



GLOBAL  
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# THE GLOBAL STATUS OF CCS | 2015

**SUMMARY** REPORT



## TRAILBLAZING PROJECTS HOLD THE KEY TO CLIMATE GAP



COP 21 in Paris is almost upon us. This meeting is expected to deliver a new era in climate change commitments and outcomes that set the world on a course to avoid serious climate change impacts. Most countries have now made their emissions commitments. But on all estimates there is a sizable gap between the total country commitments to the COP 21 talks and what science tells us we need to do.

If we are serious about tackling this reality, full use of carbon capture and storage (CCS) is required.

Independent, credible forecasts are that by 2040 the world will still be predominantly reliant on energy from fossil fuels, even with unprecedented growth in the deployment of renewables and energy efficiency.

Expert reports have shown that all low-carbon technologies are needed to tackle our climate targets. But tellingly, the IPCC's *Fifth Assessment Synthesis Report* found that most climate models could not meet emissions reduction targets without CCS. Crucially, without CCS, the cost of mitigation would more than double – rising by an average of 138 per cent.

CCS technology is proven and in use around the world. It has a key role to play in curbing CO<sub>2</sub> emissions from fossil fuel based power generation, which will experience continued growth, especially in Asia. CCS on power is a reality. The world's first large-scale CCS project in the power sector, at SaskPower's Boundary Dam facility in Saskatchewan, Canada, has just celebrated one year in operation. Two more large-scale CCS projects on power will come on stream in 2016.

CCS is also the only option available to significantly reduce direct emissions from many industrial processes. The launch of the world's first steel plant with large-scale CCS in Abu Dhabi in 2016 will, therefore, be a landmark for this sector.

CCS is a cost-effective technology for achieving large emissions reductions, as evidenced by updated Institute analysis released in July 2015. And with SaskPower stating that cost reductions of up to 30 per cent are achievable on the next project, further strong gains are available to the next generation of projects.

2016 and 2017 promise to be trailblazing years for CCS with seven large-scale CCS projects due to come on stream. Importantly, these will show CCS in action in many different countries including the United States (US), Canada, the United Arab Emirates (UAE) and Australia, as well as across many industrial sectors. It will take the number of large-scale projects in operation to 22 – three times as many as at the start of the decade.

But this number of projects is dwarfed by the thousands required by the middle of this century to meet international climate targets.

While CCS has made great progress this decade, it is abundantly clear that we must sharply accelerate its deployment. I therefore call on decision makers to:

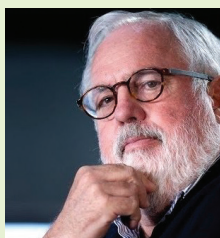
- **Recognise** the vital role that CCS must play in national strategies to tackle climate change.
- **Ensure** key projects in advanced planning get across the finish line so benefits can flow.
- **Strengthen** the foundations for widespread deployment by providing an equitable level of consideration, recognition and support for CCS along-side other low-carbon technologies. This includes:
  - Providing predictable and enduring policy arrangements that support a positive business case for CCS investment and widespread rollout
  - Implementing effective and cost-efficient CCS law and regulation internationally
  - Incentivising early storage site identification and characterisation to support project development
  - Increasing research and development resources to further reduce costs and increase the efficiency of capture and storage technologies.

Put simply, we cannot hope to tackle the scale of the climate challenge without CCS. Now is the time to implement effective policies which focus on this outcome.

**BRAD PAGE**

CHIEF EXECUTIVE OFFICER, GLOBAL CCS INSTITUTE

## INTRODUCTION BY MIGUEL ARIAS CAÑETE, EUROPEAN UNION COMMISSIONER FOR ENERGY AND CLIMATE ACTION



In December, world leaders will gather in Paris to conclude a new global climate deal. The European Union (EU) is committed to ensuring the adoption of a legally binding, ambitious and fair international agreement applicable to all and capable of keeping the world on track to limit the global temperature rise to below 2 degrees.

The EU was the first major economy to submit its contribution, a binding target to reduce EU greenhouse gas emissions by at least 40 per cent by 2030 compared to 1990 levels. This target was agreed by EU leaders in October 2014 as part of the 2030 climate and energy framework.

To conclude a deal that is fit for purpose for many years to come, a number of key building blocks must become part of the new agreement. Firstly, the new deal needs to be dynamic, which entails a process for regularly reviewing and strengthening countries' emissions reduction commitments. Secondly, we need an agreed vision on the direction of travel for the longer term. To make the below 2 degree objective operational, we should commit to reduce global emissions by at least 60 per cent by 2050, compared to 2010. Finally and crucially, we need trust and accountability. This means robust rules and reporting to ensure that all Parties deliver on their commitments.

Perhaps even more important is what will happen after Paris. Ultimately, the success of the new agreement depends on its implementation in the upcoming years. In the EU, we have already shown that ambitious climate action is compatible with economic growth. Between 1990 and 2013, EU greenhouse gas emissions fell by 19 per cent while our GDP grew by 45 per cent. Paris will be a unique opportunity to further accelerate the low-carbon transition in Europe and across the globe. Carbon capture and storage (CCS) will together with other innovative low-carbon technologies play an essential role in reaching greenhouse gas emission reduction targets around the globe.

Earlier this year the European Commission set out its strategy to achieve a resilient Energy Union with a forward-looking climate change policy. Our objective is to integrate our 28 Member States' energy markets into one Energy Union, make Europe less energy dependent and give the predictability that investors need to create jobs and growth. It is a fundamental transition towards a low-carbon and climate-friendly economy, towards an Energy Union that puts citizens first, by offering them more affordable, secure, and sustainable energy.

CCS plays a vital role as part of an economically sustainable route to meet climate mitigation goals within the 2050 timeframe, while ensuring global and regional energy security. The Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Synthesis Report* (2014) concluded amongst other things that without CCS the costs of climate change mitigation would increase by 138 per cent, and without CCS it may not be possible to limit global warming to below 2°C relative to pre-industrial levels.

