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PCOR Partnership: a catalyst for commercial CCUS deployment

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Abstract

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center with support from the University of Alaska Fairbanks and the University of Wyoming, is one of four Regional Carbon Sequestration Partnerships. The PCOR Partnership, funded by the U.S. Department of Energy (DOE) National Energy Technology Laboratory and the North Dakota Industrial Commission and with support from more than 250 public and private partners, focuses on accelerating commercial deployment of carbon capture, utilization, and storage (CCUS).

Formed in 2003 as part of DOE's Regional Carbon Sequestration Partnership Program, the PCOR Partnership continues to build upon its 20-plus-year applied research expertise and extensive stakeholder base to accelerate CCUS projects in its region. The PCOR Partnership is identifying and addressing regional capture, transport, and storage challenges throughout its region, which encompasses ten U.S. states and four Canadian provinces in the upper Great Plains and northwestern regions of North America.

Commercial CCUS projects in the PCOR Partnership region include geologic storage of carbon dioxide (CO_2) in saline formations (dedicated storage) and utilization of CO_2 stored in association with enhanced oil recovery (EOR). Commercialization of CCUS has led to the expansion of existing CO_2 pipeline transportation networks and construction of new CO_2 pipelines, connecting areas of the PCOR Partnership region with major industrial CO_2 sources to geologic formations best suited for permanent storage. Seventeen commercial CCUS projects operate within the PCOR Partnership region, with eight of the associated storage sites in the United States and three in Canada.† The remaining six active commercial projects use dedicated storage sites, three of which are located in the United States and three in Canada. In the U.S. portion of the PCOR Partnership region, seven dedicated storage projects are approved to store CO_2: six in North Dakota and one in Wyoming. These approved projects range from single-source with nearby single injector to large-volume sources or multiple sources utilizing multiple Class VI injection wells (i.e., storage hub model). In addition, North Dakota and Wyoming both require storage units and pore space access to be addressed at the time of permitting. To date, the seven approved projects consist of 11 Class VI injection well permits; eight have been issued in North Dakota and three in Wyoming.

With extensive fossil fuel resources, large-scale anthropogenic CO_2 sources, and proven geologic storage potential, the PCOR Partnership region contains the elements necessary to attract investment in essential infrastructure and widespread CCUS deployment. With financial incentives and state and national emission-reduction goals, activity in the region is at an all-time high. Thirty-five commercial-scale CCUS projects comprising 25 projects in Canada and ten projects in the United States have been announced in the PCOR Partnership region, many with anticipated construction or injection operations planned before 2034. The PCOR Partnership's engaged membership base includes the commercial, legal, regulatory, and societal stakeholders making CCUS

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† One of the Canadian storage sites is part of a cross-border project where the CO_2 is captured at the Great Plains Synfuels Plant in the United States and transported via pipeline to Canada for CO_2 EOR in the Weyburn–Midale oil fields.

a commercial reality. This industry–government partnership addresses the key business drivers motivating commercial developers as well as the current challenges facing them.

Public perception remains a significant challenge, with negative and technically inaccurate information readily disseminated via social media. Regulatory certainty, another challenge to commercial deployment, is needed to ensure continued advancements and scalability of CCUS technologies. Along with supporting a practical and comprehensive resource management regulatory framework, the PCOR Partnership played a key role in helping North Dakota secure primacy for Class VI injection well activities. This regulatory enforcement authority helped pave the way for six approved CO_2 storage facility permits, including the establishment of storage units, and eight Class VI injection well permits actively injecting. At the time of this paper, two of the three states with Class VI primacy (North Dakota and Wyoming) reside within the PCOR Partnership region.

This paper presents an overview of the PCOR Partnership and the current commercial CCUS activity in the region, discusses challenges facing CCUS in the region, and highlights important challenges that have recently been overcome to enable CCUS deployment in the region.

Keywords: carbon capture, utilization, and storage; CCS; CCUS; regional partnerships; PCOR Partnership; commercial; regulatory

1. Commercial Deployment of CCUS in the PCOR Partnership Region

The PCOR Partnership, one of the four ongoing U.S. Department of Energy (DOE) regional initiatives, covers a region comprising over 3.8 million square miles from Missouri to Alaska, including ten states and four Canadian provinces (Fig. 1).

