GLOBAL CCS INSTITUTE

GLOBAL STATUS OF CCS: SPECIAL REPORT

INTRODUCTION TO INDUSTRIAL CARBON CAPTURE AND STORAGE

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For enquiries please contact:

BY TELEPHONE: +61 (0)3 8620 7300

BY EMAIL: info@globalccsinstitute.com

BY MAIL: Global CCS Institute, PO Box 23335
Docklands VIC 8012 Australia

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Highlights

- The industrial sector is responsible for nearly one quarter of the world's annual greenhouse gas emissions.
- CCS is the only technology that can achieve deep reductions in carbon dioxide (CO_2) emissions from high-emitting industries such as steel, cement and fertiliser production.
- More than a dozen large-scale, integrated carbon capture and storage projects in the industrial sector are in operation today, showcasing just some of the broad industrial applications of carbon capture and storage.
- The first industrial large-scale carbon capture project on a natural gas processing plant commenced operation in 1972. The most recent large-scale CCS project became operational in November 2015.
- Since 1972, large-scale CCS projects have cumulatively captured, transported and permanently stored more than 100 million tonnes of CO_2.
- Failure to stimulate a future pipeline of CCS projects could see the cost of climate mitigation more than double.

1 Introduction

Carbon capture and storage, or CCS, is a process used to capture carbon dioxide gas (CO_2) that is produced by power stations or other types of industrial facilities. To keep CO_2 out of the atmosphere, it is captured from the power plant or industry, transported, and securely stored underground, permanently. CCS technology involves three major steps:

- **Capture**
  The separation of CO_2 from other gases produced from facilities including coal and natural gas power plants, steel mills and cement plants.
- **Transport**
  Once separated, the CO_2 is compressed and transported, usually via pipelines, to a suitable site for deep underground storage.
- **Storage**
  CO_2 is injected into deep underground rock formations, normally at depths of two kilometres or more. The CCS storage process simply imitates how nature has stored oil, gas and CO_2 for millions of years.

Throughout this report, references to CCS will indicate all three parts of this process – also referred to as 'full chain CCS'. References to 'carbon capture' will specifically indicate the part of the process dedicated to capturing the CO2 emissions at their source.

CCS is a vital technology for helping the world to meet the climate targets agreed at the 2015 Paris climate talks. The Intergovernmental Panel on Climate Change (IPCC) has found that achieving the deep cuts in CO_2 emissions necessary to limit global warming to 2 degrees Celsius (°C) would cost 138 per cent more without CCS.[1]

[1] (IPCC, 2014)

The International Energy Agency (IEA) has noted that the exclusion of CCS as a technology option in the electricity sector alone could increase mitigation costs by around US$2 trillion by 2050.[2] The United Kingdom (UK) Committee on Climate Change found that deploying CCS could almost halve the cost of meeting the UK's 2050 CO_2 emission reduction targets.[3]

One of the major benefits of CCS as an emissions reduction technology is that it can be applied to different types of CO_2 emissions sources, particularly those with very large volumes of emissions, such as power plants and some industrial facilities.

Importantly, CCS is a proven technology that is already in operation around the world, in a number of industrial sectors. These industrial applications are the main focus of this report, and some of them date back as far as the 1970s and 1980s.

There are several key reasons why CCS needs to be an integral part of the world's fight against climate change.

- CCS can deliver deep emissions reductions because it can be applied to large point-sources of CO_2 emissions, such as power stations and large industrial facilities.
- A single CCS project that captures and stores one million tonnes per annum (Mtpa) of CO_2 is removing emissions equivalent to taking 200,000 cars off the road.
- CCS is a proven technology around the world, ideally suited for high emitting industrial sectors.
- More than 2,400 new coal-fired power stations are planned for construction by 2030, and many hundreds of existing facilities will still be in operation for decades to come.[4]
- CCS is a solution that can be retrofitted to many existing facilities and integrated into the design and construction of planned facilities.
- CCS is the only technology that can achieve large reductions in emissions from industrial sectors such as iron and steel, cement, chemicals and petrochemicals and fertiliser manufacture.

The world will use around a third more energy in 2040, compared to 2013.

