The Global Status of CCS: 2017

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About the Global CCS Institute: the world authority on carbon capture and storage

The Global CCS 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.

Working with a large and diverse membership, the Institute drives the adoption of CCS 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 diverse international membership includes governments, global corporations, private companies, research bodies, academic institutions, and non-governmental organisations, all of which are committed to CCS as a proven and pivotal part of a decarbonised future.

List of acronyms

2DS	2°C Scenario
B2DS	Beyond 2°C Scenario
BECCS	Bioenergy with CCS
CCS	Carbon capture and storage
CCUS	Carbon capture utilisation and storage
CDM	Clean Development Mechanism
COP	Conference of the Parties
CSLF	Carbon Sequestration Leadership Forum
CTCN	Climate Technology Centre and Network
EC	European Commission
ENGO	Environmental non-governmental organisation
EOR	Enhanced oil recovery
EU-ETS	European Union's Emissions Trading System
GHG	Greenhouse gas
Gt	Gigatonne
GW	Gigawatt
HELE	High Efficiency Low Emission
IEA	International Energy Agency
IETA	International Emissions Trading Association
IPCC	Intergovernmental Panel on Climate Change
Mtpa	Million metric tonnes per annum
MW	Megawatt
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
UNFCCC	United Nations Framework Convention on Climate Change
US DOE	United States Department of Energy
WBCSD	World Business Council for Sustainable Development

About the report: taking the heat away

The Global Status of CCS 2017 documents the current status of CCS around the world and the significant operational milestones over the past 12 months. The report tracks the worldwide progress of CCS technologies and the key opportunities and challenges it faces.

It demystifies common misunderstandings about the technology and identifies where and how it can, and must, be more widely deployed.

The report is an indispensable resource for governments, policy-makers, scientists, academics, media commentators and the millions of people who care about our climate and want to save our planet.

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

With commentary from leaders and luminaries across the climate change echelon, this report makes an indelible case for CCS as an indispensable climate change solution.

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

What's inside –

Delivering the new energy economy

Suddenly, CCS is part of the political discourse, however vexed, and we find ourselves talking directly to policy parity issues around the world.

It would not be an exaggeration to say that the past year has been particularly momentous for carbon capture and storage.

Two new large-scale facilities came onstream and others, in China, Canada and Australia, moved closer to operation.

China demonstrated enormous commitment to ensuring CCS becomes a mainstay of its decarbonised future with eight large-scale facilities in varying stages of development, and levels of CCS funding and research hitting new heights.

In Europe, CCS focus shifted to industrial clusters potentially using storage options in the North Sea.

Despite ongoing climate change policy speculation in the United States, the start-up of Petra Nova in Texas and of the Illinois Industrial CCS facility proved that CCS plants can proceed in any weather.

Weather has been the operative word. In Australia, blackouts and outages caused by extreme climatic conditions and the well-known limitation of intermittent renewables to "do it all" in an integrated electricity system, made climate change and energy security major topics of conversation.

Suddenly, CCS is part of the political discourse, however vexed, and we find ourselves talking directly to policy parity issues around the world.

Globally, the year was significant in pure advocacy terms. With concerted effort, and as part of our dedicated campaign – "Join the Underground" – CCS started to enjoy wider exposure for the safe, tested, commercial and versatile clean technology it is.

The media started to sit up and take notice.

Moving CCS from marginal player to mainstream mitigator is a real focus of our efforts and we have struck a chord with a people-chain that straddles government, industry, academia and a myriad of key commentators.

There remains, however, an overriding need to extend that people-chain beyond a small fraternity. In a break from tradition, this year's report is not just intended for those "in the know". It has been specifically designed to appeal to those outside the circle who are less familiar with the technology and who do not appreciate its enormous potential.

Simply put, CCS is the conduit to a new energy economy; an economy of clean and sustainable energy across all forms – wind, solar, battery storage, hydrogen, bioenergy and the raft of CO_2 reuse applications.

CCS is the only clean technology capable of decarbonising major industrial sectors such as steel, cement, pulp and paper, refining and petrochemicals.

It is one of the few technologies able to alleviate emissions from unabated gas and coal-fired power, thus preserving jobs and sustaining communities.

And it is distinctive in its ability to remove historic CO_2 emissions from the atmosphere when bioenergy is twinned with CCS (BECCS).

These facts, well-proven in science and endorsed by pre-eminent leaders in the field, as this report attests, make CCS pivotal to a 2°C future – and indispensable to anything beyond.

2017 was a good year for CCS but there is much, much more to be done.

With your support, we can maintain the momentum of the past year and allow CCS to fulfil its true potential as the technology that delivers a new energy economy.

BRAD PAGE
Chief Executive Officer
Global CCS Institute

A time to coalesce around CCS

12 December 2015 was a seminal moment in the history of our planet and of international collaboration. Progress has continued rapidly, notwithstanding some hesitation in Washington, DC.

Over the coming 12 months, I sincerely hope CCS garners the attention and practical support it deserves.

The Paris Agreement was ratified at an unprecedented rate and much has been achieved within a very short time to agree and implement a variety of mitigation measures in pursuit of the Paris target to keep global atmospheric temperature increase to well-below 2˚C.

We have seen 195 countries commit to measures designed as the first steps towards achieving the Paris targets. The G19 at the May 2017 Hamburg G20 said, "Paris is irreversible", and the G20 as a whole declared for the 2030 Sustainable Development Goals agenda and set its objectives as "strong, sustainable, balanced and inclusive growth".

Yet, two key things remain missing.

First, we have not seen the acceleration needed to meet the ambitious targets set. That is the central issue for the next two or three Conferences of the Parties (COP) and for individual country action.

Second, we have not yet witnessed countries embracing the full array of clean technologies needed to achieve those targets.

It is no secret that along with renewables, energy efficiency and carbon pricing, I am a supporter of the need to also deploy carbon capture and storage. We must pursue the low-carbon and zero-carbon growth story across the board in our cities, infrastructure, and land use. We must recognise, however, that it is likely that the world may not transition completely away from fossil fuels in the necessary time frames. Yet, we cannot tolerate the continued emissions that are the consequence of this if Paris is to be realised. Indeed, one of the key features of the Paris Agreement was the recognition that the temperature target requires zero-net emissions in the second half of the century. That will require some substantial negatives. In both these endeavours, CCS is absolutely necessary. It is likely necessary, too, in major parts of economic activity outside the power sector.

Over the coming 12 months, I sincerely hope CCS garners the attention and practical support it deserves. Governments, policy-makers and the private sector must coalesce, in the same way as signatories did in Paris in 2015, if we are really serious about meeting those targets. The challenge is to understand how scale can be built and costs reduced. Experience, collaboration and mutual learning will be crucial.

Best wishes,

LORD NICHOLAS STERN

IG Patel Professor of Economics & Government – London School of Economics

Chairman, Grantham Research Institute

Understanding carbon capture and storage

What is CCS?

CCS is a critical CO_2 emission abatement technology. It encompasses an integrated suite of technologies that can prevent large quantities of CO_2 from being released in the atmosphere from the use of fossil fuels. It is a proven technology and has been in safe, commercial operation for 45 years.

CCS in numbers

17 **large-scale CCS facilities operating globally, four coming on stream in 2018**

these 21 facilities have a CO_2 capture capacity of 37 million tonnes per annum (Mtpa)

The equivalent of 8 million cars removed from the road each year

220 million tonnes of man-made CO_2 has been injected deep underground to date

CCS is the only technology able to decarbonise the industrial sector

To reach the Paris 2°C target...

2,500

CCS facilities operating in 2040

(Based on a CCS facility with a CO_2 capture capacity of ~1.5 Mtpa)

14%

of cumulative emissions reductions must be derived from CCS

How does CCS work?

There are three major elements to CCS:

Capture

The separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural-gas-fired power plants, steel mills, cement plants and refineries.

Transport

Once separated, the CO_2 is compressed and transported via pipelines, trucks, ships or other methods to a suitable site for geological storage.

Storage

CO_2 is injected into deep underground rock formations, usually at depths of 1 kilometre (km) or more.

Why do we need CCS: versatile, timely and utterly economic

CCS is a climate game-changer. It is one of the few technologies able to adequately displace CO_2 from coal and gas-fired power stations and the only technology capable of reducing large-scale emissions from myriad industrial sources.

CCS also has the unique capacity to be retrofitted to many existing complexes to allow them to function cleanly for the term of their natural life.

The Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) have both evidenced the critical role that CCS must play in meeting global emissions reduction goals.

CCS is 'of its time'. Through enhanced oil recovery (EOR), it is proving its commercial worth by improving oil recovery from existing fields, using these same fields to permanently store the injected CO_2.

Through cleaning old industry and giving it a second life, CCS is preserving jobs and keeping local economies alive.

Most significantly, CCS is starting to demonstrate its climate change prowess in delivering commercial returns in a new energy economy where hydrogen production and bioenergy are starting to gain traction.

And, it is proving itself economically comparable to all other clean technologies.

WHAT CAN BE DONE WITH CAPTURED CO_2?

- CO_2 can be safely stored in deep underground geological formations.
- CO_2 can be used as a value-added commodity. This can result in a portion of the CO_2 being permanently stored – for example, in concrete that has been cured using CO_2 or in plastic materials derived from biomass that uses CO_2 as one of its key ingredients.
- CO_2 can be converted into biomass. This can be achieved, for example, through algae farming using CO_2 as a feedstock. The harvested algae can then be processed into biofuels that take the place of non-biological carbon sources.

CCS: 12 key facts

1 **CCS is a climate change technology. It is probably the most versatile and vital climate mitigation technology that exists.** Irrefutable evidence by the IPCC, IEA, plus numerous other international specialist bodies concur that international climate change targets cannot be achieved without CCS.

Note: IEA findings maintain that to reach Paris climate targets of 2˚C, 14% of cumulative emissions reductions by 2060 must derive from CCS.[i]

2 **CCS has been working safely and effectively for 45 years (since the Apollo 17 moon landing in 1972).** Operations undertaken over almost half a century demonstrates that CO_2 can be safely stored deep below ground. Oil, gas and naturally occurring CO_2 reservoirs have proven that fluids can be safely sealed underground for millions of years. CCS facilities target the same geology.

CCS technology is verifiably well tested. Seventeen large-scale facilities are operating successfully around the world (with four more coming onstream shortly). These 17 facilities are currently capable of capturing more than 30 Mtpa of CO_2 per annum.[ii]

3 **There is no evidence to indicate that CCS causes earthquakes.** CO_2 injection does have the potential to cause micro-seismic activity in the same way as other customary engineering activity, including mining, dam construction and oil or gas development. This micro-seismic activity is monitored, and is of such a low magnitude, it cannot be felt on the surface of the Earth. The meticulous characterisation of CO_2 storage sites to identify and understand below-ground stress and pressure conditions minimises the risks of seismicity. It is also worth noting that the injection and geological storage of CO_2, in conventional oil and gas fields or deep saline formations, does not require hydraulic fracturing.

4 **On a like-for-like total system cost basis, CCS is cheaper than intermittent renewables and costs continue to decrease as more facilities commercialise.** In the power sector, CCS can provide the necessary backup and other services to complement intermittent renewables, and costs continue to decrease as more facilities commercialise. Since the Boundary Dam CCS facility in Canada began operations in 2014, savings of as much as 30% have been identified for construction of a like (or follow-up) facility.[iii] This demonstrates the declining costs of deployment. As a simple law of economics, costs will continue to fall as more facilities come onstream. What is expensive is not doing anything at all.

5 **CCS is commercially successful as the 17 large-scale facilities operating around the world attest.** Similarly, the four plants poised to come onstream and the raft of other facilities in development (seven in China alone) further demonstrate its commercial viability and versatility.

6 **CCS is not a "front" for the coal or wider fossil fuel industry.** Rather, it is a pragmatic technology with wide application that can bridge the gap between our current fossil fuel dependence and a future that is fossil free.

It is the only clean technology able to address emissions across major industrial sectors (including steel, cement, chemicals, fertiliser, petro-chemicals, paper and pulp).

Furthermore, CCS is the only technology able to curtail emissions from the more than 500 new coal plants (Units) currently being built around the world today (and an additional 1,000 in planning).[iv] CCS's ability to retrofit aged coal plants keeps jobs and economies alive as the world transitions to a low-carbon future. Even critical and supercritical coal technologies like HELE (high-efficiency low-emission) technology, need CCS to mitigate CO_2 emissions. There is no such thing as clean coal without CCS.

7 **CCS complements renewables by reducing emissions in industries that renewables cannot penetrate – notably, steel, cement, chemicals, fertilisers, petrochemicals, paper and pulp.** International climate change bodies (IPCC, IEA) confirm that CCS is the only mitigation technology able to decarbonise large industrial sectors. CCS and renewables are partner technologies working towards the same decarbonised objective.

8 **There is abundant global CO_2 storage resources to support widespread CCS deployment**. Detailed surveys have been undertaken in many countries, including the United States (US), Canada, Australia, Japan, China, Norway and the United Kingdom (UK), where potential storage sites are well defined and well documented. Many other countries are progressing storage studies.

9 **CCS works effectively and its wide adoption and escalating deployment supports that fact.** CCS still deserves greater awareness and increased incentivisation through policy parity with other low-carbon emission technologies (the same sort of market instruments that renewables enjoy).

10 **CCS is needed because the amount of fossil fuels we burn continues to rise.** Last year, fossil fuels reached a record 83.6 billion barrels of oil equivalent (Bboe) compared to 73.3 Bboe 10 years ago. There are no signs of abatement. In 25 of the last 26 years, we burned more fossil fuels than the year before. The only year recording a decrease in the last 25 years was 2009 (caused by the global recession). CO_2 emissions have increased every year since 1960 and in the last two years, these hit all-time records.[v]

The renewables' (solar and wind's) share of gross electricity generation is currently less than 5%, rising to 17% by 2040.[vi] Fossil fuels' share of electricity generation will equate to 50% by 2040. This confirms the urgency at which CCS must be applied to power and wider industry.

11 **The reason why some CCS facilities have not matured has nothing to do with technology, cost or capability.** For example, the Kemper CCS facility in Mississippi made the decision to run the plant with natural gas instead of coal. This made the need for a gasifier redundant. Since carbon capture was linked to the gasifier, CCS is now not applicable. The Petra Nova CCS Plant in Texas and the Boundary Dam facility in Canada are testament to the capability of CCS and its profitability in the power sector.

12 **The Global CCS Institute is an independent, member-owned climate change organisation that advocates for wider CCS deployment on behalf of its 55 members, including governments, large and small companies, researchers, academics and Environmental non-governmental organisations (ENGOs).**

As the leading world authority on CCS, the Institute is an accredited member of reputable climate change organisations including the United Nations Framework Convention on Climate Change (UNFCCC) and the IPCC, while it enjoys very close and supportive relationships with the IEA, the International Emissions Trading Association (IETA), the World Business Council for Sustainable Development (WBCSD), the Climate Technology Centre and Network (CTCN) and the Carbon Sequestration Leadership Forum (CSLF), to name a few.

Storage: safe, permanent and abundant

Many people assume that one of the biggest challenges impeding the acceleration of CCS facilities is limited underground CO_2 storage resources.

The reality is, there is more underground storage resource than is actually needed to meet Paris climate targets.

In fact, a large proportion of the world's key CO_2 storage locations have now been vigorously assessed and almost every high-emitting nation has demonstrated substantial underground storage resources. As an example, there is between 2,000 and 20,000 billion tonnes of storage resources in North America alone. Countries including China, Canada, Norway, Australia, US and the UK all boast significant storage availability, and other countries such as Japan, India, Brazil and South Africa have also proven their storage capability.[vii]

The IEA has indicated that over 100 billion tonnes of (cumulative) storage capacity is needed by 2060 if CCS is to contribute its targeted 14% of emissions reductions under the IEA's 2˚C scenario (2DS). In the year 2040, for example, the annual amount of CO_2 captured and stored deep underground under the 2DS is approaching 4 billion tonnes.[viii]

This means that the issue, and current challenge, has nothing to do with storage resources, it is all about identifying storage sites and that comes down to issues taking place above-ground – policy, funding and awareness.

This last point is very important to those who may not be familiar with storage and how it works.

CO_2 storage is safe, secure and highly effective. Storage sites can be selected, characterised, operated and sealed-off, based on well-established practices and techniques gained from decades of relevant industry experience in a variety of settings around the world. Over these years, many millions of tonnes of CO_2 have been injected and stored, with no tangible evidence of leakage.

There is considerable and very compelling evidence to support the storage aspect of CCS:

CO_2 is a common gas trapped in geological systems for millennia and CO_2 storage mimics natural processes.

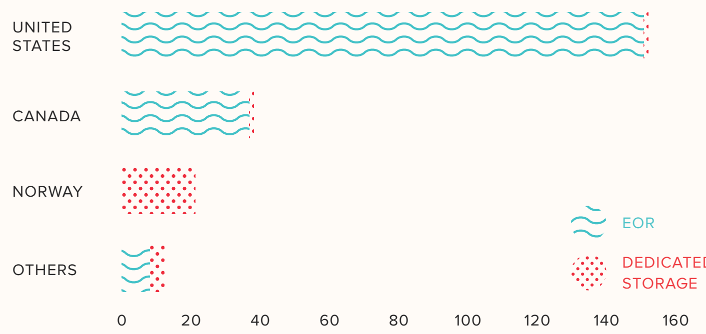
Vast amounts of naturally occurring CO_2 has been trapped underground for millions of years. The same kind of rock that keeps naturally occurring CO_2 (and oil and gas) underground for millennia will trap injected CO_2 permanently. Naturally occurring CO_2 provides an understanding of storage processes. Knowledge is also gained from naturally-occurring CO_2 formations that have been used as the primary source of CO_2 for EOR in the US for decades, providing up to 45 Mtpa.[ix]

Over 200 million tonnes of anthropogenic CO_2 has been successfully injected underground.

Accumulated experience of CO_2 injection worldwide over several decades has proven there are no technical barriers preventing the implementation of storage. Over 40 sites have or are presently safely and securely injecting man-made CO_2 underground, mainly for EOR or explicitly for dedicated geological storage.[x] Additional experience is also gained from industrial analogues such as waste water, acid-gas and natural-gas storage.

CUMULATIVE CO_2 INJECTION IN LEADING COUNTRIES

220 MILLION TONNES CO_2 INJECTED UNDERGROUND (APPROXIMATE VALUES)



Source: Global CCS Institute

Note: "Others" include Algeria, Brazil, China, Saudi Arabia, United Arab Emirates, Germany and France.

Data refers to anthropogenic CO_2.

A variety of monitoring technologies have been successfully deployed, demonstrating our ability to measure, monitor and verify injected CO_2 in the subsurface.

Monitoring of a CO_2 storage site occurs over its entire lifecycle from pre-injection to operations to post-injection; it enables the progress of CO_2 injection to be measured and provides assurance that storage is developing as expected. Operational and research experience over several decades demonstrates that injected CO_2 can be monitored to confirm its containment.

Leakage of CO_2 from geological storage presents a very low risk to human health and the environment.

Research indicates that the impacts of (unintended) CO_2 leakage on land or in marine environments are unlikely to cause permanent harm to ecosystems and communities. If CO_2 was discovered to be migrating towards the surface, operational experience from large-scale projects, and pilot-scale programs, have informed a range of interventions to control, minimise and prevent leakage.

There is very high confidence that global CO_2 storage resources are sufficient to support CCS deployment consistent with global emissions reduction goals.

