon removal. The uncomfortable recognition that most major economies won't achieve their climate targets for Paris, the unsettling facts in the IPCC's recent 1.5°C report, and the spate of climate-related disaster (fires, floods, storms and drought) reveal man-made climate change as a chronic condition.

Thankfully, dramatic progress in technology, policy, investment and business around carbon management balances the scales and drives current interest and progress on many fronts:

- Increased membership, ambition, and investment commitments in the Oil and Gas Climate Initiative culminated in the announcement that CCS will be the focus of 13 major oil and gas companies in 2019. The FUTURE Act in the US has led to multiple announcements of new projects. California has augmented its low-carbon fuel standard to include CCS as a compliance mechanism. And Net Power, Inventys, FuelCell Energy and other capture companies have announced major milestones and fundraising rounds.
- In carbon-to-value, the Carbon XPRIZE announced its finalists and the birth of two functioning testbeds. Universities around the world announced new programs and commitments to CO₂ recycling, including the University of Michigan, Columbia University and Imperial College. Solidia (cement and concrete), Econic (plastics) and Newlight (plastics) all announced production, new investment and contracts.

Perhaps the largest shift is around CO₂ removal. Front and centre are the direct air capture (DAC) companies (Climeworks, Carbon Engineering and Global Thermostat), all of which have had major project announcements, contracts for delivery and record fundraising. Perhaps the reports from the Royal Society, the National Academies, World Resource Institute and the Japanese Government played a role. They all highlighted the important role for BECCS and underscored the need for conventional CCS to succeed and thrive. At the same time, stunning speed in innovations around blockchain, AI, autonomy, material discovery and additive manufacturing suggest improvements in cost and performance are just around the corner.

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Any Questions

*Contact a member of the Advocacy
and Communications Team*

globaleccsinstitute.com/contact

Head office:

Level 16
360 Elizabeth Street
Melbourne VIC 3000
P +61 (0)3 8620 7300

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