Whilst fossil fuels are projected to provide a smaller percentage of global energy demand than today in 2040 (75 per cent vs 81 per cent), global demand for fossil fuels will actually increase.[5]

2 Understanding industrial CCS

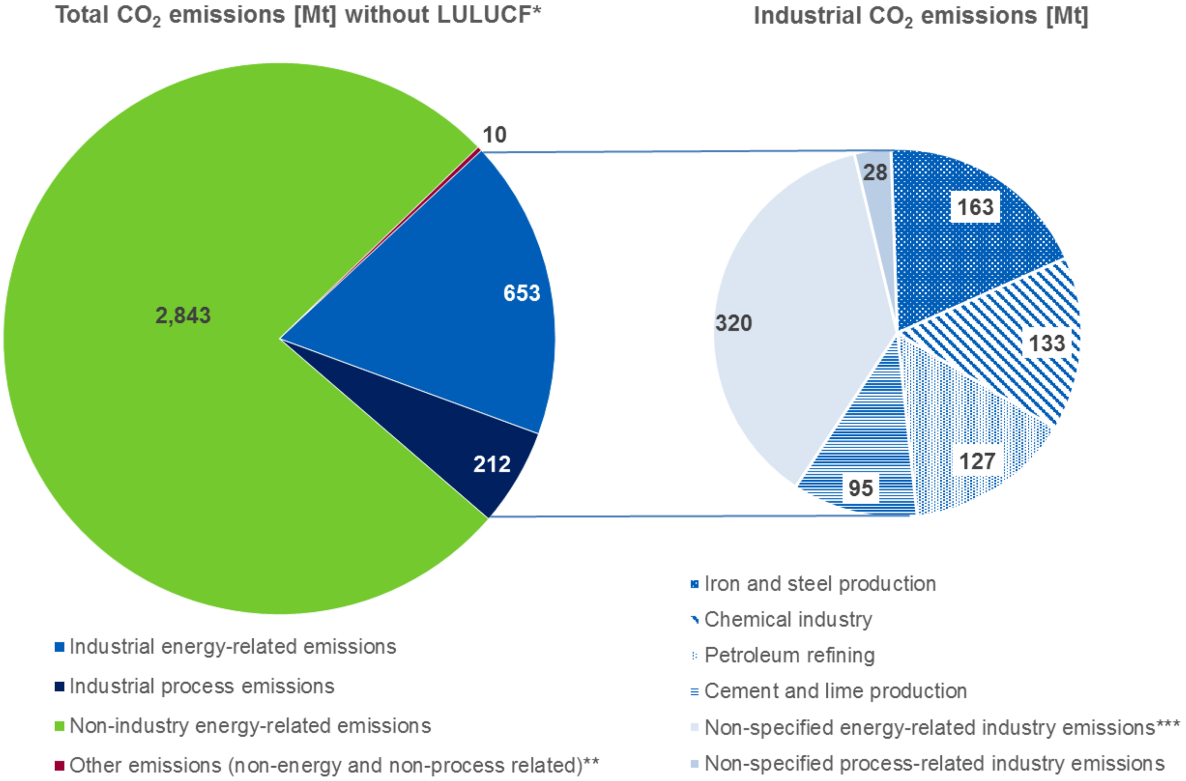
Fossil fuels are an essential input to the production process of a number of vital industries such as the steel, cement and chemical industries. Fossil fuels are utilised in these industries because of their chemical and physical properties, not as a primary energy source to generate electricity.

Just as the use of fossil fuels in power production generates large volumes of CO_2, so too does the use of fossil fuels in industrial applications. However unlike power generation, it is not possible to substitute renewable energy sources for fossil fuels in order to reduce emissions. This report focusses on the application of CCS to those industrial processes, rather than to power generation.

[2] (IEA, 2012)
[3] (The UK Committee on Climate Change, 2015)
[4] (Climate Action Tracker, 2015)
[5] (IEA, 2015)

The industrial sector accounted for around 8.5 gigatonnes (Gt) of CO_2 emissions in 2012, which is one quarter (25 per cent) of global CO_2 emissions.[5] Under a 'business as usual' scenario, global emissions from these industries are projected to grow by around 50 per cent by 2050.[6] To illustrate the point, Figure 1 gives an indication of the importance of industrial sector emissions for the European Union.