Fig. 1. Geographic extent of the PCOR Partnership region, comprising ten states and four Canadian provinces.

The 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), excellent geology for CO_2 storage and utilization, a history of CO_2 transport and an expanding pipeline infrastructure, and an established industrial/energy commercial base. The primary targets for CO_2 storage include oil and gas reservoirs and deep saline formations within several sedimentary basins; the most prominent of these are shown in Fig. 2 and briefly described below:

- The Alberta Basin, which is on the eastern side of the Rocky Mountains in western Canada and extends from British Columbia through Alberta and Saskatchewan into Manitoba
- The Cook Inlet Sedimentary Basin, which is located from the Gulf of Alaska into southcentral Alaska, just east of the Matanuska Valley
- The Denver-Julesburg Basin, which is in northeastern Colorado; southeastern Wyoming; and parts of Nebraska, South Dakota, and Kansas
- The Greater Green River Basin, which occupies the Central Rocky Mountains in southwest Wyoming, northeast Utah, and northwest Colorado
- The North Slope Basin, which is bounded on the north by the Beaufort Sea and runs from the Canadian border to the maritime boundary with Russia in the west
- The Williston Basin, which lies along the eastern edge of the Rocky Mountains in western North Dakota, eastern Montana, and southern Saskatchewan
- The Powder River Basin, which is in southeast Montana and northeast Wyoming

For over two decades working with over 250 industry and government partners, the PCOR Partnership has focused on the integration of carbon capture, utilization, and storage (CCUS) into the existing commercial industries within the region. These PCOR partners represent key industrial sectors with a stake in CCUS deployment; numerous state, regional, and federal governmental research entities; and several state and federal regulatory agencies. Over this same period, multiple outreach initiatives have also been implemented by the PCOR Partnership and its public and private sector stakeholders to foster the public acceptance of commercial CCUS.

Additionally, federal/state policies and regulations have evolved, which has provided a clearer path and timeline for advancing commercial CCUS projects. Specific examples include the 45Q federal tax credits, which have improved the potential economics of many CCUS projects in the United States, as well as U.S. Environmetnal Protecton Agency (EPA) approval of Class VI primacy applications for two states within the region, North Dakota and Wyoming, to permit and regulate the Class VI injection wells used for the geologic storage of CO_2.[‡] Equally important, as of April 24, 2024, the urgency for commercially deploying CCUS in the region (and across the entire United States) increased as EPA published its final carbon pollution standards for existing coal-fired and new gas-fired power plants[1]. The rule, which became effective on July 8, 2024, requires all coal-fired plants intending to operate past 2039 and all new baseload gas-fired plants to employ the best system of emissions reduction to control 90% of their carbon emissions based on carbon capture and storage (CCS). With the release of these standards, EPA characterized CCS as an "available and cost-effective control technology that can be directly applied to power plants," recognizing it as a "proven add-on control technology" that represents the "best system of emission reduction (BSER) taking into account costs, energy requirements, and other statutory requirements."

[‡] Louisiana is the third state in the United States to receive primacy; however, it does not lie within the PCOR Partnership region.