CCS is currently the only available technology to drastically reduce greenhouse gas emissions from certain industrial processes and it is a key technology option to decarbonise the power sector especially in countries with a high share of fossil fuels in electricity production. Successful demonstration of large scale CCS installations in Europe is our next big challenge and represents a critical step to ensure timely deployment of the technology in the future, to confirm its cost effectiveness and to achieve a positive perception of CCS among investors and the general public.

The EU is providing regulatory certainty with the Directive on geological storage of carbon dioxide and financial support through the EU funding programmes for CCS demonstration projects, namely the European Energy Programme for Recovery (EEPR), the NER 300 programme and its planned continuation through the future Innovation Fund. Indispensable for the success of these efforts is confidence among investors that the EU Emission Trading System will provide a sound business case for CCS in the long run and therefore its review based on the ambitious proposals adopted by the European Commission in July will be decisive.

**MIGUEL ARIAS CAÑETE**

EU COMMISSIONER FOR ENERGY AND CLIMATE ACTION

## CCS is essential

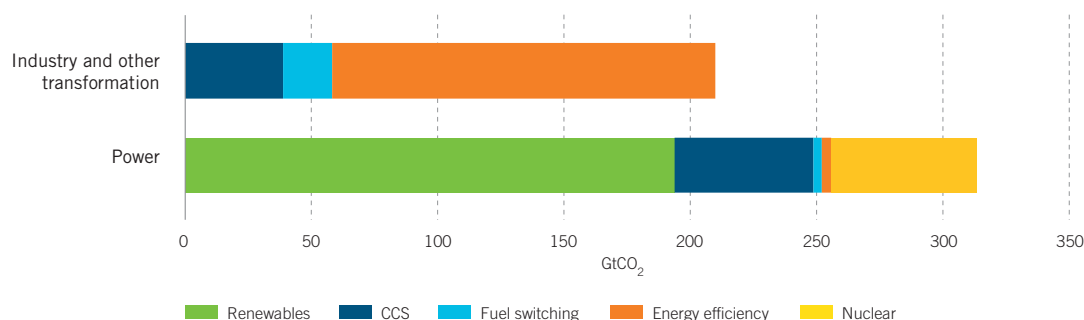
Even with concerted action by the global community to limit temperature increases to under 2°C, fossil fuels would still provide 60 per cent of the world's primary energy by 2040.<sup>1</sup> Fossil fuels currently provide around 80 per cent of primary energy demand.<sup>2</sup> Demand for fossil fuels has begun to decline in the developed world, however, demand in developing countries has been rising and will continue to rise. Investments in technologies that use fossil fuels are still being made around the world. Investments made today will lock in emissions sources for the next 30 years or more.

Coal-fired power generation is the largest contributor to carbon dioxide (CO<sub>2</sub>) emissions worldwide and currently provides around 40 per cent of total electricity output.<sup>3</sup> Coal is an abundant fuel found in many countries. Electricity from existing coal-fired plants, where investment costs are largely or entirely recovered, will have a cost advantage over other energy technologies for some time. Gas-fired generation is less CO<sub>2</sub> intensive than coal-fired generation. However, gas-fired generators still contribute around 20 per cent of power sector CO<sub>2</sub> emissions worldwide.<sup>4</sup>

Carbon dioxide emissions from industrial sources are considerable, contributing around 25 per cent of global emissions. In addition to natural gas processing, CO<sub>2</sub> is a by-product of a number of manufacturing processes, including steel, cement and chemicals production, all of which are necessary in a modern society and essential to be decarbonised.

CCS is the only technology which can reduce emissions on a significant scale from fossil fuel power plants and these industrial processes. It is also important to note that renewable technologies are not mitigation substitutes to CCS in the industrial sector. To achieve the global goal to limit temperature increases to no more than 2°C, the scale of change and the level of low-carbon technology deployment is enormous. All emissions reduction solutions are necessary, in all sectors of the economy (Figure 1).

**Figure 1** Cumulative CO<sub>2</sub> emissions reductions in industry and power (2012 to 2050, 2DS)<sup>5</sup>



In terms of the scale of CCS deployment, the 15 large-scale CCS projects currently in operation around the world have the capacity to capture up to 28 million tonnes of CO<sub>2</sub> per year (Mtpa). The IEA's modelling of least-cost outcomes to achieve the 2°C goal suggests this needs to increase to around 4,000 million tonnes in 2040 and 6,000 million tonnes in 2050.<sup>6</sup>

Beyond 2050, many climate models indicate the world will need to achieve 'net negative emissions'. CCS used in the combustion of biomass is a large-scale 'net negative' emissions technology that could play an important role in this period. The IPCC's *Fifth Assessment Synthesis Report* states that the deployment of CCS, including bio-CCS, will significantly reduce the risk of not meeting climate goals, and is also the most important technology in minimising the costs of achieving required emission reductions out to 2100.<sup>7</sup> The role of net negative technologies as a way to save the world from squandering its 'carbon budget' will be drawn into sharp focus if governments fail to take much stronger action to address climate change in the coming years.

<sup>1</sup> (IEA, 2015)

<sup>2</sup> (IEA, 2014)

<sup>3</sup> (IEA, 2014)

<sup>4</sup> (IEA, 2014)

<sup>5</sup> Based on IEA data from Energy Technology Perspectives 2015<sup>®</sup> OECD/IEA 2015, IEA Publishing; modified by the Global CCS Institute.

<sup>6</sup> (IEA, 2015)

<sup>7</sup> (IPCC, 2014)

## A landmark period for CCS projects

### A steady stream of CCS projects is starting operations worldwide

With the world's 14th and 15th large-scale CCS projects becoming operational in 2015, and key projects in the power, iron and steel, and chemical industries to be launched in the next 18 months, CCS has entered a landmark period for the technology's development.

