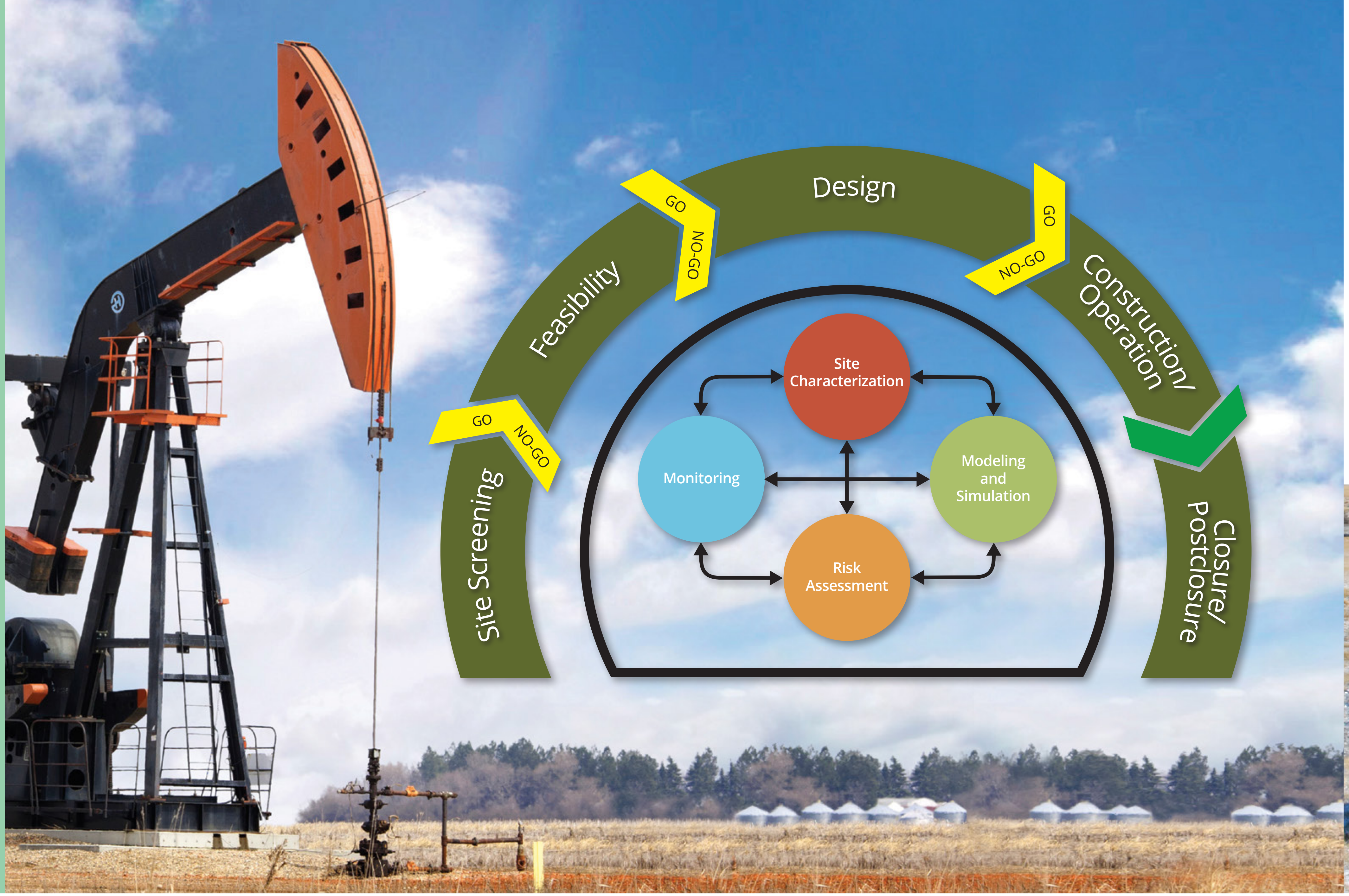
CHAPTER 5

TAKING ACTION

The pathway to developing a commercial CCUS project includes an iterative assessment of a prospective CO_2 storage location and moving efficiently through the permitting process. Several commercial CCUS projects are active in the PCOR Partnership region, with these projects containing combinations of CO_2 capture, transportation, dedicated and associated storage, EOR, and production of low-carbon fuels. The lessons learned from these projects at all stages of development are a catalyst to support future commercial CCUS development in the region.