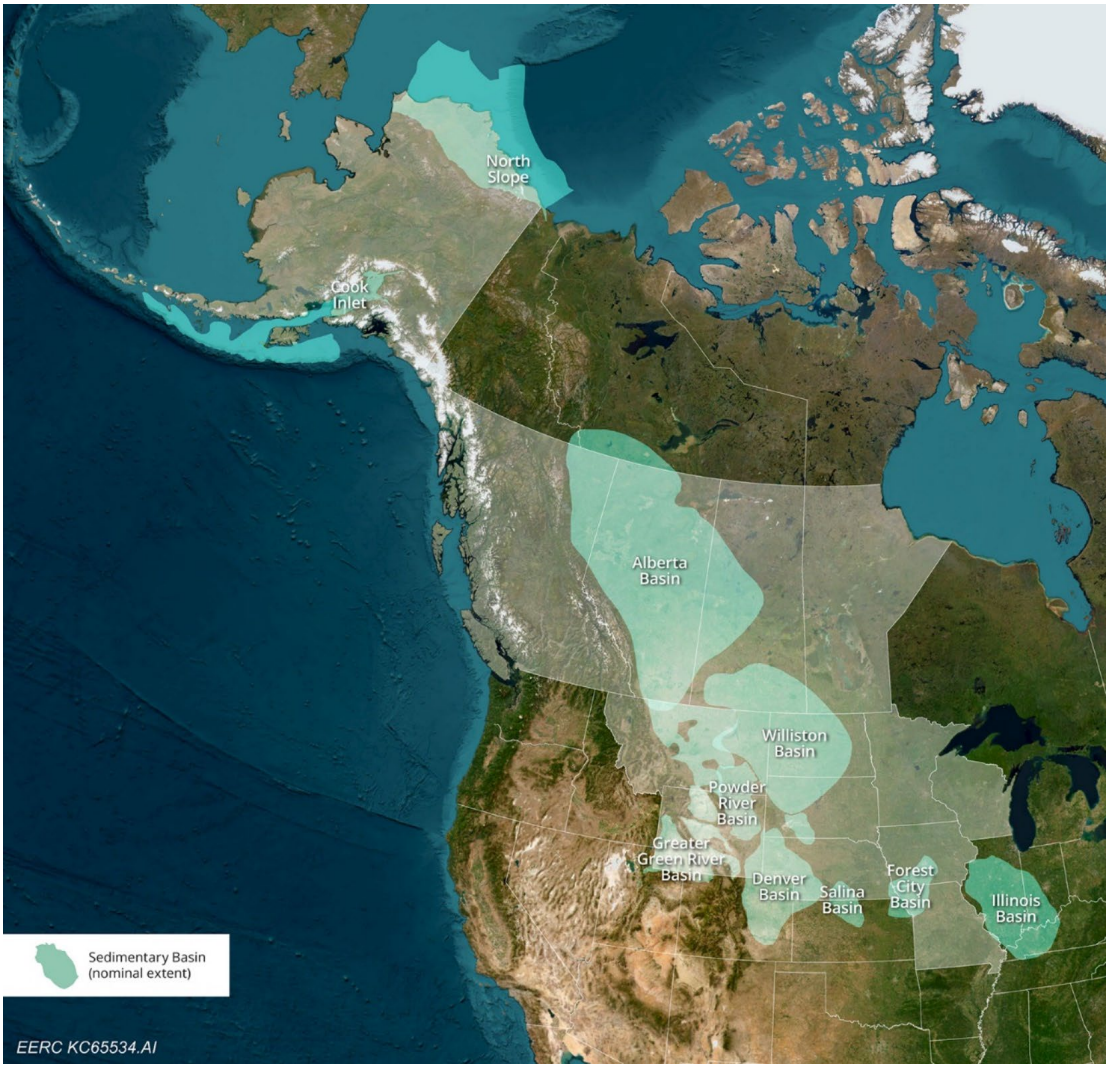

Fig. 2. Major regional sedimentary basins in the PCOR Partnership region.

EPA proposes that these standards and the installation of the necessary controls be phased in during 2030–2032. Commercial deployment of CCUS in the region is also being promoted by some of the individual states within the region, as the governors of both North Dakota and Wyoming have proclaimed that their states will achieve net-zero carbon emissions within a similar time frame. In addition, the Canadian Net-Zero Accountability Act of 2021 enshrines in legislation a commitment to reduce greenhouse gas emissions 40% below the 2005 emission levels by 2030 and net-zero emissions by 2050[2]. The commercial deployment of CCUS is a critical component of meeting these state and federal government proclamations.

