MEETING THE
DUAL CHALLENGE

A Roadmap to At-Scale Deployment of
CARBON CAPTURE, USE, AND STORAGE

APPENDIX C –
CCUS PROJECT SUMMARIES

A Report of the National Petroleum Council
December 2019

This appendix was last updated on
March 12, 2021

Appendix C

CCUS PROJECT SUMMARIES

I. CCUS LARGE-SCALE FULL-VALUE CHAIN PROJECTS

As of October 2019, there were 19 large-scale carbon capture, use, and storage (CCUS) projects operating around the world, with a total capacity of about ~32 million tonnes (Mt) of CO_2 per year.[1] Ten of these projects are in the United States, with a total storage capacity of about ~25 Mt per year. The other nine are located around the world, in Canada (2), Brazil (1), Norway (2), Saudi Arabia (1), United Arab Emirates (UAE) (Abu Dhabi) (1), China (1), and Australia (1). In addition, there were two Alberta Carbon Trunk Line (ACTL) projects under construction and expected to be operating by year-end 2019. Those projects are also included here for information in anticipation of their near-term start-up.

1 Large-scale projects are defined as those integrated projects that store at least 80,000 tonnes of CO_2 per year from a coal-based facility or at least 400,000 tonnes of CO_2 per year from other sources.

Figure C-1. *Map of Top 10 U.S. Full-Value Chain Projects*

The next two sections of this appendix provide summary information on each of these 21 CCUS projects.

A. Top 10 U.S. CCUS Value Chain Projects (in order of operational date)

The 10 large-scale CCUS projects located in the United States include:

- Terrell Natural Gas Processing
- Enid Fertilizer
- Shute Creek Gas Plant
- Great Plains Synfuel
- Century Plant
- Air Products SMR
- Coffeyville Gasification
- Lost Cabin Gas Plant
- Illinois Industrial CCS
- Petra Nova (WA Parish).

These 10 projects have a total storage capacity of about ~25 Mt per year, representing ~80% of global capacity. They span a range of CCUS supply chains from multiple industries, including natural gas processing (~17 million tonnes per annum [Mtpa]), synthetic natural gas production (~3 Mtpa), fertilizer production (~2 Mtpa), coal-fired power generation (~1 Mtpa), hydrogen production (~1 Mtpa), and ethanol production (~1 Mtpa). The Global CCS Institute estimates that these U.S. projects have captured and stored approximately 160 Mt of CO_2.

A map showing the location of each project across the United States is provided in Figure C-1. Individual summary descriptions of each project are provided in the tables that follow.

Terrell Natural Gas Processing, Fort Stockton, Texas	
Operator	Occidental Petroleum
Start Date	1972
Size	0.5 Mtpa
CO_2 Source	Natural gas processing
Transportation	220-mile Val Verde pipeline
Oil Field EOR Storage Site	Fields in West Texas Permian Basin
Key Highlights	The Terrell natural gas processing facility is the oldest operating industrial CCS project in the United States. The Terrell facility processes methane that contains between 18% to 53% of CO_2. This CO_2 must be removed from the methane to meet pipeline specifications. Since 1972, the plant has supplied CO_2 for enhanced oil recovery operations via a 220-mile pipeline linking the facility to a network of CO_2 pipelines in the Permian Basin.
References	Global CCS Institute Facilities Database, https://co2re.co/FacilityData. Occidental communication with NPC CCUS Study, 2019.

Enid Fertilizer, Oklahoma	
Operator	Koch Nitrogen Company
Start Date	1982
Size	0.7 Mtpa
CO_2 Source	Koch Nitrogen's Enid Fertilizer Plant
Transportation	120-mile pipeline
Oil Field EOR Storage Site	Northeast Purdy and the Brady Unit of the composite Golden Trend Field, as well as the Sko-Vel-Tum field, both south of Oklahoma City
Key Highlights	ARCO began EOR in a portion of the Sho-Vel-Tum field in 1982 and expanded in 1998. CO_2 from Enid Fertilizer has been used since 2003, when Koch Nitrogen Company bought the Enid facility. Operations were expanded in 2010.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/enid_fertilizer.html. Vandewater, Bob. "ARCO hunts hard-to-get state oil with gas injection," *The Oklahoman*, June 6, 1982, https://oklahoman.com/article/1986087/arco-hunts-hard-to-get-state-oil-with-gas-injection.

