GLOBAL CCS INSTITUTE

THE GLOBAL STATUS OF CCS | 2014

SUMMARY REPORT

2014-2015 – WATERSHED YEARS FOR CCS

The world's first large-scale carbon capture and storage (CCS) project in the power sector commenced operation in October 2014 at the Boundary Dam power station in Saskatchewan, Canada. Two additional large-scale CCS projects in the power sector – at the Kemper County Energy Facility in Mississippi and the Petra Nova Carbon Capture Project in Texas – are planned to come into operation in 2015 and 2016 respectively. Construction is also underway on the world's first large-scale CCS project in the iron and steel sector, the Abu Dhabi CCS Project in the United Arab Emirates (UAE). These four projects are among the 22 large-scale CCS projects in operation or construction around the world – double the number at the beginning of the decade.

With large-scale CCS power projects now a reality, an important milestone in deployment of the technology has been achieved. This means that it is time to move discussion onto how CCS can best be deployed as part of a least-cost approach to climate change mitigation. We can now move on from arguments about its 'experimental' nature or that it has not yet been applied at scale to fossil fuel power plants.

There are a further 14 large-scale CCS projects in advanced planning, including nine in the power sector, many of which are anticipated to be in a position to make a final investment decision during 2015. Not only does this further reinforce the growing confidence in the (increasing) technical maturity of CCS, it offers the prospect of a 'potential portfolio' of operational large-scale CCS projects around the 2020 timeframe across a range of industries, storage types, fuels and technology suppliers.

Now is the time for actions to help realise the potential of these advanced projects (and for those projects in earlier stages of planning). Furthermore, the data on large-scale CCS projects highlights two other areas requiring increased attention by policymakers – the lack of projects in non-OECD economies (outside of China) and the lack of progress in CCS technology development in high carbon intensive industries such as cement, iron and steel and chemicals.

Numerous international studies continue to show that CCS is essential in meeting global climate targets. We need to realise the potential of CCS projects in the development pipeline and incentivise the development of CCS across a wider range of industries and regions to provide the basis for a rapid expansion in the number and diversity of next generation projects.

For this to happen, the following actions are vital:

RECOMMENDATIONS FOR DECISION MAKERS

- Financial and policy support structures must be provided in the near term to enable transitioning the 'potential portfolio' of planned projects into an 'actual portfolio' of projects operating by 2020.
- Strong, sustainable emission reduction policies that encourage CCS are urgently needed for longer-term deployment and to give investors the policy predictability they need to invest in CCS. These policies must ensure that CCS is not disadvantaged in relation to other low-carbon technologies.
- There is an urgent need for policies and funded programs which encourage the exploration and appraisal of significant carbon dioxide (CO_2) storage capacity, so that broader deployment is not delayed by uncertainty over available storage.
- Substantial effort must be devoted to knowledge sharing, capacity development and the implementation of other policies and legal frameworks during the course of this decade to enable the increasing numbers of large-scale CCS projects needed in non-OECD economies by 2025-30 and beyond.
- CCS is the only technology that can achieve large reductions in CO_2 emissions from industries such as iron and steel and cement. Urgent attention must be given to the development of policies that incentivise the widespread deployment of CCS in such industries.

CCS is essential

Global consumption of fossil fuels continues to increase, driving growth in CO_2 emissions. Even when it is assumed that current policy commitments and pledges by governments around the world to tackle climate change are all implemented, it is expected that fossil fuels will still account for 75% of global energy demand in 2035. Demand growth is expected to be particularly strong in developing countries. In its *World Energy Outlook 2013,* the International Energy Agency (IEA) estimated that on these assumptions energy-related CO_2 emissions will rise by 20% to 2035. This leaves the world on a trajectory consistent with a long-term average temperature increase of 3.6 degrees Celsius (°C), far above the internationally agreed 2°C target.

It is clear that much more needs to be done to limit CO_2 emissions growth. Work is under way through the United Nations Framework Convention on Climate Change (UNFCCC) to reach a new global climate change agreement by the end of 2015. This agreement is vital if greenhouse gas (GHG) concentrations in the atmosphere are to be stabilised at a level that will avoid the worst impacts of climate change.