2015 saw the launch of the Quest project in Canada and the Uthmaniyah CO<sub>2</sub>-EOR Demonstration Project in Saudi Arabia. Each project delivers significant firsts to their respective region (see right).

The 15 large-scale CCS projects now in operation globally compares with seven at the start of the decade, revealing a steady stream of projects demonstrating the technology in action around the world (Figure 2).

**Figure 2** Large-scale CCS projects in operation by year



The portfolio of operational large-scale CCS projects is expected to grow to 22 over the next 18 months or so, widening the range of countries, industries and technologies represented (Figures 2 and 3). This equates to a CO<sub>2</sub> capture capacity of around 40 Mtpa.

This portfolio of large-scale CCS projects is complemented by a cohort of notable pilot and demonstration projects across the world, some capturing and storing 100,000 tonnes or more of CO<sub>2</sub> per year.

There have been significant policy and regulatory developments in the last year, including significant US-China cooperation on climate issues, release of 'final rules' and 'key principles' by the US Environmental Protection Agency (EPA) on emissions performance standards and storage issue clarifications, and reviews of various European energy and CCS-specific policies.

Key global policy and regulatory developments are highlighted in Appendix A provided at the end of this Summary Report.

### 2015 Project Highlights

#### Quest



Image provided by Shell

Launched in Alberta, Canada in November 2015, the Quest project is capable of capturing approximately 1 Mtpa of CO<sub>2</sub> from the manufacture of hydrogen for upgrading bitumen into synthetic crude oil.

Quest is the first large-scale CCS project in North America to store CO<sub>2</sub> exclusively in a deep saline formation, and the first to do so globally since the Snøhvit CO<sub>2</sub> Storage Project became operational in Norway in 2008.

A case study prepared by Shell documenting key learnings from the development of Quest is available [here](#).

#### Uthmaniyah CO<sub>2</sub>-EOR Demonstration Project



Image provided by Saudi Aramco

Launched in Saudi Arabia in July 2015, the Uthmaniyah project is the first operational large-scale CCS project in the Middle East.

The project is capable of capturing around 0.8 Mtpa of CO<sub>2</sub> from a natural gas liquids recovery plant for injection into the Uthmaniyah production unit for enhanced oil recovery (EOR). The project includes a comprehensive monitoring and R&D program.

#### Boundary Dam CCS Project

The Boundary Dam CCS Project is the world's first operational large-scale CCS project in the power sector. In 2015, it achieved the significant milestone of one year of operation.

A [recent report](#) summarises the key learnings and experiences of SaskPower in the development and early operation of CCS at Boundary Dam.



Image provided by SaskPower

## A landmark period for CCS projects

**Figure 3** Large-scale CCS projects in construction and expected to be operational in 2016 and 2017



### Illinois Industrial CCS Project

Expected to begin operations early in 2016, the Illinois Industrial CCS Project will be the world's first large-scale bio-CCS project, capturing around 1.0 Mtpa of CO<sub>2</sub> at the Archer Daniel Midlands corn-to-ethanol production facility in Decatur.

It will also be the first integrated CCS project in the US to inject CO<sub>2</sub> into a deep saline formation at a scale of 1 Mtpa.



### Kemper County Energy Facility

When operational, the Kemper County Energy Facility in Mississippi will be the largest CCS power project in the world in terms of volume of CO<sub>2</sub> captured (approximately 3.0 Mtpa, to be used for EOR).

It will be the first commercial-scale deployment of the TRIG<sup>TM</sup> coal gasification process developed jointly by Southern Company and KBR in partnership with the US Department of Energy (US DOE).



### Petra Nova Carbon Capture Project

This will be the world's largest post-combustion capture project at a power station when it is launched, planned for late 2016. Unit 8 of the W.A. Parish plant near Houston, Texas, is being retrofitted with a post-combustion system capable of capturing 1.4 Mtpa.

The captured CO<sub>2</sub> will be used for EOR.



### Abu Dhabi CCS Project

The Abu Dhabi CCS Project in the UAE is the world's first iron and steel project to apply CCS at large-scale.

Around 0.8 Mtpa of CO<sub>2</sub> will be captured from the direct reduced iron process at the Emirates Steel Plant for the purpose of EOR.



### Gorgon Carbon Dioxide Injection Project

When launched, the Gorgon Carbon Dioxide Injection Project in Western Australia will be the largest in the world to be injecting CO<sub>2</sub> into a deep saline formation.

Between 3.4 to 4.0 Mtpa of CO<sub>2</sub> will be injected in a deep saline formation at a depth of more than two kilometres.