Shute Creek Gas Plant, La Barge, Wyoming	
Operator	ExxonMobil
Start Date	1986
Size	7 Mtpa
CO_2 Source	Natural gas stream from fields in Wyoming, including LaBarge field
Transportation	142-mile pipeline
Oil Field EOR Storage Site	A series of fields in Wyoming, Colorado, and Montana
Key Highlights	Production of natural gas from LaBarge field began in 1986, which is processed at the Shute Creek Treating facility, where it is separated into CO_2, methane, and helium for sale and removing hydrogen sulfide for disposal. A concentrated acid gas stream of about 60% hydrogen sulfide and 40% CO_2 is injected into a section of the same reservoir from which it was produced, safely disposing of the hydrogen sulfide and CO_2. In 2008, an expansion of the CO_2 capture facility brought the capacity up to 7 Mtpa.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/la_barge.html. Gearino, Jeff. "ExxonMobil reduces emissions in Wyo, sends more CO_2 for oil production," *Billings Gazette*, December 15, 2010, https://billingsgazette.com/news/state-and-regional/wyoming/exxonmobil-reduces-emissions-in-wyo-sends-more-co-for-oil/article_96837618-aa96-5465-aedf-fe431fc0e161.html. U.S. Environmental Protection Agency. "ExxonMobil Shute Creek Treating Facility SubPart RR Monitoring, Reporting and Verification Plan," February 2018, https://www.epa.gov/sites/production/files/2018-06/documents/shutecreekmrvplan.pdf.

Great Plains Synfuels Plant, Beulah, North Dakota	
Operator	Dakota Gasification Company
Start Date	2000
Size	3 Mtpa
CO_2 Source	Coal gasification
Transportation	205-mile pipeline across border into Saskatchewan, Canada
Oil Field EOR Storage Site	Weyburn and Midale Fields in Saskatchewan for EOR and CO_2 storage
Key Highlights	The Synfuels Plant produces methane by gasification of a low-quality coal called lignite. The plant captures more CO_2 from coal conversion than any facility in the world. Dakota Gas captures about two-thirds of the readily available CO_2 when running at full rates. Since 2000, CO_2 emissions at the Synfuels Plant have been reduced by about 45%. The plant has captured and transported nearly 38 Mt of CO_2 for geologic sequestration since 2000.
References	Dakota Gasification Company website, CO_2 Capture and Storage page, https://www.dakotagas.com/about-us/co2-capture-and-storage. Basin Electric Power Conservative website, https://basinelectric.com/sites/CMS/files/files/pdf/Fact-Sheets-Media-Kit/DGC-fact-sheet-8-19.pdf.

Century Plant, Pecos County, Texas	
Operator	Occidental Petroleum
Start Date	2010
Size	8.4 Mtpa
CO_2 Source	Natural gas processing
Transportation	100-mile pipeline
Oil Field EOR Storage Site	Permian Basin Fields
Key Highlights	Century Plant gas processing facility is the largest single industrial source CO_2 capture facility in North America. It processes natural gas from nearby fields in the Val Verde sub-basin that contain up to 65% CO_2. Since 2010, the plant has supplied CO_2 for enhanced oil recovery operations via a 100-mile pipeline linking the facility to the CO_2 distribution hub in Denver City, Texas. The plant was designed in 2008 with a maximum capacity of 5 Mtpa and brought online in 2010. An expansion in 2012 increased capacity to 8.4 Mtpa.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database http://sequestration.mit.edu/tools/projects/century_plant.html Occidental communication with NPC CCUS Study, 2019.

Air Products SMR, Port Arthur, Texas	
Operator	Air Products
Start Date	2013
Size	1.0 Mtpa
CO_2 Source	Existing steam-methane reformers
Transportation	13-mile pipeline
Oil Field EOR Storage Site	EOR in West Hastings and Oyster Bayou oil fields, Texas
Key Highlights	CO_2 capture units were retrofitted to Air Product's two steam methane reformers located within the Valero Port Arthur refinery. This is the first-ever commercial-scale steam methane reformer (SMR) hydrogen production facility incorporating vacuum-swing adsorption carbon capture gas separation technology.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/port_arthur.html. Carolyn Preston, "The Carbon Capture Project at Air Products' Port Arthur Hydrogen Production Facility,"14th Greenhouse Gas Control Technologies Conference, Melbourne 21-26 October 2018, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3365795.