Assessments of storage resources have been undertaken in more than 60 countries and these assessments have indicated that global CO_2 storage resources available to support CCS deployment are potentially vast, and exceed what we need over coming decades.

Storage is proven across dedicated storage facilities around the world and across a range of geological environments.

There is extensive operational experience to show that properly assessed subsurface formations can easily accommodate CO_2 and in a commercially viable way. Commercial operations have injected and stored CO_2 across a range of environments from onshore through to deep offshore sites and in different geological settings, depths and storage rock types.

In short, we have the "underground" – we have the rocks, the experience and technology.

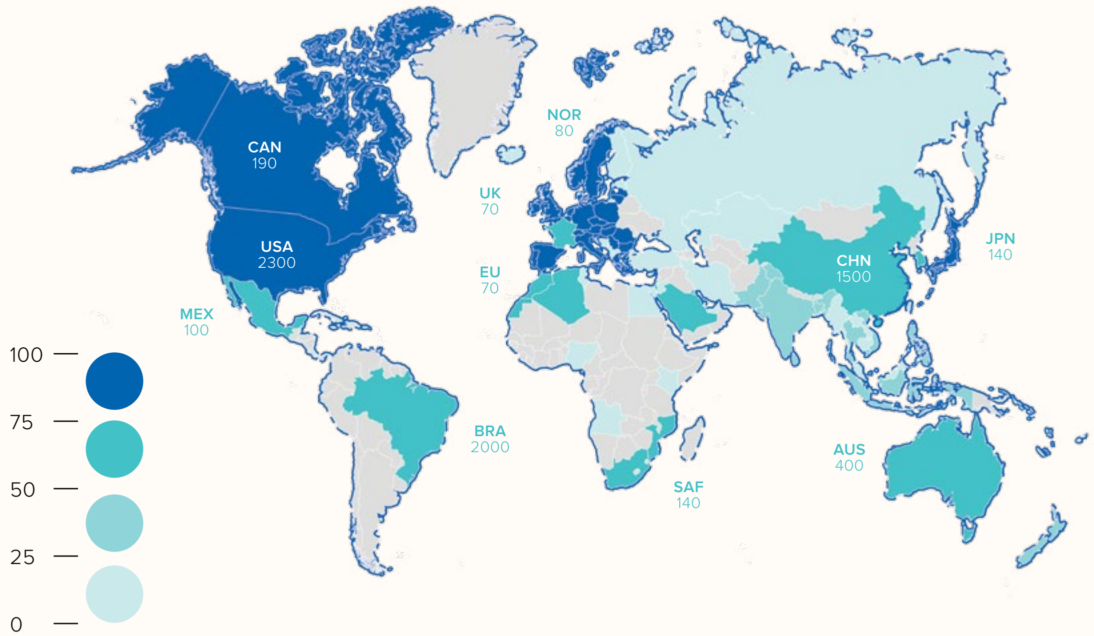
All we need is everyone standing above-ground to support the cause.

DR CHRIS CONSOLI

Senior Consultant – Storage

Global CCS Institute

Global storage resources



Source: Global CCS Institute (November 2017)

Colour scale is based on the level of detail and technical understanding of storage formations in an individual country, which reflects the confidence in storage resource estimate and storage prospectivity. The storage resource estimates (in gigatonnes CO_2) of key nations based on published national storage resource assessments.

CCS: A critical technology for saving our environment

Father of the phrase Global Warming

– PROFESSOR WALLACE SMITH BROECKER

A viable backstop against a bad CO_2 trip

Despite all the talk about reducing fossil fuel CO_2 emissions, the amount produced each year keeps rising. Little of any consequence is being done to meet the challenge. We continue to nibble when bold action is needed. Our military spends billions of dollars each year to maintain the capability to deal with a global war. The US National Institutes of Health spends untold tens of millions of dollars preparing to ward off a pandemic. Yet, we only spend a pittance preparing to cope with a global climate crisis.

Looked at in a positive way, the capture and storage of CO_2 would create an industry 10–20% the size of the energy industry, creating huge employment and economic opportunities.

It is of the utmost importance that a research and development effort is launched to enhance CO_2 capture and storage. Currently, the people carrying out the research are involved with for-profit companies and progress has been very slow. No-one has found the money necessary to move at the needed speed. Governments are only marginally involved. Industry sees it as either too far off or as a threat to its bottom line. Venture capitalists don't see any short-term profit in it. There should be a government-funded entity run along the same lines as the Manhattan Project where a wide range of scientists share in the effort and work to set goals and timetables.

Eventually the dependence on fossil fuels will come to an end and the world will be powered by renewables. But, as this energy utopia lies many decades in the future, by the time we arrive there we will be saddled with an atmosphere laden with excess CO_2.

Garbage brought disease to our streets. We learned to dispose of it. Sewage poisoned our waters. We learned to treat it. CO_2 threatens to change our climate. Hence, we must learn how to capture and bury it.

PROFESSOR WALLACE SMITH BROECKER

Newberry Professor – Department of Earth and Environmental Sciences

Columbia University

If you embrace climate science, embrace climate math.

The Paris Agreement has defined global climate targets for 2050 of 2°C and "well below" 2°C (commonly stated as 1.5°C). By setting temperature limits (and by extension, limits to atmospheric greenhouse gas concentrations) in a fixed time, one can estimate the amount of climate budget left in a global climate ledger. Many have done so, including the UNEP's annual Emission Gap Report.

The arithmetic is formidable and daunting. At current rates of GHG emissions worldwide, we have 20 years before we exceed the 2°C limit with 50% likelihood. To avoid a 1.5°C world with a 66% likelihood, we have six years. This is grim news. More grim still is that global GHG emissions continue to rise, even as CO_2 emissions appear to have plateaued, due to rising methane, black carbon, and nitrous oxides.

If the atmosphere were a business, the board would be worried and demand more action of the leadership. So it is now with the deployment of clean energy technology. Although renewables have made impressive gains, and coal use appears to be flattening in many countries, the climate faces great challenges and increasing urgency. Specific sectors, including industry, land-use, and transportation lack solutions either actionable or affordable.

This is the context in which CCS remains a critical and required part of the global solutions set.

To make deep, rapid reductions in greenhouse gas emissions, CCS must be deployed swiftly and at scale. One key application is in heavy industry, which produces 21% of global emissions. This is particularly true for cement, steel, biofuels, and petrochemicals production. Another is on the new, high-efficiency coal plants built in Asia and Europe, which will have long lives and eat up the carbon budget quickly. Another is on natural gas plants, which are becoming mainstays of the power sector. We know enough today to deploy CCS projects to capture and reduce all these emissions. The question is, really, are we smart enough to do what we know needs to be done.

The question is, really, are we smart enough to do what we know needs to be done.

DR JULIO FRIEDMANN

Distinguished Associate – Energy Future Initiative

CEO, Carbon Wrangler LLC

In December 2015, at the COP 21 in Paris, 195 countries adopted the Paris Agreement.

The Agreement's longer-term climate goals are defined as:

- Limit average global warming to well below 2°C above pre-industrial times, with the aspiration of limiting warming to 1.5°C.
- In the second half of this century, achieve a balance between emissions sources and sinks (often referred to as net-zero emissions).

There simply cannot be a cost-effective mitigation response to climate change without CCS.

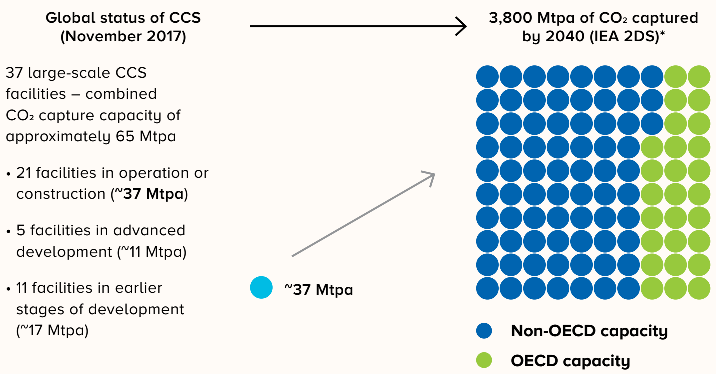
So far, global climate models have been unable to achieve cost-effective outcomes consistent with the goals of the Paris Agreement without factoring in critical technologies such as CCS, bioenergy and their combination of BECCS.

The IPCC maintains that without CCS, the cost of achieving long-term climate goals is nearly 140% more costly (much more than if other technologies are not available).

The IEA has repeatedly confirmed the importance of CCS as part of a suite of low-carbon technologies in meeting global climate goals. In its "Energy Technology Perspectives 2017" report, it states:

"Carbon capture and storage is vital for reducing energy emissions across the energy system in both the Energy Technology Perspectives 2°C Scenario (2DS) and the Beyond 2°C Scenario (B2DS). The potential for CCS to generate negative emissions when coupled with bioenergy is integral to energy use becoming carbon dioxide (CO_2) emission-neutral in 2060."[xi]

CCS as a climate mitigation technology



* **Source: Data sourced from International Energy Agency (2017), Energy Technology Perspectives 2017, OECD/IEA, Paris**

Note: 2040 IEA 2DS data includes ~600 Mtpa "negative emissions" from BECCS

These testimonials are not surprising given the inherent strengths of CCS:

- It produces dispatchable electricity that complements intermittent power from solar and wind;
- It is the only technology option available to significantly reduce emissions from industrial processes;
- It provides the major pathway to "negative emissions" when combined with biomass-fired power plants.

"So just to be clear, CCS isn't experimental – it's a reworking of existing oil and gas technologies. With CCS, the carbon dioxide will remain trapped deep below the earth's surface as oil and natural gas has remained trapped for millions of years and, yes, CCS will be necessary to solve the climate problem."

DAVID HONE

Chief Climate Change Advisor at Shell International in his latest book *Putting the Genie Back: Solving the Climate and Energy Dilemma*

CCS deployment in IEA scenarios

JUMP-STARTING OUR CLIMATE FUTURE

CCS technologies can play a critical role in the sustainable transformation of the global energy system. They offer a solution to some of the most vexing energy and climate challenges we face, including the need to significantly reduce emissions from industrial processes and from a large and relatively young global fleet of coal and gas-fired generation units. CCS also provides the means to deliver "negative emissions" to offset emissions from sectors where direct abatement is not economically or technically feasible. The versatility and potential importance of CCS is reflected in the IEA's "Energy Technology Perspectives 2017" analysis, which highlights a growing role for CCS with greater climate ambition.

One question is whether CCS is really needed now, at a time when we're seeing remarkable improvements in the cost and performance of key renewable technologies like solar and wind? The answer is unequivocally, yes. The gap between where global efforts are currently heading and a 2°C pathway is immense. It requires around 760 gigatonnes (Gt) of CO_2 emissions reductions across the energy sector between now and 2060. This is equivalent to more than 20 years of energy emissions and – importantly – comes on top of the anticipated impact of current policy efforts and contributions. Therefore, all technologies will be needed as part of a significantly strengthened and accelerated international effort to bridge this gap.

Today's investment in CCS provides a critical foundation for achieving deep emissions reductions in the future. Early CCS projects have delivered significant technology learnings with the potential to reduce future capital and operating costs by as much as 30%. Investment in CO_2 storage exploration and appraisal is supporting greatly improved confidence in the availability and integrity of storage solutions. CCS is now at a stage where the major challenge is no longer technological; it is commercial.

However, the scale of the CCS challenge can vary considerably. Some CCS plants have been operating on a commercial basis in the US since the 1970s, with limited or no public subsidies. Revenue from EOR has been a major factor, and more recently has underpinned CCS investment decisions in China and the Middle East. Other factors that have served to lower the barrier to investment include applications where relatively pure CO_2 is already being captured or separated in industrial processes, where transport infrastructure is accessible, where CO_2 storage is in close proximity, and where project revenues are sufficiently large to accommodate the additional cost of CCS operations. There is a strong case for governments and industry to work together to identify and cultivate CCS investment opportunities where one or more of the above factors converge. With strategic planning, these early opportunities could also become the launching pad for future CO_2 transport and storage networks.

Renewed momentum and substantially increased investment in CCS is both critical and urgent if we are to achieve long-term energy and climate goals. Focusing on lower-cost opportunities for CCS offers a pragmatic and effective approach to jump-starting the next wave of investment.

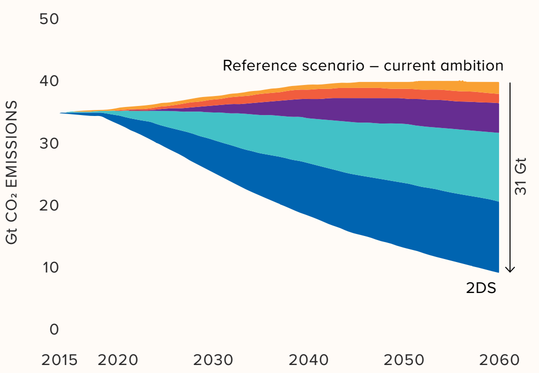
DAVE TURK

Acting Director – Sustainability, Technology and Outlooks

International Energy Agency

CCS in IEA Scenarios

CCS in the 2DS



Source: International Energy Agency, "Energy Technology Perspectives 2017", Paris: OECD/IEA, 2017

Efficiency 40%
Renewables 35%
CCS 14%
Nuclear 6%
Fuel switching 5%

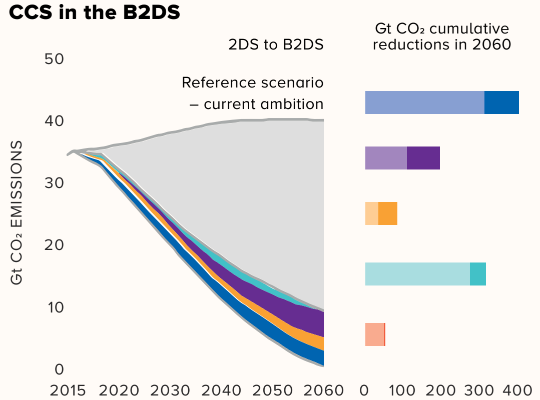
CCS IS CRITICAL TO THE 2DS PATHWAY

- Achieving a 2°C pathway is challenging and involves a radical reduction in CO_2 emissions.
- Current climate policies and pledges only slow emissions growth and fall well short of the major redirection required.
- CCS is a key technology to a 2°C pathway, providing 14% of cumulative CO_2 emissions reduction through 2060 when compared to "current ambitions". To put this in perspective, in the year 2050, over 5,000 million tonnes of CO_2 (over 5 Gt) must be captured using CCS technologies –equivalent to present-day annual CO_2 emissions in the US.
- Many thousands of CCS facilities must be deployed in the coming decades if these targets are to be achieved.

CCS IS MUCH MORE WIDELY DEPLOYED IN MOVING FROM 2DS TO B2DS

- CCS is key to achieving net zero emissions across the energy system.
- CCS accounts for 32% of the additional emission reductions needed in moving from the 2DS to the B2DS.
- In the B2DS, cumulative CO_2 captured by 2060 is nearly 100 Gt higher than under the 2DS.
- Much of this (additional) contribution is delivered through increased use of CCS in industry where CO_2 is captured from smaller streams.
- The combination of BECCS is one of the few technologies that can remove historic CO_2 emissions from the atmosphere (resulting in "net-negative emissions"). This combination is integral to achieving carbon-neutrality. In the 2DS and B2DS, BECCS accounts for 40% or more of captured CO_2 in the year 2060.
- An unprecedented increase in near-term climate mitigation actions is required if limiting warming towards 1.5°C is to be more than aspirational.

CCS in the B2DS



Source: International Energy Agency, "Energy Technology Perspectives 2017", Paris: OECD/IEA, 2017

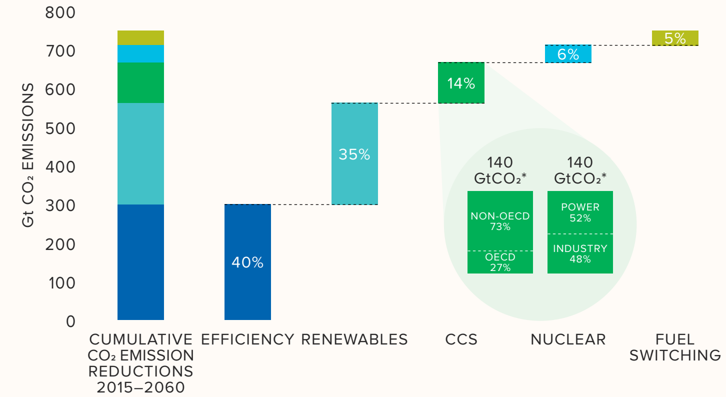
Efficiency 34%
CCS 32%
Fuel switching 18%
Renewables 15%
Nuclear 1%

CCS IS EQUALLY IMPORTANT IN INDUSTRY AND POWER AND ESPECIALLY IMPORTANT IN NON-OECD ECONOMIES

- Much of the focus around CCS has been around its application to power – what is often not appreciated is its importance in decarbonising industrial processes.
- Emissions in many OECD countries have either plateaued or are in decline; going forward, the emphasis on emissions reduction falls very much on non-OECD economies, and especially on China.

CCS by sectors and regions in the 2DS

Cumulative CO_2 captured by sectors and regions by 2060 in 2DS (approximate values)



Source: Data sourced from International Energy Agency, "Energy Technology Perspectives 2017", Paris: OECD/IEA, 2017

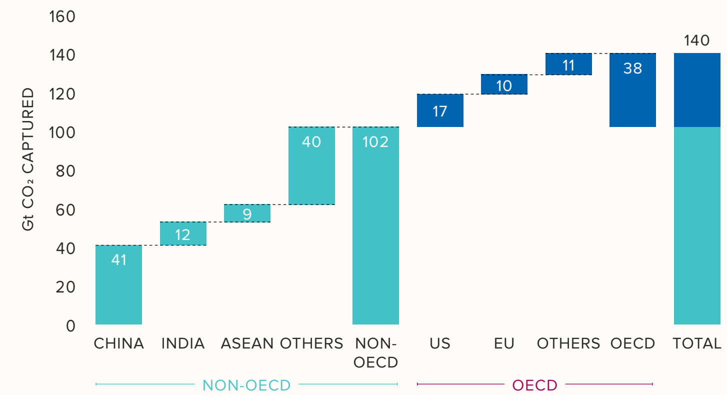
*** Note: the 140 $GtCO_2$ captured by CCS includes around 36 $GtCO_2$ in "negative emissions" from BECCS which act to compensate for emissions elsewhere in the energy system.**

CCS IS ESPECIALLY IMPORTANT IN NON-OECD ECONOMIES

- China, the US and India currently account for around half of global CO_2 emissions.
- Emissions from the US have stabilised at around 5 Gt per annum, while China's have almost doubled in the past decade at around 10 Gt. India is at 2 Gt.
- It is unsurprising that the bulk of emissions reduction effort rests with non-OECD countries, with China alone accounting for 30% of total required reductions.
- This dominance of coal-based emissions in China is reflected in both electricity generation and many industrial processes and signals the high potential for CCS in China.
- China presently has over 900 gigawatts (GW) of installed coal-fired power capacity, with around 150 GW under construction. The coal-fired generation fleet is one of the youngest in the world, with two-thirds of the plants built since 2005. Retrofitting carbon capture facilities to existing plants is a major decarbonisation opportunity.[xii]
- China's emissions from cement production at least equal the total emissions from the German economy (0.7–0.8 Gt per annum).[xiii] China accounts for around half of the world's steel production – its annual CO_2 emissions from this industry sector alone is estimated at between 1.0 and 1.5 Gt.[xiv] Petroleum processing and related petrochemical activities (along with considerable coal-to-chemical activities) are also major CO_2 emitters.