### Alberta Carbon Trunk Line (ACTL) projects

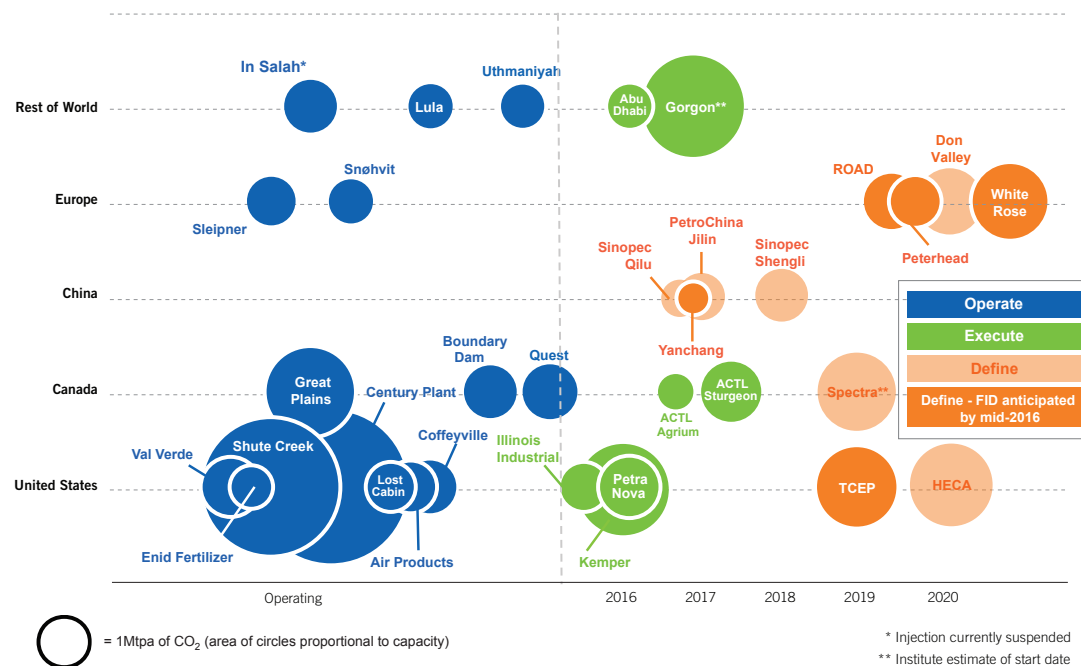
The 240 km Alberta Carbon Trunk Line (ACTL) would transport CO<sub>2</sub> from a number of sources in Alberta's Industrial Heartland to declining oil fields in Central Alberta for EOR.

Initial sources of CO<sub>2</sub> for the ACTL are the (existing) Agrium fertiliser plant and the (new build) North West Redwater bitumen refinery.

## A global portfolio of operating CCS projects is emerging

In addition to the 15 large-scale projects in operation (Operate stage) and seven due to become operational in 2016 and 2017 (presently in the Execute stage), there are a further 11 projects in advanced planning (Define stage). These 11 projects have a combined CO<sub>2</sub> capture capacity of around 15 Mtpa.

**Figure 4** Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by region and project lifecycle stage



With these 11 projects, the focus of development moves from projects in North America (three in advanced planning) towards projects in Europe and China (a combined eight in advanced planning).

Moving key European projects across the finish line has important strategic significance:

- All are in the power sector, involve different capture technologies, fuel sources, technology suppliers, and injection into both offshore deep saline and depleted hydrocarbon reservoirs.
- A number of these projects can act as 'anchor projects' to kick-start hub and cluster developments involving a range of other industries.

A global portfolio of over 30 operating large-scale CCS projects by 2020 will reinforce the maturity of CCS technologies, highlight the important role of CCS in reducing global CO<sub>2</sub> emissions and improve community understanding of CCS as an environmentally friendly technology. The lessons learnt from such a portfolio, across the full spectrum of CCS activities, will significantly lessen perceived risks associated with CCS project deployment post-2020, strengthening investor and stakeholder confidence.

## Key projects in advanced planning must be supported ‘across the finish line’

Around half of the 11 projects in advanced planning are expected to be in a position to take a final investment decision (FID) by the middle of 2016 (dark orange bubbles in Figure 4 and summarised below).

 <b>Texas Clean Energy Project</b> <p>This project would store around 2.4 Mtpa of CO<sub>2</sub> from a new build integrated gasification combined cycle (IGCC) plant producing fertiliser products, power for the Texas electricity grid and CO<sub>2</sub> for EOR. Engineering studies have been completed and contractual arrangements are under discussion.</p> <p>The project has received funding support through a cooperative agreement from the US DOE.</p>	 <b>Peterhead CCS Project</b> <p>The project would retrofit carbon capture technology to an existing coastal gas-fired power station in north-east Scotland and capture around 1.0 Mtpa of CO<sub>2</sub>. Existing pipeline infrastructure would be used to transport the CO<sub>2</sub> to an offshore depleted gas reservoir.</p> <p>The project is one of two preferred bidders eligible for capital funding under the UK CCS Commercialisation Programme.</p>	 <b>White Rose CCS Project</b> <p>The project would capture around 2.0 Mtpa of CO<sub>2</sub> from a proposed new oxy-fuel power plant in North Yorkshire. The proposed Yorkshire and Humber CCS Cross Country pipeline would transport the captured CO<sub>2</sub> to the coast linking to an offshore deep saline storage facility.</p> <p>The project is one of two preferred bidders eligible for capital funding under the UK CCS Commercialisation Programme and has been awarded funding from the European Commission (EC).</p>
 <b>ROAD</b> <p>This project would capture around 1.1 Mtpa of CO<sub>2</sub> with carbon capture technology retrofitted to a newly built power station within the Maasvlakte section of the Rotterdam industrial area.</p> <p>The CO<sub>2</sub> would be transported a short distance offshore to a depleted gas reservoir. The project has received funding support from the EC and Dutch government (and Norway has committed funds to an EC initiative seeking to close the financial gap).</p>	 <b>Yanchang Integrated CCS Demo. Project</b> <p>Between 0.4-0.5 Mtpa of CO<sub>2</sub> would be captured from gasification facilities at chemical plants in Shaanxi Province, China. The project includes a scale-up from an existing capture plant, with the CO<sub>2</sub> to be used for EOR.</p> <p>The project was identified as a China-US cooperative project in the China-US Joint Presidential Statement on Climate Change in September 2015. A final investment decision could be made shortly with support from local and federal governments.</p>	

It is vital that governments and project proponents find appropriate ways to support these five projects, and others nearing a final investment decision, ‘across the finish line’.

## Foundations for accelerating CCS deployment must be strengthened

With a further 12 projects in the early stages of planning, the total number of large-scale CCS projects currently sits at 45, with a total CO<sub>2</sub> capture capacity of 80 Mtpa. This level of capture capacity is dwarfed by the amount of CCS deployment required in the next 20-30 years to meet climate targets, estimated at approximately 4,000 million tonnes of CO<sub>2</sub> captured and stored per annum by 2040.