Figure 1 EU28 total CO_2 emissions and direct CO_2 industrial emissions (2012)[7]



** Land-use and land-use change and forestry*
*** Including emission from solvent and other product use, agriculture and waste*
**** Including non-ferrous metals, pulp & paper, food processing, and other non-specified sources (IPCC categories 1.A.2.B, 1.A.2.D, 1.A.2.E and 1.A.2.F)*

The IEA, in its *2013 CCS Roadmap*, projected that almost half (45 per cent) of the CO_2 captured between 2015 and 2050 consistent with its 2˚C Scenario would come from industrial applications.[8]

In high-emitting industries such as steel, cement, chemicals and oil refining, CCS is the only large-scale technology available that can enable deep emission cuts. Energy efficiency measures must be complemented by CCS in order to significantly reduce these emissions.

> *"If we want to live in a world where we still produce steel and cement in order to build hospitals, schools, homes and cities…if we want to live in a world where we can fertilise enough crops to feed a growing population of more than seven billion souls…if we want to live in that world, then we need to decarbonise those industries."* ***– Brad Page, CEO, Global CCS Institute***

[5] (IEA, 2015)
[6] (IEA, 2015)
[7] (European Environment Agency, 2015)
[8] (IEA, 2013b)

Steel and cement are vital to build the infrastructure needed for manufacturing renewable energy technologies, transportation networks and economic progress. Without fertiliser sufficient crops cannot be grown to feed the world's population.

Ability to refine natural gas and oil into petrochemicals provides raw materials for making plastics, advanced textiles, and food and medicine packaging. An electric car may be charged by a solar-powered grid. But it cannot be built without metals, plastics and polymers. It cannot be built without factories, production lines, or tools.

The world's industrial sectors cannot simply be 'switched' out of the economy. Nor will fuel switching achieve decarbonisation in these sectors, as many of the emissions are due to inherent chemical processes, not energy use as such. CCS is the only technology that can achieve large reductions in emissions from these industrial processes.

Deploying CCS in these sectors also provides an opportunity for countries and regions to maintain competitive economies and retain and expand employment in high value sectors, all while achieving ambitious climate change mitigation targets. Industrial CCS has the potential to secure value-adding industrial development in an increasingly carbon-constrained world.

3 Existing applications of industrial CCS

Carbon dioxide separation technology has been deployed in some industry sectors, such as in natural gas processing, for many decades. These separation technologies were developed to remove unwanted CO_2 from mixtures with other gases. In other industries, CO_2 is a by-product of the chemical processes used to produce substances such as hydrogen or fertiliser.

This by-product CO_2 can be of very high purity. At least until the 1970s, however, there were no large-scale uses for this by-product CO_2, nor any policy drivers to find such uses or otherwise dispose of it. As a result most industrially-produced CO_2 historically has been simply vented into the atmosphere.

These industries offer considerable opportunities for CCS, given that the CO_2 is already 'captured' – or in other words, separated from other gases.

In CCS applications, such as conventional power generation, up to 85 per cent of the cost of CCS can be due to the capture part of the project. Most of these costs can be avoided for industrial applications where the purity of the CO_2 emissions stream is already very high (such as ammonia and fertiliser production) and/or the cost of CO_2 capture in making the product market-ready is already embedded in the process (such as in natural gas processing and liquefied natural gas facilities).

Even in industries where separation of CO_2 from a process gas stream is required (such as in hydrogen production) the concentration of the CO_2 in the gas stream is higher and it is therefore easier and less expensive to separate.

In the early 1970s, the first large scale use for waste CO_2 was pioneered by the oil and gas industry in the southern United States (US).

Oil production from any given field typically goes through several phases. In the first phase, a fraction of the oil in place is brought to the surface by natural pressure and/or by pumps.

The second phase involves forcing a further fraction of oil from the field by injecting water or gas into the field to increase the remaining pressure.

Starting in 1972, a group of oil companies decided to try injecting CO_2 into a producing oil field to supplement these techniques, in an attempt to produce an even greater fraction of the oil in place. This third phase has come to be known as 'enhanced oil recovery' (EOR).

It has since provided by far the largest use for CO_2 that would otherwise be released into the atmosphere.