Coffeyville Gasification, Kansas	
Operator	Coffeyville Resources
Start Date	2013
Size	1.0 Mtpa
CO_2 Source	Fertilizer
Transportation	68-mile pipeline
Oil Field EOR Storage Site	North Burbank Unit in Osage County, Oklahoma
Key Highlights	The Coffeyville Resources Nitrogen Fertilizer plant was built in 2000 by Farmland Industries. It uses a petroleum coke gasification process to produce hydrogen for use in the manufacture of ammonia for fertilizer. The CO_2 is separated from the hydrogen through pressure swing adsorption, which originally was either used for urea synthesis or vented to the atmosphere. Since 2013 the plant has been delivering compressed CO_2 to the North Burbank Oil Unit for enhanced oil recovery.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/coffeyville.html.

Lost Cabin Gas Plant, Fremont County, Wyoming	
Operator	ConocoPhillips
Start Date	2013
Size	0.9 Mtpa
CO_2 Source	Lost Cabin natural gas processing facility
Transportation	232-mile Denbury pipeline
Oil Field EOR Storage Site	Denbury's Belle Creek oil field in Montana
Key Highlights	In 2010, Denbury acquired the Bell Creek field with the intention of rejuvenating the once robust field by switching from water to CO_2 injection. The injection site is the Bell Creek integrated CO_2 EOR and Storage Project, a collaboration between Denbury and the Plains CO_2 storage associated with a commercial scale EOR operation. To date the CO_2 EOR operations have injected more than 10 Mt of CO_2. Denbury is currently extending the pipeline another 110 miles northeastward into Montana to commence EOR.
References	Bleizeffer, Dustin. "Deep into Wyoming," *Casper Star Tribune*, March 9, 2003, https://trib.com/business/deep-into-wyoming/article_c1b3467a-4853-53dc-8e83-ba5351679f73.html. Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/lost_cabin.html.

Illinois Industrial CCS (ADM), Decatur, Illinois	
Operator	Archer Daniels Midland
Start Date	2017
Size	1.1 Mtpa
CO_2 Source	Ethanol production
Transportation	2-mile pipeline
Geologic Storage Site	Geological storage – Mount Simon sandstone
Key Highlights	The ADM agricultural processing and biofuels complex produces a highly concentrated stream of CO_2 from the ethanol fermentation process is captured, dehydrated, compressed and injected into the Mount Simon Sandstone reservoir adjacent to facility. This project is the only saline reservoir carbon storage project in the United States. The project has stored about 2 Mt since injection began in April 2017.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/illinois_industrial_ccs.html.

Petra Nova (WA Parish), Houston, Texas	
Operator	NRG Energy
Start Date	2017
Size	1.4 Mtpa
CO_2 Source	Coal-fired power generation
Transportation	80-mile pipeline
Oil Field EOR Storage Site	Hilcorp Energy's West Ranch Oilfield
Key Highlights	Petra Nova is the world's largest operational post-combustion CO_2 capture facility and the first commercial-scale power sector CCS project in the U.S. It is the first instance of an independent power producer (NRG) investing in all parts of the CCS value chain. The project captures CO_2 using technology from Mitsubishi Heavy Industries America on a 240-megawatt slipstream of flue gas from WA Parish Unit 8. Within 10 months of operational startup in January 2017, the plant has captured more than 1 Mt of CO_2 and boosted oil production by 1,300%.
References	Howard Herzog. Carbon Capture and Sequestration Technologies Program, MIT, CCS Project Database, http://sequestration.mit.edu/tools/projects/wa_parish.html. NRG website. Petra Nova: Carbon capture and the future of coal power case study, https://www.nrg.com/case-studies/petra-nova.html. Armpriester, Anthony. W.A. Parish Post Combustion CO_2 Capture and Sequestration Project Final Public Design Report. United States: N.p., 2017, https://www.osti.gov/servlets/purl/1344080. The Shand CCS Feasibility Study Public Report, https://ccsknowledge.com/pub/documents/publications/Shand%20CCS%20Feasibility%20Study%20Public%20_Full%20Report_NOV2018.pdf.

B. Major International CCUS Value Chain Projects (in order of operational date)

The nine large-scale CCUS projects operating worldwide (outside the United States) as of October 2019 include:

- Sleipner CO_2 storage project, Norway (offshore)
- Snøhvit CCS project, Norway (offshore)
- Petrobras Santos Basin EOR Project, Brazil (offshore)
- Boundary Dam Coal-Fired Power and CCS Project, Canada
- Quest Project, Canada
- Uthmaniyah Project, Saudi Arabia
- Emirates Steel CCS Project, United Arab Emirates
- Jilin Oil Field CO_2 EOR Project, China
- Gorgon LNG and CCS Project, Australia.