CCS is a cost-effective technology for achieving large emission reductions from fossil fuel use, and it must play a significant role alongside renewables, energy efficiency, nuclear and other mitigation options in global action on climate change. CCS has a key role in curbing CO_2 emissions from fossil fuel-based power generation. Without investment in CCS in the power sector, total mitigation costs in the sector would increase by US$2 trillion by 2050 (IEA, 2012. *Energy Technology Perspectives*). Further, CCS is the only option available to significantly reduce direct emissions from many industrial processes at the large scale needed in the longer term.

'After many years of research, development, and valuable but rather limited practical experience, we now need to shift to a higher gear in developing CCS into a true energy option, to be deployed in large scale. It is not enough to only see CCS in long-term energy scenarios as a solution that happens some time in a distant future. Instead, we must get to its true development right here and now.'

Maria van der Hoeven, Executive Director, IEA
Foreword to the *Technology Roadmap: Carbon Capture and Storage,* 2013.

CCS power projects are a reality

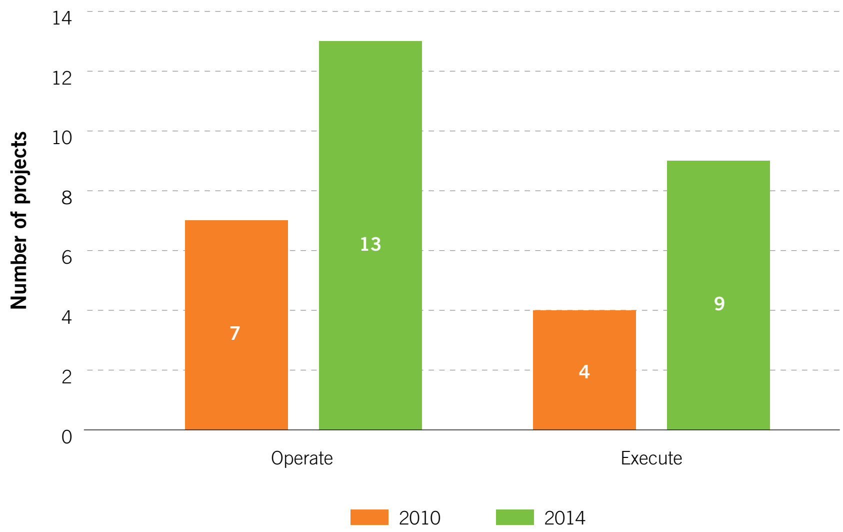
The commencement of CCS operations at SaskPower's Boundary Dam coal-fired power station in October 2014 is a significant step forward. The feasibility of capturing CO_2 from power station flue gas streams has been well established in recent years through a number of pilot and small-scale demonstration plants. The Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project represents the first example of applying CCS in a power station at large scale, and will provide important learnings for future projects as well as a clear demonstration that CCS is a real option to greatly reduce CO_2 emissions from the power sector.

Two further large-scale CCS projects in the power sector are under construction in the United States (US) – at Mississippi Power's Kemper County Energy Facility in Mississippi and the Petra Nova Carbon Capture Project at NRG Energy's W.A. Parish power station in Texas. These are expected to be commissioned in 2015 and 2016 respectively. Importantly, these three power projects will demonstrate different capture techniques (post-combustion in the case of Boundary Dam and Petra Nova, and pre-combustion in the case of Kemper County), and are using capture methods from different technology suppliers.

Construction is also under way on the world's first iron and steel project to apply CCS at large scale, the Abu Dhabi CCS Project at the Emirates Steel plant in the UAE. Iron and steel making is one of the industrial applications for which there are no real alternatives to CCS for greatly reducing emissions. Industrial applications account for about one-quarter of the world's energy-related CO_2 emissions and emissions from these sectors are projected to grow by over 50% by 2050, under a 'business as usual' approach (IEA, 2014. *Energy Technology Perspectives*). Successful demonstration of CCS in sectors such as iron and steel will be vital to future emission reduction efforts.

These four large-scale CCS projects are among the 22 across a range of industries that are now in operation (Operate stage) or construction (Execute stage) around the world, double the number at the beginning of this decade (Figure 1). The total CO_2 capture capacity of these 22 projects is around 40 million tonnes per year (Mtpa) – or equivalent to the total annual CO_2 emissions of countries such as Denmark or Switzerland.