For this reason, the vast majority of CO_2 currently captured and stored by large-scale CCS projects is from industrial sources, mainly natural gas processing. As at June 2016, there are 15 large-scale CCS projects in operation across the globe, with a combined annual capture potential of 28 Mtpa (five million cars' equivalent). Of these 15 projects, 14 apply CCS to industrial processes.

These 14 large scale operating industrial CCS projects are described in the following pages, as well as some other projects which are either close to commissioning, or are otherwise significant because of their location or a new application of CCS. The projects are grouped into the following industries:

- Natural gas processing
- Fertiliser production
- Hydrogen production
- Coal gasification
- Iron and steel making.

Other industrial applications of carbon capture technology, including examples of full-chain CCS projects, are possible and already operational. These include applications on cement manufacturing and bio-ethanol production. More information on these technologies can be found on the Global CCS Institute website, at www.globalccsinstitute.com.

It is important to note that even though carbon capture technologies are widespread in the industries highlighted by this report, at this stage CCS is not widely applied. In the absence of the appropriate additional infrastructure, such as pipelines or access to permanent geological storage, or without strong policy support or commercial incentives, most of the captured CO_2 from the hundreds of other industrial facilities around the world will continue to be vented into the atmosphere.

CCS on natural gas processing

Natural gas, as used by consumers, is a highly-processed product that differs greatly from the raw natural gas extracted from underground.

Gas suitable for use or 'sales' gas is composed almost entirely of methane, which is extracted from the natural gas through a series of processes. In addition to methane, raw natural gas can contain a range of other substances including water, petroleum fluids, carbon dioxide, nitrogen, sulphur compounds, and other hydrocarbon gases such as propane and butane (which constitute liquefied petroleum gas or LPG).

Natural gas processing plants use a range of different processes to remove these various impurities and produce pipeline quality dry natural gas. Some of these substances, such as hydrocarbon liquids, LPG and sulphur, have commercial value and can be sold separately. Others, such as water and nitrogen, usually have no value and are re-injected into the gas reservoir or released.

> Techniques for removing CO_2 from raw natural gas streams to meet sales gas requirements have been in use since the 1930s. While historically there have been small-scale uses for CO_2 captured in such a way, usually the vast bulk of the separated CO_2 has been vented to the atmosphere.

Val Verde Natural Gas Plants

The first of these projects started in 1972, using a waste stream of by-product CO_2 from several natural gas processing facilities in the Val Verde area of southern Texas. Instead of being vented, the CO_2 that had already been separated from the natural gas stream in the Val Verde gas plants was compressed and transported through the first large scale, long distance CO_2 pipeline to an oilfield several hundred kilometres away elsewhere in Texas. The CO_2 was then injected into the SACROC

(Scurry Area Canyon Reef Operators Committee) Unit of the KellySnyder Field in Scurry County, West Texas.

The output of the Val Verde plants is dependent upon the quality of the natural gas being treated. The CO_2 content of the inlet gas stream can vary between 25-50 per cent in many cases. The total capture capacity of the Val Verde plants is around 1.3 Mtpa.

The increased production of the SACROC petroleum reservoirs in response to the injected CO2 convinced several other major oil companies of the viability of this technique.

The SACROC project demonstrated the excellent properties of CO_2 as an agent for EOR. Experience at SACROC and many other EOR operations has shown that subject to minor losses, all purchased CO_2 is stored in the reservoir(s) by EOR operations.

In any given reservoir, the amount of CO_2 co-produced with oil will increase with time; but the recycling systems employed at sites ensure that the vast majority of this CO_2 is reinjected into the reservoir in a closed loop system. EOR sites are designed to optimise oil recovery and minimise CO_2 purchases, so the storage resulting from EOR is often termed *associated* or *incidental*.

Natural gas processing plants supplying CO_2 for EOR thus provide the underlying facilities for some of the longest-running CCS projects anywhere in the world. They are also home to the largest integrated CCS projects, with single projects in the United States capable of capturing up to 8.4 Mtpa of CO_2 – equivalent to almost ***1.7 million cars being taken off the road***.

Shute Creek Gas Processing Facility

The Shute Creek, Wyoming, US gas treating facility began operation in 1986 and an expansion in plant capacity was completed in 2010. The plant processes gas from production units in the nearby LaBarge gas field. The Shute Creek plant handles among the lowest hydrocarbon content natural gas commercially produced in the world. The raw gas entering Shute Creek contains about 65 per cent CO_2 and 20 per cent methane, as well as nitrogen, hydrogen sulphide, helium and other gases. Carbon dioxide production capacity is 7 Mtpa.