Future commercial deployment of CCUS in the PCOR Partnership region will build upon the existing commercial project base that has evolved over the past 20-plus years. Fig. 3 provides an overview of the currently active/operating and partially permitted commercial CCUS projects in the region along with the commercial projects that have

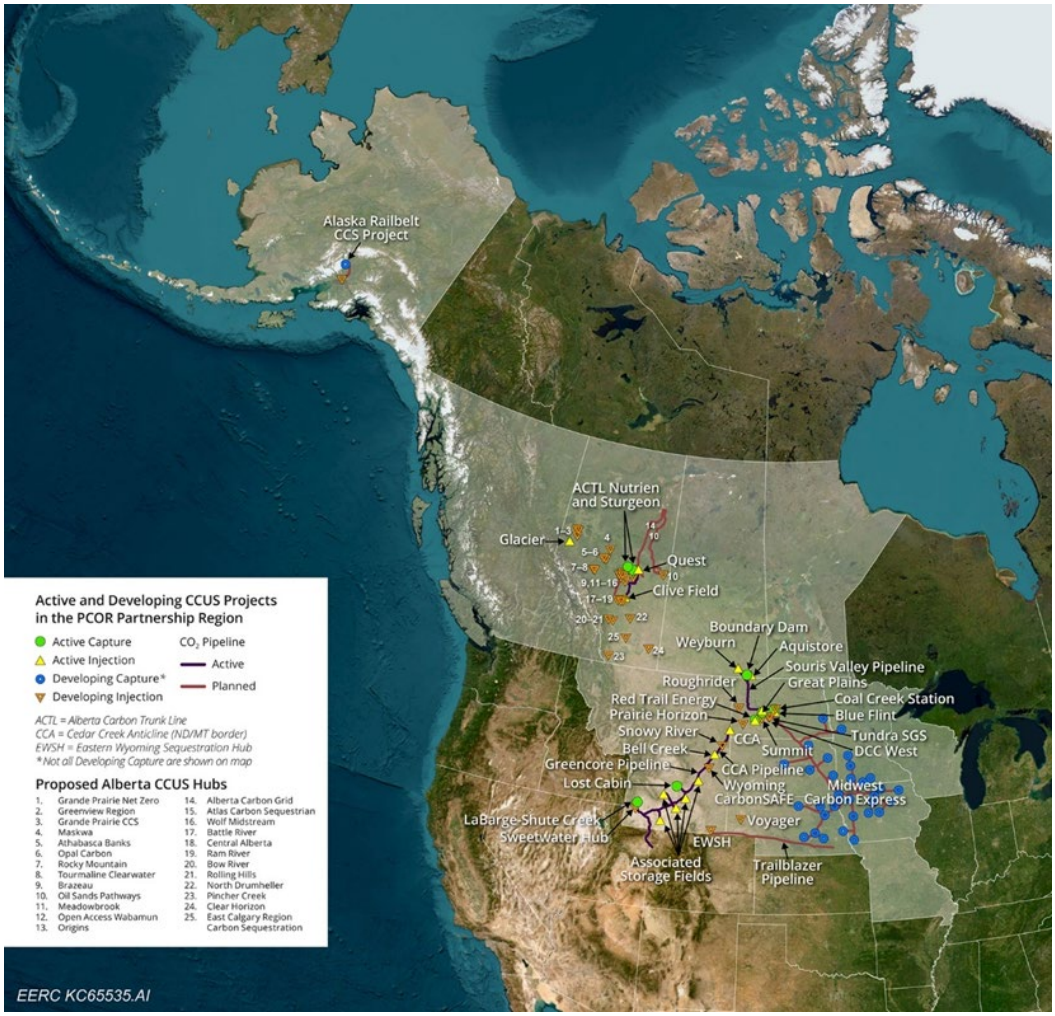

Fig. 3. Active/operating, partially permitted, and announced commercial CCUS projects in the PCOR Partnership region.

been announced.[§] In total, 56 projects, comprising 17 active/operating projects, four partially permitted projects, and 35 announced projects, are identified in Fig. 3.

[§] "Partially permitted" projects refer to the fact that CCUS projects in North Dakota and Wyoming require both a storage facility permit or permit to construct, respectively, as well as a permit to inject before CO_2 injection can begin. To operate a commercial project, both permits must have been approved; projects that have only the first-phase permit in-hand have been designated as "partially permitted" projects. Additionally, "announced" projects are in varying stages of planning, ranging from conceptual plans to completion of front-end engineering and design (FEED) studies to filing Class VI permits.

