Plains CO_2 Reduction (PCOR) Partnership
Energy & Environmental Research Center (EERC)

CCUS BUSINESS MODELS IN THE PCOR PARTNERSHIP REGION

Plains CO_2 Reduction (PCOR) Partnership Initiative
Task 5 – Deliverable 4

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EXECUTIVE SUMMARY

Comprising ten states and four Canadian provinces, the Plains CO_2 Reduction (PCOR) Partnership Initiative region is home to abundant and diverse sources of anthropogenic CO_2 (e.g., coal- and gas-fired power plants, gas-processing plants, ethanol plants), fitting geology for CO_2 storage and utilization, a history of CO_2 transport and expanding pipeline infrastructure, and an established industrial/energy commercial base.

Whether from a capture-ready, nearly pure CO_2 source associated with an ethanol plant or from the retrofit of a 1000-MW coal-fired power plant, implementing carbon capture, utilization, and storage (CCUS) is an expensive endeavor. Recent reports have detailed several business model frameworks that address the varied contractual relationships between CO_2 source, capture, transport, and storage components of the CCUS chain. These models range from full vertical integration where one entity manages all aspects of the CCUS chain to a CCUS transporter model with separate management and oversight on each individual component of the chain. The existing and developing projects in the PCOR Partnership region fit within one or more of these described business models.

For an industry to move forward with a CCUS project, a business model catalyzed with one or more viable drivers (e.g., CO_2 enhanced oil recovery [EOR], tax credits) must be adopted that does not negatively impact a company's bottom line. A diverse and robust commercial CCUS industry has evolved in the PCOR Partnership region over the past 30 years. Pathways, business models, and drivers that have facilitated existing and emerging CCUS development in the PCOR Partnership region have recently shifted from resource recovery (CO_2 EOR and associated CO_2 storage) to green growth dominated by dedicated storage. This fundamental shift can be shown based on the list of newly announced CCUS projects in the PCOR Partnership region. Although these projects include CO_2 EOR, most are being driven by tax credit or product value enhancement.

To incentivize dedicated CCUS where a market does not exist, the U.S. government has established a tax credit program for storing CO_2. The value of these tax credits drives a business case forward to enable the realization of CCUS projects. Some CCUS projects, like those associated with ethanol plants, can bolster their business case for CCUS by capitalizing on increased commodity values (higher value per gallon of ethanol). Leveraging low-carbon fuel standards, like those established by the California Air Resources Board (CARB), can provide direct financial gain to an ethanol company implementing CCUS. In fact, the ethanol company can stack the financial benefits of increased commodity prices and the tax credits gained from the U.S. government. This combination is the driver for two recently announced projects for large-scale

gathering and transport of CO_2 from ethanol plants in the United States. In Canada, the federal government has put a price on CO_2 emissions (currently Can$30/tonne). Under this situation, there may be financial benefit to capture and store the CO_2 rather than pay the tax. This potential financial benefit would be a business driver for CCUS. Specific examples include the updates to the U.S. Section 45Q federal tax credits, which have improved the economics of potential CCUS projects, and the planned Canadian investment tax credit program and carbon-pricing framework. In addition, the recent U.S. Environmental Protection Agency approval of primacy applications by North Dakota and Wyoming for underground injection control Class VI regulations (wells used for geologic storage of CO_2) have provided potential CCUS project developers with the additional regulatory certainty needed to invest in commercial-scale CCUS projects.

CCUS BUSINESS MODELS IN THE PCOR PARTNERSHIP REGION

INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership Initiative is one of four projects operating under the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Regional Initiative to Accelerate CCUS (carbon capture, utilization, and storage). The PCOR Partnership region encompasses ten U.S. states and four Canadian provinces in the upper Great Plains and northwestern regions of North America (Figure 1. Alaska not shown). The PCOR Partnership Initiative is led by the Energy & Environmental Research Center (EERC), with support from the University of Wyoming and the University of Alaska Fairbanks, and includes stakeholders from the public and private sectors. The goal of this joint government–industry effort is to identify and address regional capture, transport, use, and storage challenges facing commercial deployment of CCUS throughout the PCOR Partnership region.

A diverse and robust commercial CCUS industry has evolved in the PCOR Partnership region over the past 30 years. Pathways and business models that have facilitated existing and emerging CCUS development in the PCOR Partnership region are presented. Whether from a capture-ready, nearly pure CO_2 source associated with an ethanol plant or from the retrofit of a 1000-MW coal-fired powerplant, implementing carbon capture and storage (CCS) is an expensive endeavor. For an industry to move forward with a CCUS project, a business model catalyzed with a viable driver must be adopted that does not negatively impact a company's bottom line.

Being able to sell captured CO_2 as a commodity is the easiest model to consider if there is a willing buyer and the selling price of the CO_2 and a long-term contract works for the buyer and seller. This type of arrangement might work well in a CO_2 EOR (enhanced oil recovery) situation. Without market price for the CO_2 and an amicable buyer–seller relationship, business cases become harder to generate. To incentivize dedicated CCUS where a market does not exist, the U.S. government has established a tax credit program for storing CO_2. The value of these tax credits drives a business case forward to enable the realization of CCUS projects. Some CCUS projects, like those associated with ethanol plants, can bolster their business case for CCUS by capitalizing on increased commodity values (higher value per gallon of ethanol). Leveraging low-carbon fuel standards, like those established by the California Air Resources Board (CARB), can provide direct financial gain to an ethanol company implementing CCUS. In fact, the ethanol company can stack the financial benefits of increased commodity prices and the tax credits gained from the U.S. government. This combination is the driver for two recently announced projects for large-scale gathering and transport of CO_2 from ethanol plants in the United States. In Canada, the federal government has put a price on CO_2 emissions (currently Can$30/tonne). Under this situation, there may be financial benefit to capture and store the CO_2 rather than pay the tax. This potential financial benefit would be a business driver for CCUS.

COMMERCIAL CCUS GROWTH IN THE PCOR PARTNERSHIP REGION

The PCOR Partnership Initiative region comprises ten U.S. states and four Canadian provinces and is home to abundant and diverse sources of anthropogenic CO_2 (e.g., coal- and gas-fired power plants, gas-processing plants, ethanol plants), fitting geology for CO_2 storage and utilization, a history of CO_2 transport and expanding pipeline infrastructure, and an established industrial/energy commercial base. For nearly two decades, working with nearly 200 industry and government partners, the focus of the PCOR Partnership has been the integration of CCUS into commercial industries within the region. The PCOR Partnership partners include key industrial sectors with a stake in CCUS deployment; numerous state, regional, and federal governmental research entities; and several state and federal regulatory agencies.

Recently, developing federal/state/provincial policies and regulations have provided pathways for advancing commercial CCUS. Specific examples include the U.S. Section 45Q federal tax credits, which have improved the economics of potential CCUS projects, the planned Canadian investment tax credit program, and the Canadian carbon pricing framework. In addition, the recent U.S. Environmental Protection Agency (EPA) approval of primacy applications by North Dakota and Wyoming for Class VI (wells used for geologic storage of CO_2) regulations have provided potential CCUS project developers with the additional regulatory certainty needed to invest in commercial-scale CCUS projects (Figure 1).

Figure 1. Existing and planned commercial-scale CCUS projects in the PCOR Partnership region. ACTL = Alberta Carbon Trunk Line; CCA = Cedar Creek Anticline.

BUSINESS MODELS

Businesses invest capital and incur operating expenses in anticipation of receiving income. To be viable, a business must have cumulative income more than the sum of capital and operating expenses, e.g., not lose money. Zott and Amit (2008) state that business models can be characterized by their design themes, which capture the common threads that organize and connect an entity's transactions with external parties. A major challenge surrounding business models for CCUS is to find a driver and framework which shares risks and rewards such that acceptable returns are earned by all partners involved (Kapetaki and Scowcroft, 2017).