The separated CO_2 is transported from the Shute Creek facility under sales contract via the ExxonMobil, Chevron and Anardarko Petroleum pipeline systems to oil fields in Wyoming and Colorado for use in EOR. Pipeline distance from Shute Creek to the larger volume customers of Salt Creek and Rangely is approximately 460 km and 285 km respectively.

Sleipner CO_2 Storage Project

The Sleipner area gas development is located in the Central North Sea, near the border between the UK and Norway and approximately 240 km west-southwest of Stavanger, Norway. The CO_2 content of the gas stream from the Sleipner West field within the development is in the range of 4-9 per cent, which must be reduced to meet customer requirements.

Since 1991, the Norwegian government has implemented a CO_2 tax on a number of sectors, including offshore petroleum production. The need to process Sleipner West gas to meet market specifications, the CO_2 tax, and a commitment to sustainable energy production, led operator Statoil to capture and store CO_2 in a deep geological formation at Sleipner. Since production began in 1996, the gas has been processed at an offshore platform, and the captured CO_2 compressed and injected from another offshore platform into a sandstone reservoir 250 metres thick at a depth of 800-1,100 metres below sea level. The seal to the reservoir is provided by a 700 metre thick gas-tight caprock. Approximately 0.85 Mtpa of CO_2 is injected.

This development was the world's first demonstration of CCS technology for a deep saline storage reservoir and the first large-scale CCS project to become operational in Europe.

Snøhvit CO_2 Storage Project

Snøhvit is a liquefied natural gas (LNG) development in the Barents Sea offshore northern Norway. Snøhvit Area gas contains 5-8 per cent CO_2 by volume, which will solidify into dry ice under the pressure and temperature conditions of liquefying natural gas. It must therefore be removed before the gas is processed into LNG. LNG-separated CO_2 is typically released to the atmosphere; however, the Norwegian State mandated CCS as a condition of the license to operate for Snøhvit.

The unprocessed raw natural gas stream is transported 143 km to shore and into an LNG plant located at Melkøya, Norway. The CO_2 removal process at the LNG plant is designed to capture 0.7 Mtpa of CO_2 when the facility is at full capacity. A separate pipeline then transports the CO_2 from the LNG plant back to the Snohvit field offshore where it is injected into a geological storage reservoir. Injection of CO_2 started in April 2008.

Century Plant

The Century Plant natural gas processing facility in Texas, US, has the largest CO_2 separation capacity in the world. Located in Pescos County, Century Plant processes high CO_2-content (more than 60 per cent) gas from various fields in West Texas. The CO_2 is then compressed and transported for use in Permian Basin EOR operations elsewhere in Texas.

Construction of the Century Plant facility was completed in two stages – the first stage was on-stream in late 2010, the second became operational in late 2012. Full CO_2 capture capacity is 8.4 Mtpa.

Lost Cabin Gas Plant

The Lost Cabin Gas Plant is a natural gas processing facility in Wyoming, US. It began operation in 1995 and had a number of major expansions in 1998/1999 and 2002. The feed gas contains a high percentage of CO_2 at around 20 per cent.

For much of the plant's history, the captured CO_2 was vented to the atmosphere. However, in 2010 Denbury and ConocoPhillips (owner and operator of the Lost Cabin Gas Plant) entered into an agreement for Denbury to purchase approximately 0.9 Mtpa of CO_2. Denbury would also build compression facilities adjacent to the gas plant and a new 374 km pipeline from the plant to an EOR injection site at the Bell Creek oil field in Montana, US (the Greencore CO_2 pipeline).

ConocoPhillips began CO_2 deliveries in March 2013 and CO_2 injection began in May 2013.

Petrobras Lula Oil Field CCS Project

Petrobras Lula Oil Field CCS Project is located approximately 300 km off the coast of Rio de Janeiro, Brazil. Lula was discovered in 2006 and is one of the largest oil field discoveries in Brazil. The hydrocarbon reservoirs are located in waters that can exceed 2,000 metres in depth. The reservoirs range in depth from 5,000 to 7,000 metres below sea level, under a salt layer that is more than 2,000 metres thick in places. The natural gas stream associated with oil production at Lula also contains CO_2. Application of EOR methods (including CO_2 injection) was considered from the early planning stages of field development.