Nomenclature

ACTL	Alberta Carbon Trunk Line
CCS	carbon capture and storage
CCUS	carbon capture, utilization, and storage
CO_2	carbon dioxide
DAC	direct air capture
DOE	U.S. Department of Energy
EERC	Energy & Environmental Research Center
EOR	enhanced oil recovery
EPA	U.S. Environmental Protection Agency
FEED	front-end engineering and design
LCFS	Low-Carbon Fuel Standard
PCOR Partnership	Plains CO_2 Reduction Partnership

1.1. Active/Operating and Partially Permitted Commercial CCUS Projects in the PCOR Partnership Region

The 17 active and four partially permitted commercial CCUS projects in the PCOR Partnership region (as of 2024) are shown in Fig. 4. Eleven of the active CCUS commercial projects store CO_2 concurrently with the production of oil, i.e., associated storage, during CO_2 EOR, with eight of the associated storage sites located in the United States and three located in Canada.[**] The remaining six active commercial projects use dedicated storage sites, three of which in the United States and three in Canada.

The four partially permitted commercial CCUS projects are in the United States and are targeting the dedicated storage of CO_2. Three of these dedicated storage projects are in North Dakota and are linked to a developing project proposing postcombustion capture on a coal-fired power plant; the remaining dedicated storage project, in Wyoming, is part of a carbon storage hub for key industrial emitters across the Mountain West and direct air capture (DAC) partners.

The first of these active commercial CCUS projects was initiated in the late 1980s by gas-processing plants that captured CO_2 for transport and use in CO_2 EOR; however, these operations were not optimized to maximize the storage of CO_2. Moving forward in time, the capture of CO_2 from these and similar facilities continued to increase but with more attention on process optimization, which focused on a combination of CO_2 utilization, oil production, and CO_2 storage. Other sources of captured CO_2 that appeared in the region over this time included coal gasification plants, ethanol production plants, oil and bitumen refineries, and coal-fired power plants. Ethanol production plants and coal-fired power plants have dominated the recent landscape in the United States, whereas Canada has emphasized both coal-fired power plants and other industrial sources such as oil and bitumen refineries and ammonia production.

To support these commercial projects, more than 500 miles of commercial CO_2 pipelines in the region primarily focus on delivering CO_2 for CO_2 EOR, e.g., the Souris Valley pipeline delivering CO_2 from North Dakota to the Weyburn–Midale oil fields in southern Saskatchewan; the Salt Creek/Greencore pipeline in Wyoming delivering CO_2 to CO_2 EOR fields in Wyoming, southeastern Montana, and southwestern North Dakota; and Alberta Carbon Trunk Line (ACTL) near Edmonton, Alberta, delivering CO_2 from North West Redwater Partnership Sturgeon Refinery and Nutrien Redwater Fertilizer to CO_2 EOR fields near Clive, Alberta.

[**] One of the Canadian storage sites is part of a cross-border project where the CO_2 is captured at the Great Plains Synfuels Plant in the United States and transported via pipeline to Canada for CO_2 EOR in the Weyburn–Midale oil fields.

Fig. 4. Active/operating and partially permitted CCUS projects in the PCOR Partnership region.

1.2. Announced Commercial CCUS Projects in the PCOR Partnership Region: 2024–2034

To date, 35 commercial CCUS projects comprising 25 projects in Canada and ten projects in the United States have been announced in the PCOR Partnership region (Fig. 5), with many of these slated to begin construction or injection operations by 2034. Unlike the commercial development to date, this next generation of commercial CCUS projects in the PCOR Partnership region is dominated by the dedicated storage of CO_2. This shift in commercial activity to dedicated storage has been occurring in the U.S. portion of the region largely because of the investments of the federal government (i.e., the DOE CarbonSAFE projects and the funding provided by the Infrastructure Investment and Jobs Act, otherwise known as Bipartisan Infrastructure Law) and the 2022 enhancements to the 45Q tax credits, which are greater for dedicated storage [3]. Another driving force in the region is the movement in Canada to develop a hydrogen economy, which requires rapidly scaling up the production of blue hydrogen.