The lead times to translate lessons from operational projects and research and development (R&D) into a next generation plant can take years. It can also take a number of years to properly characterise a storage site to support a final investment decision. The same applies to policy and legal and regulatory improvement timelines.

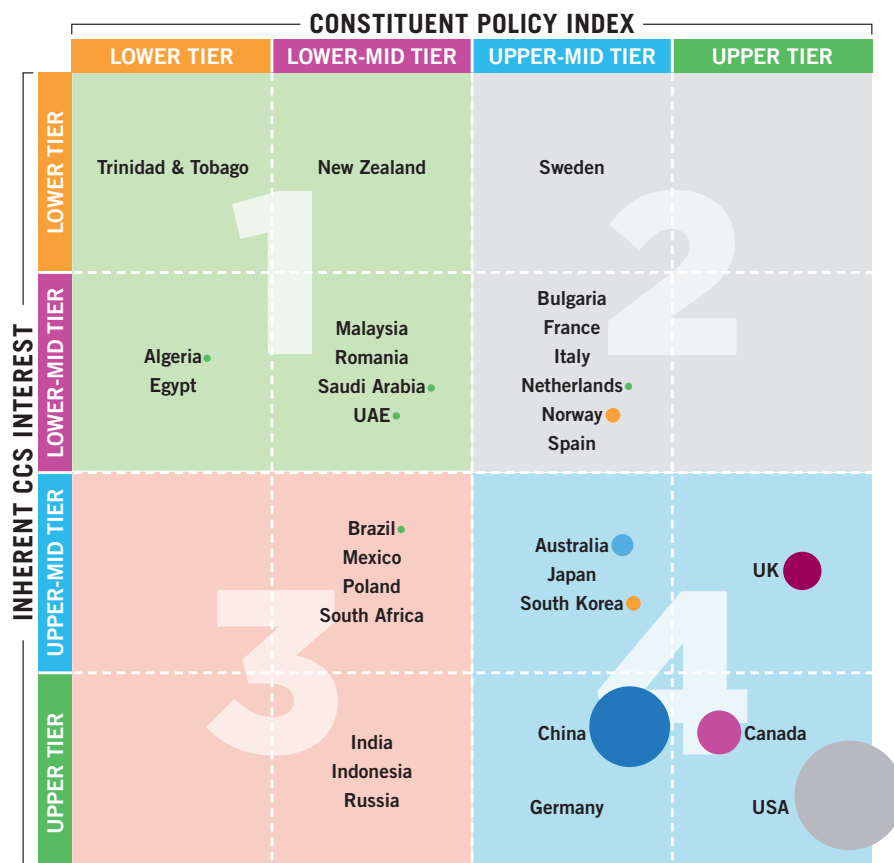
Strong policy is vital to the challenge of accelerating deployment of CCS to the levels required to meet international climate targets. Urgent action is required this decade to implement the incentive frameworks that can help drive cost-effective CCS deployment in the 2020s and beyond. Key areas for action are discussed below:

### 1. Predictable policies for investors that do not disadvantage CCS

The Institute published an update of its *CCS Policy Indicator*<sup>8</sup> in August 2015. In it, countries are ranked into four quadrants depending on their policy support for CCS, relative to the level of interest they should have in the technology. The United Kingdom (UK), the US and Canada are in the 'upper tier'. These countries have together implemented a combination of:

- Direct regulation to require power generators to reduce emissions intensity
- Government funding of large-scale CCS projects and R&D
- Fiscal and market-based incentives, including carbon pricing and tax credits
- Supportive legal and regulatory frameworks governing CO<sub>2</sub> storage.

Figure 5 CCS Policy Indicator 2015 results<sup>9</sup>



<sup>8</sup> (Global CCS Institute, 2015a)

<sup>9</sup> Size of bubbles denotes number of projects as of October 2015.

Large-scale investment in emerging technologies requires stable, clear policies developed on the back of robust public support. Individual CCS projects have a 30-plus year lifetime in addition to lead times in planning, including identification, appraisal and permitting of suitable geological storage sites.

Technological deployment can only be undertaken in a least-cost manner where policies recognise the relative importance of all technologies. Through the application of the principle of policy parity – where an equitable level of consideration, recognition and support is given to CCS relative to other low-carbon technologies – the risk of misallocating valuable public resources is also minimised. Governments should set appropriate incentives in line with strong emissions reduction goals and allow investors to determine the mix of technologies that is consistent with the particular technical and economic characteristics in each location.






Robust policies in the countries named above are the product of a strategic commitment to CCS. These governments also recognise that CCS is necessary amongst a portfolio of technologies that will deliver emission reductions in a least cost manner. Notwithstanding this, there is scope for all governments to take further action if the full benefit of CCS in mitigating climate change is to be realised.

## 2. Further deployment of CCS-specific law and regulation across the globe

The development of CCS-specific law and regulation remains a critical issue globally, for both governments and project proponents alike.

The Institute's recently released *CCS Legal and Regulatory Indicator*<sup>10</sup> reveals that only a small number of countries to date have developed comprehensive frameworks capable of addressing the many issues associated with project deployment. Australia, Canada, Denmark, the US and the UK, all possess CCS-specific laws or existing laws that support most parts of the CCS project lifecycle.

**Table 1** Legal and Regulatory Indicator results

COUNTRY		TOTAL SCORE (out of a possible 87)
<b>BAND A:</b> CCS-specific laws or existing laws that are applicable across most parts of the CCS project cycle (5 countries)		Average score: 65
	Australia	67.0
	Canada	65.5
	United Kingdom	65.0
	United States	64.0
	Denmark	62.0
<b>BAND B:</b> CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle (27 countries)		Average score: 47
<b>BAND C:</b> Very few CCS-specific or existing laws that are applicable across parts of the CCS project cycle (21 countries scored)		Average score: 26

The large majority of jurisdictions, however, have yet to develop comprehensive frameworks and have limited legislation capable of regulating CCS projects. As such, it will be increasingly important for countries in this group that have strong policy commitments to the technology, and projects in the development pipeline, to progress their domestic legal and regulatory regimes.