All production and processing is done at a floating facility on the ocean surface above the oil and gas fields. Large-scale production began in June 2013. The produced oil is offloaded into tankers and transported to shore. Gas processing units onboard the floating facility are designed to separate the CO_2 from the natural gas stream. Once separated, the gas output is transported to an onshore facility by pipeline. The CO_2 is compressed and re-injected into the producing oil and gas reservoir. The ultra-deep waters make the Lula field a pioneer in CO_2-EOR development, with the deepest CO_2 injection well in operation.

Approximately 0.7 Mtpa of CO_2 can be re-injected into the Lula field.

Uthmaniyah CO_2 EOR Demonstration Project

The Uthmaniyah CO_2-EOR Demonstration Project is located in a small area at the Uthmaniyah production unit, which forms part of the giant Ghawar field in Saudi Arabia (the largest oil field on Earth). The project compresses and dehydrates CO_2 from the Hawiyah NGL (natural gas liquids) Recovery Plant, then transports the CO_2 stream 85 km to the injection site within the Uthmaniyah production unit. Around 0.8 Mtpa will be injected for three to five years from commencement of the project, which was in July 2015.

The Kingdom of Saudi Arabia has abundant conventional hydrocarbon reserves and EOR is not likely to be required at production scale for decades to come. However, the Uthmaniyah Demonstration Project has been developed to gain experience with this technique, including determining incremental oil recovery.

CCS on fertiliser production

Nitrogen-based fertilisers are widely used around the world to replace nutrients removed from the soil by crops. Typically, such fertilisers are produced by energy-intensive processes using natural gas as initial feedstock and deriving the required nitrogen from the air. These processes produce a CO_2 stream that is relatively pure, and well-suited for capture. It is important to remember that these process CO_2 emissions cannot be reduced as they are an inherent by-product of the production process. The only way to reduce the emissions from the production process is to make less of the product – in this case, fertiliser. However, these emissions are used in a variety of ways including the manufacture of urea, beverage production, and also for CCS. [9]

Enid Fertilizer CO_2-EOR Project

The Koch Nitrogen Company facility in Enid, Oklahoma, US is one of the largest fertiliser production plants in North America, producing ammonia, liquid fertiliser and urea. The plant was built in 1974 and purchased by Koch Nitrogen in 2003. Plant upgrades were undertaken in 2011 and an expansion commenced in late 2014, with completion expected in 2017.

Since 1982, Chaparral Energy and Merit Energy have sourced around 0.68Mtpa of CO_2 from the Enid Fertiliser plant and transported it 225 km through a pipeline to depleted oil fields in southern Oklahoma for EOR purposes.

Coffeyville Gasification Plant

Coffeyville Resources Nitrogen Fertilizers, LLC, owns and operates a nitrogen fertiliser facility in Coffeyville, Kansas, US. The plant began operation in 2000 and is the only one in North America using a fertiliser production process based on petroleum coke instead of the more typical natural gas. The petroleum coke is generated at an oil refinery adjacent to the plant.

In March 2011, Chaparral Energy announced a long-term agreement for the purchase of CO_2 from the plant for use in EOR operations at their North Burbank Oil Unit in north-eastern Oklahoma. Chaparral Energy undertook the installation of CO_2 compression and dehydration facilities at the fertiliser plant, the laying of a 112 km CO_2 pipeline to the injection site and the construction of facilities for the injection (and recycling) of CO_2 into the oil field.

The compression facility is capable of delivering approximately one Mtpa of CO_2 into the pipeline. Injection of CO_2 into the North Burbank Unit began in June 2013.

[9] (The Fertilizer Institute, 2016)

Alberta Carbon Trunk Line with Agrium CO_2 stream

The Alberta Carbon Trunk Line (ACTL) plans to transport CO_2 from a number of sources in Alberta's Industrial Heartland, northeast of Edmonton, Canada, to oil fields in central Alberta for the purpose of EOR. When at full capacity, the pipeline is designed to transport up to 14.6 Mtpa of CO_2. One of the initial sources of CO_2 for the ACTL is the Agrium fertiliser plant, close to Redwater, Alberta.