Two new large-scale CCUS projects are expected to start up by end of 2019, both in Canada and associated with the Alberta CO_2 Carbon Trunk Line. Project summaries of these two projects are also included below in anticipation of their existence by the time this report is published:

1. Alberta Carbon Trunk Line with Sturgeon Refinery CO_2 Stream, Canada
2. Alberta Carbon Trunk Line with Agrim CO_2 stream, Canada

Individual summary descriptions of each project follow.

Sleipner CO_2 Storage, Offshore North Sea, Norway	
Operator	Statoil
Start Date	1996
Size	1 Mtpa
CO_2 Source	Natural gas processing
Geologic Storage Site	Utsira saline formation
Key Highlights	Sleipner is the world's first offshore CCS facility. CO_2 from the nearby Alfa Nord and Gudrun fields is also separated here.
References	Scottish Carbon Capture & Storage, Global CCS Map, http://www.sccs.org.uk/expertise/global-ccs-map.

Snøhvit, Norway	
Operator	Equinor
Start Date	2008
Size	0.7 Mtpa
CO_2 Source	Natural gas – LNG facility on the island of Melkøya
Geologic Storage Site	Snøhvit field offshore
Key Highlights	The Snøhvit CO_2 storage facilities form part of the development of gas fields in the Barents Sea, offshore Norway. The CO_2 is captured at an LNG facility on the island of Melkøya, northern Norway, where the offshore sourced gas stream is processed. The captured CO_2 is transported via pipeline back to the Snøhvit field offshore where it is injected into an offshore storage reservoir, more than 4 million tonnes of CO_2 has been stored to date since 2008.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

Petrobras Santos Basin Pre-Salt Oil Field, Brazil	
Operator	Petrobras
Start Date	2013
Size	1 to 3 Mtpa
CO_2 Source	Natural gas
Oil Field EOR Storage Site	Lula, Sapinhoa, and Lapa fields
Key Highlights	Ten CO_2 separation and injection systems aboard floating production, storage, and offloading vessels anchored in the Santos Basin, off the coast of Rio de Janeiro. This is the first application of CO_2 EOR in an offshore oil field.
References	Oil and Gas Climate Initiative, 2019 Annual Report, https://oilandgasclimateinitiative.com/policy-and-strategy/#annual-report.

Boundary Dam, Saskatchewan, Canada	
Operator	SaskPower (owned by Government of Saskatchewan)
Start Date	2014
Size	1 Mtpa
CO_2 Source	Coal-fired power
Oil Field EOR Storage Site	Weyburn Oil Unit
Key Highlights	It is the world's first post-combustion CO_2 capture process on a coal power plant at Boundary Dam Unit 3. CO_2 sold to Cenovus for use in EOR. Unit 3 at the Boundary Dam coal-fired power station completed a refurbishment program in October 2014 that included retrofitting CO_2 capture facilities with a capture capacity of approximately 1 Mtpa of CO_2. The majority of the captured CO_2 is transported via pipeline and used for enhanced oil recovery at the Weyburn Oil Unit, also in Saskatchewan. A portion of the captured CO_2 is transported via pipeline to the nearby Aquistore Project for dedicated geological storage.
References	Sask Power. "2030 Emission Reduction Goal Progressing," news release July 9, 2018, https://www.saskpower.com/about-us/media-information/news-releases/2030-emission-reduction-goal-progressing. Scottish Carbon Capture & Storage, Global CCS Map, http://www.sccs.org.uk/expertise/global-ccs-map. Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

Quest, Fort Saskatchewan, Alberta, Canada	
Operator	Athabasca Oil Sands Project – JV between Canadian Natural Resources (70%), Chevron (20%), Shell (10%) and Operator.
Start Date	2015
Size	1 Mtpa
CO_2 Source	Process gas streams from hydrogen manufacturing units
Geologic Storage Site	Basal Cambrian Sands saline formation
Key Highlights	Quest is the world's first oil sands CCS project. It captures and stores about one third of the CO_2 emissions from the Shell-operated Scotford Upgrader which turns oil sands bitumen into synthetic crude that can be refined into fuel and other products.
References	Scottish Carbon Capture & Storage, Global CCS Map, http://www.sccs.org.uk/expertise/global-ccs-map. Shell communication with NPC CCUS Study, 2019.