CCS deployment in non-OECD and OECD countries in the 2DS

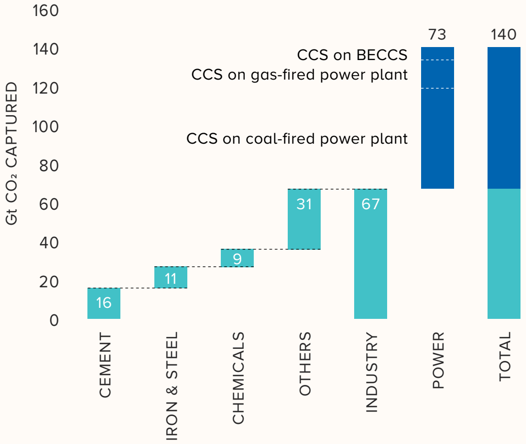
Cumulative CO_2 captured by non-OECD and OECD countries by 2060 in 2DS (approximate values)



Source: Data sourced from International Energy Agency, "Energy Technology Perspectives 2017", Paris: OECD/IEA, 2017

CCS in industrial and power sectors in the 2DS

Cumulative CO_2 captured by industry and power sectors by 2060 in 2DS (approximate values)



Source: Data sourced from International Energy Agency, "Energy Technology Perspectives 2017", Paris: OECD/IEA, 2017

CCS IS EQUALLY IMPORTANT IN INDUSTRY AND POWER

- Industrialisation will continue to drive major economies. Cities will multiply and expand and infrastructure requirements will follow suit.
- This will require massive amounts of industrial goods such as steel, cement and petrochemicals, the production of which emits high levels of CO_2.
- CCS is the only technology available to make deep emissions cuts in these industries.
- In the 2°C pathway, near half of the cumulative emission reductions to 2060 come from industry (around 70 Gt).
- Many industry sectors (examples include fertiliser production and natural-gas processing) already separate out CO_2 as part of their production processes and provide lower-cost "beacons" for supporting further development.

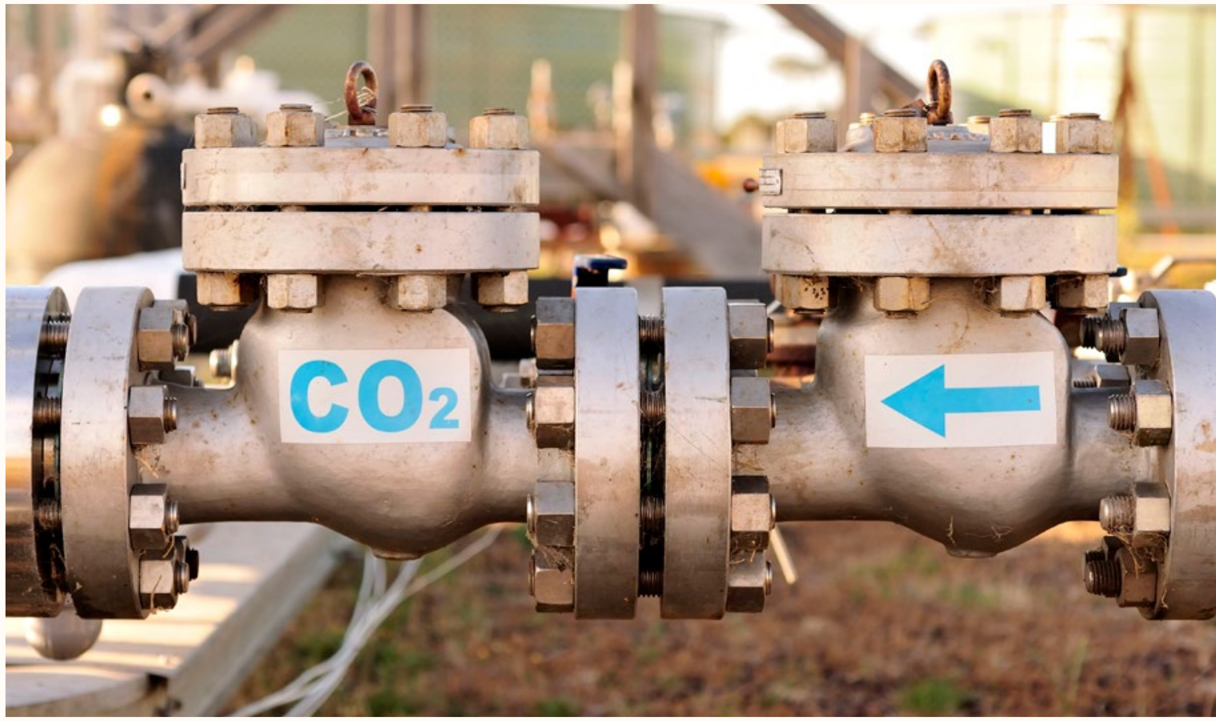
POWER:

- Simply encouraging renewables and fuel switching to unabated natural gas and/or the adoption of best available coal technology will not deliver the necessary emissions reductions to meet climate goals.
- Around 40% of the world's electricity presently comes from coal, with the youngest coal "fleet" witnessed in decades. More than 500 gigawatts (GW) of capacity has been added since 2010, mainly in emerging economies.[xv]
- These plants have the potential to operate for another 30 to 40 years and are unlikely to be retired in a timeframe adequate for meeting long-term climate goals.
- Retro-fitting carbon capture facilities to existing generating plants presents a considerable opportunity to decarbonise the power sector in many regions.
- There has been a "dash for gas" in many countries over recent years and gas now accounts for over 20% of global electricity generation, with more plants slated for construction.
- While a gas-fired power plant is considered "cleaner" than a coal-fired plant, it is far from being low-carbon (a combined cycle plant has an emissions profile of around 370 grams of CO_2 per kilowatt hour (gCO_2/KWh) vs around 700 gCO_2/ KWh for an ultra-supercritical coal plant).[xvi]
- Application of CCS technologies to these plants is therefore vital.

CCS has considerable health benefits

- Poor air quality is a major threat to human health. Globally, about 3 million premature deaths are annually attributed to outdoor air pollution with predictions that this will rise to 6–9 million by 2060.
- Children remain most vulnerable to bronchitis and asthma, but the health risk extends to the wider population and increases in hospital admissions, health expenditure and restricted work days.
- The annual global welfare costs associated with the premature deaths from outdoor air pollution are staggering – US$3 trillion currently and projected to rise to US$18–25 trillion by 2060.[xvii]
- Depending on the type of CO_2 capture and conversion technologies applied, in addition to other installed pollution control measures for regulatory and/or operational requirements, deployment of CCS technologies can deliver significant reduction in conventional atmospheric pollutants:
  - A 90% reduction in sulphur oxide emissions can be achieved (through integrated flue gas desulfurisation);
  - A reduction of over 70% in nitrogen oxides emissions (from selective catalytic reduction);
  - 100% removal of fly ash from electricity generation (electrostatic precipitators and fabric filters), which can be recycled for use in the construction industry;
  - Heavy metals (mercury) and particulate matter can also be effectively managed.

Otway Facility. Photography courtesy of CO2CRC.



CCS and the new energy economy

CCS is a key component in reconciling the so-called “energy trilemma” – the challenges associated with meeting international climate change commitments, keeping the lights on, and reducing electricity costs, all at the same time.

Inclusion of CCS within a portfolio of low-carbon technologies is not just the most cost-effective route to global decarbonisation, it also delivers energy reliability and lower costs.

As the energy matrix continues to evolve, CCS also facilitates the creation of new energy economies, which are yet to reach their zenith. A good example is the work Kawasaki Heavy Industries is undertaking with Iwatani, J-Power and Shell Japan to scope a hydrogen energy supply chain in Australia’s Latrobe Valley.

The opportunity to turn Victoria’s brown coal into clean hydrogen is just one example of the new opportunities CCS can create; and to set the stage for a clean energy hub that harnesses jobs and creates a new, decarbonised economy.

The clean energy revolution can also open new opportunities for CCS elsewhere:

- Deployment of CCS can generate economy-wide employment growth in the provision of services (such as project management, engineering, finance, legal and environment), the manufacture of components (such as boilers and turbines), CO_2 infrastructure development (such as storage characterisation) and general construction activities;
- CCS transforms high-emission industries to low-carbon factories of the future that can prosper under increasingly stringent carbon constraints. This has stimulated several industrial hub and cluster initiatives, most notably in Europe, aimed at maximising economies of scale. These initiatives will retain skilled jobs, create new industries at cluster-points and in Europe’s case, give life to a globally significant CO_2 storage industry in the North Sea;
- Early deployment of CCS, and especially retrofits to existing facilities, avoids the early retirement of highly productive assets. It provides significant benefits to local communities that have grown up around high-emitting industries and face significant dislocation and economic hardship from premature closures.

Inclusion of CCS within a portfolio of low-carbon technologies is not just the most cost-effective route to global decarbonisation, it also delivers energy reliability and lower costs.

Teesside Collective, United Kingdom. Photography courtesy of Teesside Collective UK. Photographer: Dave Charnley.

The Teesside Collective

Developing a full-scale industrial carbon capture cluster in the Tees Valley region in the UK shows significant economic benefits:[xviii]

- Creation of hundreds of long-term jobs, directly and indirectly associated with the operation (including maintenance) of the CCS network;
- Around 6,000 jobs moved to the low-carbon economy, including those associated in the relevant supply chains;
- An annual increase of around £85 million in gross value-added flowing to the UK economy over the first four years of operation.

CCS and renewables for electricity surety

> Dispatchable fossil-based generation with CCS requires no additional grid integration costs or risks making it affordable and reliable.

The most affordable and reliable low-emissions electricity system requires everything – fossil-based dispatchable power with CCS, and intermittent renewable energy sources with energy storage.

Safe, reliable and affordable electricity is reliant on a suite of technologies to meet changing supply and demand patterns. Intermittent renewable energy with energy storage will be an important part of the future global energy mix but renewable energy alone cannot provide reliable electricity at acceptable cost and risk.

An electricity system with a high penetration of intermittent renewable generation requires back-up and augmentation systems to ensure reliability and resilience. Dispatchable fossil-based generation with CCS requires no additional grid integration costs or risks making it affordable and reliable.

A power system comprising renewables complemented by a suite of decarbonised fossil energy plants will supply electricity day and night, at times of low wind and poor sunlight, and during peak needs.

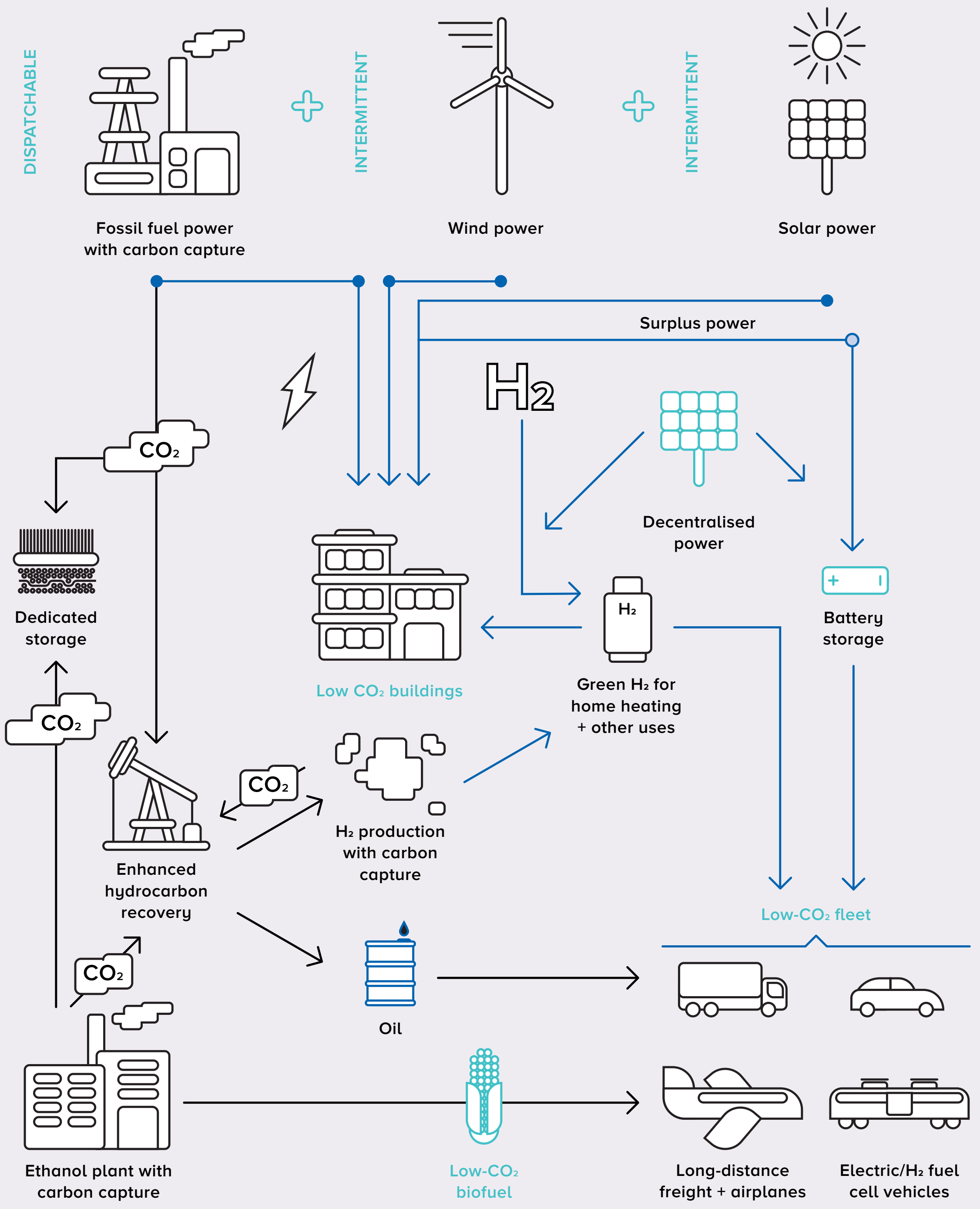
Electricity generated by this system that is not dispatched can be stored in batteries for other purposes such as powering electric vehicles, which can further be complemented by a fleet of long-distance vehicles operated on fuels from refineries using capture technologies on crude oil produced from CO_2-EOR systems.

Such vehicles could also employ hydrogen fuel cells with the hydrogen produced from fossil fuels with CCS.

These long-distance vehicles may be transporting chemical or fertiliser products from plants that have captured carbon for permanent storage. These vehicles will pass through major cities that have redesigned existing natural-gas grids to use "green" hydrogen for home heating purposes backed by significant CCS development.

This integrated energy system enables both renewable and CCS technologies to develop and flourish while also securing the most cost-effective global mitigation response.

A vision for an integrated low-carbon energy system that allows both renewable and CCS technologies to flourish

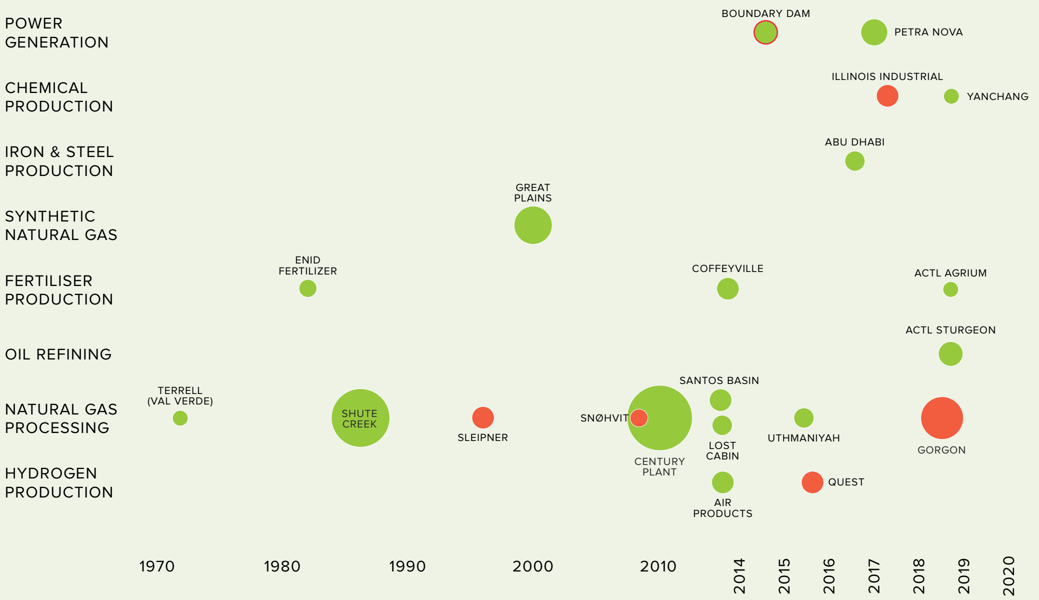


CCS facilities around the world

Carbon capture and storage is proven and highly versatile.

It has been applied in a wide range of industries since 1972 when several natural-gas processing plants in the Val Verde area of Texas began employing carbon capture to supply CO_2 for EOR operations.

CCS large-scale facilities in operation and construction by industry and operations start date



1 MTPA OF CO_2 (AREA OF CIRCLES PROPORTIONAL TO CAPACITY) EOR DEDICATED STORAGE

Since then, more than 200 million tonnes of CO_2 has been captured and injected deep underground.

Early application of CCS technologies in the 1970s and 1980s involved processes in which CO_2 was already routinely separated, such as in natural-gas processing and fertiliser production. This was then augmented with the demand for CO_2 for use in EOR. Today, the portfolio of CCS facilities is much more diverse, including applications in coal-fired power, steel manufacture, chemical and hydrogen production and BECCS. While CO_2-EOR remains a key business driver for CCS, wider geological storage solutions are now represented among operating projects.

Much has been achieved over the last four decades:

- Capture technologies are now widely employed at scale globally, and costs are falling rapidly as new facilities come onstream and next generation technologies are unleashed;
- More than 6,000 kilometres (km) of CO_2 pipelines are operational with an excellent safety record;
- CO_2 is injected securely into a variety of strata with no evidence of leakage to the atmosphere.

There are 17 large-scale CCS facilities in operation globally, capturing more than 30 Mtpa of CO_2.

Four additional large-scale facilities are currently in construction, all planned to be operational in 2018, and capable of capturing an additional 6 Mtpa of CO_2.

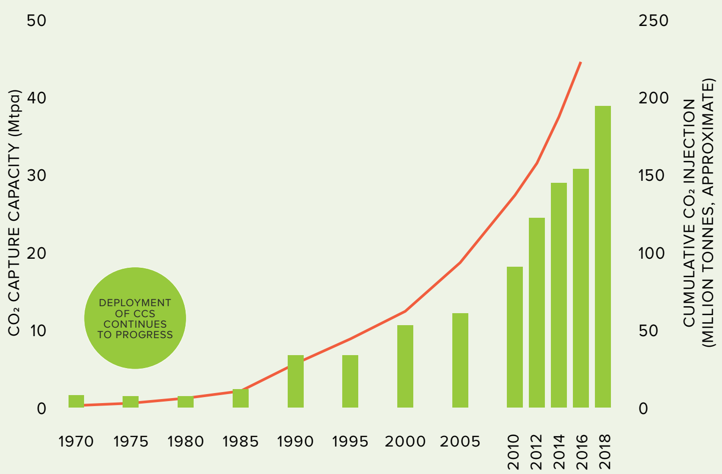
There are around 15 smaller-scale CCS facilities in operation or under construction around the world. The CO_2 capture capacity of these individual facilities ranges from around 50,000 to almost 400,000 tonnes per annum. In total, these facilities can capture over 2 Mtpa of CO_2.

