IEAGHG Information Paper: 2017-IP26; CCUS, Status, Issues and Needs

IEAGHG was invited to participate in an event organised by Resources for the Future Foundation of the USA. For reference, Resources for the Future (RFF) is an independent, nonpartisan organisation that conducts rigorous economic research and analysis to help leaders make better decisions and construct smarter policies about natural resources and the environment[1].

The event entitled ***"The Future of Carbon Capture, Utilization, and Storage (CCUS): Status, Issues, Needs"*** was designed to inform members of the new US administration on the status of CCUS.

The GM presented in two sections; the Opening Plenary and in Panel Session 3 - Lessons Learnt from Completed Projects. The preceding presentation in this panel outlined the achievements to date the NRG Parish CCS demonstration project. The GM's presentation aimed to build on the NRG one by presenting a summary of achievements from key CCS demonstration projects around the world.

An event summary has been produced by RFF, which is appended for members' reference.

A more detailed summary including a web cast of the meeting and links to all the presentations given can be found at:

http://www.rff.org/events/event/2017-05/future-carbon-capture-utilization-and-storage-ccus-status-issues-needs

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[1] http://www.rff.org/about

Carbon Capture, Utilization, and Storage (CCUS): Status, Issues, Needs

Summary of May 24, 2017 event hosted by Resources for the Future

According to the International Energy Agency the overall costs to keep CO_2 emissions low enough to limit future warming to the international goal of 2°C would be much higher (by about 140%) if more cost effective carbon capture and storage (CCS) technology is not available. [1]

The world has been storing large quantities of carbon dioxide underground for over 20 years in the North Sea and for over forty years via enhanced oil recovery (EOR) in Texas and New Mexico. Twenty-seven large-scale CCS projects are in operation or under construction globally with the US having the most projects in number and volume. CCS technology is proven. Experience in operational projects, such as the 16 year long Weyburn project in Canada, have demonstrated the security of CO_2 storage underground. The U.S. and the world have many decades' worth of geological storage capacity for CO_2 in depleted oil reservoirs and other deep geological formations.

Although the technologies are proven, implementing new projects requires detailed geologic storage characterizations. Significant reductions in capture costs are anticipated with the learning that comes from additional projects. In addition, government policy can provide direct incentives (e.g., through R&D spending to fuel further innovation and pilot testing of advanced capture technologies) or incentives through the policy itself. Bills have been introduced in Congress that will provide effective financial support for more deployment (tax credits, private activity bonds, etc.). Government support for development of CO_2 pipelines would also help facilitate carbon capture and bring CO_2 to oil fields where it can be used for EOR. Unless significant regulatory incentives to reduce carbon dioxide emissions are in place, government support will still be needed to help drive down costs, finance Investment in CO_2 transportation structure and prove the capability of particular storage resources.

Converting captured CO_2 into long-lived marketable products is in its early stages, with the Department of Energy (DOE) supporting a number of research projects and new technologies. Successes here will reduce the amount of CO_2 that needs to be sequestered, but because most of the applications being studied will take years to mature and markets are unlikely to be large enough to utilize all the CO_2 being produced, progress is needed on CCS.

In short, as Dr. Julio Friedmann (Lawrence Livermore National Laboratory) said: (a) CCS is versatile and can be used for industrial emissions and power generation; (b) experience to date indicates that it can be affordable; (c) under the right circumstances it can be profitable; (d) CCS can save communities with fossil fuel fired power plants; (e) the U.S. has the potential to be the world's prime export source of CCS experience and technology; and (f) the world needs CCS (according to the International Energy Agency and others) to achieve climate change goals in the least cost fashion.

Capturing CO_2, Dr. Ed Rubin, Carnegie Mellon University; Lynn Brickett, National Energy Technology Laboratory

[1] The term CCUS, carbon capture utilization and storage, is also used in cases where utilization of CO_2, such as for enhanced oil recovery (EOR), can reduce the overall cost of capture and storage.