Uthmaniyah, Saudi Arabia	
Operator	Saudi Aramco
Start Date	2015
Size	0.8 Mtpa
CO_2 Source	Natural gas
Oil Field EOR Storage Site	Ghawar oil field
Key Highlights	Uthmaniyah CO_2 – EOR Demonstration compresses and dehydrates CO_2 from the Hawiyah NGL natural gas liquids recovery plant in the Eastern Province of the Kingdom of Saudi Arabia. The captured CO_2 is transported via pipeline to the injection site in Ghawar oil field a small flooded area in the Uthmaniyah production unit for enhanced oil recovery.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

Abu Dhabi CCS – Emirates Steel Industries, UAE	
Operator	ADNOC
Start Date	2016
Size	0.8 Mtpa
CO_2 Source	Steel production
Oil Field EOR Storage Site	Various ADNOC oil reservoirs
Description	Abu Dhabi CCS is the world's first fully commercial CCS facility in the iron and steel industry and involves the capture of CO_2 via a new build CO_2 Compression Facility using high purity CO_2 produced as a by-product of the direct reduced iron-making process at the Emirates Steel Industries factory in Mussafah. The captured CO_2 is transported via pipeline to Abu Dhabi National Oil Company ADNOC oil reservoirs for enhanced oil recovery.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

CNPC Jilin Oil Field CO_2 EOR, China	
Operator	CNPC
Start Date	2018
Size	0.6 Mtpa
CO_2 Source	Natural gas
Oil Field EOR Storage Site	Jilin oil field
Key Highlights	This facility injects CO_2 for EOR in low permeability reservoirs of the Jilin oil field in northeast China. The CO_2 is captured from a nearby natural gas processing plant at the Changling gas field and transported by pipeline. After 12 years of pilot and demonstration tests, the commercial operation, as Phase III, began in 2018, reaching 600,000 tonnes CO_2 per annum. Cumulative CO_2 injection of 1.12 million tonnes for pilot and demonstration scale operation was reached in the 2017.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

Gorgon, Australia	
Operator	Chevron
Start Date	2019
Size	3.4 to 4.0 Mtpa
CO_2 Source	Natural gas
Geologic Storage Site	Saline formation beneath Barrow Island
Key Highlights	Gorgon CO_2 Injection is part of the wider Gorgon gas development project offshore Western Australia. Reservoir CO_2 would be separated and compressed at facilities located on Barrow Island and then piped a short distance to CO_2 injection wells on the Island where the CO_2 would be injected deep in the subsurface.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

The following two ACTL projects are planned to be operating by year-end 2019 after ACTL construction is completed. The projects are listed here for information in anticipation of their near-term start-up. However, they are not included in the count of 19 large-scale CCUS full-value chain projects in operation at the time of this report's preparation.

Alberta Carbon Trunk Line with Sturgeon Refinery CO_2 Stream, Canada	
Operator	Enhance Energy and North West Redwater Partnership
Start Date	2019
Size	1.2 to 1.4 Mtpa
CO_2 Source	Petcoke gasification plants for hydrogen
Oil Field EOR Storage Site	Devonian carbonate in a depleted oil field near Red Deer in central Alberta
Key Highlights	The initial sources of CO_2 for the ACTL includes the new build North West Redwater NWR Partnerships Sturgeon Refinery. The refinery includes a new CO_2 compression and cooling facility owned by Enhance Energy that will be able to capture 1.2 to 1.4 Mtpa CO_2 for transport via ACTL. The ACTL aims to transport CO_2 from a number of sources in Alberta's Industrial Heartland, near Redwater, to declining oil fields in Central Alberta for the purpose of enhanced oil recovery.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.

Alberta Carbon Trunk Line with Agrim CO_2 Stream, Canada	
Operator	Enhance Energy and Agrium
Start Date	2019
Size	0.3 to 0.6 Mtpa
CO_2 Source	Agrium fertilizer plant
Oil Field EOR Storage Site	Devonian carbonate in a depleted oil field near Red Deer in central Alberta
Key Highlights	The initial sources of CO_2 for the ACTL include the existing Agrium fertilizer plant. The plant will have a CO_2 recovery facility retrofitted by Enhance Energy that will be able to capture 0.3 to 0.6 Mtpa CO_2 for transport via ACTL. The ACTL aims to transport CO_2 from a number of sources in Alberta's Industrial Heartland, near Redwater, to declining oil fields in Central Alberta for the purpose of enhanced oil recovery.
References	Global CCS Institute, Facilities database, https://co2re.co/FacilityData.