Several CCUS model constructs have been introduced over the past decade (Esposito and others, 2011; Yao and others, 2018; Hardy, 2019; Ku and others, 2020; and Muslemani and others, 2020). Although with minor differences, the models all revolve around the contractual relationships and drivers between the three main components of CCUS, namely, capture, transport, and storage. This paper focuses on the more expanded models discussed by Yao, Ku, and Muslemani.

Ku and others (2020) identified three business model archetypes: resource recovery (RR), green growth (GG), and low-carbon grids (LCGs) (Figure 2). RR focuses on the management of carbon in the production of hydrocarbons, primarily the storage of CO_2 incidental to CO_2 EOR operations. Ku and others define GG as prioritizing CO_2 reductions in support of climate action, using CCUS to reduce the carbon footprint of economic activity. LCG development emphasizes the value of CCUS as an alternative (or complement) to grid-scale energy storage to enable a lower-cost and more stable grid with high renewables penetration. These business models are discussed as a framing mechanism to help translate experience across global regions.

Resource Recovery

The RR model focuses on profitable operations between the CO_2 seller and the CO_2 end user. The at-scale aspect of this model is achieved through increasing the number and size of projects. A strategic advantage of the RR model is the existing infrastructure and legacy knowledge from the CO_2 EOR industry. A paradigm shift is needed to optimize CO_2 retention in the reservoir rather than only focusing on oil production. This shift could lead to much "greener" oil (trending toward CO_2 neutral oil). Potential revenue associated with the RR business model comes from the sale of incrementally recovered hydrocarbons.

Green Growth

The GG business model described by Ku and others (2020) supports CO_2 emission reduction through government regulations, incentives, or social pressure. As an example, Canada is actively evolving its carbon tax policy (essentially a CO_2 levy on fossil fuels). This could be an important driver for GG or hybrid GG–RR projects. In the United States, the 45Q federal tax credit and the California Low Carbon Fuels Standard (LCFS) credits are examples of incentive drivers for the GG business model. In specific cases, the sale of conversion products associated with carbon utilization projects can provide additional revenue.

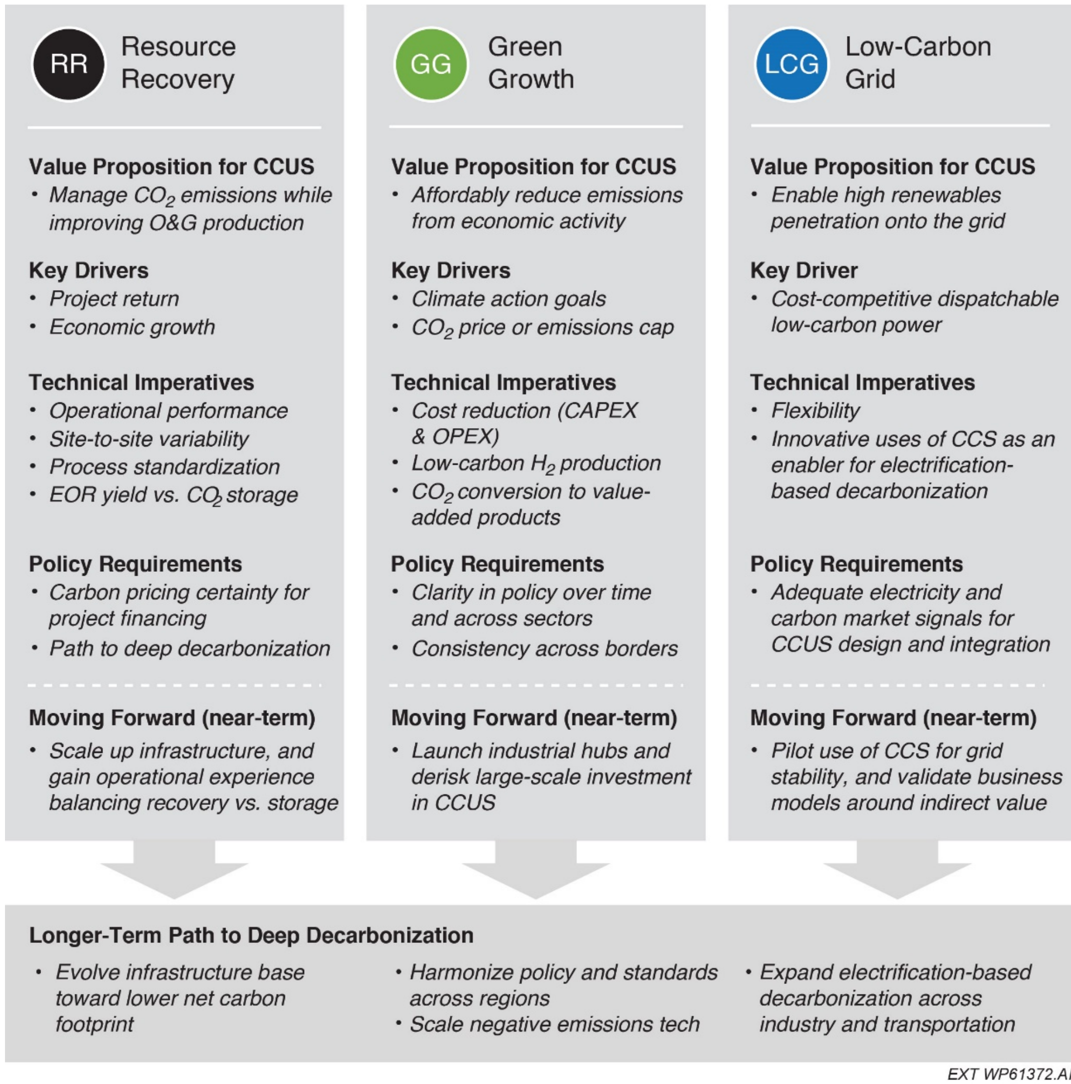

Figure 2. Archetypes for CCUS development as defined by Ku and others (2020). An individual CCUS project can have characteristics of more than one archetype.

Low-Carbon Grid

Ku and others (2020) base their LCG archetype on an idea that dispatchable power from CCUS-equipped power plants can enable a low-carbon electrical grid with high levels of variable renewable energy. Their premise is that CCUS lowers overall system costs by reducing the need to overbuild infrastructure for reliability.

Early CCUS development in the PCOR Partnership region was built under the RR model framework of Ku and others (2020). Capturing CO_2 from high concentration sources where CO_2 was already being separated from a process stream was readily sold to EOR operations. Capture from the Shute Creek gas processing and Great Plains Synfuels plants provided a long-term marketable stream of CO_2 for EOR. RR remains a solid foundation for newer CCUS projects in the region; however, there is greater focus being put on the GG framework where climate action goals and tax benefits are replacing CO_2 sales and hydrocarbon recovery. Projects such as Shell Quest, Red Trail Energy, and Summit Carbon Solutions are examples of this newer focus.

Minnkota Power Cooperative's Project Tundra aims to capture nearly 4 million tonnes per year (Mtpy) from the Milton R. Young power generation station and store the CO_2 beneath the plant and adjacent property. This planned effort falls in the LCG model of Ku and others (2020) in an approach to compete with renewables and provide dispatchable low-carbon power.

Yao and others (2018) and Muslemani and others (2020) categorized existing large-scale CCUS projects within three overarching business model types: 1) vertically integrated models (within an individual company), 2) joint venture models (with more than one company), and 3) in collaboration with external CCS service provider companies. Yao and others (2018) split the collaborative service provider model into CCUS operator and CCUS transporter models.