There are many ways to separate and capture CO_2 from gases resulting from power plants or industrial processes like ethanol or steel manufacture. They include absorption, adsorption, cryogenics, membranes and microbial/algal systems. The three most common current approaches for power plants are post-combustion CO_2 capture, being used at Sask Power's Boundary Dam power plant in Canada and NRG Energy's Petra Nova power plant in Texas; oxy-combustion CO_2 capture, demonstrated at large pilot plants such as Vattenfall's Schwarze Pumpe Station in Germany; and pre-combustion CO_2 capture, widely deployed commercially for capture in industry today and to be used in the Kemper Power Plant in Mississippi. While significant commercial experience with carbon capture exists in certain industrial sectors, too few facilities have been built and tested in the power sector to have resulted in enough learning by doing to bring costs down significantly. Thus, new plants using current CCS technology are estimated to cause increases in electricity generation cost varying from about $20-$50/MW-hr. (2013$) for a natural gas combined cycle(NGCC) plant to $30-$70/MW-hr. for a supercritical pulverized coal (SCPC) plant, with the added cost for an integrated gasification combined cycle (IGCC) plant being midway between those values. In all cases, the cost of capture (including compression) accounts for the major portion (approximately 80%) of this cost, with the remainder due to transport and storage costs based on deep geological storage. The corresponding costs per metric ton of CO_2 emissions avoided for the three different technologies are estimated to range from approximately $60 to $140 for NGCC, $50 to $100 for SCPC and $40-$80 for IGCC relative to the same plant type without CCS. As before, the capture system accounts for the major portion of these costs. In all cases, the overall cost of CCS can be reduced significantly if the captured CO_2 is sold for use in EOR (with the magnitude of savings dependent on the prevailing oil price).

The participants expect that second generation technologies will improve CCS economics, and could have 25-30% lower capital cost and 20-30% lower operating costs if current R&D goals are met. But these would not be ready for use at scale until 2025. Since capture accounts for most of total CCS cost, this is where substantial efforts are needed and are underway at DOE and elsewhere. Fortunately, there are many ideas in various stages of development that may reduce capture costs such as using membranes, fuel cells, solid sorbents, biomass co-firing, ionic liquids and advanced, more efficient power plant designs. Hybrid approaches where two different capture technologies are used in sequence need to be evaluated as they may be a cheaper approach to CO_2 capture. One conclusion from the foregoing is that strong policy drivers that create markets for CCS would help to spur innovations that significantly reduce the cost of capture.

Transporting and Storing CO_2; Enhanced Oil Recovery, Dr. Julio Friedmann, Lawrence Livermore National Laboratory; Daniel Kim, Occidental Petroleum

The domestic geological potential for storing CO_2 both onshore and offshore is enormous, equaling a hundred years of current emissions or more. The CO_2 can be stored in formations indefinitely – these formations lie much deeper than the roughly 1,000-foot depth of potable water resources (commonly a mile deep or more). Such formations can be ones from which oil has been produced or saline formations. The largest and longest offshore storage of CO_2 has been in saline storage in the Sleipner field off Norway for 20 years. The longest onshore EOR project has been the SACROC project in West Texas for over 40 years and the largest onshore EOR project, with 7 million tons of CO_2 per year used in EOR or stored, is the Shute Creek operation in Wyoming.

We have a good understanding of mechanisms of pore scale CO_2 displacements and other aspects of long term storage such as secondary trapping mechanisms, saline formations, site characterization and geomechanical effects. These provide high confidence to assure safe storage indefinitely. Because each site is somewhat different, detailed evaluation of the relevant formations will be required to identify potential risks to manage, such as potentially transmissive faults or induced seismicity. Monitoring technologies are well understood from decades of use, and can help to confirm the absence of leaks and assist in management of risks.