PHILOSOPHY OF APPROACH

The PCOR Partnership employs a philosophy that integrates site characterization, modeling and simulation, risk assessment, and MVA strategies into an iterative process to produce meaningful results for large-scale CO_2 storage projects. Elements of any of these activities are crucial for understanding or developing the other activities. For example, new knowledge gained from site characterization reduces uncertainty in geologic reservoir properties. This reduced uncertainty can then propagate through modeling, risk assessment, and MVA efforts. Because of this process, the PCOR Partnership Program is in a strong position to refine characterization, modeling, risk assessment, or MVA efforts based on the results of any of these activities and has produced a best practices manual for this adaptive management approach.

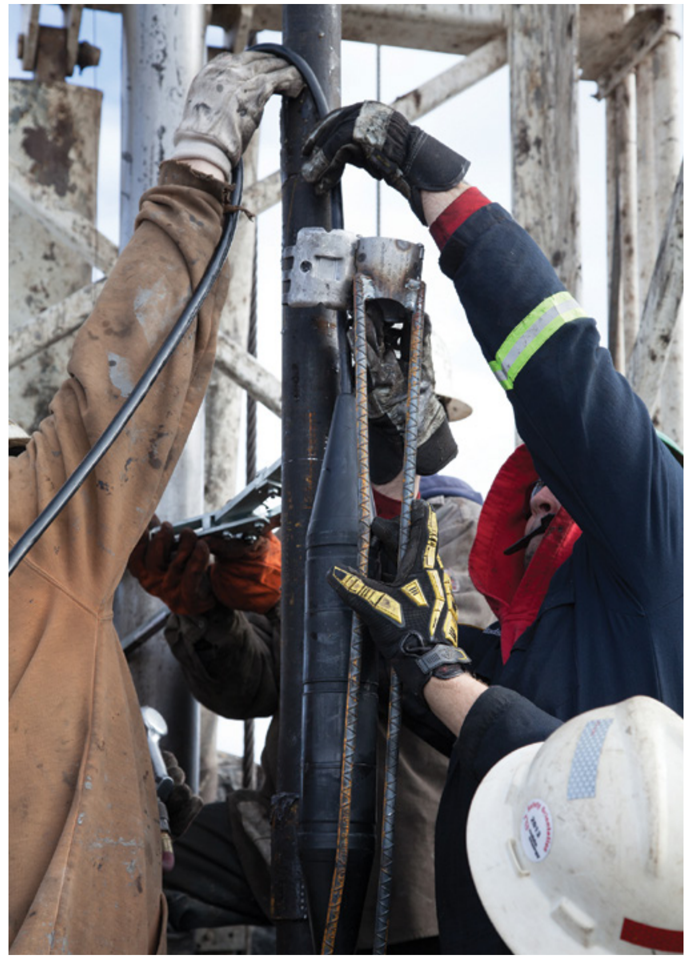


SITE CHARACTERIZATION

Site characterization comprises collection, analysis, interpretation, and application of data to understand CO_2 storage potential and assess factors that could impact CO_2 storage project performance. Data collection methods range from accessing existing reports and documentation available from public and private sources to using a wide array of field technologies for determining or measuring various geologic/physical/chemical properties of subsurface and surface environments.

Site characterization activities serve as direct inputs into the various modeling and simulation activities to better predict CO_2 migration pathways, assess technical subsurface risks, and aid in the monitoring of CO_2 migration in the subsurface. These elements of the project help evaluate expected and actual performance during commercial-scale CO_2 injection, storage, and EOR.