Vertically Integrated Model

A vertically integrated business model brings in previously outsourced or newly targeted operations in-house. The vertical integration can either be upstream (backward, e.g., a power plant operator acquires an adjacent coal mine) or downstream (forward, e.g., a power plant operator adds in a business unit to manage CO_2 capture, transport, and storage). Although this business model greatly lowers the risks associated with coordination and contracts between different sectors, the approach is limited to entities with the resources to heavily invest in the technical and commercial resources to manage and operate the full CCUS chain in addition to the business associated with the large stationary CO_2 source. Potential revenue to offset the large investment in this business model approach could come from government subsidies/tax credits, crude oil sales if associated with CO_2 EOR, or selling carbon emission credits. Figure 3 depicts the structure of a generic vertically integrated CCUS model which may be applicable in both the industrial and power sectors.

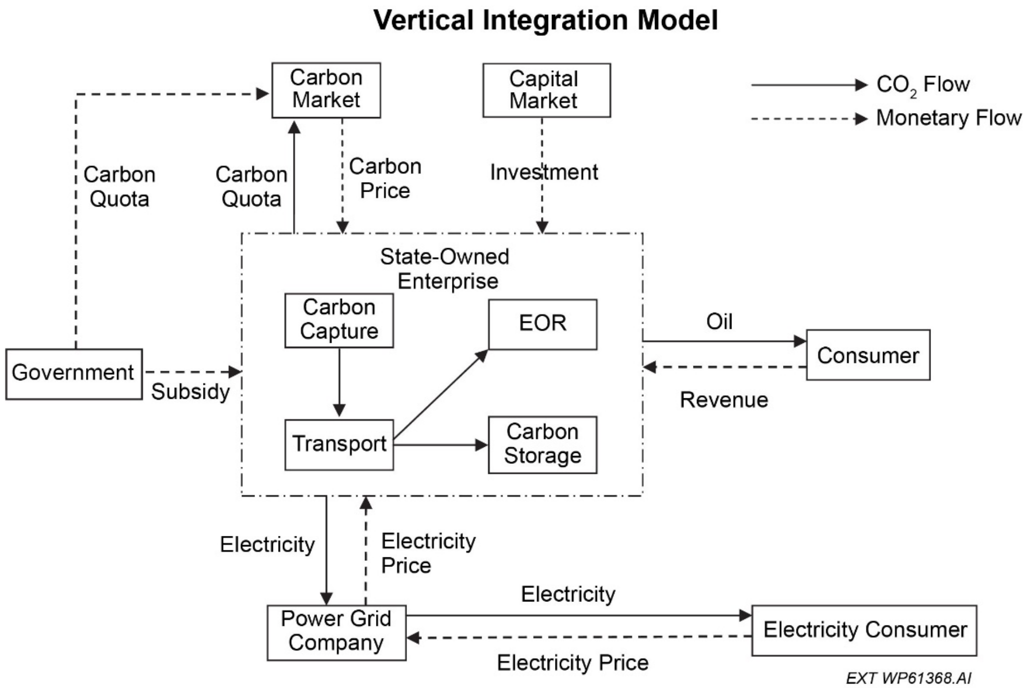

Figure 3. The CCUS vertical integration model as portrayed by Yao and others (2018).

Joint Venture Model

A joint venture business arrangement is where two or more parties agree to pool their resources for the purpose of accomplishing a task. Investment in, and management of, the major components of the CCUS chain are split/shared among multiple parties with a common interest. The goal of this arrangement is more equitable distribution of risks and revenues. Yao and others (2018) and Muslemani and others (2020) describe this model in an example where an industrial company may be liable for the capture of CO_2, but transportation and storage would be managed jointly. Revenue streams in this model for the capture entity would come from CO_2 sales to an oilfield operator or from government subsidies/tax credits from dedicated CO_2 storage. The oilfield operator would generate revenue from increased oil production via CO_2 EOR. Muslemani and others (2020) cite the Quest CCS project as an example of a joint venture business model. Figure 4 depicts the structure of a generic joint venture CCUS business model.

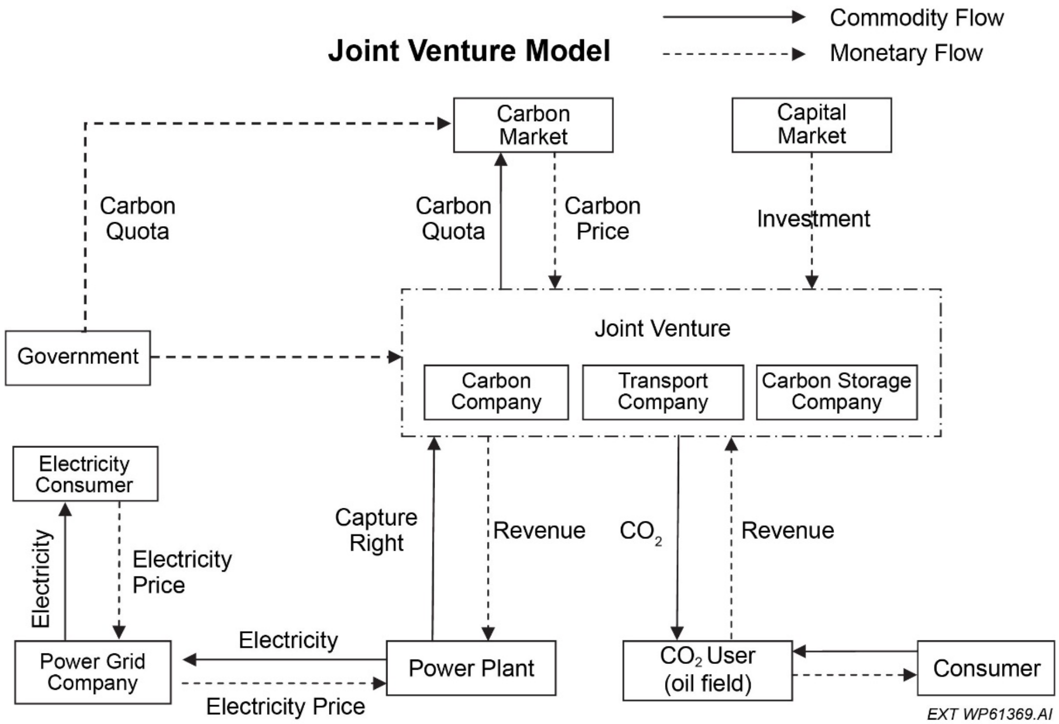

Figure 4. The CCUS joint venture model as portrayed by Yao and others (2018).

CCUS Operator Model

Muslemani and others (2020) describe the CCUS operator model as a pay-at-the-gate scenario where an industrial entity partners with a third party to handle the CO_2 after it has been captured. In this model, the transportation infrastructure can be associated with the capture entity or the third-party end user (Figure 5). Muslemani and others (2020) cite the Great Plains Synfuels Plant tied with Canada's Weyburn-Midale project as an example of CCUS projects adopting an operator model. Revenue in the Great Plains Synfuels Plant example comes from contracted CO_2 sales to a CO_2 EOR project which, in turn, generates revenue via increased hydrocarbon sales for the oil company. Minnkota Power Cooperative's Project Tundra can also be viewed as using a CCUS operator model. Overall, if the CO_2 capture company is an industrial plant, it could generate profit either through a premium on produced low-carbon goods/fuel, carbon credits, and/or a government subsidy. Because there is no joint ownership in the CCUS chain, risks and rewards are parsed out to the individual entities, thus the transaction costs are assumed to be higher.