Figure 1 **Number of large-scale CCS projects in the Operate and Execute stages**



To ensure consistency across years, the 2010 record of large-scale operating CCS projects combines the Rangely and Salt Creek EOR Projects. In Institute reporting, these projects were combined and included under the Shute Creek Gas Processing Facility Project from 2011 onwards.

The portfolio of operating CCS projects needs to be broadened

With the exception of the Boundary Dam Project, operating large-scale CCS projects are in sectors where, as part of the industrial process, CO_2 is routinely separated from other gases (such as in natural gas processing) or CO_2 is produced in a relatively pure stream (such as in fertiliser or ethanol production). In such industries, the application of CCS is well understood and could readily be expanded given the right incentive structures and availability of suitable storage sites in reasonable proximity to the industrial plant.

Large-scale CCS projects in the power and iron and steel industries, such as Boundary Dam and those commencing operation in the next two years, are important for broadening the portfolio of CCS into areas where capturing CO_2 is more challenging. There are a further nine large-scale power sector CCS projects in the most advanced stage of development planning (Define stage), which are approaching the point of making a final investment decision. Given the right conditions, all of these projects could be in operation by around the 2020 timeframe. These projects would further expand the scope of power sector CCS application into new capture techniques (including oxyfuel combustion), new plant configurations (such as poly-generation of power with other outputs) and new feedstocks beyond coal (natural gas and biomass). At this stage there are no further large-scale projects contemplated in the iron and steel industry, even though this industry accounts for about 9% of global CO_2 emissions. Nor is any large-scale project planned in the cement industry, which accounts for about 6% of emissions.

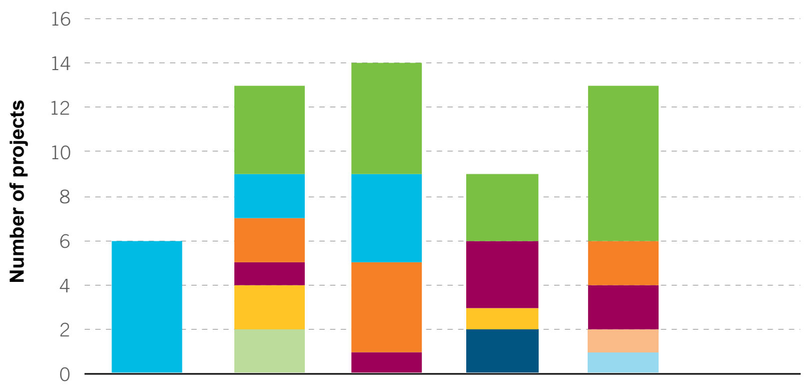
Chemicals and petrochemicals are a rapidly increasing source of emissions. Between 2011 and 2050, CO_2 emissions from these industries in a 'business as usual' scenario are expected to almost triple to 3.7 billion tonnes a year, by which time they are expected to match 'business as usual' emissions from the iron and steel sector (IEA, 2014. *Energy Technology Perspectives*). There are four operating projects in the fertiliser, synthetic natural gas and hydrogen production parts of the chemical industry, with a further two under construction or in advanced planning. Broader experience in applying CCS to the chemicals and petrochemicals industries will be gained through a further five projects under construction or in advanced planning in the ethanol production, refining, coal-to-chemicals and coal-to-liquids sectors. Importantly, two of these projects are in China, where the coal-to-chemicals industry is expanding rapidly.

More widespread experience is also needed in the countries and regions in which CCS is being applied, and in the types of storage being utilised. The present suite of large-scale CCS projects in operation, under construction or in advanced planning is heavily weighted towards projects in North America utilising CO_2 for enhanced oil recovery (EOR).

North America accounts for nine of the 13 operating projects, six of the nine under construction, and six of the 14 in the Define stage (Figure 2). The other 15 projects at these stages of the development lifecycle are spread across nine different countries, but of these countries only China (four), the United Kingdom (UK) (three) and Norway (two) have more than one project in operation, construction or advanced planning.