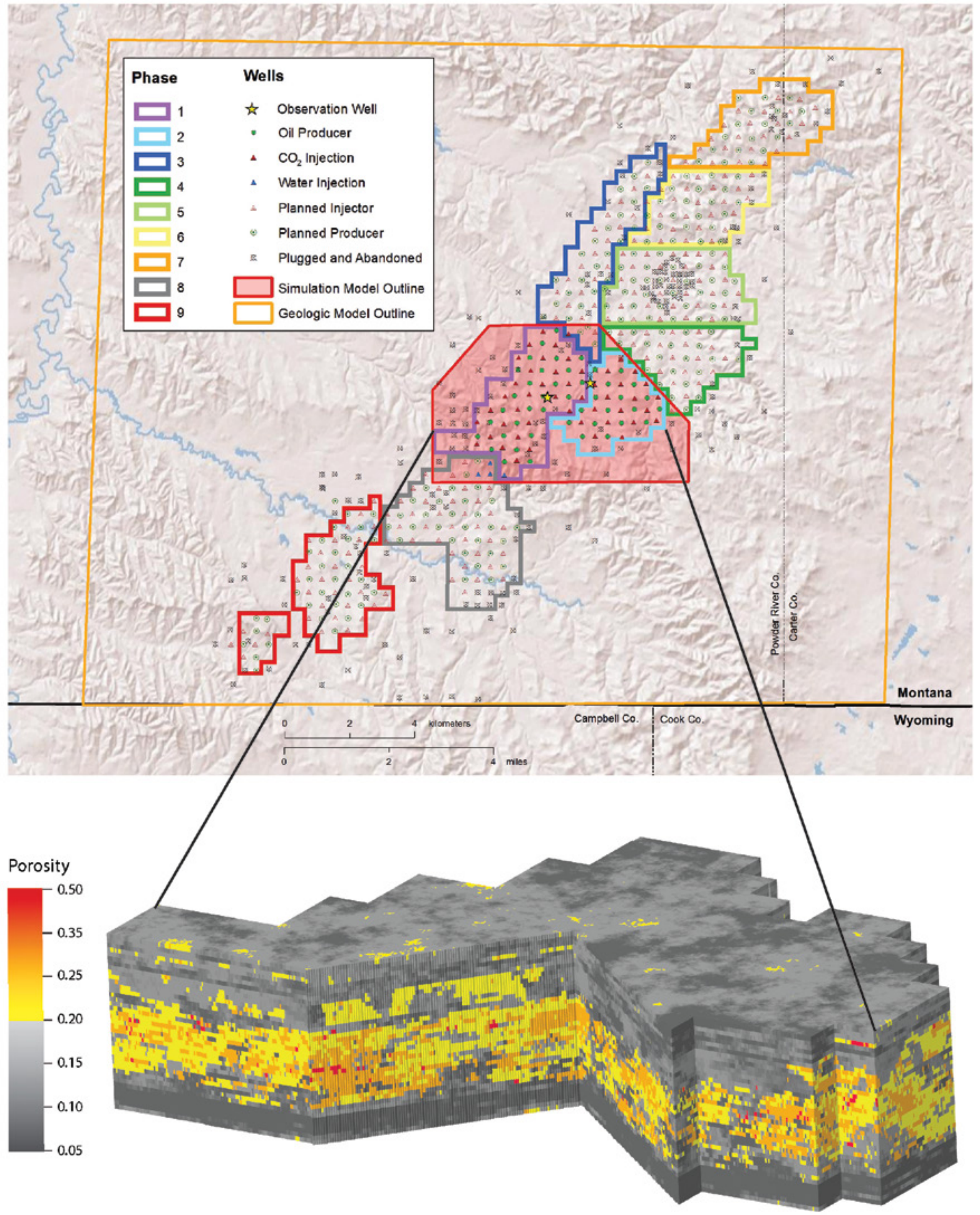
Site characterization objectives and associated activities are largely driven by project- and site-specific risk and uncertainty and the need to inform site design and operation. Depending on the project phase, several different types of data may be collected, including petrophysical, mineralogical, geomechanical, and geochemical. Data acquisition occurs throughout the entire project, although the intensity of the effort and the characterization techniques employed vary with the different phases of the project.