All this carbon capture capacity adds up to the equivalent of over 8 million motor vehicles taken off the roads.

LARGE-SCALE CCS FACILITIES BY REGION

	Early Development	Advanced Development	In Construction	Operating	Total
Americas					
- United States	-	2	-	9	11
- Canada	-	-	2	3	5
- Brazil	-	-	-	1	1
Asia Pacific					
- China	6	1	1	-	8
- Australia	1	1	1	-	3
- South Korea	2	-	-	-	2
Europe					
- Norway	-	1	-	2	3
- UK	2	-	-	-	2
Middle East					
- Saudi Arabia	-	-	-	1	1
- United Arab Emirates	-	-	-	1	1
Total	**11**	**5**	**4**	**17**	**37**

CO_2 capture history



Source: Global CCS Institute (November 2017)

CO_2 capture capacity (Mtpa) — large and smaller-scale facilities in operation and under construction

Cumulative CO_2 injection (Mt, approximate)

Power

Applications: post-combustion, IGCC, geothermal and Allam Cycle technology.

Industry

Applications: natural-gas processing, fertiliser production, synthetic natural-gas, hydrogen production, chemicals production, iron and steel production and oil refining.

Global CCS facilities in operation and under construction

This map indicates CCS facilities in operation and under construction at large and smaller scale in the power and industry sectors that use or intend to use permanent CO_2 storage options.

The larger symbols on the map represent large-scale facilities, the smaller symbols represent smaller-scale facilities.

Note: Large-scale CCS facilities are facilities with annual CO_2 capture capacity of 400,000 tonnes or more; for the purposes of this map, smaller-scale facilities are with CO_2 capture capacity of ~50,000 to 400,000 tonnes.

For further information on the facilities listed in this map, please visit the Institute's website at www.globalccsinstitute.com/files/global-ccs-status-report-2017-facilities-map.xlsx

2017 highlights

2017 saw major advances in CCS deployment with several new facilities deployed and a raft of new facilities moving closer to operation.

In the US, key large-scale facilities became operational:

- On 29 December 2016, Petra Nova Carbon Capture, a joint venture between NRG Energy and JX Nippon Oil & Gas Exploration, began CO_2 capture operations on Unit 8 at the W.A. Parish power plant near Houston Texas. At a capture rate of 1.4 Mtpa, this is the world's largest post-combustion capture facility at a power plant.
- In April 2017, the world's first large-scale bio-energy with CCS facility was launched into operation in Illinois. This facility can capture and store approximately 1 Mtpa of CO_2. It is operated by Archer Daniels Midland and administered by the US Department of Energy's (US DOE's) Office of Fossil Energy.

Other significant milestones around the world included:

- In Norway, the offshore Sleipner and Snøhvit facilities exceeded 20 million tonnes of CO_2 captured and stored, and the EFTA Surveillance Authority (ESA) approved a three-year extension of Norway's aid scheme for carbon capture testing at the CO_2 Technology Centre Mongstad.[xix]
- In Canada, the Shell-operated Quest CCS facilities exceeded 2 million tonnes of CO_2 captured and stored since operations began in 2015, a milestone that is being approached by the capture facilities at the Boundary Dam Unit 3 generating plant in Saskatchewan.
- In the US, CCS facilities at a refinery in Port Arthur, Texas, have captured approximately 4 million tonnes of CO_2.
- In Brazil, the Santos Basin offshore facilities have injected over 4 million tonnes of CO_2.

A fiberglass duct routes the flue gas from the generating unit to the carbon capture system at Petra Nova. Photography courtesy of NRG.

CONSTRUCTION: CHINA, CANADA AND AUSTRALIA LEAD LARGE-SCALE COMMISSIONING

Four facilities are currently in construction and are slated to become operational in 2018:

- In China, one major facility, Yanchang CCS, began construction in March 2017. This is the first large-scale CCS development to move into construction in China and Asia. Carbon dioxide capture will take place at two separate gasification facilities in central China, with a total CO_2 capture capacity of around 0.4 Mtpa.
- In Australia, commissioning activities on the Gorgon Carbon Dioxide Injection facilities are underway, with a formal launching anticipated in 2018. The facilities can inject up to 4 Mtpa of CO_2 more than 2 km beneath Barrow Island (offshore Western Australia), making this the largest geological storage facility in the world.
- In Alberta, Canada, all the rights-of-way for the 240 km Alberta Carbon Trunk Line have been secured and construction will begin once all approvals are gained. The initial two capture facilities near Redwater will provide up to 2 Mtpa of CO_2 for pipeline transportation and subsequent use in EOR operations in central Alberta.

Sleipner CO_2 Storage, Norway.
Photo courtesy of Statoil.
Photographer: Oyvind Hagen

Sleipner CO_2 Storage

LOCATION:
Central North Sea, offshore Norway

INDUSTRY:
natural-gas processing

CAPTURE CAPACITY:
1.0 Mtpa of CO_2

CO_2 CAPTURE START DATE: 1996

Over 17 million tonnes of CO_2 captured and securely injected deep below the seabed.

ADVANCED DEVELOPMENT: NORWAY AND THE US DEMONSTRATE INDUSTRIAL DIVERSITY

In 2017, two new large-scale CCS facilities entered advanced development, with the total number of facilities in this category moving to five:

- In Norway, Gassnova has awarded contracts to Norcem AS (a cement plant), Yara Norge AS (an ammonia plant); Klemetsrudanlegget AS (a waste-to-energy-recovery plant) and Statoil (CO_2 storage). Detailed studies of full-scale carbon capture at the three industrial plants are now underway. Total CO_2 injection capacity of all three CO_2 capture plants is approximately 1.3 Mtpa. The progress made by Norway is especially significant since it includes CO_2 capture from cement and waste-to-energy plants, which are new areas for the large-scale application of CCS. A final investment decision is targeted for 2019 with ambitions to begin operation in 2022;
- In Louisiana, US, the proposed new Lake Charles Methanol gasification facility is designed to convert petroleum coke sourced from oil refineries in the Gulf Coast region into synthetic gas, which would then be further processed to produce methanol and other products. Carbon dioxide capture capacity would be designed at over 4 Mtpa.

Advancements in CCS deployment have not been restricted to large-scale facilities.

SMALLER-SCALE CCS FACILITIES: CHINA AND JAPAN AS PATH-FINDERS

Advancements in CCS deployment have not been restricted to large-scale facilities. In Asia, a series of smaller-scale CCS facilities are operating or in construction. In China, these smaller-scale facilities can capture around 1 Mtpa of CO_2, and have included several path-finding facilities in the power sector and in CO_2 storage development. Japan is testing advanced technologies in the power sector (at the Mikawa plant and at the new Osaki CoolGen facility) with the intention of progressing to larger-scale CCS deployment in the next decade.

Novel technologies are in development that can significantly reduce CO_2 capture costs. Advanced technologies are being tested at various scales around the world including:

- Technologies that use low-cost process heat to regenerate capture solvents or solid sorbents;
- Manufactured versions of naturally occurring enzymes that are being used to catalyse, or speed up, solvent absorption of CO_2;
- Power systems that use CO_2 as a working fluid to generate electricity.

The policy landscape

LAWRENCE IRLAM

Senior Consultant – Policy and Economics

Global CCS Institute

Policy equality for CCS – renewables growth illustrates the power of policy support

The scale of CO_2 capture and storage required to keep global warming to "well below" 2°C is huge.

Fortuitously, the vital role of CCS is beginning to be better appreciated by policy-makers, climate experts and the media. This heightened understanding can now be translated into policies that give business the incentive to develop and deploy CCS technologies.

Its deployment to date has occurred in the absence of systematic policy support for CCS as a climate change mitigation technology.

CCS has not attracted the same level of support as other clean energy technologies – especially renewables. CCS simply must receive "policy parity" – equitable consideration, recognition and support that other low-carbon technologies enjoy – if we are serious about meeting Paris climate targets.

The rapid deployment and cost reductions achieved by some renewable electricity generation technologies has been the direct result of hundreds of billions of dollars of subsidies globally. This illustrates how strong and sustained policy support could similarly drive CCS deployment and wider commercialisation.

TAILORED POLICY SUPPORT WILL BE REQUIRED

Unlike many other low-emissions technologies, CCS deployment faces unique challenges, requiring tailored policy solutions:

- **Predictability in policy setting is paramount:** CCS facilities typically involve very large capital investments, have long gestation periods and asset lives, so a stable policy environment is essential.
- **Need for multi-industry focus:** CCS will need to be applied across various industries, and so policy must accommodate different emission footprints, markets and cost structures.
- **Commercial integration across all three elements of the CCS chain:** CCS deployment typically involves multiple actors across the value chain and aligning interests has proved challenging in many projects and made financing difficult.
- **Early identification and characterisation of suitable geological storage sites:** consistent with the roll-out of historical industrial infrastructure, there is little prospect of CO_2 transport and storage infrastructure being developed privately if strong policy incentives are not in place.
- **Legal and regulatory regimes that provide clear obligations and liability provisions:** this especially concerns storage activities (and must be designed to accommodate the thousands of facilities that will need to emerge over the course of the next few decades).
- **Robustness in research and development (R&D) efforts:** various CO_2 capture methods exist and are being refined and newer, potentially much lower cost techniques are being tested at pilot scale. Choices for wide spread deployment are dependent on robust R&D support.
- **Increasing community awareness of the importance of CCS:** social licence issues that associate CCS with polluting fuels and industries, must be addressed.

POLICY FUNDAMENTALS THAT SET THE FOUNDATION FOR ACCELERATED CCS DEPLOYMENT

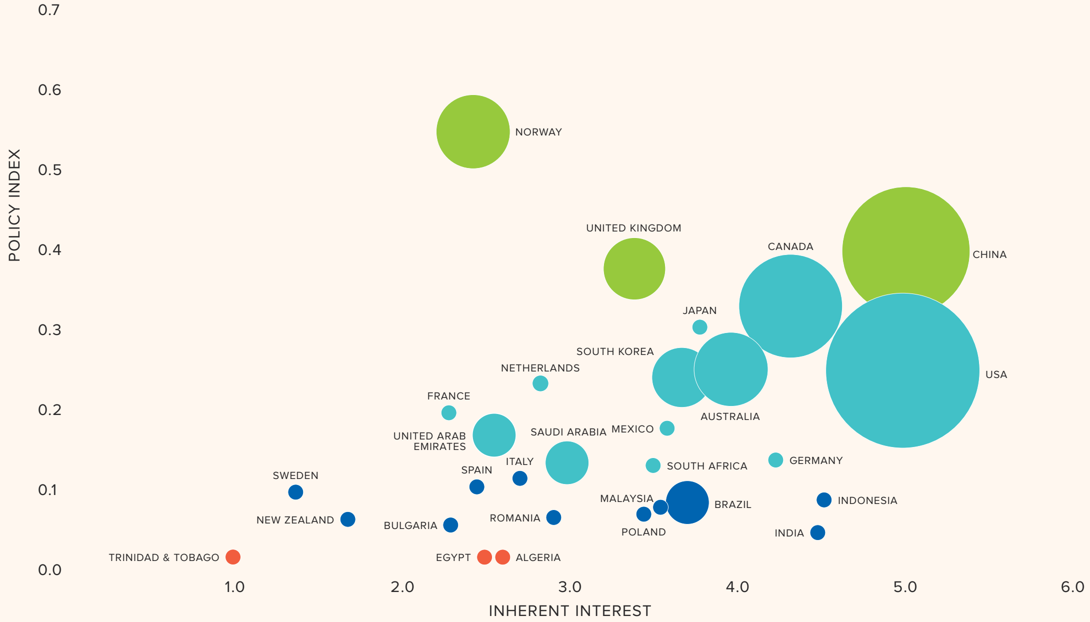
There are several reinforcing elements of the policy-making process that are critical to accelerate the deployment of CCS. These include:

- Setting of credible and economy-wide emissions reduction targets, consistent with the aims of the Paris Agreement.
- Designing policy to achieve medium-term emissions reductions in a range of sectors and in line with these longer-term targets, combined with measures that meaningfully deal with or compensate those who lose from transitioning to a low-carbon future.
- Explicitly including CCS in national climate action plans or similar flagship policy statements, which either implicitly or explicitly acknowledge how CCS can play a role alongside other low-carbon technologies.
- Securing policy certainty via a government commitment that has been demonstrated to extend beyond political cycles and to be resilient to conflicting political demands.
- Establishing (region-relevant) public/private business models that better manage risk allocation between the capture, transport and storage elements of the CCS chain, thus reducing overall risks.
- Devoting special attention to accelerating investment in storage exploration and characterisation, in view of the long lead times for development in certain regions.

The Global CCS Institute Policy Indicator 2017

The Global CCS Institute tracks levels of national policy support for CCS across many countries. The Institute's CCS Policy Indicator Index outlines how these policies help drive domestic action on CCS.

Global CCS Institute Policy Indicator 2017: summary highlights



The Institute's CCS Policy Indicator captures the status of CCS policy around the world. The Policy Indicator plots the overall strength of a government's policy stance on CCS in the form of a "Policy Index", as well as its "Inherent interest" in CCS, which reflects the country's relative propensity towards fossil fuel production and consumption. The colors represent the tiers of policy support: upper (green), middle-upper (light blue), middle-lower (dark blue), lower (red). The size of the bubbles signifies the number of large-scale CCS facilities in each country.

Key highlights from the CCS Policy Indicator include:

- Norway is taking concrete steps towards CCS deployment in the form of concept and FEED studies on industrial facilities, and continues a consistent policy narrative about the need for CCS to achieve climate goals, which are set in legislation.
- Continued support for carbon capture utilisation and storage (CCUS) has been demonstrated in China via targeted project activity, including the decision to commence construction of China's first large-scale CCS facility, and a similarly consistent and considered pursuit of smaller-scale CCS activity in Japan.
- The US has backtracked from a range of climate-related mitigation arrangements entered under the Obama administration (including against the introduction of emissions performance standards in the power sector) and there is uncertainty regarding the new administration's stance towards CCS overall. These overarching positions are balanced against supportive activity at the state level and moves to extend/enhance tax credits for CCS projects.
- After a long period of reassessment, the UK government has renewed its commitment to CCS investment with its inclusion in the newly released Clean Growth Strategy. The UK's Committee on Climate Change has consistently emphasised the importance of CCS to future UK energy and climate policies and other parliamentary and audit reports have provided useful learning from close examination of the cancellation of the UK's Commercialisation Competition.
- There is growing momentum towards valuing carbon, including progress on emissions trading in China, reforms underway in Europe (including new innovation-funding mechanisms) and carbon pricing in the UK, France and Canada.
- There have been references to "technology neutral" policies in Australia, in the form of proposals for electricity market incentive mechanisms and around the broadening of concessional loans to include CCS.
- Policy momentum is clear in the highest-ranked countries in the Institute's Indicator but much more effort is required to maintain a deployment trajectory consistent with the Paris Agreement.
- Further government deliberations in support of CCS and other mitigation technologies will hopefully arise from the UNFCCC's "Facilitative Dialogue" and the IPCC's "Special Report" on the impacts of limiting global warming to 1.5°C, both to be released in 2018. These are highly likely to reinforce the important role of CCS and potentially lead to enhanced awareness and pressure on governments to implement measures that will strengthen the business case for CCS.
- The "Global Stocktake on Mitigation" in 2023 and the second round of Nationally Determined Contributions (NDCs) expected in 2025 are critical decision points for governments to review their commitments; however, waiting for these junctures to act on CCS will lock in a much higher level of emissions and make meeting the Paris climate targets prohibitively expensive.

LAWRENCE IRLAM

The Global CCS Institute Legal and Regulatory Indicator 2017

The Institute updated the "Legal and Regulatory Indicator" this year.

Key features from the Legal and Regulatory Indicator include:

- There has been little or no material change in the status of CCS legal and regulatory models in many jurisdictions worldwide.
- A small number of countries included in Band A of the Indicator, those with CCS-specific or existing laws that are applicable across most parts of the CCS project lifecycle, remain unchanged from the 2015 edition:
  - Assessment scores recorded for these five countries are similarly unchanged;
  - The pace of legal and regulatory development among these nations has stalled in recent years;
  - All possess sophisticated legal and regulatory regimes that address many aspects of the CCS process, but there has been a conspicuous absence of further improvement or strengthening of these models in the past two years – likely a result of policy inertia/uncertainty in those jurisdictions.
- Amongst those countries listed in Bands B and C, there have been a slim number of changes that largely seek to address administrative processes and further improve existing legal and regulatory frameworks. None of these countries has changed band as a result of the updated assessment.
- The greatest concern is the absence of change amongst those nations that continue to highlight CCS as a core component of their national mitigation response. A key example is China, which has several facilities in development planning.

GLOBAL CCS INSTITUTE LEGAL AND REGULATORY INDICATOR 2017: SUMMARY HIGHLIGHTS

COUNTRY	TOTAL SCORE (Out of a possible 87)
Band A: CCS-specific laws or existing laws that are applicable across most parts of the CCS project cycle	**Average score:** 65
Australia	67.0
Canada	65.5
Denmark	62.0
United Kingdom	65.0
United States	64.0
Band B: CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle (27 countries)	Average score: 47
BAND C: Very few CCS-specific or existing laws that are applicable across parts of the CCS project cycle (21 countries scored)	Average score: 26

Source: Global CCS Institute (2017)

Note: The Institute's Legal and Regulatory Indicator is only available to Members. You can find further information about the Indicator on the Institute's website.

IAN HAVERCROFT

Senior Consultant – Legal and Regulatory, Commercial

Global CCS Institute

As the urgency of climate change becomes more obvious and the constraints of the Paris Agreement more entrenched, strong policy support for CCUS is a means to a better and wealthier future for all nations. Policy makers must champion a wider policy set that includes overt carbon management to achieve their national and international goals. Attention must be paid, and speed is needed.

DR JULIO FRIEDMANN

Distinguished Associate – Energy Future Initiative

CEO, Carbon Wrangler LLC

Global climate advocacy

The Global CCS Institute on the international climate agenda

Our primary focus at the Global CCS Institute has been on ensuring that CCS is not discriminated against or disadvantaged in the evolving “rulebook” that is being negotiated by the Parties to the Paris Agreement (those countries that have ratified, or given formal consent to, the Agreement).

It is very important that this rulebook remains neutral on the types of mitigation technologies that might be supported within the UNFCCC governance arrangements in the post-2020 climate architecture. Only with the broadest portfolio of technologies available to support domestic mitigation efforts will nations be able to realise and enhance the full potential of their indigenous emissions reduction opportunities.

The legal text of the Paris Agreement is purposefully agnostic on technologies; however, the rules of its implementation provide significant scope for Parties to embed quite prescriptive provisions on how future climate actions are to be pursued. These provisions can reflect the preferences of quite minor yet powerful constituencies (including nation states) if left unchecked.

MARK BONNER

Program Lead – International Climate Change Engagement

Global CCS Institute

A recent example is the rules for including CCS in the Clean Development Mechanism (CDM) under the Kyoto Protocol, after Parties agreed to its eligibility at COP 16 (Cancun).