Transportation of CO_2 via pipelines in the U.S. is not significantly different than transporting oil, gas or natural gas liquids, all of which are currently regulated by the U.S. Department of Transportation. Over 5,000 miles of CO_2 pipelines operate today in the U.S., and over their 40-year history have an outstanding safety record with zero associated fatalities from CO_2 release. Pipeline pressures can be higher because the CO_2 is transported in a dense phase liquid state to sites where it is stored. Most CO_2 pipelines operate under a standard which requires low water content and low concentrations of H_2S.

Currently, one type of CO_2 storage common in North America is CO_2-EOR, a process that has been used for over forty years, particularly in West Texas and New Mexico. The CO_2 is pumped down into existing mature oil fields to the oil bearing formation and then, often in conjunction with injected water it mobilizes remaining oil which is recovered at the production wellbore. Much of the injected CO_2 remains in the reservoir; that which does return to the surface with the produced oil is recovered and reinjected creating a closed-loop system that results in safe and permanent geologic storage of the CO_2 purchased and used by the oil industry. Currently about 65 million tons of CO_2 (mostly from natural sources with the rest from industrial and power plants) are used annually for EOR in over 5,000 wells. Larger companies like Occidental Petroleum and smaller ones like Denbury Resources are active EOR operators. Under the Greenhouse Gas Reporting Program, EPA allows companies to receive credit for carbon stored via CO_2-EOR by reporting data on CO_2 injected and stored (mass balance) in the oil field and implementing a measurement, reporting and verification plan. The participants indicated that leakage of injected CO_2 (outside the reservoir) has not been observed in over 40 years of practice.

Lessons Learned from Completed Projects, David Greeson, NRG Energy; John Gale, IEA Greenhouse Gas Programme

CCS technology is proven and in use around the world. Twenty-seven large-scale CCS projects are in operation or under construction globally (See attached list) of which 13 are in the United States. If this continues, the U.S. can be the world's resource for CCS technology and relevant suppliers of goods and services. The current global CO_2 capture capacity is about 40 M tons per year, which is a tiny fraction of the 36 billion tons per year of CO_2 emitted around the globe from fossil and industrial sources.

NRG Energy's Petra Nova project near Houston, Texas was completed **on time and on budget**, capturing 90% of the CO_2 from a 240 MWe slipstream of flue gas from a 640MW coal-fired power unit. The CO_2 is used in an enhanced oil recovery project specifically designed for the amount of CO_2 being captured at the power plant (see photo attached). One challenge for retrofitting existing plants with CCS is the additional steam and electricity required for use by the CCS facilities. In the Petra Nova project, steam and electricity is provided by a highly efficient and built for purpose natural gas-powered cogeneration plant - effectively reducing the parasitic energy needed by over 30% vs extracting that energy from the host coal unit.

Significant progress has been made on CCS demonstration project deployment. Most of the projects required government financial support, although some involving industrial emissions did not. The early projects have identified cost reductions for next build plants. In this area, as with most new technologies, costs are reduced through R&D and learning from experience with multiple projects. To date multiple business models have been utilized with no single one being applicable to all situations. Unless a significant regulatory limit on carbon dioxide emissions is enacted, government support will still be needed to help drive down costs, finance investment in CO_2 transportation infrastructure, and prove the capability of particular storage resources.

Other CO_2 Utilization Possibilities, Daniel Matuszak, Department of Energy

Captured CO_2 can be converted to other marketable products, which themselves have varying sequestration possibilities. Some such products, like long-lived building products, can essentially sequester the CO_2 permanently while others, like dry ice or carbonated beverages, do not. DOE has supported a range of technologies that convert CO_2 to chemicals and solid products, and some such technologies transitioned to commercial operation (e.g. Novomer and Skyonic). Recently DOE is supporting early stage research to develop technologies that use biological or mineralization-based concepts or novel physical and chemical processes, which aim to generate economic value while having a lower carbon footprint relative to existing approaches. Recent projects selected by DOE include direct electron beam synthesis to create chemical products, using microalgae to convert CO_2 to bioplastics, and CO_2-negative construction materials via industrial waste re-processing and power plant heat integration. Unfortunately, although successes here will reduce the amount of CO_2 that needs to be sequestered, most processes will take years to mature and markets are unlikely to be large enough to utilize all the CO_2 being produced. Hence, sequestration in storage projects will be necessary as well to meet climate goals.