Overall, including 19 projects in the early stages of development planning (Evaluate and Identify stages), the Global CCS Institute (the Institute) has identified 55 large-scale CCS projects around the world.

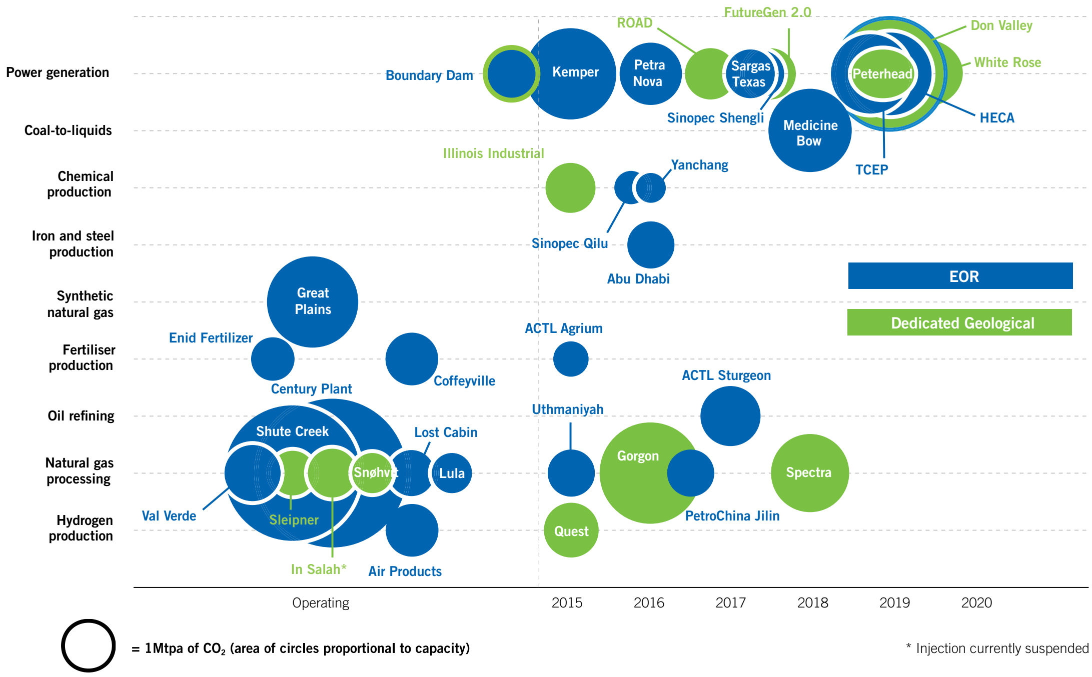
Figure 2 **Large-scale CCS projects by lifecycle and region/country**



	Identify	Evaluate	Define	Execute	Operate	**Total**
United States	0	4	5	3	7	**19**
China	6	2	4	0	0	**12**
Europe	0	2	4	0	2	**8**
Canada	0	1	1	3	2	**7**
Australia	0	2	0	1	0	**3**
Middle East	0	0	0	2	0	**2**
Other Asia	0	2	0	0	0	**2**
South America	0	0	0	0	1	**1**
Africa	0	0	0	0	1	**1**
Total	**6**	**13**	**14**	**9**	**13**	**55**

An important reason for this geographic concentration of projects is the potential in North America for sales of CO_2 for the purpose of EOR. The revenue stream EOR offers has been important in helping to make the business case for all of the operating CCS projects in the US and Canada (Figure 3). EOR is also a feature of the single project operating in Brazil, the two projects under construction in the Middle East, and the four projects in advanced planning in China. In all of the regions where EOR offers revenue potential, it is supporting early deployment of CCS.

Figure 3 Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by industry and storage type



If CCS is to reach its full potential in emissions mitigation, the majority of CO_2 will eventually have to be stored in dedicated geologic reservoirs, such as deep saline formations. Resource estimates indicate a much greater potential for dedicated geologic storage options than EOR to meet longer-term CO_2 capture and storage requirements.