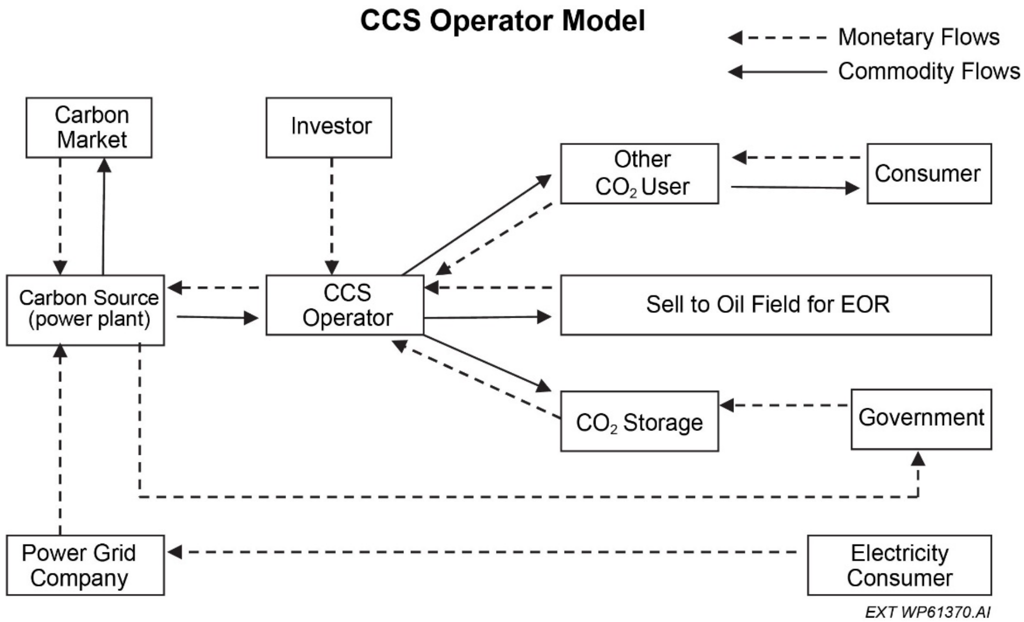

Figure 5. The CCUS operator model as portrayed by Yao and others (2018).

CCUS Transporter Model

In the CCUS transporter model, the three main components of the CCUS chain are separated completely, resulting in an entity for capture, transport, and storage, with each entity covering its own respective operating and maintenance (O&M) costs (Figure 6). Yao and others (2018) call out that the CCUS transporter model exhibits vertical disintegration and requires a higher specialization level. In this model, revenue for the capture entity is established through a long-term CO_2 purchasing contract. The pipeline transport component of the chain will receive revenue through a transport fee on the CO_2, and the CO_2 end user establishes revenue if it maintains larger profit margins on its products (i.e., incremental oil and/or tax credits). Examples of CCUS projects using a transporter model include the Shute Creek capture and associated connected CO_2 EOR projects (e.g., Bell Creek or Cedar Creek anticline fields) with all or portions of the CO_2 transportation infrastructure owned by a third party.

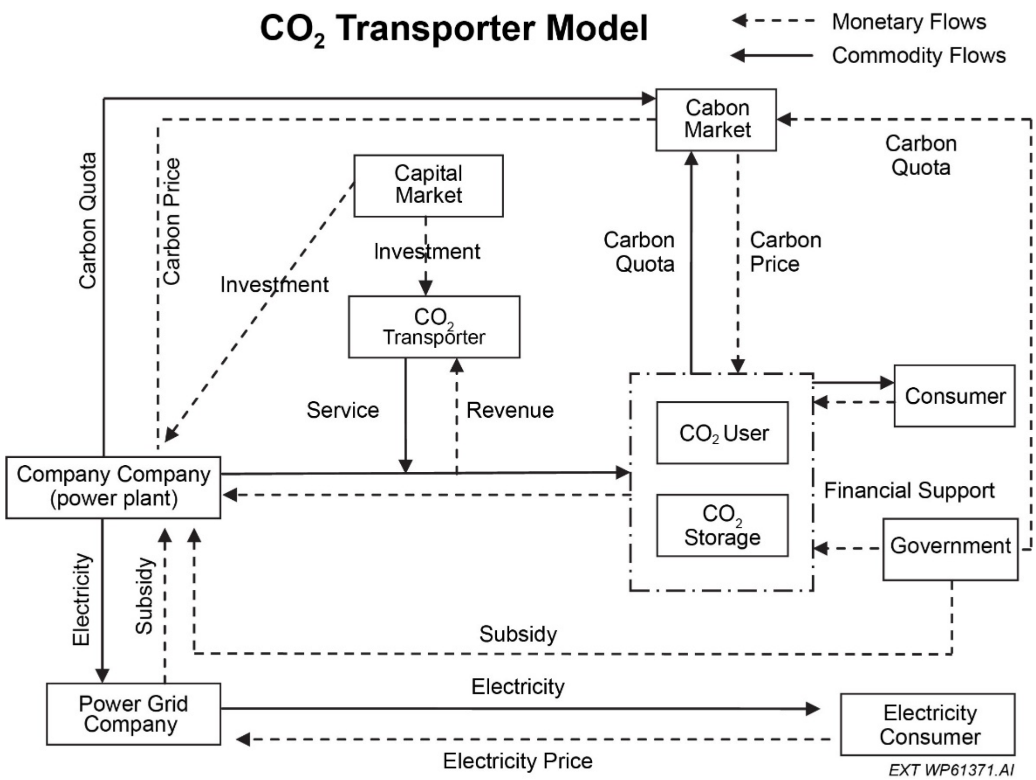

Figure 6. The CCUS transporter model as portrayed by Yao and others (2018).

ELEMENTS AND DRIVERS

Within the business model arrangements discussed above are primary drivers (elements) to incentivize and support the inception of some form of one of those models. Durusut and Mattos (2018) and Muslemani and others (2020) define revenue as the central element in creating value for CCUS business models, around which the elements of funding sources, capital sourcing and ownership, and risk management are then structured and defined (Figure 7).

Within the PCOR Partnership region, the primary drivers for existing and announced CCUS projects, regardless of the contractual arrangements between the three primary components (i.e., business model), are tax incentives (credits or avoidance) and CO_2 sales (Table 1). Supporting drivers are policies such as long-term liability assumptions, state primacy for UIC (underground injection control) Class VI wells, and the growing focus on environmental, social, and governance ratings. As will be seen later, the two noneconomic risk reduction policies of long-term liability and primacy have a strong impact on CCUS project development when paired with sales and tax incentives.