Commercial CCUS development is driven in the United States by ethanol production facilities. These facilities, which are relatively small emitters of CO_2, are moving toward sharing critical infrastructure, such as CO_2 pipelines and storage operations, as a means of cost-effectively storing CO_2 and producing ethanol that meets the Low-Carbon Fuel Standards (LCFSs) of the West Coast. In Canada, the province of Alberta is leading the way on the development

Fig. 5. Announced commercial CCUS projects in the PCOR Partnership region.

of CO_2 storage hubs as part of its hydrogen road map. Alberta has introduced the concept of CO_2 storage hubs and put a process in place where companies can apply to the government for the right to inject CO_2 while ensuring open and affordable access is provided for the hub's use. Alberta is allocating carbon sequestration rights through a competitive process. As part of this carbon sequestration tenure management process, six evaluation agreements were awarded by the provincial government in March 2022, with a focus on the decarbonization of the Industrial Heartland emitters around Edmonton; an additional 19 evaluation agreements were awarded in October 2022 to address the areas outside of the Industrial Heartland area. While there is no guarantee that all these agreements will move forward, this approach has many advantages including the collaboration that it fosters for the decarbonization of industrial hubs as well as the increased efficiency and lowering of the costs of pore space use. These benefits could grow commercial CCUS deployment at the basin scale and throughout the PCOR Partnership region.

Pipeline development efforts are a critical component of infrastructure required to support carbon storage hubs such as those proposed in PCOR Partnership region. Efforts in the region are in place to investigate this potential barrier to commercial deployment at both an individual project level and on a more regional scale, including the potential to extend the efforts of Wyoming, which has designated CO_2 pipeline corridors under the Wyoming Pipeline Corridor Initiative, to lay the groundwork for CCUS project expansion across the entire region.

In summary, this next round of commercial CCUS deployment in the PCOR Partnership region will focus on the development of carbon storage hubs and the deployment of CO_2 pipelines as critical components of the infrastructure required for this approach to commercial growth and expansion. Storage hubs also have the advantage of facilitating pore space management at the basin scale, a major concern of DOE, as more and more projects begin to compete for pore space within those basins that offer the best geologic opportunities for CO_2 storage. A mixture of dedicated and associated storage will continue to be developed, although the current tax policies are clearly increasing interest in dedicated storage over associated storage in contrast to the past commercial activity in the region.

Moving forward, CO_2 capture at coal- and natural gas-fired power plants is likely to increase across the region as the recent EPA regulations are implemented. At the same time, CO_2 capture at gas-processing facilities will likely continue to grow as these facilities expand, as will CO_2 capture and storage at ethanol facilities, given the combined incentives associated with meeting the LCFSs of the West Coast and other developing low-carbon markets, and the current 45Q tax credits. The driving force in Canada is likely to be its shift to a hydrogen economy, which will focus on the production of blue hydrogen from the natural gas reserves of Alberta.

1.3. Announced Commercial CCUS Projects in the PCOR Partnership Region: 2024–2034

Other potential, but more speculative, commercial CCUS opportunities have been identified for the region over the time horizon from 2024–2034. To date, the following types of commercial CCUS projects are deemed possible and are being explored for commercial deployment:

- Direct ambient air capture of CO_2 followed by its conversion into synthetic fuels in Canada
- CO_2 capture from gas-processing plants in Alaska followed by pipeline transport for associated storage during CO_2 EOR on the North Slope
- CO_2 capture from multiple ethanol plants in Iowa, Minnesota, Nebraska, North Dakota, and South Dakota followed by pipeline transport for utilization and/or dedicated geologic storage in saline aquifers (including stacked storage) in the Williston and Denver-Julesburg Basins
- Installation of key commercial CO_2 pipelines to facilitate the anticipated growth and expansion of a commercial CCUS industry

Other than DAC, these potential future commercial CCUS projects include the use of known capture and storage technologies; however, their application in challenging environments, e.g., Alaska, and the viability of the business model for combining the CO_2 captured from multiple ethanol plants for transport through a common pipeline to a CO_2 storage hub require further investigation. In addition, the full implementation of the recently promulgated New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil-Fuel Fired Electric Generating Units, combined with any new policy and/or financing incentives that are put in place, may result in the evolution of other viable business models to advance the commercialization of CCUS in the region.