The Institute's *2015 CCS Perceptions Survey* reveals a clear dichotomy in project-level perceptions of domestic CCS legal and regulatory frameworks. Projects in Europe and North America have once again indicated they believe their regulatory environments are largely supportive and have highlighted instances where their national regimes address key regulatory elements.

<sup>10</sup> (Global CCS Institute, 2015b)

For projects in the Asian region, however, the absence of CCS-specific law and regulation (coupled with the lower price of oil), is impacting upon their ability to proceed to a final investment decision. For a third consecutive year, projects have highlighted standards to account for cross-border movement of CO<sub>2</sub>, post-operational transfer of operator's liability, and all liabilities in the event of post-operations transfer, as critical issues largely unaddressed by their national legal and regulatory regimes.

There is considerable scope for the further deployment of CCS-specific law and regulation across the globe. For countries in the preliminary stages of developing legislation, it is positive to note that there are aspects of existing national legal and regulatory regimes which may afford a foundation for further development and expansion, as well as lessons from other countries with more advanced frameworks.

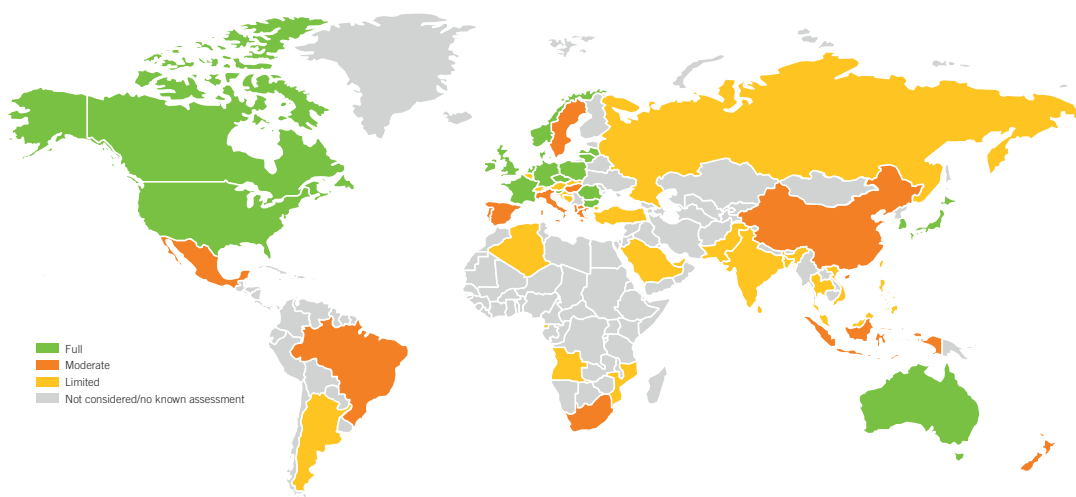
### 3. Incentivise selection and characterisation of storage sites to support final investment decisions by projects

Secure CO<sub>2</sub> geological storage at large-scale has already been demonstrated at a number of successful projects around the world. The technology is already available to select, characterise, safely operate, complete and close storage projects.

To support the acceleration of CCS deployment required by emissions reduction targets, storage needs to be achieved on a much larger scale than at present.

Detailed regional surveys of storage resources have already been undertaken in several key nations including the US, Canada, Australia, Japan, Norway and the UK. Multinational initiatives in Europe and South East Asia have also improved the global knowledge base of available resources. Several other nations including China, Brazil, Mexico and South Africa have assessed resources at a more theoretical level and are progressing towards refined estimates (Figure 6).

**Figure 6** Geographical coverage of storage resources assessments<sup>11</sup>



These various assessments have all shown, even using conservative assumptions, that storage resources available to support CCS deployment are vast and far in excess of projected capacity requirements over the coming decades. For example, a conservative assessment of the US made by the US DOE indicates that 1,600 Gt of CO<sub>2</sub> could be stored in deep saline formations – subject to regulatory and economic factors.<sup>12</sup>

Regional resource assessments can assist project proponents with the site selection process and are important to provide context for policy makers and regulators. However, the precise geology of each storage project will be uniquely site-specific. Detailed site investigations are required to provide sufficient confidence in storage capacity for a final investment decision to be made by a project proponent.

<sup>11</sup> (Global CCS Institute & Causebrook, 2015)

<sup>12</sup> This is equivalent to around 300 years of current annual CO<sub>2</sub> emissions in the US.

The length of time required to prove site-specific storage capacity to support a final investment decision is variable. For storage in depleted oil and gas fields or associated with EOR, existing detailed knowledge of the subsurface and available infrastructure may allow rapid formulation of plans and regulatory applications to store CO<sub>2</sub>. In contrast, proposals to store CO<sub>2</sub> in deep saline formations where characterisation data is sparse may require up to a decade.

Given the required scale of CCS deployment post-2020 to meet climate goals, the challenge of proving appropriate storage capacity may increase considerably. In some cases, projects may need to investigate several storage targets to mitigate the exploration risk that one possible storage site proves unsuitable. Accordingly, the importance of undertaking storage-related actions this decade to prepare for widespread CCS deployment post-2020 cannot be overstated.