The Agrium fertiliser operation at Redwater is the largest in Canada. A CO_2 recovery facility, situated on the boundary of the Agrium plant, is being constructed by Enhance Energy. The mass of CO_2 available for transport will vary depending on the actual outputs from the Agrium plant. When fully operational, the CO_2 recovery facility would provide between 800-1,600 tonnes of CO_2 a day (equivalent to around 300,000 to 600,000 tonnes a year) and reduce process CO_2 emissions by 95 per cent.

CCS on coal gasification

Fossil fuels in solid (such as coal), or liquid forms, and other carbon-rich materials (including biomass) can be gasified, rather than being combusted. Gasification can have several advantages, including the production of fuel that can be transported more easily, burnt more cleanly, and used in a wider range of applications than the original feedstock. The process of gasification is energy-intensive, however.

Coal (or other fuel) gasification initially produces syngas, or synthesis gas – a mixture consisting primarily of hydrogen, carbon monoxide (CO) and CO_2. Syngas can be used as a fuel or chemical feedstock, or it can be further processed to produce synthetic natural gas – methane.

Great Plains Synfuel Plant and Weyburn-Midale Project

The Great Plains Synfuel Plant in North Dakota is the only commercial-scale coal gasification plant in the US that produces synthetic natural gas and other by-products. The plant began operating in 1984. The processes used result in a waste CO_2 stream that is very dry and about 95 per cent pure, so it requires no further processing prior to transport and storage. Since October 2000, around 3 Mtpa of CO_2 has been compressed and transported to oil fields in Canada for EOR. This amounts to around 50 per cent of the annual CO_2 produced at the plant when running at full capacity.

The CO_2 is transported 329 km by pipeline to the Weyburn and Midale Oil Units in Saskatchewan, Canada. At present, approximately 2.4 Mtpa of (new) CO_2 is injected into the Weyburn field and approximately 0.6 Mtpa of (new) CO_2 is injected into the Midale field. The main injection target zones are 1500 metres underground.

The Weyburn-Midale CO_2 Monitoring and Storage Project was conducted alongside CO_2-EOR operations between 2000 and 2011 (at an estimated cost of around CAN$85 million). This research project, supported by the IEA Greenhouse Gas R&D Programme, is considered the largest full-scale CCS field study ever conducted. It included the study of seals that contain the CO_2 reservoir, CO_2 plume movement, and the monitoring of permanent storage.

Kemper County Energy Facility

The Kemper County Energy Facility in Mississippi, US is due to become operational in the second half of 2016. The Integrated Gasification Combined Cycle (IGCC) project comprises two major systems: lignite gasification (including CO_2 capture) and combined-cycle power generation with a peak capacity of 582 MW. Carbon capture will be applied to the syngas produced by the initial coal gasification system. After carbon capture and removal of sulphur and other impurities, the syngas will be used as fuel for combined–cycle power generating units.

The project will capture at least 65 per cent of the carbon dioxide produced, equivalent to approximately 3 Mtpa of CO_2, with resulting carbon emissions comparable to a similarly sized natural gas power plant.[10]

Mississippi Power, the project operator, has built a 98 km CO_2 pipeline from the plant to connect with an existing CO_2 pipeline system near Heidelberg, Mississippi. Denbury Resources has contracted for the majority (70 per cent or around 2 Mtpa) of the CO_2 for use in EOR at its Heidelberg oil field where it will displace CO_2 currently sourced from Jackson Dome (a natural CO_2 reservoir). Captured CO_2 not piped to Heidelberg will be sent to another oil field in the vicinity of West King, Mississippi, using a pipeline collocated with the pipeline to Heidelberg for 87 km before turning to connect with the oil field.

CCS on hydrogen production

Currently, most of the world's hydrogen is used either to produce ammonia as part of fertiliser production; or for converting heavy petroleum components into lighter and more useful products, in oil refineries and other processing facilities. Hydrogen is also used in oil refineries to remove sulphur and other impurities from crude oil and its products.