The Institute (amongst others) advocated earnestly over a five-year period for the subsequent modalities and procedures (or rules) to be as simple and as non-prescriptive as is appropriate. These efforts saw a formal proposal to impose an unnecessary additional financial cost on CCS-CDM projects in the form of a General Reserve withdrawn at COP 22 (Marrakech). If this condition had been adopted, the prospects for CCS projects under the CDM would be very much reduced due to the totally disproportionate and prohibitively costly nature of such a provision.

A formal decision on the rulebook is expected to be made at COP 24 in 2018 (scheduled for Katowice, Poland), since this meeting will mark the conclusion of the 1st Session of the Paris Agreement's ultimate decision-making body known as the CMA.

The Institute continues to monitor core issues within the UNFCCC that could potentially affect CCS developments going forward. One of these issues is an emerging opposition by a few Parties and accredited ENGOs to the awarding of financial support or recognition of fossil-based technologies (such as CCS) within the various UNFCCC vehicles and mechanisms. This includes the Green Climate Fund (GCF) as well as discussions on market mechanisms (Article 6 of the Paris Agreement).

As it has done in past years, the Institute continues to attend and actively participate in all the meetings of the UNFCCC's Technology Executive Committee, CTCN and GCF as well as the UNFCCC's mid-year intersessional meeting of its subsidiary bodies. As an indication of the Institute's highly regarded reputation in this space, it was recently elected by the business constituency (BINGO) to represent it on the CTCN Advisory Board.

As an accredited observer to the IPCC, the Institute nominated several CCS experts to be considered for participation in the scoping meetings of the "Special Report on 1.5˚C Global Warming" and the "Sixth Assessment Report", as well as to contribute as authors to both. It is important that there is demonstrated progress on CCS in these reports as they will both feed into the Global Stocktake scheduled for 2023. This stocktake is important because it will evaluate how mitigation outcomes compare to the nearer-term goal of peaking global emissions, and the long-term goal of achieving net-zero emissions by the second half of this century. This is needed to encourage Parties to elaborate their strategic interest on CCS in their Nationally Determined Contributions due in the first half of 2020 – and within the context of a post-2030 technology vision.

In the run-up to COP 23 in Bonn (November 2017), the Institute has again been engaging and advocating extensively to represent the merits and authenticity of global CCS mitigation efforts.

While the UNFCCC provides the major international platform in which the Institute implements its climate change advocacy efforts, it also has an eye on future hot topics that will likely come into play within the negotiations and related policy discussions. One of these topics is the nexus between mitigation efforts and sustainable development. This relationship will increasingly influence the type and scale of support made available by national governments to solutions like CCS. It is critical for the CCS community to be in a position where it can better articulate the full net-value of CCS benefits (direct and indirect CO_2 and non-CO_2 benefits), especially in regard to helping to develop a country's future plan for CCS. The Institute intends to explore and communicate this type of analysis going forward.

MARK BONNER

"CCS would also be required should a late 21st century or 22nd century strategy of carbon dioxide capture from air be implemented, designed to start reducing the atmospheric concentration. And yet, as noted, CCS is struggling for recognition, even at UNFCCC conferences."

DAVID HONE, CHIEF CLIMATE CHANGE ADVISOR AT SHELL IN HIS LATEST BOOK
Putting the Genie Back: Solving the Climate and Energy Dilemma

The addition of CCS to unabated power and industrial facilities can result in additional costs of as low as 2% and up to 70% to the lifecycle or levelised unit cost of production.

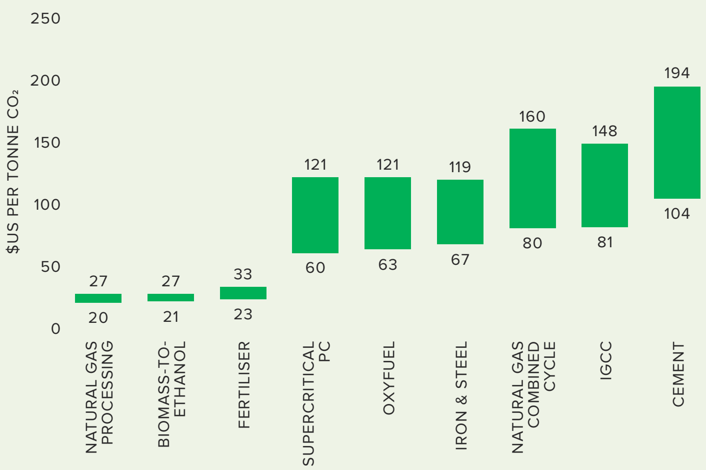
The cost of CCS

CCS is commonly misrepresented as "too expensive". The fact is, CCS has become just as, and in some cases, more competitive than other low-carbon technologies.

The cost of CCS on several industrial applications is far below what many would expect. Recent forecasts show that for "first-of-a-kind" commercial-scale facilities:

- The addition of CCS to unabated power and industrial facilities can result in additional costs of as low as 2% and up to 70% to the lifecycle or levelised unit cost of production;
- The facilities with the lowest-cost increases already produce concentrated CO_2 streams as part of the production process, which is currently vented into the atmosphere. These include natural-gas processing (increase of 2%), fertiliser manufacturing (4%) and bio-ethanol production (5%) facilities;
- The higher cost increases for power generation (45–70%), steel manufacturing (30–41%) and cement production (68%) reflect that CO_2 separation is not included in the production process without CCS. Therefore, a greater incremental cost is incurred to separate CO_2 when compared to those processes with inherent CO_2 separation;
- Higher-cost industries also exhibit wide variations across different countries owing to differences in labour and fuel costs. Lower-cost industries show less variation given that incremental costs are mostly for CO_2 compression, transport and storage, which are commercially mature practices;
- Industries where the addition of CCS adds relatively higher incremental costs are also industries in which advanced capture techniques and technologies are developing. For these industries, the potential future cost reductions are likely to be relatively larger.

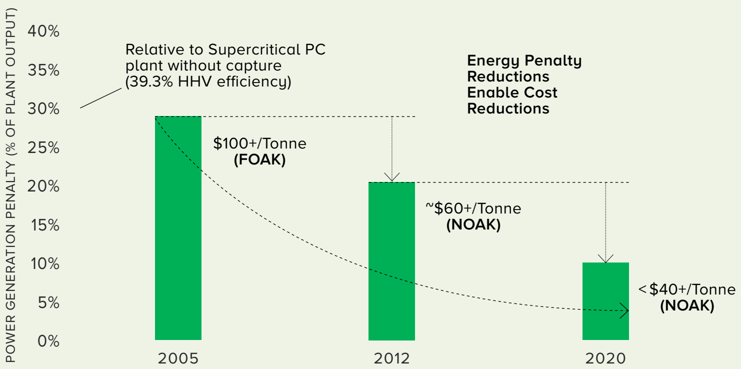
First-of-a-kind CCS costs in different industries



Source: Global CCS Institute (November 2017)

This figure shows the costs of implementing CCS technologies in the power sector and across a number of industrial processes, with costs defined as the cost per tonne of CO_2 avoided (in US$).

R&D driving costs reductions



Source: Michael Matuszewski. "DOE/NETL CO2 Capture R&D Program". 2014 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, 29 July–1 August 2014

Note: HHV = Higher Heating value, FOAK = First of a Kind, NOAK = Nth of a Kind.

Considerable R&D efforts have been devoted to addressing the cost of CCS, particularly those arising from the "energy penalty" from CO_2 capture in power generation. The US DOE research program has contributed to delivering cost reductions from over US$100/tonne in 2005 to US$60/tonne currently, and is targeting US$40/tonne by the 2020–2025 timeframe.

The Petra Nova 240 MW carbon capture facility at the WA Parish generating station. Photography courtesy NRG.

LEARNING-BY-DOING

Costs reductions are possible through learning-by-doing, improvements in existing technologies, and new, innovative technologies and processes. Learning-by-doing refers to the ability to perform tasks and processes more efficiently each subsequent time they are done. This produces very large cost reductions early in the deployment phase compared to "first-of-a-kind" attempts.

Contingencies associated with "overbuilding" and conservativism in plant design are also quite prevalent in 'first-of-a-kind' CCS facilities given their size and complexity, and these can be removed once confidence is gained in constructing and operating facilities at the relevant scale. Other reductions take the form of avoided costs in plant design, approvals, management inefficiencies and project risk.

Many of these were specifically identified by NRG in its claim that Petra Nova – if repeated – could be achieved at 20–30% less cost through:

- Streamlining procurement, reducing structural steel used;
- Standardisation of design and prefabrication of modular components, which can then be more rapidly and easily assembled on-site;
- Improvements in the efficiency and performance of the solvent used, which will reduce the amount of energy needed to run the CO_2 capture process;
- Improvements in financing costs such as reduced fees, less due diligence required, reduced time to complete financing, and higher debt-to-equity leverage.

SaskPower claims that a 30% capital cost saving could be realised if the learnings from the Boundary Dam Unit 3 capture development are applied in future retrofits. SaskPower and BHP have partnered to apply these lessons in other sectors where post-combustion retrofits are relevant.

IMPROVEMENTS IN EXISTING TECHNOLOGIES

Improvements in existing technologies drive cost reductions by making known processes more efficient. In CCS technologies, this is typically focused on capture techniques, and can include modifying the chemical and physical characteristics of solvents to reduce the energy penalty associated with solvent regeneration.

A prominent recent example is the Carbon Clean Solutions CDRMax™ proprietary solvent, which has been demonstrated to reduce operational costs by 30% relative to conventional capture technologies. This low-corrosion solvent also allows capital cost reductions by allowing the use of carbon steel instead of stainless steel.

INNOVATIVE TECHNOLOGIES AND PROCESSES

Significant reductions in capture cost are expected through the introduction of new methods, many of which are now being tested at pilot scale. Successful testing can lead to commercial deployment through the course of the next decade.

Global efforts are now focussed on these “transformational” technologies:

- In North America, examples include testing of Allam Cycle Technology and Fuel Cell carbon capture technology for power generation, and testing of the VeloxoTherm™ process being developed by Inventys;
- In Europe, pilot plants testing capture applications in steel-making and cement are well advanced, and a new low-emission geothermal power system that re-injects the CO_2 produced will soon be operational;
- In Asia, Taiwan is testing advanced approaches to CO_2 capture in cement production, while in Japan the Osaki CoolGen project will be testing new capture approaches at a newly built coal-fired power facility.

CCS facilities are already in use in those industries where the incremental costs of capture are low and where the captured CO_2 has ready access to mature transport and storage infrastructure. Specific policy and regulatory challenges, rather than cost structures, are the main inhibitors to faster uptake.

In higher-cost applications, the evidence is promising. Costs have fallen substantially in the past decade. With the learnings gleaned from just a handful of first-of-a-kind large-scale facilities and new transformational technologies under development, further substantial cost reductions are in train within the next 5–7 years.

CCS facilities are already in use in those industries where the incremental costs of capture are low and where the captured CO_2 has ready access to mature transport and storage infrastructure. Specific policy and regulatory challenges, rather than cost structures, are the main inhibitors to faster uptake.

REGIONAL OVERVIEWS

Americas –

Timeline

Terrell Natural Gas Processing Plant
1972

Enid Fertilizer
1982

Shute Creek Gas Processing Plant
1986

Great Plains Synfuels Plant and Weyburn-Midale
2000

Century Plant
2010

Petrobras Santos Basin Pre-Salt Oil Field CCS
Air Products Steam Methane Reformer
Lost Cabin Gas Plant
Coffeyville Gasification Plant
2013

Boundary Dam Carbon Capture and Storage
2014

Quest
2015

Petra Nova Carbon Capture
Illinois Industrial Carbon Capture and Storage
2017

CO_2

>190 million
tonnes cumulative anthropogenic CO_2 stored in the Americas

>30 sites
with anthropogenic CO_2 storage in the Americas

87%
of total anthropogenic CO_2 stored worldwide is stored in the Americas

45 years
Since CO_2 capture and injection operations began at large-scale in Texas

5 sectors

biofuel · hydrogen · natural gas processing · power · fertilizer

CCS: a climate game changer in an ever-changing game

2017 was a critical year for carbon capture in the Americas. The US and Canada continue to dominate activity in the region. Twelve of the 17 operating large-scale CCS facilities are located in these two countries. In Canada, Quest and Boundary Dam continue to hit new storage milestones. And in the US, this year, two large-scale carbon capture facilities, Petra Nova and Illinois Industrial, came onstream and a third, Lake Charles Methanol, entered advanced development.

Located near Houston, Petra Nova garnered the greatest global attention and for good reason.

Representing the world's largest CCS system on a coal-fired power plant, it was completed on-time and on-budget to capture about 1.4 million tonnes of CO_2 annually – and it is predicted to pay for itself within 10 years. Ninety percent of CO_2 emitted from Unit 8 of the W.A. Parish power plant is being captured and used in EOR.

Illinois Industrial has become the world's first large-scale CCS application on bioethanol production, producing corn ethanol and capturing all CO_2 generated as part of the fermentation process.

And, backed by a provisional US$2 billion loan guarantee from the US DOE, Lake Charles Methanol will convert petroleum coke (petcoke) sourced from oil refineries in the Gulf Coast region into synthetic gas (syngas), capturing more than 4 million tonnes of CO_2 per annum.

These facilities have advanced the place of CCS as a technology that is dexterous, commercial and right for our time.

These, together with smaller scale facilities – such as Chaparral/Connestoga (in Kansas), Bonanza Bioenergy CCUS EOR (also in Kansas), and Core Energy (in Michigan) – are demonstrating CCS's value as a source of employment, economic growth and innovative achievement, as well as a key tool to address climate change. Notably, five of these six facilities are in the industrial sector, reflecting that the near-term opportunity for CCS in the Americas is higher on industrial plants than it is in power generation. Numerous efforts are underway to create hub-and-spoke CCS systems, linking together numerous industrial CO_2 sources to a common pipeline for CO_2 storage or EOR.

We would be remiss if we did not acknowledge the disappointment that the Kemper County Energy Facility was not able to demonstrate how a combination of technologies can combine to dramatically reduce emissions from coal-fired power plants. While the CCS components of the plant proved to operate as designed, other elements of the plant were problematic. Ultimately the plant owners decided to run the power plant on natural gas, rather than to gasify coal and capture the CO_2.

There are numerous new technologies under development that have the potential to dramatically change the future of carbon capture.

One of these is NET Power's first-of-a-kind natural-gas-fired demonstration power plant located near Houston, currently under construction. Utilising NET Power's proprietary Allam Cycle Technology, the plant captures CO_2 as an inherent element of power production, without the use of add-on carbon capture equipment – a technology "first".

Fuel Cell Energy, based in Connecticut, US, and Inventys based in British Columbia (Canada) are also pushing the CCS innovation envelope in new directions.

However, early stage innovation can only advance to commercialisation if it is supported by government policy. Without such policy, technology developers cannot bridge the commercialisation "valley of death".

Incentives remain critical to advance CCS deployment, and currently there are not enough. In the US, there is much discussion about an incentive colloquially known as "45Q". This refers to a provision in the US Internal Revenue Service (IRS) Code that currently awards companies US$10 per tonne for CO_2 stored as a part of an EOR process and US$20 per tonne of CO_2 injected into a dedicated storage site, with a cap of 75 million tonnes of CO_2 stored. However, the volume cap and the incentive amounts are seen as inadequate to drive new investment in CCS facilities.

A bipartisan bill to expand the existing 45Q provision, introduced in July 2017, secured 25 co-sponsors in the US Senate.[xx] The proposed bill, the FUTURE Act (Furthering Capital Carbon Capture, Utilisation, Technology, Underground storage, and Reduced Emissions), would remove the cap for the total amount stored, expand the eligibility criteria for companies that can claim the tax credit, award US$35 per tonne of CO_2 stored via EOR and US$50 per tonne of CO_2 used for dedicated storage, and allow a 12-year period for companies to claim the credit. A similar bill has been introduced in the House of Representatives. While bipartisan support exists for both bills, their fate will likely be tied to the broader tax reform effort in the US, not only on the merits of the bills themselves.

As the 45Q revisions are advanced, no clear direction on CCS from the new US administration is evident. The President has signed an executive order to dismantle the Clean Power Plan (the Obama Administration's signature climate change policy package that directed power producers to reduce CO_2 emissions), and has announced that the US will withdraw from the Paris Climate Accord. However, the administration continues to state its support for expanded use of "clean" fossil fuels, and Energy Secretary Rick Perry has made several statements in support of CCS development.

While an uncertain policy environment exists at the national level in the US, many sub-national jurisdictions, particularly in the US and Canada, have become more active and prominent in addressing climate change.

In recent years, US state governments have established policies such as Renewable Portfolio Standards, which mandate levels of electricity production required to be produced from wind, solar, and other clean power sources (CCS is typically not included).[xxi]

Many states and provinces have also established various incentives for renewable energy and coupled them with carbon-pricing mechanisms such as the Regional Greenhouse Gas Initiative[xxii] and the California-Québec-Ontario cap-and-trade system.[xxiii] Similar shifts from federal to state action can be seen for carbon capture.

California's Air Resources Board is considering a comprehensive quantification methodology to allow carbon capture facilities to receive credit under the state cap-and-trade system and Low-Carbon Fuel Standard (a law incentivising lower carbon intensity transportation fuels).

In Canada, home to the successful Boundary Dam CCS facility in Saskatchewan and the Quest CCS Facility in Alberta, the Federal government is implementing the Pan-Canadian Framework,[xxiv] imposing a carbon price beginning in 2018. Over the past year, carbon pricing has dominated discussion about climate change in Canada, and several provinces (Alberta, Nova Scotia and Ontario) have advanced their local carbon-pricing mechanisms.

On balance, we are encouraged about the future of CCS in the Americas. While significant challenges remain, the perseverance of the private sector and the growing awareness of the critical role of CCS by governments in the region are advancing the technology, reducing the costs, and creating the incentives to accelerate the deployment of CCS.

JEFF ERIKSON

General Manager – Client Engagement

Global CCS Institute

CCS facilities

PETRA NOVA CARBON CAPTURE – TEXAS, UNITED STATES

As we entered 2017, the largest post-combustion carbon capture facility on a coal-fired power plant in the world commenced operation at NRG's W.A. Parish power plant, on schedule and on budget. Petra Nova is a retrofit application with a capture capacity of 1.4 million tonnes of CO_2 per year (240 MW equivalent).

The facility employs the Kansai Mitsubishi Carbon Dioxide Recovery flue gas CO_2 capture process that was previously tested at pilot scale (25 MW) at Southern Company's Plant Barry in Alabama. Petra Nova employs a separate gas-fired combined heat and power unit to provide steam and electricity to the carbon capture system. This approach was taken to fully separate the power required to run the CCS facility from the power sold to NRG's customers.

Ninety percent of emitted CO_2 from Unit 8 of the power plant is captured and used in EOR. NRG co-owns the oil field where it transports CO_2 for EOR. This innovative business model will allow Petra Nova to pay for itself in less than 10 years even if oil prices remain low.

A bird's-eye view of Petra Nova carbon capture facility. Photography courtesy of NRG.

Lake Charles Methanol, United States. Render courtesy of Lake Charles Methanol LLC.