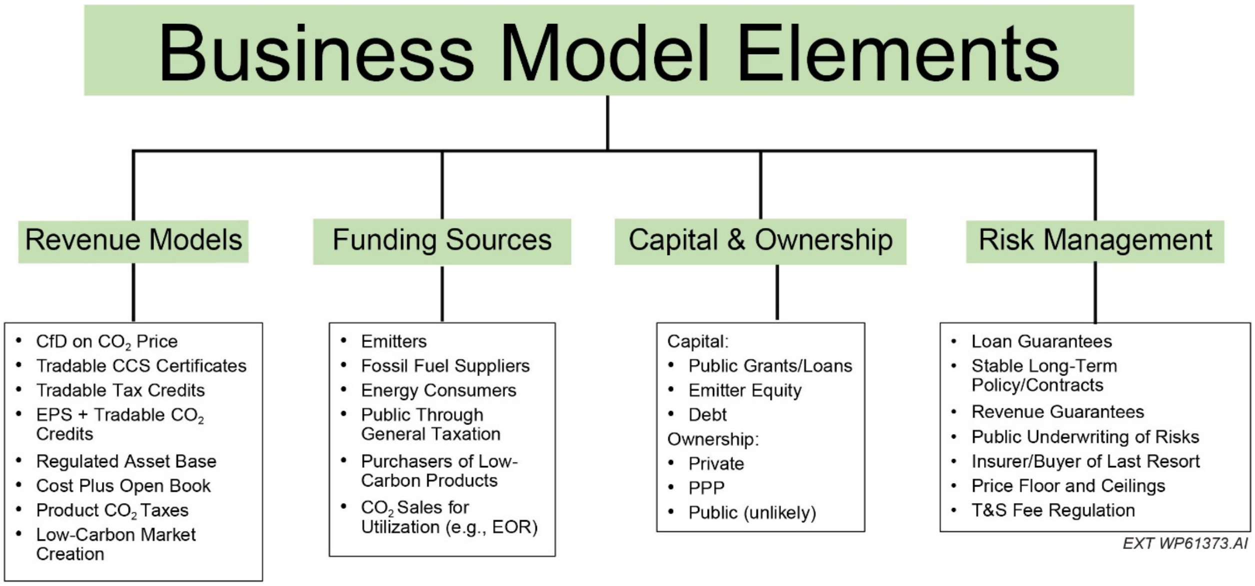

Figure 7. Elements of a CCUS business model: CfD = contract for deed; EPS = emission performance standard; T&S = transportation and storage; PPP = public–private partnership (from Muslemani and others, 2020).

Table 1. Primary Drivers for CCUS Projects in the PCOR Partnership Region

Tax Incentives	Product Sales	Other
• Section 45Q • Investment tax credit • Tax penalty avoidance	• CO_2/offtake • Hydrocarbons • LCFS markets for lower carbon intensity fuel	• Assumption of long-term liability • State Class VI primacy • ESG

In the spring of 2021, the Canadian federal government announced that it would introduce an investment tax credit (ITC) for capital invested in CCUS projects. The goal effort of the ITC is to promote the reduction of annual CO_2 emissions by at least 15 Mt, support technological advancement of CCUS and, ultimately, lower the cost of CCUS. In contrast, the Section 45Q tax credit program in the United States which awards credits after the large up-front financial investment for infrastructure and ultimate storage of CO_2, the Canadian ITC would award tax credit on the front end of the process. The premise is that the up-front credit will provide greater certainty, increase value, and reduce risk in CCUS projects.

Environmental, social, and corporate governance (ESG) are intangible factors relating to the sustainability and ethical impact of investments. Approach, assessment, and reporting of ESG factors are growing considerations for investors, shareholders, and the public who seek greater levels of transparency to evaluate risk exposure. An increasingly central aspect of many ESG assessment and rating schemes is a corporation's exposure to climate change-related risks. Despite broad awareness of the potential for CCUS within the investment and rating communities, substantial uncertainty remains regarding its more widespread deployment. As such, CCUS is undervalued in its potential for improving a company's ESG performance (Havercroft, 2020). Perhaps as CCUS matures, it will have a more positive impact on ESG ratings. In the near term, ESG factors can be a contributing driver in the development of commercial CCUS projects that are founded on more robust business cases.

45Q DEAL STRUCTURES

Connors and others (2020) provide a discussion of deal structures that could be used for CCUS financing. A primary example, the partnership flip structure, is based on solar and wind tax equity arrangements. The flip structure allocates nearly all the income, loss, and tax credits to the equity investor (often cited as 90+%) until a target return is reached. Once the target level of return is met, the allocations flip so that project sponsor member receives most of the credit items (www.irs.gov/pub/irs-drop/rp-20-12.pdf). Figure 8 from Connors and others (2020) depicts an example of the tax equity flip structure where a CO_2 capture company (project company) establishes a contract with a CO_2 emitter for the rights to capture CO_2. The project company also enters into agreement with an offtaker: an entity that will buy the captured CO_2 for EOR.

Another partnership flip structure presented by Connors and others (2020) involves assigning 45Q credit where a tax equity investor takes equity ownership in the project company (Figure 9). In this structure, the power plant diverts captured CO_2 to the project company for a fee. In exchange, the power plant assigns tax credits to the project company under the election in Section 45Q. The project company can put the CO_2 in secure geologic storage either as a tertiary injectant in EOR or dedicated storage in a saline formation. Connors and others (2020) state that further Internal Revenue Service (IRS) guidance will be needed to address the mechanics of a partnership flip that is assigned the 45Q credit in connection with the use and/or storage of the CO_2. Alternatively, under the same election option under Section 45Q, the credit could be assigned to an offtaker such as an oilfield owner who will use the CO_2 as a tertiary injectant and provide documentation of secure geologic storage (Figure 10).

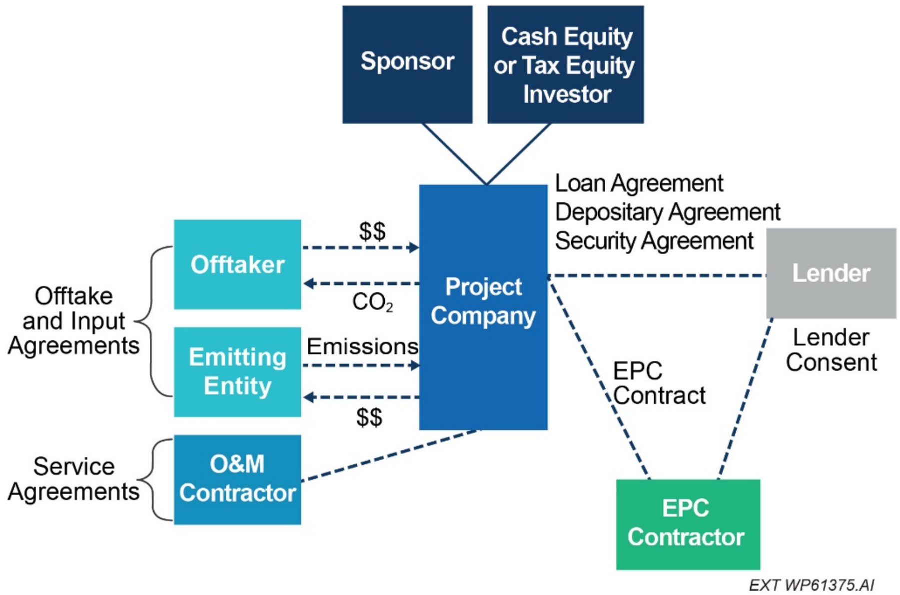

Figure 8. Representative tax equity partnership flip structure (Connors and others, 2020). EPC stands for engineering, procurement, and construction.

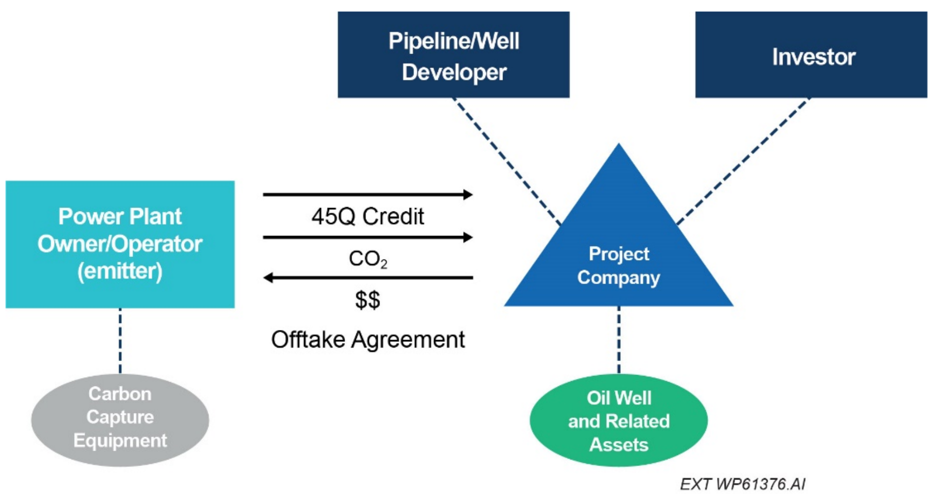

Figure 9. Partnership flip structure with assignment of 45Q credits to project company (Connors and others, 2020).