Major US Policy Issues and Needs, Michael Moore, North American Carbon Capture Association; Brad Crabtree, Great Plains Institute

Fossil fuels will be needed for the foreseeable future in transportation, power, building heating and industry, both in the U.S. and abroad. However, as a result of the Paris Accord and the pledge to decarbonize all fossil fuels by 2050, activities by many investment funds, demonstrations and opposition from the "Keep it in the Ground" movement and others, there is increasing public pressure on users of fossil energy to reduce their use. Thus, CCUS/CCS matters significantly for the U.S. and other countries with significant fossil fuel resources by providing a way to decarbonize consumed fossil fuels while taking advantage of low cost and abundant fossil fuels. A desirable U.S. path forward is to provide policy parity for low carbon fuels, which include fossil energy complemented by CCS.

Environmental and energy policy NGOs, unions, project developers, industrial suppliers of CO_2, technology vendors, ethanol producers, electric utilities, oil and gas producers, coal companies and others are jointly urging and supporting federal financial support for CCS. They support legislation which increases the financial certainty for carbon capture project investors; increases the credit value for EOR and other geologic storage; expands industrial participation in CCS; and enhances flexibility in utilization of the tax credit to allow multiple business models. S 3179 and HR 4622 in the prior Congress satisfied these principles; they were both sponsored by a significant bi-partisan number of members. Each will be re-proposed in this Congress. In addition, bills to make CCS projects eligible for private activity bonds have been proposed on a bi-partisan basis in both houses. Bi-partisan sponsored legislation was introduced in the past two Congresses to allow CCS facilities to qualify for the Master Limited Partnership structure. Some groups have also requested the President to include several identified carbon capture projects as part of any major infrastructure effort.

There is growing state support for CCS and CO_2-EOR. There is also a 16 state CO_2-EOR bipartisan work group, which is helping state policy makers better understand states' potential for CCS and recommending policies for states and the federal government. The group urged the Trump Administration and Congress in February to make pipelines a priority component of a broader national infrastructure agenda.

Large Scale CCS Projects Around the World as Reported by the Global CCS Institute

Project name	Location	Operation date	Industry	Capture type	Capture capacity (Mtpa)	Transport type	Primary storage type	Stage
Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants)	**United States**	**1972**	**Natural Gas Processing**	**Pre-combustion capture (natural gas processing)**	**0.4 - 0.5**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Enid Fertilizer CO_2-EOR Project	**United States**	**1982**	**Fertilizer Production**	**Industrial Separation**	**0.7**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Shute Creek Gas Processing Facility	**United States**	**1986**	**Natural Gas Processing**	**Pre-combustion capture (natural gas processing)**	**7**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Sleipner CO_2 Storage Project	Norway	1996	Natural Gas Processing	Pre-combustion capture (natural gas processing)	1	No transport required (direct injection)	Dedicated Geological Storage	Operate
Great Plains Synfuels Plant and Weyburn-Midale Project	Canada	2000	Synthetic Natural Gas	Pre-combustion capture (gasification)	3	Pipeline	Enhanced oil recovery	Operate
Core Energy/South Chester Gas Processing Plant	**United States**	**2003**	**Natural Gas Processing**	**Pre-combustion capture (natural gas processing)**	**0.4**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Snøhvit CO_2 Storage Project	Norway	2008	Natural Gas Processing	Pre-combustion capture (natural gas processing)	0.7	Pipeline	Dedicated Geological Storage	Operate
Chaparral/Conestoga Energy Partners' Arkalon Bioethanol Plant	**United States**	**2009**	**Ethanol Production**	**Dehydration and compression from fermentation.**	**0.17**	**Pipeline**	**Enhanced Oil Recovery**	**Operate**
Century Plant	**United States**	**2010**	**Natural Gas Processing**	**Pre-combustion capture (natural gas processing)**	**8.4**	**Pipeline**	**Enhanced oil recovery**	**Operate**