2. Challenges/Opportunities Associated with the Continuation of the Commercial Growth of CCUS in the PCOR Partnership Region

Commercial deployment of CCUS has been in progress for many years. The first 30 years were largely organic, predominantly relying on a resource recovery business model with collaboration arrangements for either the transportation or storage operators or both. Toward the end of that period, the green growth and low-carbon grid business models began to materialize. The former evolved as a market and began to develop on the West Coast for low-carbon fuels, such as ethanol produced from plants outfitted with CCUS, and blue hydrogen was produced to convert Canadian oil sands bitumen into synthetic crude for refining into fuels and other products. Other blue hydrogen projects involving a refinery and fertilizer plant were also spawned in Canada, serving as anchor projects for the ACTL system that transports the captured CO_2 to CO_2 EOR operations. Lastly, Unit 3 of SaskPower's Boundary Dam coal-fired power plant installed a fully integrated postcombustion CCUS facility, making it the only CCUS facility

operating on a coal-fired power plant at that time. The CCUS operation projected a 90% capture rate of CO_2 emissions, extending the life of the plant by 30 years.

Another indication of the current commercial CCUS activity in the region is the number of approved Class VI permits. For example, in addition to the three dedicated storage projects operating in the U.S. portion of the PCOR Partnership region, an additional four commercial dedicated storage projects have been permitted to store CO_2 (three in North Dakota and one in Wyoming). These projects range from single-source with nearby single injector (Red Trail Energy) to large-volume sources with multiple injection wells (Dakota Gasification Company). At the time of this report, Summit Carbon Solutions has three pending storage permits in North Dakota and multiple pending CO_2 pipeline routing permits for a project targeting the aggregation of multiple sources, transporting CO_2 via multistate pipeline network, and utilizing multiple Class VI injection wells. In addition, North Dakota and Wyoming both require storage units and pore space access to be addressed at the time of permitting. To date, the seven approved projects consist of 11 Class VI injection well permits; eight Class VI permits have been issued in North Dakota and are actively injecting, and three Class VI well permits have been approved in Wyoming.

This pattern of commercial deployment of CCUS projects demonstrates the technical readiness of CCUS technology as well as the ability to secure permits for its construction and operation in the PCOR Partnership region. However, the recent urgency of the trend toward deep decarbonization to meet power sector regulations and net-zero emission targets as early as 2035 requires faster commercial growth and expansion of CCUS.

2.1. Commercial Roadblocks and Hurdles to the Growth of CCUS

Based on a review of the barriers to the commercial deployment of CCUS, four primary roadblocks exist to growing commercial CCUS for the deep decarbonization of the PCOR Partnership: 1) government/regulatory, 2) technical, 3) financial/market, and 4) public perception. These four categories are interconnected. For example, removing roadblocks/hurdles to reduce permitting costs and timelines will improve the financial viability of projects which, in turn, would lead to further commercial deployment. Additional commercial applications would improve the understanding of the technology through the process of "learning by doing" and even further reduce costs. Successful commercial operations would also increase the confidence of the public in the use of CCUS. The previous success of the commercial deployment of emissions control technologies for sulfur and nitrogen oxides provides evidence that such learning-by-doing cost reductions are possible for CCS technologies as well [4].

Some solutions to overcoming the roadblocks/hurdles in each of the above categories are as follows [5]:

<u>Government/Regulatory</u>

- Make legislative and regulatory changes that accelerate the build-out of CO_2 pipelines, e.g., expediting CO_2 pipeline permitting and development.
- Address Class VI permitting cost and timeline challenges by:
  1. Developing an expedited process for delegating primacy to states given that EPA may not have the resources to manage an influx of Class VI applicants.
  2. Allowing area permits for multiple CO_2 injection wells instead of requiring permits for individual wells.
  3. Moving to site-specific, risk-based assessments of Class VI wells similar to the statutory standards imposed by the Safe Drinking Water Act.
  4. Basing closure of a carbon storage facility on a demonstration of a stable CO_2 plume and modifying or eliminating the 50-year postinjection site-care period.
  5. Allowing monitoring flexibility by emphasizing indirect monitoring over direct monitoring (i.e., dedicated monitoring well[s]), which would drive technology innovation, minimize the potential for creating possible leakage pathways, and potentially reduce project costs.
  6. Allowing underground injection control Class VI permits for CCUS demonstration projects.
  7. Allowing for new aquifer exemptions and the use of existing aquifer exemptions for Class VI injection.