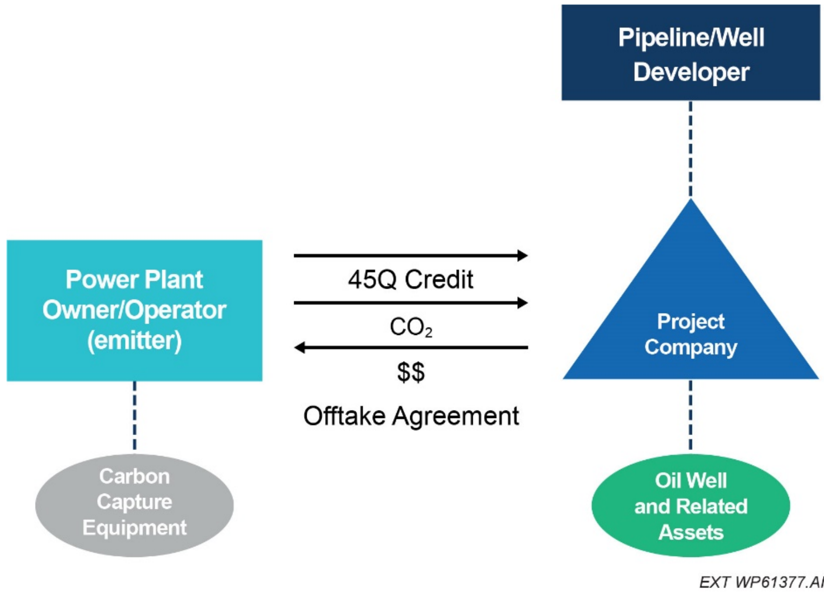

Figure 10. Assignment of 45Q credits to offtaker (Connors and others, 2020).

COMMERCIAL CCUS ACTIVITY IN THE PCOR PARTNERSHIP REGION

Several different business models have been, and will be, used to achieve the commercial deployment of the CCUS industry in the PCOR Partnership region. The business models of choice will be driven by the overall economics of the commercial projects, which, at a minimum, will require that the capital investment promise desired returns based on the current market conditions and financing environment.

Any gaps between the project costs of capture, transport, and storage and project revenues can be addressed by a combination of federal and state support that reduces the costs of technology and infrastructure deployment (e.g., production and investment tax credits, master limited partnerships, private activity bonds) and creates an environment of increased investment certainty (e.g., extension of 45Q) and financing feasibility (e.g., U.S. Department of Agriculture [USDA] and DOE loans and/or loan guarantees, tax-exempt bond financing, or enhanced 45Q transferability) (National Petroleum Council, 2019; Abramson and others, 2020). Many of the existing and planned CCUS have been or will be heavily supported by state/provincial/federal dollars (e.g., Quest, Alberta Carbon Trunk Line [ACTL], Project Tundra). Beyond direct financial support, tax credit programs in the United States and Canada are poised to support several new CCUS projects (e.g., Midwest Carbon Express and Carbon Vault).

The business models that drove the existing commercial CCUS development in the region, as well as those that are driving the planned commercial ventures, can be characterized by various ownership configurations like the joint venture, CCUS operator, and CCUS transporter models described by Yao and others (2018) and Muslemani and others (2020).

Although not with the specific primary goal of storing CO_2, CCUS activities have been occurring in the PCOR Partnership region since 1986. These efforts were initiated by gas-processing plants that captured CO_2 for transport and use through CO_2 EOR. Since that time, other industries have put CCUS into practice, with the most recent commercial geologic storage of CO_2 beginning injection in 2016 (Boundary Dam/Aquistore). As of the end of 2021, six commercial CCUS operations are in place within the PCOR Partnership region: two projects located entirely in Canada, three projects in the United States, and one cross-border project. The CO_2 in these projects is being captured at a variety of industrial facilities, including a coal-fired power plant, a coal gasification plant, gas-processing plants, and a bitumen-upgrading plant. In all of the projects, the captured CO_2 is transported via pipelines ranging in length from 50 to 230 miles. Geologic storage is occurring primarily via associated storage (CO_2 EOR), although dedicated storage in saline aquifers is also a component of the two Canadian projects.

A general description of these operations is provided below:

- 1986 – Shute Creek: CO_2 captured at a gas-processing plant is transported via pipeline approximately 250 miles for associated storage during CO_2 EOR. The CO_2 is removed from the product gas stream to meet product specifications; however, this CO_2 was vented to the atmosphere prior to being used for CO_2 EOR. The CO_2 pipeline was built by a commercial venture, which uses the CO_2 at its CO_2 EOR fields in the region for tertiary oil recovery. The venture purchases the CO_2 from the gas plant and receives revenues associated with the additional oil that is produced at the oil fields. The pipeline was built with sufficient capacity to allow additional CO_2 to be transported to other CO_2 EOR fields, which the venture owns or will purchase, as additional sources of CO_2 are identified and the EOR fields are poised for the tertiary recovery of oil.

- 2000 – Great Plains Synfuels: CO_2 capture from the Great Plains Synfuels coal gasification plant in North Dakota followed by pipeline transport of the CO_2 to an oil field in Canada for associated storage during CO_2 EOR. The coal gasification plant produces a CO_2 stream during the purification of its raw syngas. This CO_2 was vented to the atmosphere until a dedicated 210-mile pipeline was constructed to transport the CO_2 to an oil field located in Canada. However, this pipeline has additional capacity and can transport larger volumes of CO_2. Taps are available along the pipeline route to supply CO_2 to other buyers.

- 2013 – Lost Cabin: CO_2 capture from the Lost Cabin gas-processing plant in Wyoming followed by pipeline transport to oil fields in Montana for associated storage during CO_2 EOR.

- 2015 – Shell Quest: An oil sand conversion plant in Canada captures CO_2 and transports it via pipeline to a dedicated geologic storage site. The capture plant and pipeline were constructed using funds from a three-party, commercial joint venture combined with government funds from the province of Alberta and the Canadian federal government. While the CO_2 capture project does not produce revenue, it does reduce the carbon tax burden of the plant operator. The carbon tax in the province was initially $20 per metric ton of CO_2 in 2017, was increased to $30 per metric ton in 2018, and is tied to a 2% increase in future years based on rising inflation.

- 2016 – Boundary Dam: CO_2 capture from the Boundary Dam coal-fired power plant in Saskatchewan, Canada, followed by pipeline transport for dedicated geologic storage in a saline aquifer (as part of the Aquistore project) and for associated storage during CO_2 EOR in the Weyburn oil field, also in Canada. The Boundary Dam power plant, which has benefited from the involvement of the provincial government in financing the CCUS project, as well as the ability to avoid paying a Canadian carbon tax for the captured CO_2, transports the captured CO_2 to both dedicated and associated storage sites, both of which are near the plant.

- 2020 – ACTL: CO_2 captured from refinery and a fertilizer facility in Alberta, Canada, transported via pipeline for associated storage as part of a CO_2 EOR project. The pipeline was designed as part of an expandable network to support future CO_2 emissions solutions.