Hydrogen is often touted as a 'clean fuel', since when it is combusted it does not produce CO_2. At present, global hydrogen production depends heavily on processing fossil fuels including natural gas, oil and coal. The chemical bonds between the hydrogen and carbon in these fuels are broken to produce pure hydrogen, with CO_2 as an unavoidable by-product of the process.

Air Products Steam Methane Reformer EOR Project

Air Products started capturing CO_2 from two hydrogen production units at its Port Arthur, Texas, US, energy refinery in late 2012 and early 2013. When operating at full capacity both units capture a total of approximately 1 Mtpa of CO_2.

The captured CO_2 is transported a total of 158 kilometres through two pipelines to an oil field elsewhere in Texas, where the CO_2 is injected for EOR. The first 21 kilometres of transport is through a dedicated, relatively small diameter pipeline, which then feeds into the much larger diameter Green Pipeline owned and operated by Denbury Resources Inc. The Green Pipeline currently transports CO_2 from four different sources.[11]

Quest

Shell's Quest project is located near Edmonton, Alberta, Canada. Quest was officially launched in November 2015. It is designed to capture and safely store more than one million tonnes of CO_2 each year.

Quest captures the CO_2 produced from three hydrogen production units at the Scotford Upgrader facility, which uses the hydrogen to convert bitumen from the Athabasca Oil Sands Project into synthetic crude oil. The CO_2 is then transported through a 64 km pipeline, and injected more than two km underground into a sandstone rock layer. Sophisticated monitoring technologies will help ensure the CO_2 is permanently and securely stored. Shell is freely sharing knowledge and data derived from Quest to help benefit future CCS projects.

Tomakomai CCS Demonstration Project

Tomakomai is a fully integrated project using carbon capture, compression, transport and geologic storage technology located in Hokkaido, Japan. Since April 2016, CO_2 from a hydrogen production unit in an oil refinery has been captured and purified, before compression and subsequent injection

[10] (Mississippi Power, 2016)
[11] (Denbury Resources Inc., 2016)

into sub-sea geological formations located a few kilometres offshore from the refinery. The project will capture 100,000 tonnes of CO_2 each year for three years. This notable demonstration project will provide important knowledge that will help drive the next phase of development for CCS in Japan.

CCS on iron and steel making

Abu Dhabi CCS Project

The world's first iron and steel project to apply CCS at large-scale is now under construction in the United Arab Emirates (UAE). Phase 1 of the Abu Dhabi CCS Project is the Emirates Steel Industries (ESI) CCS Project. It involves the capture of approximately 0.8 Mtpa of CO_2 from the direct reduced iron (DRI) process used at the ESI plant in Abu Dhabi and transportation of the CO_2 though a 43 km pipeline to the Rumaitha oil field, operated by the ADNOC group, for the purpose of EOR.

Injection of CO_2 is planned to commence in 2016.

4 Conclusion

As this report has highlighted, CCS is the only technology that can achieve deep reductions in CO_2 emissions from high-emitting industrial applications such as natural gas processing and commercial production of chemicals such as nitrogen fertilisers and hydrogen. Global steel and cement industries are also developing CCS for their industrial processes. These important industries are critical to the development of global infrastructure, irrespective of the world's energy technology mix, and currently account for one quarter of global CO_2 emissions.

The technology to capture, transport and permanently store CO_2 from many industrial processes is proven and mature, demonstrated by more than a dozen projects in operation around the world. Commencing in 1972, industrial CCS projects have already collectively captured, transported and permanently stored more than 100 million tonnes of CO_2 during their operational lifespans.

Existing applications of CCS to industrial processes include the production of hydrogen, fertiliser and synthetic natural gas, and the processing of natural gas. The world's first application of CCS to a steelworks is expected to become operational in 2016.

The important role for CCS in decarbonising the industrial sector globally cannot be ignored, and must not be delayed through inaction. More needs to be done by governments and industry, to create a compelling business case for industrial CCS. The time for action is now.

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6 Abbreviations and acronyms

CCS	carbon capture and storage
CO_2	carbon dioxide
EOR	enhanced oil recovery
GHG	greenhouse gas
IEA	International Energy Agency
IEAGHG	IEA Greenhouse Gas R&D Programme
Mt	million tonne/s
Mta	million tonnes a year
SCSS	Scottish Carbon Capture & Storage
TUC	Trade Union Congress
UK	United Kingdom