A geologic model is a computerized 3D rendering of the subsurface that provides a digital framework of CO_2 reservoir complexities, critical to understanding CO_2 storage. The model provides a 3D understanding of the storage horizon and associated cap rock to allow design and implementation of a CO_2 injection project. Common components of geologic models include information generated from site characterization activities, with estimates of rock properties (e.g., rock type, porosity, permeability) and structural framework (i.e., geologic surfaces, geologic layers, faults).

Predictive multiphase fluid flow simulations, geomechanical modeling, and geochemical simulation are used to interpret and analyze the geologic, reservoir, and fluid data and conduct predictive multiphase flow, geomechanical, and geochemical simulations to identify data gaps, identify potential risks, and guide the MVA program.

Geologic models serve as the basis for the fluid flow simulations to predict the subsurface extent of the injected CO_2 and the potential pressure effects associated with storing CO_2. These predictions are important for the design of a CO_2 storage system, assessment of project risks, and design and interpretation of the results of a monitoring and accounting program. Geomechanical and geochemical simulations are also conducted to identify potential risks and guide monitoring programs.



Muddy Sandstone (Bell Creek Field reservoir)

Risk assessment is a vital component of the adaptive management approach for CO_2 storage project development.

Risk is the severity of negative consequences of an event weighed against how likely those consequences are to occur. In the context of a CO_2 storage project, risks can affect operational performance and long-term reliability of CO_2 storage. Risk assessment is the iterative process of identifying, analyzing, and evaluating potential project risks.

For over a decade, the PCOR Partnership has conducted risk assessments for CO_2 storage projects in ways consistent with international standard protocols.[40–43] These best practices provide reliable methods for identifying project-related risks, including analyzing probability and potential impacts and evaluating risk treatment and priority.

Identifying and assessing potential risks for a CO_2 storage project start early in the development of a project when the project team identifies and evaluates potential risks grouped into broad categories (e.g., capacity, injectivity, and lateral and vertical migration).[44] These risks are refined over time as more data become available.

Risk assessment outcomes inform CO_2 storage project development through every phase. Additionally, the risk assessment informs the monitoring, reporting, and verification (MRV) plan for a CO_2 storage project, ensuring higher-ranking risks are being monitored by one or more measurements.

ESTABLISH THE CONTEXT

- Define the storage project.
- Define the storage facility and storage unit(s).
- Define the risk criteria that will be used to evaluate the identified risks.

RISK IDENTIFICATION

- Use an independent risk management expert to facilitate the process.
- Elicit input from project stakeholders and subject matter experts.
- Generate a functional model of the storage complex.
- Identify potential risks that would negatively impact the storage project.
- Ensure that the following four technical risk categories are considered:
  - Storage capacity
  - Injectivity
  - Lateral and vertical containment of CO_2 and formation fluids
  - Induced seismicity
- Thoroughly document each potential risk, and generate a risk register.

RISK ANALYSIS

- Develop a set of quantifiable physical consequences and a means to link these to project impacts.
- Consult the available site characterization, geologic modeling, and reservoir simulation results.
- Evaluate predictive simulations to forecast storage project performance during CO_2 injection.
- Capture risk probability and impact scores from subject matter experts.
- Quantify uncertainty in the risk scores.