Planned Commercial CCUS Operations in the PCOR Partnership Region

Commercial CCUS projects have been announced in the PCOR Partnership region and are slated to begin construction or injection operations before 2026. In addition, other commercial projects are undergoing feasibility studies for deployment on a similar schedule. A brief description of these projects is provided below:

- Project Tundra: CO_2 captured from the Milton R. Young coal-fired power plant in North Dakota will be transported via a local pipeline for dedicated geologic storage in a saline aquifer in North Dakota.

- Dry Fork Station: CO_2 captured from the Dry Fork coal-fired power plant near Gillette, Wyoming, followed by pipeline transport for dedicated geologic storage in stacked saline aquifers.

- The Red Trail Energy project: CO_2 capture at a single ethanol plant coupled with on-site or near-site dedicated storage is currently moving toward construction, with operation expected in 2022. The capture plant, storage facility, and short CO_2 pipeline associated with this project will be entirely owned by the ethanol producer. The business model for this project is relying on both the 45Q tax credits for the dedicated storage of the CO_2 and the revenue associated with the sale of the ethanol product as a low-carbon fuel on the U.S. West Coast, where lower-carbon-intensity ethanol commands a high price.

- Summit Carbon Solutions (Midwest Carbon Express project): CO_2 captured from 31 agriculture processing facilities (ethanol and fertilizer plants) in Iowa, Minnesota, Nebraska, and North Dakota will be transported via a 1500-mile regional pipeline network to a dedicated geologic storage site in central North Dakota.

- Navigator Heartland Greenway project: CO_2 to be captured from about 20 agriculture processing facilities (ethanol and fertilizer plants) in Iowa, Minnesota, Nebraska, South

Dakota, and Illinois will be transported via a 1300-mile regional pipeline network to a dedicated geologic storage site in central Illinois.

- Shute Creek expansion: Additional CO_2 to be captured from a gas-processing plant in Wyoming would be transported by existing pipeline associated storage during CO_2 EOR in central and eastern Wyoming, eastern Montana, and southwestern North Dakota.

- Dakota Carbon Pipeline project (Carbon Vault): Additional CO_2 captured from the Great Plains Synfuels Plant would be transported less than 7 miles for dedicated geologic storage in a saline reservoir.

- Alberta Carbon Grid (ACG): In June of 2021, pipeline companies TC Energy and Pembina announced the ACG, which is planned to be an open-access CCUS network with the capacity to transport for up to 20 million tons of CO_2 per year. With multiple inlets and outlets, customers will have flexibility to decide delivered CO_2 end uses, including industrial processes and sequestration. A key component of this proposed system is repurposing unused existing pipeline capacity in and around depleted oil and gas fields. Long-term fee-for-service contracts would sell access to the new pipeline network for tolls to be less than the rising provincial and national emission penalties. In addition, a marketing and trading pool to facilitate CO_2 and carbon offset transactions would be established. Operation of the ACG could start as early as 2025.

This next generation of commercial CCUS operations in the PCOR Partnership region will involve a mixture of dedicated and associated storage; however, there is an increase in interest in the former as compared to the existing commercial activity in the region. The increased focus on dedicated CO_2 storage is driven by the 45Q tax credits and an increasing uncertainty in the expansion of CO_2 EOR caused by oil price fluctuations and social pressures to decarbonize the economy (ESG).

FUTURE DEVELOPMENT

CO_2 Capture

Next-generation solvents and capture technologies have reduced CO_2 capture costs significantly over the past 5 years, and research investment remains robust. This trend will make CO_2 capture more feasible for point sources with lower-concentration streams, which could increase the number of commercial projects that rely on business models that include capture equipment owned and operated by the CO_2 generator or, alternatively, owned and operated by a separate business entity. Until the technology matures further there will be a strong bias toward nonpower applications for CCUS (e.g., ethanol) as a function of business case attractiveness.

CO_2 Transportation

In those instances where the CO_2 storage facility is close to the source of CO_2, e.g., 1–10 miles, it is possible that project economics will support the in-house construction or subcontracting of a dedicated CO_2 pipeline. However, the cost-effective transport of CO_2 over longer distances will require a broad-scale vision and coordinated actions by federal and state governments to address key logistical issues in the region (e.g., interstate/intercountry CO_2 transportation corridors, interconnected pipeline networks operated or shared by multiple private entities, and state/federal support for the "super-sizing" of pipelines). The ACTL is an example of this type of coordination. In the absence of these developments, the two most likely CO_2 transportation business models for commercial CCUS projects in the PCOR Partnership region are 1) small regional pipelines (50 to 100 miles) that transport CO_2 collected from a few sources to moderately sized dedicated storage facilities and/or CO_2 EOR oil fields for associated storage or 2) large trunk systems, extending hundreds of miles, that connect numerous emission sources and storage facilities.

CO_2 Storage

Looking ahead, commercial CO_2 storage in the PCOR Partnership region will likely comprise a combination of small- to moderate-scale dedicated storage facilities (Red Trail Energy and Midwest AgEnergy Group) or oil fields near the sources and/or large-scale storage hub opportunities with CO_2 transported by regional trunk lines (Summit, Denbury, Navigator). Ownership options for the storage facilities may include ownership by the CO_2 generator, CO_2 EOR field operator(s), and/or a separate storage company. These types of arrangements are expressed in joint venture and CCUS operator models discussed earlier.

Hub and Cluster Networks

The hub and cluster scenario aggregates CO_2 emissions from numerous independent operators for long-distance transport via high-capacity trunk lines to dedicated storage hubs or basins with multiple fields conducting EOR operations. The business model for such a development involves several complex issues such as credit and liability apportionment, material and operational specifications because of mixing of CO_2 streams, and interstate or intercountry transport issues.

To help manage growth of the CCUS industry in Alberta, the province is exploring a competitive process that enables the development of carbon storage hubs. Through this hub approach, successful operators would collect, transport, and permanently store captured CO_2 from various industrial emission sources. Depending on the contractual arrangements that develop, the business models that would be employed around the Alberta storage hub initiative would likely involve aspects of the joint venture and CCUS operator models. Ensuring open access to the storage hub infrastructure and the potential to provide competitive market service rates for the transport and storage of CO_2 will provide additional attractive drivers for a wide range of CO_2 emitters that would otherwise not contemplate the heavy investment into CCUS.

In addition to promoting the overall implementation of CCUS, the Alberta storage hub initiative also aims to ensure that carbon capture and storage will be deployed in a strategic manner that best manages the CO_2 storage resource (increased efficiency) and avoids challenges associated with numerous, and potentially overlapping, CO_2 storage projects. Aspects of the storage hub approach that would help avoid those challenges is to ensure storage operators plan for additional volumes and accommodate other sources of CO_2 and avoid stand-alone injection operations where possible.

An example of how the complex CCUS development of hubs and clusters can rapidly evolve based on shifts in business models and associated drivers can be seen in a comparison between a recently developed predictive model and actual announced project scenarios.

Abramson and others (2020) report that “there is immediate economic potential for geographically concentrated, low-cost industrial sources in the Midwest (e.g., ethanol facilities) to aggregate their CO_2 supply and deliver to storage locations at petroleum basins in Kansas, Oklahoma, and Texas.” This statement is depicted in Figure 11. In their analysis, Abramson and others focus the business driver for CO_2 storage and related infrastructure buildout on potential revenue from CO_2 EOR and 45Q tax credits from associated storage with CO_2 EOR and dedicated storage in adjacent saline formations. Based on this focus, the resulting output from use of the SimCCS model shows the optimized network of CO_2 transport moving captured CO_2 from the concentrated location of ethanol plants to the southwest.