ILLINOIS INDUSTRIAL CARBON CAPTURE AND STORAGE – ILLINOIS, UNITED STATES

One of the most significant successes of the year was the official start of operation at the Archer Daniels Midland (ADM) Illinois Industrial CCS facility. ADM produces corn ethanol at its Decatur, Illinois, plant and captures all the CO_2 generated as part of the fermentation process. Carbon capture on ethanol production is inexpensive and requires less energy because CO_2 separation from other gasses is inherent in the ethanol production process, thus the facility only needs to dewater and compress the already separated CO_2 and store it. ADM is storing the CO_2 in a saline formation located deep underneath the facility. This saves on transportation since the storage site is in the immediate proximity. Start-up of this facility demonstrates that biofuel-based negative emissions are achievable at scale.

LAKE CHARLES METHANOL – LOUISIANA, UNITED STATES

The largest industrial facility with CCS in advanced planning, Lake Charles Methanol is backed by a provisional US$2 billion loan guarantee granted by the US DOE. The projected total cost of the facility (including CO_2 separation and compression equipment) is around US$3.8 billion. The facility would convert petroleum coke sourced from oil refineries in the Gulf Coast region into synthetic gas (syngas). The syngas would then be processed to produce methanol (the project's primary product), hydrogen gas, sulfuric acid and CO_2. Lake Charles would be designed to capture over 4 million tonnes of CO_2 per annum; overall, the project would capture 77% of total CO_2 produced. The captured CO_2 will most likely be transported 225 km/140 miles to oil fields in the Houston area for EOR. There is some uncertainty regarding the future of the US DOE loan guarantee program, but as of now, the project proponents are still moving forward toward a final investment decision.

Core Energy-South Chester Gas processing plant. Photography courtesy of the US Department of Energy's National Energy Technology Laboratory

Smaller-scale CCUS facilities

Large-scale facilities seem to garner most CCS attention with regard to progress of carbon capture deployment, but smaller facilities play an important role in advancing broad deployment of CCS and also demonstrate the versatility and relevancy of CCS in various industries.

CHAPARRAL/CONESTOGA ENERGY PARTNERS' BIOETHANOL PLANT – KANSAS, UNITED STATES

The first bioethanol plant to deploy carbon capture (2009), it captures around 200,000 tonnes of CO_2 per year that is used by Chaparral Energy for EOR at the Booker and Farnsworth Oil Units in Texas. The Institute estimates that the facility has captured around 1.5 million tonnes of CO_2 since start-up.

BONANZA BIOENERGY CCUS EOR – KANSAS, UNITED STATES

PetroSantander owns and operates the dehydration, compression, transport and CO_2 injection sites for CO_2 sourced from the Bonanza BioEnergy ethanol plant in Kansas, US. The facility began operations in 2012 and captures up to 100,000 tonnes of CO_2 per year, which is used for EOR in the nearby Stewart oil field. Since the start of operations, the Institute estimates that the facility has captured around 0.5 million tonnes of CO_2.

CORE ENERGY/SOUTH CHESTER GAS PROCESSING PLANT – MICHIGAN, UNITED STATES

Core Energy owns a CO_2-EOR facility located in Michigan that uses CO_2 captured from a natural-gas processing plant. The facility began operating in 2003, and has captured over 2 million tonnes of CO_2 to date. Core Energy works with the US DOE and the Midwest Regional Carbon Sequestration Partnership, and is currently participating in a Phase 3 long-term high-volume CO_2 sequestration project.

Core Energy-South Chester Gas Processing Plant. Photography courtesy of the US Department of Energy's National Energy Technology Laboratory

Research and development

The US Department of Energy has funded research and development aimed at reducing costs associated with CCS for nearly 20 years. Over that period, costs associated with first-generation capture technologies have decreased from over US$100 per tonne of CO_2 captured to approximately US$60 per tonne for power sector applications. Current efforts are focused on the development of second generation and transformational technologies. Second-generation technologies are currently being tested at pilot scale and are targeted to be available for demonstration testing in the 2025 timeframe with costs 20% lower than currently available technologies. Transformational technologies are targeted to reduce costs by 30% compared to currently available technologies, and should be available for demonstration testing by 2030.

Costs associated with first-generation capture technologies have decreased from over US$100/tonne of CO_2 captured to approximately US$60/tonne for power sector applications.

There are many technologies under development that have the potential to meet or exceed US DOE cost targets. The three highlighted below are being developed by NET Power, Fuel Cell Energy and Inventys:

NET POWER CLEAN ENERGY LARGE-SCALE PILOT PLANT – TEXAS, UNITED STATES

Construction is nearly complete on a 50 MW thermal (25 MW electric) first-of-a-kind natural-gas-fired power plant located near Houston, Texas. The plant will test NET Power's proprietary Allam Cycle Technology, which uses CO_2 as a working fluid in an oxy-fuel, supercritical CO_2 power cycle to generate electricity. In effect, the Allam Cycle Technology concept inherently captures CO_2, eliminates nitrogen oxide/sulphur oxide concerns, and produces pipeline-ready CO_2 without the use of add-on carbon capture equipment. According to NET Power, the benefits of the Allam Cycle Technology concept include near-zero air emissions (>97% carbon capture), low capital cost (comparable to NGCC (natural gas combined cycle) without carbon capture at US$900–1,200/kW), and flexible water usage (when air-cooled it becomes a net producer of water).

FUELCELL ENERGY (FCE) CAPTURE PILOT PLANT – ALABAMA, UNITED STATES

In cooperation with the US DOE and ExxonMobil, a pilot-scale testing program of a system that utilises molten carbonate fuel cells to capture CO_2 will take place at Southern Company's Plant Barry in Alabama. A portion of the flue gas from Plant Barry will be directed to the fuel cell's air intake system (where it will be combined with methane). As the fuel cell generates power, a side reaction allows the CO_2 in the flue gas stream to be concentrated and captured. With conventional capture systems, electricity production from the host power plant is often used to operate the capture equipment. With the FuelCell Energy system, additional electricity is produced in the process of capturing CO_2, substantially offsetting costs.

INVENTYS AND HUSKY ENERGY – SASKATCHEWAN, CANADA

The VeloxoTherm™ capture system developed by Inventys is slated for pilot-scale testing in 2018 at Husky Energy's Pikes Peak South Lloyd thermal project in Saskatchewan, Canada. The system uses a structured solid adsorbent material in a rotating bed to enable a rapid cycling temperature swing adsorption/desorption process. This approach eliminates many of the energy inputs required in solvent-based capture processes. The structured sorbent also minimises sorbent attrition issues commonly associated with fluidised-bed solid sorbent processes. Early estimates indicate substantial cost savings are possible.

REGIONAL OVERVIEWS

Asia and the Pacific (APAC) –

1,500 billion

tonnes of underground storage resources in China

2 large-scale

CCS facilities (in China and Australia) targeted to be operational in 2018

11 large-scale

CCS facilities in varying stages of development planning across APAC

400,000 tonnes

per annum will be captured by the Yanchang CCUS faciltiy in China

China

CCS: an indelible mark on the Chinese landscape

This year, China made an indelible mark on the CCS landscape.

Centre-stage was the announcement in March that Yanchang Petroleum's industrial CCUS facility moved into construction. This reaffirmed CCS's emergence as a rapid climate change mitigation technology, representing the first large-scale CCS/CCUS development to take a final investment decision in China – and Asia.

Located near Xi'an (Shaanxi Province), Yanchang CCUS will capture more than 400,000 tonnes of CO_2 per annum from two coal to gasification (syngas) plants. It will reinject captured CO_2 into previously developed oil fields to release oil from existing formations in the process known as EOR.

EOR remains a major storage option for Chinese enterprises progressing CCS deployment, and is the predominant driver, along with enhanced water recovery, of CCS utilisation.

Yanchang's progress from conception to final investment is unrivalled. Four years ago, it was an industrial plant venting CO_2 into the atmosphere and now it is a standard-bearer for Chinese clean technology – expected to capture between 6 and 8 million tonnes of CO_2 over the course of its life.

CCS success has not been singular. China also moved its CCS agenda forward with the announcement that the Haifeng Power Plant in Guangdong plans to invest CNY 100 million (US$15 million) to progress CO_2 capture test facilities (to support future large-scale carbon capture) with an annual CO_2 capture capability of around 20,000 tonnes. Also at Haifeng, the selected CO_2 capture technology will be installed at the Unit 3 and Unit 4 generator to achieve capture capacity of 1 million tonnes per annum in the future.

SINOPEC Zhongyuan Oilfield has launched a series of projects in Henan Province which have the capacity to recover 1 million tonnes of CO_2 per annum and established China's first CO_2 storage base of water-flooding abandoned oil reservoir with an annual injection of 160,000 tonnes, a total injection of around 0.5 million tonnes and an increase in production of around 0.1 million tonnes of crude oil.

Further facilities are in different stages of development and various provinces, including Guangdong, Sichuan, Guizhou, Hebei, Tianjin, Fujian, Jilin and Gansu, have identified CCS demonstration as a crucial technology to reduce industrial greenhouse gas emissions in their provincial 13th five-year plans.

A major push by the Institute to "inform through fora" – facilitating the transfer of CCS information between key stakeholder groups through high-level dialogues – has helped thrust CCS into the limelight.

Major initiatives include:

- The Yanchang Petroleum – Global CCS Institute CCUS Project Symposium in Xi'an (March 2017);
- The Symposium on Decarbonisation: CCUS Perspective in the Steel Sector, jointly organised by the Global CCS Institute and BHP at Peking University (May 2017);
- The Eighth Clean Energy Ministerial (CEM8) and Second Mission Innovation Ministerial (MI-2) in Beijing (June 2017), which included a dedicated CCS side-event;
- The 4th Beijing International Forum on CCUS Technology was held by China Technology Strategic Alliance for CCUS Technology Innovation (CTSA-CCUS) in April 2017.

Proactive support by the Chinese government for ongoing CCS policy design, and its "all-industry, all-institutional" approach to building consensus, has been instrumental in allowing CCS to take shape.

Dialogue, policy design and the physical manifestation of China's first large-scale CCS facility – combined with a whirlpool of media interest – demonstrates that CCS has made its mark on China and is here to stay.

DR XIANGSHAN MA

Country Manager – China

Global CCS Institute

Japan

CCS: the energy anchor to new economies

Japan has a significant place in the history of climate change mitigation.

It is the birthplace of the Kyoto Protocol which lay the foundations for the Paris 2˚C targets, and Japan therefore feels a great obligation to meet its climate change commitments and lead by example.

Japanese emissions make up 2.8% of the world total, and they are in decline through reductions in electricity consumption by the introduction of HELE technology and end-use energy conservation efforts.

However, the ongoing construction of coal-fired generating capacity will make targets unattainable unless CCS is deployed.

It is the only technology capable of taking emissions from industries such as steel, chemicals and fertiliser, and burying it in the 140 billion tonnes of underground storage resources that Japan has at its disposal.

Since Kyoto, Japan has put in place a comprehensive CCS program, which has been expanding for several years and is now bearing fruit.

For this, we must acknowledge the methodical approach developed between the Japanese government, through the Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment and Japan's leading industrial technology companies.

The program includes the investigation of potential CO_2 storage sites, CCS feasibility studies, and the assessment of legal and regulatory structures necessary for the management of long-term liability for stored CO_2. It also includes wide-ranging studies into the environmental, economic and social impacts of CCS.

The strategic nature of Japan's CCS program is further demonstrated by its choice of pilot and demonstration facilities, which are creating much needed knowledge centres in areas where CCS is proving itself a clear leader and differentiator – in industrial CCS processes, hydrogen production, power generation, and CCUS.

As CCS knowledge in Japan expands, so too does the scale-up of much-needed CCS facilities.

The past 18 months have been characterised by five significant CCS milestones:

- Commencement of CO_2 injection at the Tomakomai CCS Demonstration Facility by Japan CCS with METI's full support – Asia's first full-cycle CCS hydrogen plant, which will capture more than 300,000 tonnes of CO_2 by 2020;
- Retrofit of Toshiba Corporation 49MW Mikawa power plant in Omuta (Fukuoka Prefecture) to accept biomass (in addition to coal) with a carbon capture facility;
- 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 Ōsakikamijima (Hiroshima Prefecture), which will separate and capture CO_2;
- Completed construction of Toshiba's carbon capture and utilisation system at the Saga City Waste Incineration Plant (on Japan's Kyushu Island), using captured CO_2 for algae culture;
- Announcement by Kawasaki Heavy Industries of a Japanese hydrogen supply chain that plans to gassify Australian brown coal in Victoria's Latrobe Valley and transport it by ship as carbon-free hydrogen to Japan for use in transportation.

These developments are the catalyst to a new CCS-driven energy economy.

Japan sees a future that is fuelled by the intelligent and environmentally sensitive use of fossil fuels, with CCS as its primary energy anchor.

HIROSHI NAMBO

Branch Representative – Japan

Global CCS Institute

TOMAKOMAI: A MODEL FOR CCS INNOVATION

The Tomakomai CCS Demonstration Project, the first full-cycle CCS system in Asia, will capture and store more than 300,000 tonnes of CO_2 in sub-seabed reservoirs over a three-year period, and play an important role in showing how practical and necessary CCS is in meeting Paris climate change targets.

Since the commencement of CO_2 injection in 2016, and with understanding and support of local communities, Japan CCS has undertaken CO_2 capture and injection smoothly and without incident. The cumulative CO_2 injection volume is expected to exceed 100,000 tonnes by the end of 2017.

By achieving full-scale sub-seabed geological storage safely and reliably in an earthquake-prone country, the Tomakomai Project is becoming a model for technological innovation contributing towards the development and deployment of CCS worldwide.

MR SHOICHI ISHII

President

Japan CCS Co., Ltd.

Tomakomai CCS Demonstration Facilities located at Tomakomai City, Hokkaido. Photography courtesy of JCCS © 2017 Japan CCS Co., Ltd.

South Korea

While the South Korean government revises its CCS Master Plan, the government's policy has supported a number of test and pilot facilities, involving a wide variety of agencies and technology providers in the power-generation and steel-making industries.

This includes the Korea Electric Power Corporation's (KEPCO) testing of post-combustion capture technologies at its Boryeong and Hadong coal-fired power stations. Small-scale CO_2 capture facilities at both power stations were increased in scale in 2013/2014 to approximately 200 tonnes per day (equivalent to a 10 MW flue gas slipstream).

The Hadong thermal power complex is used to test dry regenerable solid sorbent technology (with a fluidised-bed CO_2 capture process). Start-up of the first stage of research was in late 2010 with a 0.5 MW test-bed slipstreamed from the 500 MW coal-fired Unit 3. The second stage of research involves a scale-up of the CO_2 capture facilities to approximately 200 tonnes per day (equivalent to a 10 MW or 35,000 Nm3/h flue gas slip-stream from a coal-fired unit, Unit No.8). Commissioning of the 10 MW pilot plant was in April 2014, with testing planned to continue to September 2017. The results of this research will be used to contribute to a Front-End Engineering Design Study of a 300 MW-scale dry-sorbent CO_2 capture facility.

Unit 8 (500 MW capacity, coal-fired) of the Boryeong thermal power complex is being used to test an advanced amine CO_2 capture solvent developed by KEPCO. Start-up of the first stage of research was in late 2010 and accomplished 90% CO_2 capture from a 0.1 MW test bed. CO_2 capture capacity was around 2 tonnes per day. The second stage of research involves a scale-up of the CO_2 capture facilities to approximately 200 tonnes per day (equivalent to a 10 MW flue gas slip-stream from Unit 8). There is also an active storage exploration program focusing on the offshore Korean basins.

Taiwan

Taiwan's reliance on fossil fuels makes CCS an essential option for decarbonising its economy.

This has been recognised by the Taiwan government which has funded various programs to develop CCS technology and support pilot projects. Ideal locations for CO_2 storage have been identified, but more work needs to be done to appraise those sites before they can be utilised at commercial scale.

The Bureau of Energy under the Ministry of Economic Affairs is managing Taiwan's CCS technology development. The Taiwan Environmental Protection Administration and the Ministry of Science and Technology also support the development of CCS in different capacities.

A highlight of Taiwan's CCS technology development programs is the world's largest calcium-looping plant at a cement factory operated by the Taiwan Cement Company in Hualien.

This award-winning technology developed by the Industrial Technology Research Institute has now evolved to its third generation, achieving a higher efficiency and lower cost. Taiwan Cement, China Steel Corporation and other key industry stakeholders have all, to various extents, been working to develop carbon capture and utilisation technology, including aqueous ammonia, membrane and microalgae.

In the electricity sector, Taiwan Power Company has been working on various capture technologies in collaboration with research institutions and universities. It plans to build and operate a post-combustion pilot plant (10 tonnes per day capture capacity) at Taichung Power Plant in Chuanghua County, central Taiwan. Nearby storage sites (16 km away) have also been identified and a preliminary study has indicated adequate effective capacity for large-scale storage. A 10,000 tonne CO_2 injection pilot facility has been planned for this site. Local community engagement will precede storage appraisal as a vital part of plant development.

Taiwan continues to focus on improving carbon capture technologies, especially in the industrial sector where it has taken a leadership position on capturing CO_2 from cement manufacture. Consistent with the wider region, government policy and community support are needed to ensure whole chain CCS project development.

Australia

Finding public prominence in Australia

Over the past several years there has been a growing sense of foreboding amongst Australia's energy intensive industries.

The domestic gas market was tightening as international liquefied natural gas (LNG) export terminals came online and regulation in a few states effectively proscribed additional supply. Low cost thermal generators were exiting the wholesale power market. Disconnected energy and climate policy had caused a capital strike in investment in dispatchable generators to replace them and there was great uncertainty about how future electricity demand would be met.

Despite Australia's enviable position as an advanced and affluent economy, there was a perception that electricity was becoming a scarce commodity. In any market, perceptions of scarcity put upwards pressure on price. And whilst electricity prices in Australia more than doubled since 2009, a comprehensive response by government (federal or state) remained "missing in action".

There is no greater call to action than a crisis, and concerns about electricity cost and security reached crisis levels in Australia in 2016/17 largely due to three key drivers:

- Blackouts in South Australia, including an unprecedented state-wide "system black" that called into question the resilience of its electricity system which generates 40% of its electricity from intermittent renewable generation;
- Escalating natural gas prices following completion of LNG export facilities contributing to increasing wholesale electricity prices caused by gas generators, that supply peaking electricity load;
- The decommissioning of a 52-year-old, 1,600 MW, brown-coal-fired power station (Hazelwood) in the state of Victoria, which again called into question energy supply reliability and the impact of industrial power closures on local jobs and economies.

This confluence of events served as a wake-up call. Achieving a true low-emissions electricity system whilst maintaining first-world levels of electricity security at the lowest possible cost requires active planning and management. The folly of simply hoping that a renewable only future would meet all the country's future needs was recognised and CCS rose to public prominence in the Australian energy and climate debate.

ALEX ZAPANTIS

General Manager – Commercial

Global CCS Institute

The Australian Government responded, initiating a review of the Australian national energy market led by Chief Scientist, Dr Alan Finkel.[xxv]

This ensured the energy debate became highly politicised and publicly charged.

It also ensured that CCS became part of a wider conversation about energy solutions – a debate that has been a long time coming but one that we were ready to promote.

The introduction of federal government legislation to allow CCS to be given the same concessional loans as other clean technologies under clean energy financing was one small win on the road to policy parity, although it is still "early days" in terms of outcomes.

Uncertainties remain regarding bans on unconventional gas extraction in several states (which would expand domestic supply and arguably lower prices) and the introduction of a “Clean Energy Target”, which could potentially subsidise CCS-equipped power stations in a similar way as mandated renewable generation targets. This forms part of a growing discussion around “technology neutral” policy.