Valuable experience in deep saline formation storage has been gained from large-scale projects in Norway (the Sleipner and Snøhvit CO_2 Storage Projects) and in Algeria (the In Salah CO_2 Storage Project) and a range of pilot test facilities around the world, such as Lacq in France, Ketzin in Germany and Otway in Australia. Three large-scale CCS projects in construction are pursuing onshore deep saline formation storage – the Quest Project in Canada, the Gorgon Carbon Dioxide Injection Project in Australia and the Illinois Industrial Carbon Capture and Storage Project in the US. These projects will be operational in 2015-16.

A further six projects in the Define stage have confirmed or are exploring storage in deep saline formations or depleted gas reservoirs, including the ROAD Project in the Netherlands, the FutureGen 2.0 Project in the US and all of the UK projects. Anticipated operational dates are in the 2017-20 period. Taken together, the experience gained from these projects will greatly add to the knowledge base on dedicated geological storage. In this context, advancing projects from planning into construction and operation in Europe (where no large-scale CCS project has entered construction in over a decade) will play an important role in establishing a positive perception of CCS both in the region and globally.

Further policy support is vital

Within the next year there is the potential for ten or more projects to be in a position to make a final investment decision. Current policy settings and any new initiatives taken in the next 12-18 months will therefore largely shape the CCS projects portfolio out to 2020. It is important that financial and policy structures in the near term support the transitioning of this ‘potential portfolio’ of planned projects into an ‘actual portfolio’ of operating projects by 2020.

In addition to near-term actions needed to bring planned projects into operation, the future pipeline of projects must be greatly expanded. Important lessons will be learnt from the projects in operation this decade that will help to reduce costs, increase confidence and expand the applications of second- and third-generation CCS technologies in the 2020s and 2030s. But the total absence of any projects in the earliest stage of project planning, except in China, is of concern. This situation must be rectified if CCS is to play its full part as a mitigation option, commensurate with IEA scenarios. As a result, strong sustainable emissions reduction policies that encourage CCS are urgently needed for longer-term deployment and to give investors the longer-term predictability they need to invest in CCS.

Immediate and longer-term policy support is vital. However, a majority of respondents to the Institute’s 2014 Perceptions Survey reported that they had not noticed a material change to their CCS policy environment over the last year. More than three-quarters of respondents cited policy uncertainty as a major risk to their project’s viability, and a similar proportion stated that their project’s viability depends on new government policy settings.

Existing policy support alone over the past five years has not been enough to ‘launch’ the number of large-scale CCS projects anticipated at the start of the decade. In fact, more than 40% of respondents to the Perceptions Survey indicated that the incentives currently in place are inadequate for ensuring projects are not commercially stranded.

The need for supportive policies has been recognised in a number of countries and regions. The UK policy environment continues to promote progress of large-scale projects. The US policy, legal and regulatory environment for CCS/carbon capture, utilisation and storage (CCUS) continues to advance, and projects are also progressing there, particularly when supported by EOR opportunities. The European Commission (EC) is reviewing European Union (EU) CCS policy, against a backdrop of only one project (ROAD) in development planning in mainland Europe. Several developing countries are also progressing policy reviews or including CCS in broader climate change policy considerations. Governments are also supporting efforts through the International Organization for Standardization (ISO) to develop essential supporting technical infrastructure for future CCS development.

Progress must be accelerated in developing countries

It is not surprising that to date, most large-scale CCS projects are in the developed world. This is where key project enablers such as public support programs, marketable opportunities for CO_2, storage assessments and regulatory frameworks are most advanced. However, non-OECD economies will account for the vast majority of growth in energy demand in coming decades. Meeting longer-term climate goals will involve significant capture and storage of CO_2 from facilities in these economies. In its 2012 *Energy Technology Perspectives,* the IEA estimated that 70% of CCS deployment will need to happen in non-OECD countries by 2050 to achieve the 2°C global emission scenario.

Important progress is being made in a number of non-OECD and developing countries in CCS project and policy development. These efforts must continue, and substantial effort devoted to the implementation of policies and frameworks (including knowledge sharing and capacity development programs) during the course of this decade to support the increasing numbers of large-scale CCS projects required in non-OECD economies by 2025-30 and beyond.