Conestoga Energy Partners/PetroSantander Bonanza Bioethanol Plant in Kansas	**United States**	**2012**	**Ethanol Production**	**Dehydration and compression from fermentation.**	**0.1**	**Pipeline**	**Enhanced Oil Recovery**	**Operate**
Air Products Steam Methane Reformer EOR Project	**United States**	**2013**	**Hydrogen Production**	**Industrial Separation**	**1**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Coffeyville Gasification Plant	**United States**	**2013**	**Fertilizer Production**	**Industrial Separation**	**1**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Lost Cabin Gas Plant	**United States**	**2013**	**Natural Gas Processing**	**Pre-combustion capture (natural gas processing)**	**0.9**	**Pipeline**	**Enhanced oil recovery**	**Operate**
Petrobras Santos Basin Pre-Salt Oil Field CCS Project	Brazil	2013	Natural Gas Processing	Pre-combustion capture (natural gas processing)	1	No transport required (direct injection)	Enhanced oil recovery	Operate
Boundary Dam Carbon Capture and Storage Project	Canada	2014	Power Generation	Post-combustion capture	1	Pipeline	Enhanced oil recovery	Operate
Quest	Canada	2015	Hydrogen Production	Industrial Separation	1	Pipeline	Dedicated Geological Storage	Operate
Uthmaniyah CO_2-EOR Demonstration Project	Saudi Arabia	2015	Natural Gas Processing	Pre-combustion capture (natural gas processing)	0.8	Pipeline	Enhanced oil recovery	Operate
Abu Dhabi CCS Project (Phase 1 being Emirates Steel Industries (ESI) CCS Project)	United Arab Emirates	2016	Iron and Steel Production	Industrial Separation	0.8	Pipeline	Enhanced oil recovery	Operate
Illinois Industrial Carbon Capture and Storage Project	**United States**	**2017**	**Chemical Production**	**Industrial Separation**	**1**	**Pipeline**	**Dedicated Geological Storage**	**Operate**
Petra Nova Carbon Capture Project	**United States**	**2017**	**Power Generation**	**Post-combustion capture**	**1.4**	**Pipeline**	**Enhanced oil recovery**	**Operate**

Gorgon Carbon Dioxide Injection Project	Australia	2017	Natural Gas Processing	Pre-combustion capture (natural gas processing)	3.4 - 4.0	Pipeline	Dedicated Geological Storage	Execute
Kemper County Energy Facility	**United States**	**2017**	**Power Generation**	**Pre-combustion capture (gasification)**	**3**	**Pipeline**	**Enhanced oil recovery**	**Execute**
Alberta Carbon Trunk Line ("ACTL") with Agrium CO_2 Stream	Canada	2018	Fertilizer Production	Industrial Separation	0.3 - 0.6	Pipeline	Enhanced oil recovery	Execute
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO_2 Stream	Canada	2018	Oil Refining	Industrial Separation	1.2 - 1.4	Pipeline	Enhanced oil recovery	Execute
Yanchang Integrated Carbon Capture and Storage Demonstration Project	China	2018	Chemical Production	Pre-combustion capture (gasification)	0.4	Combinati on	Enhanced oil recovery	Execute
Tomakomai Carbon Capture and Storage Demonstration Project	Japan	2017	Hydrogen Production (Oil Refining)	Industrial Separation	0.1	No transport required direct injection	Dedicated geological storage	Operate
Osaki CoolGen Project	Japan	2019	Power Generation	Pre Combustion Capture (Gasification)	1	No transport involved	Storage not involved	Execute

Note: Three U.S. projects, Core Energy/South Chester, Chaparral/Conestoga Energy Partners, and Conestoga Energy Partners/Petro Santander, were identified by Great Plains Institute and added at their suggestion.

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