One thing is for sure: the debate that has transpired in Australia, especially at media level, has been instrumental in putting CCS on the table, demonstrating its role in providing low-carbon controllable electricity, and proving its cost competitiveness when total system costs of a true low-emissions grid are considered. We have welcomed that scrutiny and we have, where possible, fanned its flames.

The Institute and its members are proactive participants in all relevant reviews and we will continue to actively engage with the Australian government to positively influence national climate change policies. Our message is simple. Do the math; climate targets agreed in Paris in 2015 are impossible to meet unless every low emission technology, including CCS, is available to play its full role. It is time for climate and energy policy to grow up and place us on a trajectory towards success.

ALEX ZAPANTIS

Project activity

KEY ACTIVITY IN AUSTRALIA INCLUDES:

- Commissioning of the Gorgon Carbon Dioxide Injection facility in Western Australia in 2018;
- Location of a proposed storage site and securing of a greenhouse gas permit for the CarbonNet facility in Victorian state waters;
- Planning for the trial injection of CO_2 at the SouthWest Hub facility in Western Australia;
- Collation of baseline data on air, shallow groundwater and soil vapour for the Integrated Surat Basin Carbon Capture and Storage facility in Queensland;
- Progression of drilling under Stage 3 of the CO2CRC Otway facility in Western Victoria, which aims to inject 40,000 tonnes of CO_2 for monitoring and verification;
- Discussions between the Victorian government and Kawasaki Heavy Industries regarding the potential for brown coal to hydrogen production with CCS, with export opportunities to Japan.

Otway Facility, Australia.
Photography courtesy of CO2CRC.

Legal and regulatory development in the APAC region

The status of CCS legal and regulatory development in countries across the APAC region largely reflects a global trend – a marked slow-down in the pace and scale of CCS-specific activity in recent years. A detailed assessment, undertaken as part of the preparation of the Institute’s “Legal and Regulatory Indicator 2017”, reveals there has been little or no change in the status of law and regulation in many APAC countries in the past two years.

Despite no substantive developments during this time, Australia’s legal and regulatory frameworks remain some of the most advanced and supportive CCS-specific models in the world.

Elsewhere in the region, there has been little activity to develop and improve CCS-specific models, with exceptionally few advances in recent years. Legal and regulatory regimes, which support the deployment and operation of projects, remain underdeveloped and incomplete in many countries across the APAC region.

The recent period of inertia and underdevelopment observed within the APAC region, is perhaps symptomatic of the dearth of more stringent climate-related legislation. CCS is viewed as essential for achieving deep reductions in global emissions and for achieving the climate targets agreed in Paris. Despite this, the legislation necessary to drive these deep reductions is not in place across many global jurisdictions. While this is perhaps not entirely unexpected, an ambiguous or incomplete domestic legal and regulatory environment will undoubtedly prove a hindrance to project proponents and investors. For APAC countries hosting projects, or that continue to view CCS as an intrinsic part of their future mitigation effort, it is imperative that efforts are made in the near term to address deficiencies in their current regimes and develop more comprehensive regulatory frameworks.

For those countries with more detailed regimes, including those listed within Band A of the Institute’s Legal and Regulatory Indicator and that possess substantive CCS-specific models, the emphasis must now turn towards resolving outstanding issues and completing regulatory frameworks. In addition, several regimes would benefit from improvements to administrative procedures and the development of further guidance.

Despite this recent slow-down, the APAC region offers some significant opportunities for legal and regulatory development.

The growth of projects in Australia, China, Korea and Japan, as well as interest in the technology amongst the ASEAN nations, suggests that expedience in the development of law and regulation is essential. Increased government and commercial interest in the development of CCS-specific legal and regulatory regimes across the region, however, suggests that further expansion is to be anticipated in the forthcoming years.

The recent period of inertia and under-development observed within the APAC region, is perhaps symptomatic of the dearth of more stringent climate-related legislation.

CCS: bridging the gap

The Paris Agreement is the first ever truly collective response to the global threat of climate change.

Signed by 195 countries and ratified by 150, the Paris Agreement has entered into force with historic speed. Parties have made significant commitments to reduce emissions, and are updating their policy settings accordingly.

There remains however, a large gap between countries' pledges and the Paris Agreement's long-term goals to keep temperature increases to well below 2˚C, let alone 1.5˚C, and to reach net-zero emissions in the second half of this century.

We must pull all levers to successfully implement the Paris Agreement and bridge the emissions gap. This includes more renewable energy, reducing emissions from fossil fuels, and nuclear energy for countries with that option. A key element must also include a renewed push on CCS and its sister application, carbon capture utilisation and storage (CCUS).

CCS and CCUS are now well-demonstrated technologies. Costs are falling through learning-by-doing and we can expect future projects to be significantly cheaper.

Innovative approaches to using carbon dioxide are emerging as scientists and engineers race to make useful products out of carbon dioxide.

A few shining examples include:

- Saudi Arabian company, SABIC's use of CO_2 waste carbon dioxide as a feedstock in fertiliser production;
- India's Carbon Clean Solutions, which is creating soda ash from carbon dioxide captured from a coal-fired power station;
- German polymer company, Covestro, which is pioneering the use of carbon dioxide in the production of foams used in mattresses and upholstered furniture;
- Australia's Mineral Carbonation International, which is piloting a process to combine carbon dioxide with minerals to produce building products such as bricks and cement;
- Iceland's CarbFix project, which is literally turning carbon dioxide into stone.

Achieving the Paris Agreement's goals will require a renewed focus on innovation and international collaboration.

Countries the world over are stepping up their efforts and there are a range of existing and new fora to break ground.

For example, the US and Saudi Arabia are co-leading the Carbon Capture Innovation Challenge under Mission Innovation with a raft of other countries as far flung as Australia, Indonesia, Italy and United Arab Emirates. A ministerial-level international climate change initiative called the CSLF is focused on the development of improved cost-effective technologies for CCUS.

Domestic settings and actions, coupled with international collaboration, are essential to see the next wave of large-scale projects come to fruition and establish long-term project pipelines.

Collaboration, policy and tangible action is how carbon capture and storage will ultimately bridge the emissions gap.

AMBASSADOR PATRICK SUCKLING

Australian Ambassador for the Environment

REGIONAL OVERVIEWS

Europe, Middle East and Africa (EMEA) –

MORE THAN

20 million

tonnes of CO_2 successfully and safely captured and stored by Sleipner and Snøhvit facilities in Norway

2 operating large-scale CCS facilities in Norway

2 operating large-scale CCS facilities in the Middle East

2 large-scale CCS facilities in early development in the UK

CCS: from narrow focus to high resolution

To summarise the status of CCS in Europe, Middle East and Africa (EMEA) is not easy. Not only is it a vast region with a complex geopolitical overlay, but CCS advancement has varied wildly from place to place.

Deployment in Europe has been held back by a series of policy reversals and the inability of several large-scale facilities to reach a final investment decision.

More recently, however, we have seen CCS move from a myopically viewed emissions fix for "just the power sector" to a more magnified climate change solution – and the only sensible and sustainable way of addressing emissions across Europe's diverse industrial sector.

In many ways, Norway continues to pave the way for much of this advancement.

It hosts Europe's two pioneer large-scale CCS natural gas facilities, Sleipner and Snøhvit, with collectively more than 30 years operational experience and more than 20 million tonnes of CO_2 successfully and safely captured and stored.

The concept of CCS hubs and clusters has re-energised CCS discussions in Europe with growing recognition of the vast North Sea storage option sitting at Europe's back door, and the need to address large quantities of industrial emissions across Europe that cannot be mitigated by any other technology. Initiatives focused on industrial CCS clusters with shared CO_2 infrastructure in Norway, the UK and the Netherlands are helping to move this agenda forward.

The European Commission (EC) has signalled a strong interest in this shared CO_2 infrastructure approach through its 2017 Projects of Common Interest consultation.

CCS research, development and innovation also continues to benefit from EC and national support in the form of the Accelerating CCS Technologies fund – a €41 million (US$47 million) program that comes from the EC's Horizon 2020 Program with match funding from nine individual European countries (Germany, Greece, the Netherlands, Norway, Romania, Spain, Switzerland, Turkey and the UK).[xxvi]

The UK has emerged from a period of inertia to reconfirm its commitment to CCS deployment, with the UK government including the technology in the country's Clean Growth Strategy. The UK has always maintained support for CCS R&D activity; for example, through the award of a £6 million (US$7.8 million) grant to the UK CCS Research Centre. The strong regional support for CCS deployment also continues, particularly in the industrial north-east of England and in Scotland, where efforts are largely focused on promotion of industrial CCS and the dramatic emissions reductions that CCS can facilitate within a whole energy system approach, including emission reductions in hard to tackle sectors such as heat and transport.

Also, the Dutch Government has made encouraging announcements about enhanced investment and potential legal commitments to enable the Netherlands to achieve a 49% emission reduction against 1990 levels by 2030. This substantial climate mitigation agreement looks to be at a level of around 4 billion euros per annum. The investment agreement would mean an overall reduction of 56Mt of CO_2 in 2030, 20Mt of which is to be achieved with CCS technology.

In the Middle East, CCS efforts have been personified by the November 2016 start-up of Al Reyadah CCS, the Emirates Steel CCUS facility in Abu Dhabi. This joint venture between Masdar and Abu Dhabi National Oil Company can capture up to 800,000 tonnes of CO_2 per annum from the Emirates steel factory and transport it by pipeline to oilfields for EOR.

In Saudi Arabia, the Uthmaniyah CO_2-EOR demonstration facility owned by Saudi Aramco can capture 800,000 tonnes of CO_2 annually, also for use in EOR. The Middle East is showing the commercial worth of CCS and its easy application to wider industry.

Africa is also advancing its CCS agenda with the South African Centre for CCS scoping onshore geological storage in the Zululand Basin (KwaZulu-Natal), and Nigeria requesting technical assistance from the UNFCCC to establish a CCS framework in that country.

After a period of stasis, particularly across Europe, interest in CCS appears to be reigniting. The versatility of this technology with its ability to drastically reduce CO_2 emissions at quantity and from industries and sectors previously thought too difficult to decarbonise is finally seeing this technology embraced as a critical part of a much bigger climate change picture and a key mitigation tool for a growing number of countries in the EMEA region. Our challenge is to ensure that it remains in focus and highly illuminated.

KIRSTY ANDERSON

Senior Consultant – Public and Community Engagement

Global CCS Institute

Aeroview of the Port of Rotterdam. Photography courtesy of Port of Rotterdam Authority.

ALEX CUNNINGHAM MP

Chair of the UK All Party Parliamentary Group for Carbon Capture and Storage

The time is now for [the UK] government not just to outline their policy on CCS but to embrace it as a vehicle for jobs, investment and environmental protection. The technologies are proven and the government can no longer hide behind its claims that it is too expensive to implement. It is too expensive not to implement and we need a long-term view if we are to reap the potential benefits. A good place to start would be the Teesside Collective project, which is innovative, robust and costed. Developed in an area where unemployment is over double the national average, it could drive a jobs revolution.

Europe – Large-scale CCS facilities

The Institute lists five large-scale CCS facilities in Europe, all of which use (or intend to use) dedicated offshore geological storage. Norway is home to the two operational large-scale CCS facilities in Europe: Sleipner CO_2 Storage and Snøhvit CO_2 Storage (both in natural-gas processing).

Combined, these pioneering facilities have almost 30 years of operational experience and have captured and stored more than 20 million tonnes of CO_2. The extensive monitoring programs associated with both facilities have greatly improved our understanding and modelling of how CO_2 behaves underground.

Norway is also home to Europe's only CCS facility in advanced development and potentially the region's first full-chain industrial CCS operation.

Norway Full Chain CCS builds on the feasibility studies completed by Gassnova for the Norwegian Ministry of Petroleum and Energy in 2016. In April 2017, all three industrial emission sites that had participated in the initial feasibility study – Norcem AS (cement plant), Yara Norge AS (ammonia plant) and Klemetsrudanlegget AS (waste-to-energy-recovery plant) – were awarded financial support to continue into detailed studies, and later in 2017, Statoil received funding to complete the associated CO_2 storage studies. In early October 2017, Statoil entered into a partnership agreement with Shell and Total to undertake these storage studies.

A total of NOK 360 million (US$46 million) was allocated in the 2017 Norwegian budget to support detailed technical, economic and costing studies. Should a positive final investment decision be made in 2019 (targeted date) commissioning of the full-scale CCS facilities could begin in 2022. If all three capture sources proceed into construction, total CO_2 capture capacity would be approximately 1.3 Mtpa.

The remaining two large-scale CCS facilities are both in the UK and are in the initial stages of development.

Sleipner CO_2 Storage. Photography courtesy of © Statoil. Photographer: Harald Pettersen.

Caledonia Clean Energy is considering construction of a new natural gas power plant with integrated CO_2 capture facilities located near Grangemouth, Central Scotland (with a CO_2 capture capacity of approximately 3 Mtpa). The Teesside Collective is a cluster of leading energy-intensive companies that are investigating the opportunity to build one of Europe's first CCS equipped industrial zones in the Tees Valley in the industrial north-east of England – current planning envisages an initial annual CO_2 capture capacity of approximately 0.8 Mtpa with a long-term target of 10 Mtpa. Both developments are targeting a mid-2020s operations date.

In addition to developing their individual proposals, both these facilities have been working cooperatively, alongside other potential CCS clusters on the east coast of the UK in the informally titled East Coast Network. They have been developing the social and economic arguments for strategic investment in east-coast CCS facilities and infrastructure in the UK to ensure value for money and make best use of existing assets.

Smaller-scale facilities

Perhaps it is as a reflection of the relatively slow progress being made with large-scale European CCS facilities, that several smaller-scale, but potentially very significant initiatives, are appearing across Europe.

Under study, and recently awarded additional Scottish government funding, is Acorn, a possible full-chain industrial CCS development designed to make use of existing infrastructure in the north-east of Scotland. Such a development can create a low-cost operational CCS system that can act as a seed (Acorn) from which to grow a network of CCS infrastructure. In June 2017, Acorn was awarded Horizon 2020 funding under the Accelerating CCS Technologies program and an additional phase of this initiative, the CO_2 SAPLING Transport Infrastructure Project, is currently being considered as a potential Project of Common Interest.

Teesside Collective. Photography courtesy of Teesside Collective UK. Photographer: Dave Charnley

Projects of Common Interest

The EC operates a biennial support scheme to enable the development of key infrastructure projects – known as Projects of Common Interest (PCIs).

Selected projects can benefit from accelerated permitting procedures, improving regulatory conditions and may be eligible for financial support from the Connecting Europe Facility (CEF).

The 2017 list of proposed PCIs included, for the first time, “Cross-Border Carbon Dioxide Transportation Infrastructure” – a thematic area focused on the development of CO_2 transportation networks.

In April 2017, four projects from this thematic area were submitted for CEF funding. Each of these projects involve CO_2 crossing national borders and connect multiple countries bordering the North Sea Basin. The projects identify infrastructure concepts that could form the first parts of a network of multiple CO_2 emitters across Europe, which share access to strategically sized transport and storage infrastructure. The initiatives are:

- **CO_2 Cross Border Transport Connections**
  The CO_2 Cross Border Transport Connections project will investigate the potential to move emission sources from the UK’s Teesside industrial cluster and the Eemshaven area in the Netherlands, to a storage site on the Norwegian Continental Shelf. This initiative is based on the development of a large storage site as part of the Norwegian CCS project, CCS studies by the Teesside Collective in the UK and the project to convert Vattenfall/Nuon’s Magnum gas-fired power station in the Netherlands to hydrogen. The concept is to develop new infrastructure for CO_2 transport by ship.
- **The Rotterdam Nucleus**
  Led by the Port of Rotterdam Authority, this is proposing a modular CO_2 transport infrastructure that will connect the Rotterdam Harbour to storage reservoirs in the Dutch and UK sections of the North Sea using new build pipelines.
- **The Teesside CO_2 Hub**
  Led by the Tees Valley Combined Authority, this builds on the planned CCS infrastructure in Teesside by developing and expanding the planned CO_2 terminal, importing CO_2 from around the North Sea, and using pipeline transport to a large offshore CO_2 storage site.
- **The CO_2 SAPLING Transport Infrastructure Project**
  Led by Pale Blue Dot, this is building out CO_2 transportation infrastructure from the Acorn CCS Project using existing North Sea pipelines and repurposing the St Fergus gas processing plant into a strategic European CO_2 sequestration hub.

Europe is also home to several research and development efforts seeking to develop suitable technologies for CCS in industrial applications and to reduce their cost. Examples of such projects include the LEILAC and CEMCAP projects in the cement sector that are advancing new concepts for CO_2 removal at cement plants through pilot testing.

In the steel sector, new production concepts are being investigated, including the HIsarna technology developed by TATA STEEL. This produces an almost-ready stream of CO_2 for transport and storage and can generate significant savings in capital and operating costs associated with CO_2 capture, creating a persuasive case for CCS-equipped steel plants in the future.

The new hydrogen economy

There is burgeoning interest in hydrogen as a potential emission-free fuel for industry, transport and heating, particularly in the UK where a whole portfolio of hydrogen-related studies and test cases are underway.

The reason is simple: CCS applied to hydrogen generated from coal and methane (natural gas) creates no CO_2 emissions.

The cost of clean hydrogen production from fossil fuel is more competitive than renewable hydrogen generation by electrolysis, creating potential opportunities for large-scale emissions reductions from sectors previously considered difficult to decarbonise.

Several CCS clean hydrogen initiatives are underway in Europe:

- Swedish energy giant Vattenfall (through Dutch subsidiary Nuon) announced a partnership with the Dutch gas infrastructure company Gasunie and Norway's Statoil. This initiative is studying the possibility to convert a unit of the Magnum Power Plant in Eemshaven in the Netherlands into a hydrogen-powered plant, with a potential CO_2 emissions reduction of 4 million tonnes per annum and offshore storage in the Norwegian Continental Shelf;[xxvii]
- The Northern Gas Networks H21 Leeds City Gate Project has completed technical and economic feasibility studies, and is now seeking to convert the existing natural-gas network in Leeds, one of the largest UK cities, to 100% hydrogen;[xxviii]

The reason is simple: CCS applied to hydrogen generated from coal and methane (natural gas) creates no CO_2 emissions.

- Cadent (the Gas Network Operator in north-west England) announced the Liverpool-Manchester hydrogen project – a feasibility study similar to the Leeds City Gate Initiative, but with a scope that includes the decarbonisation of gas supply to large industrial users of gas in oil-processing clusters;[xxix]
- In Scotland, Scottish Gas Networks also began work on a hydrogen feasibility project (the 100% Hydrogen Project) to establish the technical and commercial viability and an approved safety case for a 100% hydrogen network demonstration project;[xxx]
- In April 2017, the UK government established a £25 million (US$32 million) program (Hydrogen Innovation for Heating) that aims to define a hydrogen quality standard, and to develop and trial domestic and commercial hydrogen appliances;[xxxi]
- The HyDeploy Project is already underway to blend hydrogen at levels of up to 20% into the UK's current natural-gas grid.[xxxii]

Climeworks Plant Drone Shot.
Photography courtesy of Climeworks.
Photographer- Julia Dunlop

Greenhouse gas removal technologies

Given recent developments in the field of direct air capture technologies, such as the launch of the Swiss Climeworks,[xxxiii] and the emerging concerns over the high dependency of post-2040 climate models on large volumes of bio-energy CCS, the April 2017 launch of the UK's £8.6 million (US$11 million) Greenhouse Gas Removal Research Programme was well timed.[xxxiv]

This comprehensive research program involving over 40 UK universities and partners will shape and streamline future greenhouse gas removal strategies.