Technical challenges and risks are well understood

Capture research, development and demonstration is essential to drive down costs

Carbon capture refers to that part of a CCS project concerned with separating or isolating a relatively pure stream of CO_2 from other gases and liquids, so that it can be transported for use or storage elsewhere. The cost of capture varies greatly depending on the industrial process involved. In industries like natural gas processing, naturally occurring CO_2 is routinely stripped from the methane-rich sales gas component, so there is little or no additional 'capture' cost involved beyond compression if this CO_2 was subsequently to be transported and stored, rather than vented to the atmosphere. By contrast, in industries like power generation or blast furnace steel making, CO_2 is usually a small fraction of the nitrogen-rich exhaust gas stream from the plant, and separating this CO_2 is a complex and costly undertaking. In such industries, capture is by far the largest component of the CCS cost chain.

The three CCS projects in the power sector that have made a positive final investment decision, together with the nine in the Define stage, illustrate that significant progress has been made in tackling these challenges and demonstrating the feasibility of capturing CO_2 at large scale from fossil fuel power stations. The range of projects in the Define stage which are approaching a final investment decision would further expand the types of capture techniques and technologies demonstrated in these applications. Such demonstration of a range of possible capture techniques and technologies is essential to enhance understanding of different operating conditions and to drive further research and development (R&D) in this area.

Cost reduction has been and will continue to be the key focus of much capture R&D and technology improvement. First-generation technologies will be demonstrated in the first-of-a-kind large-scale CCS projects currently being operated or built. The portfolio of R&D capture projects to improve on these technologies is very broad. Although not all the concepts will progress at the same pace nor are they expected to fully transition to pilot and subsequent demonstration, the most promising technologies have the potential to significantly reduce investment and operating costs in the next 10-20 years.

To achieve further improvements in carbon capture, it is critical for governments, researchers and industry to work collaboratively to support next generation large-scale CCS projects. It is equally important to continue R&D and share acquired knowledge to leverage resources to achieve better, faster results to produce future game changing capture technologies needed to accelerate broad CCS deployment. Capture technologies are being developed globally in several programs with support of governments, academia and industry, especially in Europe, North America and Asia. Such international collaboration is key to accelerating the deployment of newer technologies.

Transportation is mostly a scale issue

The transportation of large volumes of CO_2 by pipeline has been practised for decades, particularly in the US. These pipelines have been operated with an excellent safety record, applying internationally adopted standards and codes of practice which continue to be further developed. The technology for CO_2 pipelines is thus well established and CO_2 transportation infrastructure continues to be commissioned and built.

While pipelines are – and are likely to remain – the most common method of transporting the large quantities of CO_2 involved in CCS projects, ship transportation can be an alternative option for a number of regions of the world, especially in regions where onshore and near shore storage locations are not available. Transport of CO_2 by ship already takes place on a small scale in Europe, and larger-scale shipment of CO_2 is likely to have much in common with the shipment of liquefied petroleum gas (LPG), which is now commonplace. Truck and rail transport of industrial and food grade CO_2 has also been undertaken for over 40 years, and may be useful for pilot and small-scale CCS projects.

The main transport issue is scale. For CCS to fulfil its potential in the IEA's least-cost pathway to halve energy-related CO_2 emissions by 2050, the estimated distance of CO_2 transportation infrastructure to be built in the coming 30-40 years is roughly 100 times larger than currently exists.

The costs of CO_2 pipeline transportation differ from project to project due to factors such as pipeline length, volumes of CO_2 and the corresponding pipe diameters, cost of labour, and economic life of the infrastructure. An important option to reduce the cost of CCS is to realise economies of scale by sharing a single CO_2 transportation and storage infrastructure system among several operators of separate CO_2 generating plants. In this sense, it is important to think about CO_2 transport infrastructure through a regional lens (as opposed to point-to-point systems).

Given the scale of CO_2 transportation infrastructure required, experience is needed outside the US in planning, designing and implementation of large-scale CO_2 transport networks connecting multiple CO_2 sources and sinks. Governments can play a role here by providing incentives for projects to invest in CCS transport solutions that will accommodate the future development of other CCS projects and large CO_2 transportation networks.

Early-stage storage site characterisation is important for accelerating CCS deployment

Carbon dioxide is stored in the same kind of porous rock that can contain deposits of crude oil or natural gas. Similarly, the same kind of impermeable cap rocks that keep oil and gas underground and prevent it migrating to the surface can be expected to trap CO_2 over geological timescales.