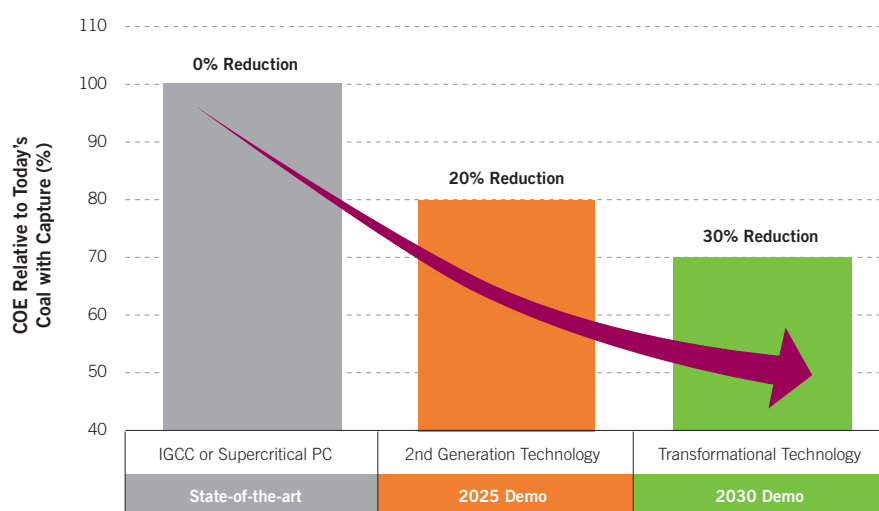
To lessen the risk of widespread CCS deployment being slowed by uncertainty over available storage, there is an urgent need to incentivise the selection and characterisation of storage sites to support final investment decisions by project proponents. This is especially the case in regions where deep subsurface data is limited. Regional resource assessments can assist with this process and provide valuable context for policy makers and regulators.

#### 4. Research and development efforts to advance more cost-effective capture technologies

As we look to the future of carbon capture technology, it is clear that the integration of two key focus areas will drive down capital and operating costs. First, the lessons learned from the portfolio of projects described earlier will provide valuable information for decreasing the cost of design, construction and operation of future carbon capture facilities. Second, there must be a continuing focus on R&D efforts to further reduce costs beyond those that emerge from the learnings of operational projects.

Second generation technologies are targeted to be available for demonstration testing in a 2025 timeframe with costs 20 per cent lower than currently available technologies (in terms of cost of electricity) (Figure 7). Transformational technologies are targeted to reduce costs by 30 per cent compared to currently available technologies and be available for demonstration testing in a 2030 timeframe.

**Figure 7** Relative US DOE cost reduction targets and timing for second generation and transformational carbon capture technologies<sup>13,14</sup>



Pilot-scale testing of second generation technologies using actual process gases is a critical step in advancing more cost-effective capture technologies. There are several second generation capture technologies that are currently being tested at pilot scale (or soon will be) worldwide. These are candidates for the next significant wave of lower-cost demonstrations that can eventually lead to widespread deployment.

<sup>13</sup> (Plasynski, 2015)

<sup>14</sup> Comparison to an 'nth-of-a-kind system' using current technologies.

Pilot-scale testing may also offer the opportunity to accelerate the designation of ‘n<sup>th</sup>-of-a-kind’ status to some technologies through commercial deployment of modular capture systems. The benefits of modular systems could include improved reliability and quality through shop fabrication, lower front-end costs, and the flexibility to add subsequent capture units as needed in response to changing regulations. This deployment approach could reduce costs and accelerate deployment through replication, mass production and ‘learning by doing’ at the modular scale rather than at a full-scale demonstration.

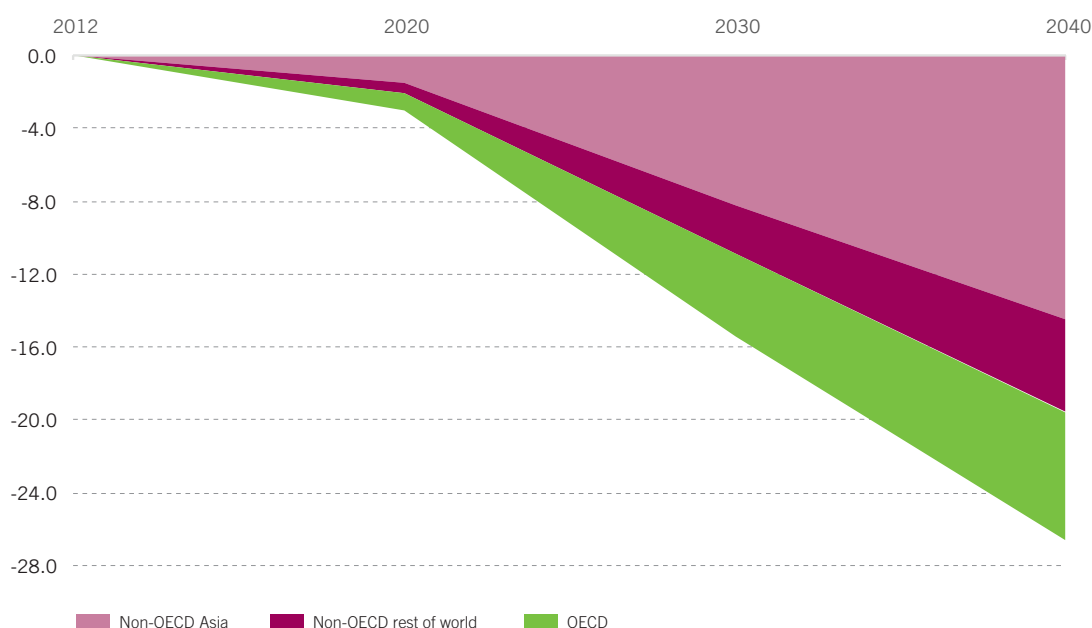
R&D is also underway on transformational capture approaches. These include development of liquid and solid materials that are optimised at the molecular level for the task of CO<sub>2</sub> removal, the use of technologies not traditionally used in gas separation, such as supersonic expansion and electrochemical processes, and the development of hybrid approaches that combine the benefits of multiple technologies. These hybrid technologies may yield synergistic benefits for further cost and performance improvements than might be achievable from a single technology approach.