Technical

- Expand the funding of research and development of advanced CCUS technologies such as catalysts, chemical looping, membranes, and solvents.

Financial/Market

- Establish a means of assigning the tax credits for those that capture the CO_2 to those parties that store or utilize the CO_2 in permitted applications.
- Provide loan guarantees to project investors and cost-sharing of FEED studies.

Public Perception

- Focus efforts on strategies to gain public acceptance for the full CCUS value chain (e.g., CO_2 pipeline infrastructure).
- Show economic benefits and value (e.g., job creation and retention, new economic opportunities, the development and sale of low-carbon marketable products) of CCUS at the local, state, and regional levels.
- Provide fact-based, science-based information on safe transport and storage, how CCUS can contribute to local and state economies, and the potential benefit for monetizing pore space resources.

The investigation of various aspects of these solutions is already in progress within the PCOR Partnership region. For example, both North Dakota and Wyoming have already been granted Class VI primacy by EPA, and efforts to create a well-defined permitting process and reporting templates for CCUS projects based on the permits that have been submitted and approved and are under consideration. As part of the current permits, North Dakota has permitted projects by addressing pore space property rights through amalgamation (for dedicated storage) and has established provisions for the transfer of regulatory responsibility for long-term caretaking and monitoring of a closed site starting at 10 years postinjection. In addition, the PCOR Partnership has performed life cycle analyses of selected CCUS commercial operations using state-of-the-art conventions established by the DOE National Energy Technology Laboratory; is advancing the use of risk-based approaches for establishing the area of review for Class VI permitting; and, through the Wyoming Pipeline Corridor Initiative, is investigating strategies associated with expanding the rights of way for CO_2 pipelines on private, state, and Bureau of Land Management-managed lands in Wyoming.

At the same time, three of the states within the PCOR Partnership region (North Dakota, Wyoming, and Montana) also have in place tax incentive programs to complement the federal 45Q tax credits. These incentives include state tax credits and exemptions for an array of taxes, such as property taxes, severance taxes, gross receipt taxes, and sales taxes [4].

2.2. Continuation of the Growth of the Commercial Deployment of CCUS in the PCOR Partnership Region

An “all of the above” approach is needed to tackle the rapid decarbonization of the world’s economy. Given the goal of decarbonization, high reliability, and low cost, CCUS-mitigated fossil fuels are an existing solution that must be supported both nationally and within the PCOR Partnership region to address the gap that remains between projected CO_2 reductions and the publicly stated goals of political leaders [5].

Building on the current commercial efforts, the pace of the growth of the commercial deployment of CCUS in the PCOR Partnership region will be increased, to the extent possible, to maximize its contribution to achieving the current decarbonization objectives of the region from 2024 through 2034. This will be done by 1) facilitating the deployment of the current commercial CCUS projects that are in the planning stages (Section 1.2) and 2) more thoroughly investigating and addressing the regional knowledge gaps in several areas, including the capture of CO_2, advanced geologic characterization of onshore carbon storage, targeted characterization of associated storage from conventional and unconventional CO_2 EOR, active reservoir management, regional pipeline infrastructure, and risk assessment and

management tools. These efforts will be implemented keeping in mind the following guiding principles for large-scale CCS development [3]: 1) adopting a portfolio approach to development, 2) encouraging development of a supporting infrastructure, 3) recognizing the value of information and mitigating uncertainty, 4) acknowledging the absence of firm legislative guidance, 5) affirming the roles of multiple stakeholders, and 6) ensuring that basic research can maintain a concurrent track with commercial development.

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