In contrast to the modeling predictions of Abramson and others (2020), two independent regional CO_2 agglomeration projects have recently emerged that capture CO_2 from the network of ethanol and fertilizer plants centered in and around Iowa and transport the CO_2 to the northwest and to the southeast—90 degrees from the prediction of Abramson and others (2020) (Figure 12). The business drivers for these announced projects are 45Q and an increase in ethanol price based on West Coast LCFS programs. CO_2 EOR, which has long been considered the vanguard of a growing CCUS industry, has been bypassed in the United States by the business driver combination of 45Q and LCFS. In addition to those financial drivers, project risk reduction factors are in play. Large-scale CO_2 storage projects have been successfully permitted in Illinois (e.g., Archer Daniels Midland), demonstrating that there is an established pathway for execution, thus reducing risk for subsequent projects. The attraction for moving captured CO_2 to the northwest into central North Dakota is strongly related to North Dakota having primacy authority for UIC Class VI CO_2 injection wells, long-term liability arrangements, and favorable geologic conditions for storage.

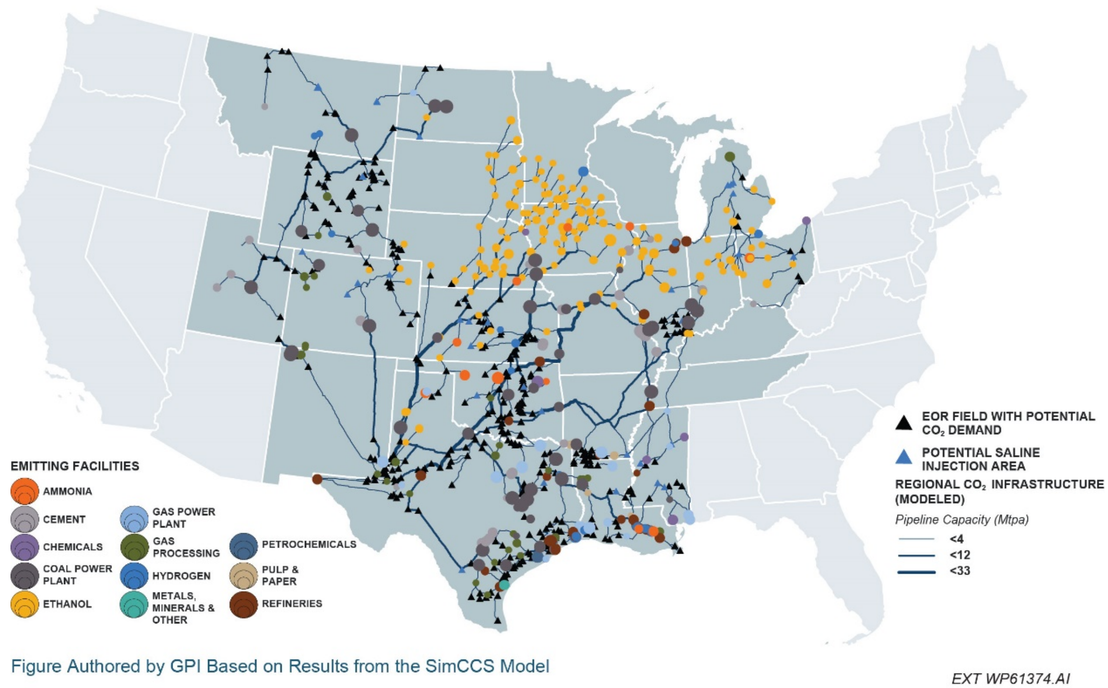

Figure 11. Optimized transport network for economy-wide CO_2 capture and storage. Figure authored by GPI based on results from the SimCCS model (Abramson and others, 2020).

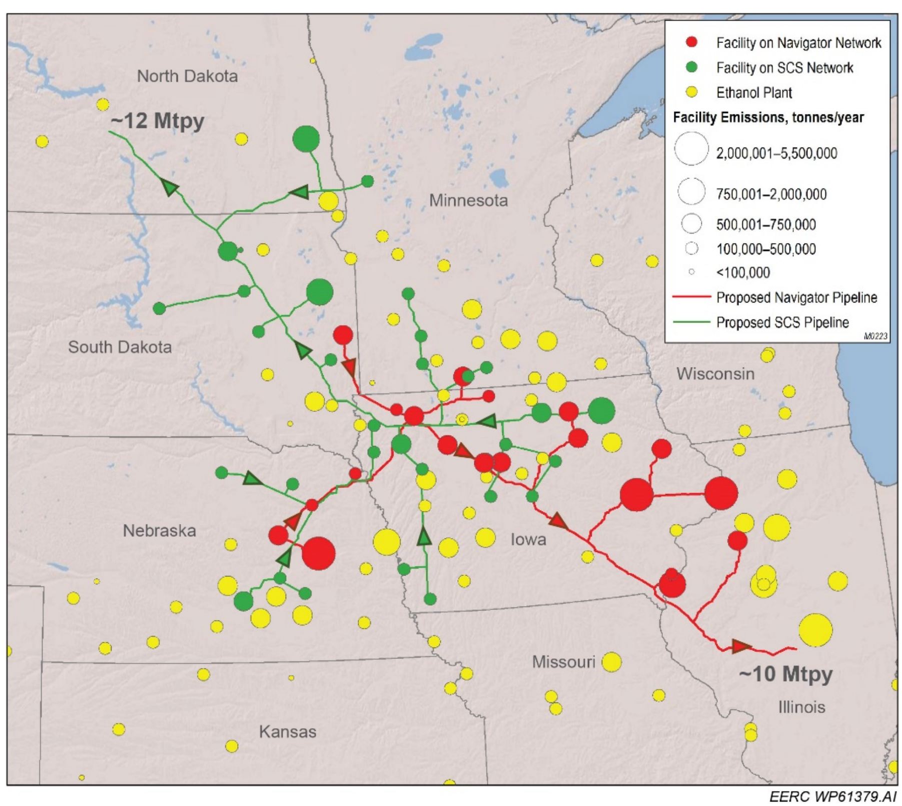

Figure 12. Two planned regional pipeline networks focused on capturing and gathering CO_2 from ethanol and fertilizer plants. The Midwest Carbon Express is shown in green and the Navigator Heartland Greenway in red. The arrow indicates the flow of CO_2.

SUMMARY

The primary components of a commercial CCUS project (the carbon chain) are the CO_2 capture facilities, the transportation of the captured CO_2 to the storage site, and the geologic CO_2 utilization/storage facilities. Ownership of these different components can vary depending on the characteristics of the commercial project and the various federal and/or state policies that are in place to catalyze these projects. For example, in those instances where the source of CO_2 is near a dedicated or associated storage opportunity, the generator of the CO_2 will likely be the owner of all three of the primary components of a commercial project (e.g., Red Trail Energy) and form a vertically integrated CCUS model. However, if the CO_2 must be transported long distances for storage, each of the primary project components will likely be owned by individual entities. Other ownership scenarios may also be employed if the 45Q tax credits are to be transferred to another party by the CO_2 generator. In this instance, it is possible that a different party may build and own the CO_2 capture facilities in return for both the tax credits as well as any revenues associated with the sales of CO_2 for associated storage during CO_2 EOR. This ownership arrangement could permit the CO_2 generator to reduce, or perhaps even eliminate, the cost penalty associated with the parasitic energy load of the CO_2 capture by selling both steam and electricity to the owner of the CO_2 capture facilities.

Commercial CCUS deployment in the PCOR Partnership region in the future will likely be the result of numerous permutations of different ownership options, which will be dictated by overall project economics and the implementation of various state/federal policies and incentives. As the number of projects grow, and the primary CO_2 storage target areas get more attention, the need for hubs and clusters will become more important so as to most efficiently use these prime areas.

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