International collaboration is a key element in accelerating the development and deployment of new capture technologies. It is critical that researchers work collaboratively and leverage each other’s knowledge resources to achieve better, faster results and generate technologies that will speed deployment of capture systems. Encouraging steps are being taken in this direction as illustrated in the recent US DOE selection of projects for large pilot-scale testing that plan to use facilities at the CO<sub>2</sub> Technology Center Mongstad in Norway.

## 5. Progress must be accelerated in developing countries

The majority of the world’s CO<sub>2</sub> emission reductions under a 2°C scenario must be realised in developing (non-OECD) countries, primarily in Asia (see Figure 8).<sup>15</sup>

**Figure 8** Reduction in energy-related CO<sub>2</sub> emissions: 450 scenario relative to Current Policies



A particular challenge for developing countries is the ‘energy trilemma’ – balancing the goals of energy access, energy security and environmental sustainability. CCS can help developing countries achieve these goals by enabling them to continue to utilise their indigenous fossil fuel reserves.

Reducing the costs of CCS deployment and access to international funds are critical to support its widespread use in developing countries through 2030 and beyond.

<sup>15</sup> Based on IEA data from *World Energy Outlook 2014*, *OECD/IEA 2014*, *IEA Publishing*; modified by the Global CCS Institute.

In particular, access to funding through the UNFCCC's Green Climate Fund (GCF) could be an important opportunity for developing countries. The Governing Instrument which established the GCF explicitly recognises CCS as eligible for funding. The UNFCCC's Climate Technology Centre and Network (CTCN) may also provide an important source of policy, regulatory and technical assistance for developing countries in regards to enhancing institutional capacity and support for CCS projects.

Many developing countries lack rigorous climate change policies to drive investment in CCS, however, developing countries can lay the groundwork for widespread CCS deployment in the medium term, through building capacity through learning by doing. This includes investing now in storage assessments, pilot projects, and further developing legal and regulatory frameworks. Learning by doing can be enhanced and fast-tracked through knowledge sharing and skills transfer from countries already undertaking CCS.

## APPENDIX A: KEY POLICY AND REGULATORY DEVELOPMENTS

The key policy and regulatory developments relevant to CCS in the last 12 months were:

- **US-China cooperation:** In November 2014, the Chinese and US governments made their historic Joint Announcement on Climate Change, which provided renewed funding for CCS research and an undertaking to construct a large-scale CCS project in China involving enhanced water recovery. In August 2015, they further announced a memorandum of understanding on clean coal technology, which will provide for the development of six CCUS pilot projects in China.<sup>16</sup> In September 2015, both countries reaffirmed the US-China Joint Announcement on Climate Change of November 2014 and '*...their determination to move ahead decisively to implement domestic climate policies, to strengthen bilateral coordination and cooperation, and to promote sustainable development and the transition to green, low-carbon, and climate-resilient economies*'.<sup>17</sup> These announcements reflect both countries' '*conviction that climate change is one of the greatest threats facing humanity*' and expectation that CCS will play an important role in responding to climate change.<sup>18</sup>
- **Emissions performance standards:** The US EPA published its final rule for the Clean Power Plan for existing power plants and emission performance standards for new, modified, and reconstructed power plants.<sup>19,20</sup> In Canada, emission performance standards also came into effect for new coal-fired power plants and units that have reached the end of their useful life.<sup>21</sup>
- **European Union CCS Directive Review:** The CCS Directive (2009/31/EC)<sup>22</sup> was reviewed during 2014 and the final report was delivered to the EC in January 2015. A key finding of the Review was the need for policies outside of the CCS Directive to enable a transition from demonstration to commercially viable CCS projects. The EC is expected to release its own implementation report in late 2015.
- **European Union reforms:** The structural reform of Europe's emissions trading scheme (ETS) is underway, with changes designed to ensure it sets a price on carbon sufficient enough to support the transition to a low-carbon economy. The EU's New Entrants Reserve (NER) financial mechanism has also been renewed, with 400 million emission allowances to be dedicated to establishing an Innovation Fund in the post-2020 period. For the period pre-2020, the market stability reserve (MSR) places 50 million allowances for low-carbon innovation projects to supplement the existing NER 300.
- **Carbon pricing:**
  - China's seven pilot ETSS continued operation, with learnings to be applied in the development of a national trading system expected to launch in 2017.
  - South Korea's ETS commenced on 1 January 2015; however, emission prices and trading volumes have remained at low levels.
  - The Alberta Government increased its carbon tax on industrial facilities, including oil sands operations and coal-fired power plants that emit more than 100,000 tonnes of CO<sub>2</sub> per year.<sup>23</sup>
  - Ontario announced its intention to join the Western Climate Initiative cap and trade system.<sup>24</sup>
- **US regulatory guidance:** The US EPA released a statement of 'key principles' to clarify its previous guidance on the issue of transition from Class II EOR wells to Class VI storage wells.<sup>25</sup> The EPA clarified that CO<sub>2</sub>-EOR does indeed store CO<sub>2</sub> while producing oil during EOR operations and that CO<sub>2</sub> injection under Class II rules could recognise the incidentally stored volumes. This clarification mitigates a major uncertainty for commercial CCUS projects.

<sup>16</sup> (United States Energy Association, 2015)

<sup>17</sup> (The White House, 2015)

<sup>18</sup> (The White House, 2015)

<sup>19</sup> (US EPA, 2015a)

<sup>20</sup> (US EPA, 2015b)

<sup>21</sup> (Government of Canada, 2015)

<sup>22</sup> (EC, 2009)

<sup>23</sup> (Government of Alberta, 2015)

<sup>24</sup> (Office of the Premier, Ontario, 2015)

<sup>25</sup> (US EPA, 2015c)

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