Today, over 150 sites are injecting CO_2 underground, either for EOR or for dedicated CO_2 storage. EOR represents the majority of these sites and began over 40 years ago in the US. The first dedicated CO_2 storage project started in 1996 at the Sleipner offshore gas field in Norway. The underground storage of natural gas for seasonal and strategic reserves also has several similarities to CO_2 storage and has a long track record that can inform risk management of CO_2 storage sites.

Experience gained from these sites and existing CCS projects, as well as experience from the petroleum industry, gives a high degree of confidence in the feasibility and operation of CO_2 storage. Although all of the required technologies are already available 'off-the-shelf' to develop a large number of secure CO_2 geological storage sites, the geosciences and subsurface engineering communities are still producing considerable innovations to both improve overall solutions and to widen the range of suitable storage sites. Further data from a greater variety of real world large-scale storage scenarios will further inform these efforts.

It can take a considerable period of time, possibly up to ten years, to fully appraise a greenfield site ready for a final investment decision. This is a much longer time frame than is generally required for the capture and transportation elements of a CCS project. In the early phases of project development, storage availability is also the most uncertain element, and may require a significant allocation of resources. The characteristics of a particular storage site may have important influences on the design of the CO_2 capture plant and transportation system.

Given the required scale of CCS deployment post-2020 to meet climate goals, the challenge of finding appropriate storage capacity may increase considerably. Projects may need to investigate several storage targets to mitigate the exploration risk. 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 for policies and funded programs that encourage the exploration and appraisal of significant CO_2 storage capacity.

Public engagement is an important part of the picture in all countries

The most advanced CCS projects have shown they are fully committed to public engagement and long-term outreach activity, not just with their local stakeholders, but also on the international stage. This engagement and outreach is critical for increasing understanding and ensuring acceptance of CCS generally, and with regard to specific projects. The engagement methods ranked most effective by projects are generally direct in nature, such as face-to-face meetings, site visits, formal consultation events and education programs.

The three large-scale power sector CCS projects that have taken a positive final investment decision (and those that will follow) will be vital in establishing a positive perception of CCS as an important part of an effective and efficient CO_2 emission reduction portfolio. Leveraging these milestones in CCS deployment is critical to creating awareness and building enthusiasm to empower communication efforts, not just around CCS technology, but also on climate change and low-carbon energy more generally.

The first-mover projects that have progressed to the most advanced stages of the project lifecycle since the beginning of this decade lie almost exclusively in the Americas and Europe, Middle East and Africa (EMEA) regions. By contrast, most of the large-scale CCS projects in the early stages of project development are in the Asia Pacific region. While the Institute's 2014 Perceptions Survey indicated that around one-third of the projects in the Asia Pacific region are either actively engaged with stakeholders or developing a public engagement strategy, a substantial number are yet to develop such a strategy. This makes those projects that are adopting best practice approaches important and instructive case studies for others in the region.

The majority of CCS social research carried out to date has focused on the developed world, shedding very little light on the role of CCS within developing countries. This is not surprising given the areas of the world where CCS is most developed. However, these results underline the urgent need to improve access to the learnings and experiences of CCS projects and researchers in the developed world. This will help to understand differences in needs in developed and developing regions and allow projects in the latter to benefit from lessons learnt.

International collaboration is vital to accelerate CCS

While some large-scale CCS projects have been operating for decades, the overall industry is still in its infancy. As with all industries at this stage of development, great benefits can be obtained from knowledge sharing and collaboration along the entire development chain, from early laboratory concept to scalable pilot testing and large-scale projects. Project case studies and comments from leading voices in the CCS and climate change community highlight the value of collaborating with others.

The transfer of large-scale project experience from successfully operating projects to new projects will help to reduce costs and risks, as well as build confidence about CCS among the general public, governments and the finance community. In particular, transferring experience from developed to developing economies will be vital given the future scale of the mitigation task and the role of CCS in helping to achieve mitigation goals in those countries at least cost.

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Cover image: Final calibration on the sulphur dioxide stripper of the SaskPower Boundary Dam Integrated CCS Project, Canada. Image provided by SaskPower.

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