Europe CCS policy developments

THE EU-ETS REFORM AND THE INNOVATION FUND

The European Union's Emissions Trading System (EU-ETS) is the world's largest carbon trading scheme. Launched in 2005, it covers some 11,000 power stations and industrial plants in 31 countries, whose carbon emissions make up around 45% of Europe's total.[xxxv]

The current EU target is to reduce emissions in 2020 to 21% below their 2005 level. The EU-ETS reform, adopted by the EC in July 2015, is a legislative proposal to revise the scheme for the period 2021–2030. Part of the EC's 2030 Energy Climate package, it will set a reduction target of 43% for covered installations. The EU-ETS reform also establishes supporting mechanisms – an Innovation Fund and a Modernisation Fund.

THE EUROPEAN STRATEGIC ENERGY TECHNOLOGY PLAN

The European Strategic Energy Technology Plan is an EU initiative to accelerate the development and deployment of low-carbon technologies. It seeks to improve technologies and bring down costs by coordinating national research efforts and helping to finance projects. Under the Plan, a Working Group was established to recommend key areas of research and innovation for CCUS.

The group comprised 11 participating countries together with representatives from business and other organisations. In its final report to the SET Steering Committee in 2017, the Working Group recommended several key actions including:

- Establishment of a CCS hub/cluster (including projects in the Netherlands, UK and Norway);
- Progress PCIs;
- Establish a European CO_2 Storage Atlas;
- Establish three new CO_2 storage pilots.

EU-ETS Supporting Mechanisms

The **Innovation Fund** is a follow-on from the previous NER300 scheme. It is designed to boost EU low-carbon innovation technologies and processes, including demonstration projects for the development of CCS and innovative renewable energy technologies. It is funded through the sale of 400 million CO_2 emissions allowances (ETS allowances) from the New Entrants' Reserve. It is due to start operating in 2021.

The Directorate General for Climate Action of the Commission launched the "Finance for Innovation: Towards the Innovation Fund" expert consultations in January 2017.

The consultations provided an opportunity to address the barriers that prevented many CCS projects from applying for and/or receiving financing from the original NER300 process. The consultation highlighted the need to address CCS commercial and business issues and to foster cooperation between member states, industry, regional authorities and the Commission.

The **Modernisation Fund** is designed to support lower income member states in meeting the high investment costs related to energy efficiency and the modernisation of their energy systems. Between 2021 and 2030, 2% of the allowances, some 310 million allowances in total, will be set aside to establish the fund. All member states will contribute to the fund, which will benefit 10 member states with a GDP per capita of less than 60% of the EU average (in 2013). The countries eligible to receive support are: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia.

CCS is essential to realise the Paris goals

When it comes to mitigating climate change, the Paris climate agreement constitutes a clear step forward. Not only have the signatories committed to a variety of concrete objectives: the fact that nearly 200 countries have signed the agreement has also had a positive impact on public opinion. We can see growing confidence that we will be able to keep global temperature increases in check, and stronger public support for positive changes.

However, too many members of the general public still believe that to limit climate change, all we need to do is adopt solar panels, wind turbines and electric vehicles. Nothing could be further from the truth. We will actually have to pull out all the stops to limit global temperature increases to no more than 2˚C. And according to the calculations of both the IPCC and the IEA and to a recent Wuppertal Institute study commissioned by the Port of Rotterdam Authority, CCS will play an indispensable role in this context.

Aeroview of the Port of Rotterdam. Photography courtesy of Port of Rotterdam Authority

I believe that the private sector needs to make a stronger effort to explain to administrators, ENGOs and the general public that CCS will play an essential role in keeping climate change within bounds. We need to do a better job making it clear that CCS is indispensable in this context.

CCS is certainly necessary for Rotterdam. Our local industry is responsible for close to 20% of total CO_2 emissions in the Netherlands. A large share of these industrial activities concern products that – at least for the time being – lack viable zero-emission alternatives. CCS and CCU form the most effective methods for swiftly scaling back CO_2 emissions. The Port Authority's chosen strategy is to continue facilitating the existing fossil fuel-based industrial sector, while simultaneously supporting it in its reduction of CO_2 emissions. Increased efficiency, CCS, CCU and the utilisation of the industry's residual heat will play a crucial role in helping the Netherlands realise the agreed-upon climate objectives. At the same time, the implementation of these technologies will ensure that refining and petrochemical activities can be continued in Rotterdam for many years to come. Besides facilitating existing industrial activities, Rotterdam is also committed to the development of bio-based industry, as well as facilitating renewable energy and circular initiatives. We call this our "and/and" strategy: renew the existing and support the new.

Regarding CCS, for a number of years, all eyes in Rotterdam were on ROAD, a large-scale demonstration project focusing on the capture of CO_2 at one of the region's new coal-fired plants. The key participants in this project – the power station operators – recently announced that after years of research and postponements, they would not be going forward with the implementation of CCS at their facilities after all.

Since the Port of Rotterdam Authority is convinced of the necessity of developing CCS, we have taken the lead in setting up a "backbone" that traverses Rotterdam's port area for the transport of CO_2, combined with facilities for storing CO_2 in empty gas fields off the coast of the North Sea. This transport and storage infrastructure will be managed by a neutral, semi-public, non-discriminatory agency. Companies in the port area can capture their industrial CO_2 emissions and supply them, for a fee, to the network operator. The basic idea is that by participating in this program, these companies also transfer their responsibility for storage. Rotterdam is uniquely positioned to realise such a backbone, thanks to its combination of a large industrial complex and its proximity to empty gas fields in the North Sea. In addition, the region offers concrete opportunities for CCU; for example, various companies already have years of experience with supplying CO_2 to nearby greenhouses. A number of public and private parties are presently working together within a project organisation on the elaboration of a plan geared towards a final investment decision in 2018.

As a sector, it's up to us to convince our stakeholders of the vital role CCS can play when it comes to mitigating climate change. And it's up to us to undertake new projects, because delivering projects is what is needed to make progress.

ALLARD CASTELEIN

Chief Executive Officer

Port of Rotterdam Authority

Middle East and Africa

In November 2016, the Gulf region celebrated the commencement of operations of the Emirates Steel Carbon Capture, Utilisation and Storage facility (or Abu Dhabi CCS). This is the first project under Al Reyadah – a joint venture between Masdar and Abu Dhabi National Oil Company. The Al Reyadah facility in Mussaffah can capture up to 800,000 tonnes of CO_2 per annum emitted from the Emirates Steel factory. After further processing, the captured CO_2 is transported by pipeline to oilfields for EOR operations.

In Saudi Arabia, the Uthmaniyah CO_2– EOR Demonstration facility (owned and operated by Saudi Aramco) has maintained steady progress since it first became operational in 2015. It also involves the capture of 800,000 tonnes of CO_2 annually from the Hawiyah NGL Recovery Plant for use in enhanced oil operations.

The South African Centre for CCS is targeting the onshore Zululand Basin in KwaZulu-Natal for a suitable geological site to host the Pilot Carbon Dioxide Storage Project. This involves the injection, storage and monitoring of 10,000–50,000 tonnes of CO_2 and puts CCS on South Africa's roadmap.

In Sub-Saharan Africa, the UNFCCC's CTCN has received a request from the Nigerian government for technical assistance in laying the groundwork for the establishment of a CCS framework in that country.

Al Reyadah facility, United Arab Emirates. Photography courtesy of Masdar.

A commercial, consummate technology with no mitigation equal

The struggle to make the world a better place is an ever-continuous process. When the international community adopted the Paris agreement in 2015, the world gained a desperately needed boost towards taking serious steps, after a long debate of when, who and what to do regarding climate change. This collective achievement was further enhanced when the agreement was signed by 195 countries in mid-2017.

On the other hand, some resistance remained and was articulated by the new US administration decision to pull out of the Paris Agreement. Nevertheless, the recent extreme and deadly weather disasters hitting parts of America and Asia at a more frequent pace has reignited attention to the effects of climate change and how much it may cost humanity if serious measures are not implemented. It is true that scientists maintain that no single weather event can be attributed to climate change, but we cannot eliminate the effect of rising temperatures to record levels due to CO_2 concentration increases, and the intensity and frequency of extraordinary hurricanes.

According to various organisations, the cost of hurricane Harvey is estimated to between US$200 to $300 billion. This cost is way above all the investments the world has seen so far in CCS, for example. Moreover, this range is near the required global investments to address climate change in 2030 according to the climate group report of 2008. If other hurricanes costs are also considered in the equation with the frequency of occurrence, we will see that the world has done so little to address climate change, and that the loss is going to be gigantic if preference is given to short term development objectives.

What the world needs is to expand some of the serious steps already taken in some parts of the world, in particular CCUS projects. CCUS projects can capture huge volumes of emitted CO_2 and accordingly reduce the net CO_2 emissions in a fossil fuel based economy. They will also enable oil companies to become resilient in the new world of low carbon and compete with other cleaner sources of energy. This requires responsible leadership and an innovative mindset that sees the importance of reducing emissions while meeting the expectations of the stakeholders and investors.

In the recent years, we have seen such serious steps taken by leading national and international oil companies. Many remarkable CCS and CCUS projects have been constructed and some are already in operational phase, proving that CCUS, despite the challenges is a very practical business solution for climate change.

In UAE, Al Reyadah has become the world's first CCUS installation in the steel industry. It demonstrates that CCUS can be commercially applied to the huge global steel sector which has virtually no mitigation equal. Al Reyadah is allowing the capture of 800,000 tonnes of CO_2 per year – the equivalent of CO_2 emissions from 170,000 cars.

Saudi Arabia has done the same with Al Othmaniya CCS facility, while other regional national oil companies are preparing themselves for similar investments in CCUS.

The challenge now is to enhance collaboration and create a domino effect of technology development and policy incentivisation so the wider world can see the perfect sense in this consummate technology.

ARAFAT AL YAFEI

CCS & EOR expert
Chief Executive Officer

Al Reyadah
United Arab Emirates

Communicating CCS: taking it to the streets

In 2017, the Global CCS Institute created a major step-change in the way it advocates on CCS' behalf.

As a relatively small climate change organisation, mindful of the need to build understanding and broaden our constituency, the Institute launched a viral campaign across social and mainstream media.

Called "Join the Underground", a salute to French WWII resistance efforts and Paris climate change targets, the campaign unveiled periodic "memes" (virally transmitted cultural symbols) defining key themes intrinsic to CCS understanding.

The Institute is ever mindful that not enough people know about CCS and the simple fact that Paris climate change targets cannot be reached without it.

As a result, we created a call-to-arms through an evolving cascade of memorable images and straplines, each emphasising the key role that CCS technology needs to play in a sustainable, decarbonised future.

It has one overarching catchcry: "the answer to climate change is right beneath our feet".

Over the past year, five new straplines have been unfurled: "Join the Underground", "No longer up in the air", "Less talk, more action", "Set in stone since 1972", and "Wake up the world".

These have become event themes, dinner dialogues, media headlines and stand-alone posters from Brussels to Beijing.

Research has shown that this campaign has reached more than 15 million people, proof that making our work bold and impactful is essential to connecting with stakeholders and moving the debate from the tent to the coal-face.

The language and livery has resonated across a swathe of stakeholder audiences; media interest has surged, membership has increased and we have attracted the support of highly decorated climate experts and influencers from around the world.

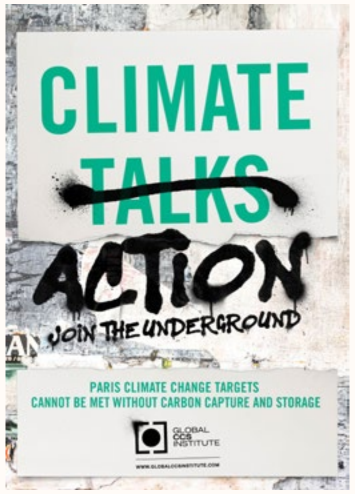
Building awareness, creating debate and "taking it to the streets" sit at the heart of our advocacy efforts as the need for CCS becomes clearer and clearer.

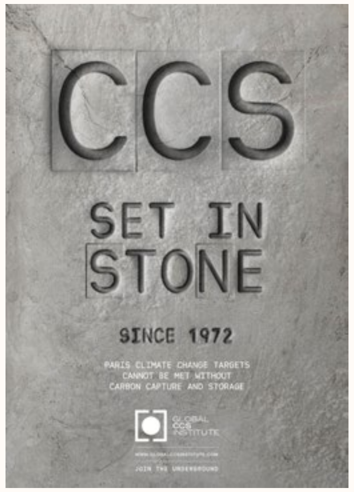
Because all the big battles are won on the street.

ANTONIOS PAPASPIROPOULOS

Global Lead – Advocacy and Communications

Global CCS Institute





How well do you speak carbon?

In New York this year, we convened a carefully curated sustainability basecamp to discuss the emerging concept of carbon productivity. As part of that process, it became evident that we are all having to learn how to "speak carbon".

I gave up science at 14–largely because I refused to cut up animals in biology experiments.

But then carbon resurfaced in the late 1970s, when I was writing a short report for the Hudson Institute analysing four key environmental challenges of the 21st century. The fourth challenge was climate change. And I still remember what the Institute's co-founder Herman Kahn said on receipt of the report: exactly what you would expect from an environmentalist!

I don't think he was denying the challenges so much as reflecting on the best way of tackling them. He went on to say that most ordinary mortals – and certainly most environmentalists – heading towards a chasm would automatically stamp on their brakes, trying to steer away. **What if, he asked, you stamped your foot on the accelerator instead – and steered straight for the chasm?** (This, incidentally, was shortly after various attempts by the motorcyclist Evel Knievel to launch himself across immense barriers, including part of the Grand Canyon.)

At the time, I thought he was clinically insane. But now that our planet is showing every sign of running a fever reaction due to a rampant infection of carbon-burning humans, his prescription for breakthrough change feels increasingly prescient.

That said, park the motorbike for a moment. The real challenge now is to reimagine our relationship with carbon. This magical element, the most critical to life on Earth, is increasingly demonised as the main chemical culprit in accelerated climate change.

Our carbon productivity basecamp examined how we can generate radically greater economic, social and environmental value from the carbon we use, whether it comes "durable", "living" or "fugitive" sources. These words are used by design chemist, Bill McDonough, to frame the new carbon language across three key types:

- **Living carbon**: "organic, flowing in biological cycles, providing fresh food, healthy forests and fertile soil; something we want to cultivate and grow."
- **Durable carbon**: "locked in stable solids such as coal and limestone or recyclable polymers that are used and reused; ranges from reusable fibers like paper and cloth to building and infrastructure elements that can last for generations and then be reused."
- **Fugitive carbon**: which "has ended up somewhere unwanted and can be toxic; includes CO_2 released into the atmosphere by burning fossil fuels, 'waste to energy' plants, methane leaks, deforestation, much industrial agriculture and urban development."

Clearly, our initial focus should be on fossil fuels and new fossil fuel value that can be created.

We must learn how to draw down fugitive carbon from the atmosphere in massive quantities, and how to regenerate living systems that capture and store huge amounts of carbon that otherwise would end up back in the atmosphere.

Pioneer carbon-capture-and-use companies such as Covestro and Carbon Clean Solutions are already doing this – not just pumping CO_2 into holes in the ground but turning it into useful, commercially viable products.

Covestro has developed a novel catalyst which creates cardyon, an innovative raw material for the production of high quality, flexible polyurethane foams — the sort of thing that goes into car seats and mattresses. It is produced with up to 20% carbon dioxide captured from the atmosphere. The net result: manufacturers increasingly have more sustainable raw materials to help cut their reliance on fossil fuels.

Carbon Clean Solutions has unveiled a novel process which recovers carbon dioxide at a cost of around US$40 per metric ton, offering 40% savings compared with conventional processes.

The landscape of opportunity is changing.

We are witnessing a growing number of key actors in the closely intertwined worlds of climate change and carbon productivity, moving closer together. Wherever we look, brilliant minds are beavering away on ways to better understand, manage and regenerate the planet's increasingly wobbly carbon cycle.

Our basecamp culminated with a progress review called the Carbon XPRIZE, promoting the development and deployment of breakthrough technologies. The Carbon XPRIZE mandate — to Reimagine CO_2 — has been a profound source of inspiration for our own efforts.

None of this undermines the case for carbon capture and storage, which will also be vitally important if we are to have any chance of meeting the Paris Climate Accord objectives, but it is surely more likely that capital will flow to areas where there are commercially viable uses of the recovered carbon?

JOHN ELKINGTON

Co-founder, chairman of Volans and co-author of *The Breakthrough Challenge: 10 Ways To Connect Today's Profits With Tomorrow's Bottom Line* with Jochen Zeitz. He tweets as @volansjohn.

Let's Capture...
It's getting hot in here
Too much carbon in the atmosphere
Can we renew all of this, with sheer
Amounts of money, without fear?

Let's Capture...
It matters not how long it's been there
Capture it, put it somewhere
While it's still fresh in the air
Isn't that fair?

Let's Capture...
It may look like an adventure
But the economy may still have a future
And while it may not shine
At least nature won't fracture

Let's Capture...

Hazim Azghari is a climactic poet and CCS proponent from Morocco, pictured here at COP 22 in Marrakech, 2016. A modern-day Beatnik battling climate change in his home country with poetry in one hand and permaculture (he studies sustainable agricultural ecosystems) in the other, Hazim is part of the CCS advocacy army whose work is a favourite on YouTube.

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Follow us on

Carbon capture and storage (CCS) is one of the last remaining clean mitigation technologies able to turn the tide on climate change.

The process of capturing CO_2 from fossil fuel industry and safely burying it deep below ground has been around since the Apollo 17 moon landing, but only now in 2017, 45 years later, is it truly touching down.

The world authority on CCS, the Global CCS Institute, is a member-led climate change organisation comprising governments, industry, think-tanks, research agencies and academic institutions.

Based in Melbourne (with offices in Brussels, Washington DC, Beijing and Tokyo) and led by geologists, economists, regulatory experts, educators and advocates, its mission is to accelerate the commercial deployment of CCS to address climate change and ensure energy security.

CCS science is proven through pre-eminent research and respected pedagogy including the Intergovernmental Panel on Climate Change and the International Energy Agency.

Their findings are resolute: Paris climate change targets cannot be met without CCS.

The Global Status of CCS: 2017 is the Institute's flagship publication, a communication, a conversation and a discourse on "everything CCS".

It makes the compelling case for CCS as an imperative part of our climate change future – and the conduit to a new energy economy.

It looks at the 17 large-scale commercial facilities currently in global operation and the swathe of new plants coming onstream.

It debunks common myths and misconceptions about the technology.

And with commentary from a diverse group of leaders and luminaries – from the man who coined the phrase "global warming" in the 1970s, Professor Wallace Broecker, to former US Department of Energy Advisor, Dr Julio Friedmann, and celebrated British climate economist, Lord Nicholas Stern, as well as ambassadors, environmentalists and industry leaders – it concludes that the CO_2 quandary we face demands this revolutionary climate game-changer.

The Global Status of CCS: 2017 encourages you to "join the underground" and embrace CCS as a tried and true technology that is integral to a "no" emission future.