RISK EVALUATION

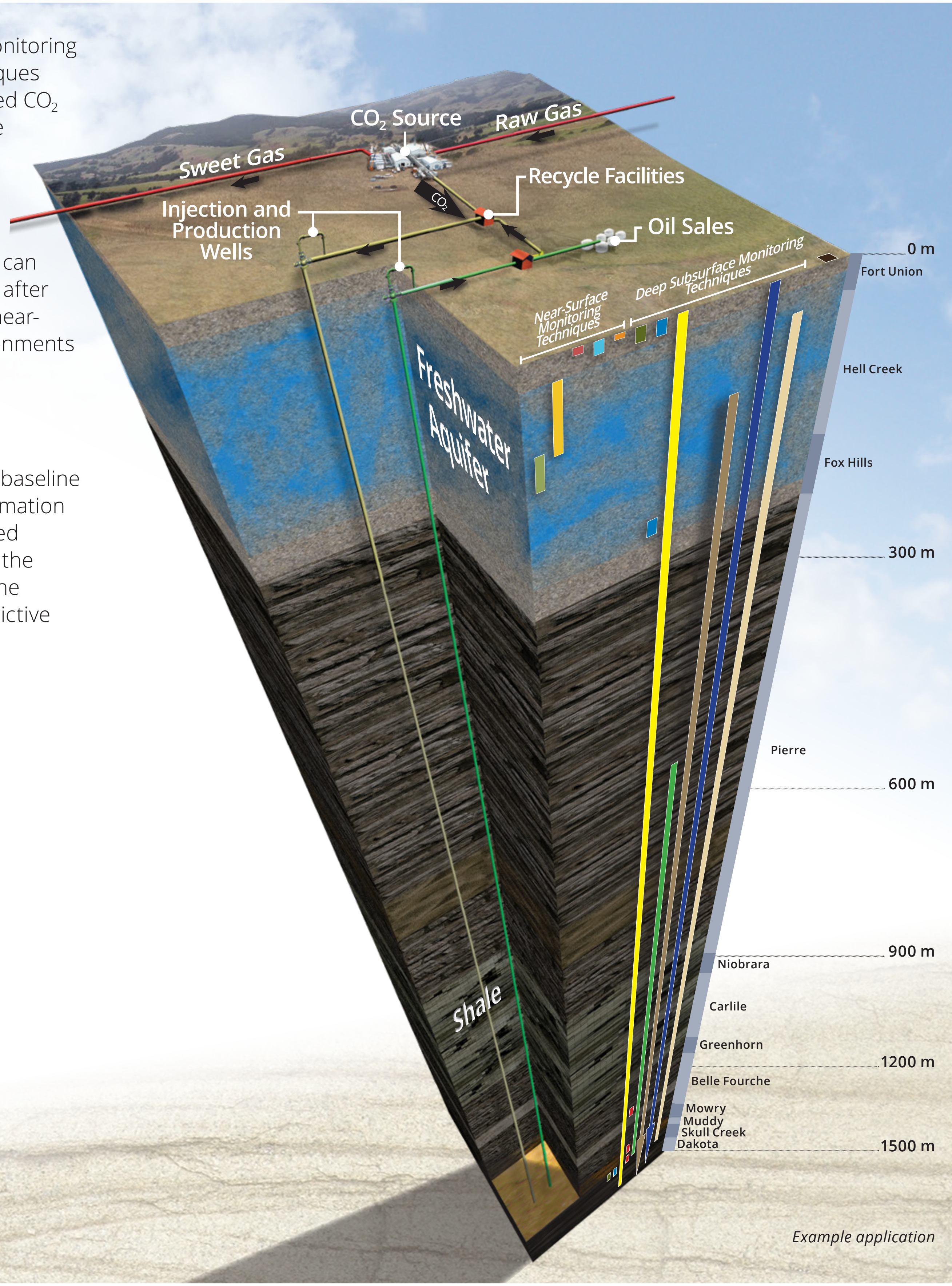
- Plot each individual risk onto a risk map, and evaluate uncertainty in the risk scores.
- Identify moderate and high-ranking risks.
- If a more quantitative evaluation is needed, then employ a probabilistic method such as Monte Carlo simulation or Bayesian methods.

MONITORING, VERIFICATION, AND ACCOUNTING

MVA is the combination of monitoring technologies and techniques used to track the migration of injected CO_2 as well as to confirm that the surface and subsurface environments are not negatively impacted by injection activities.

A variety of monitoring technologies can be implemented before, during, and after injection operations in the surface, near-surface, and deep subsurface environments at a CO_2 storage site.

MVA data collected before injection operations (often as part of the site characterization process) serve as a baseline framework for the storage site. Information collected after injection begins is used to monitor the dynamic response of the system and provide feedback to refine the geologic model and update predictive simulations.



Example application

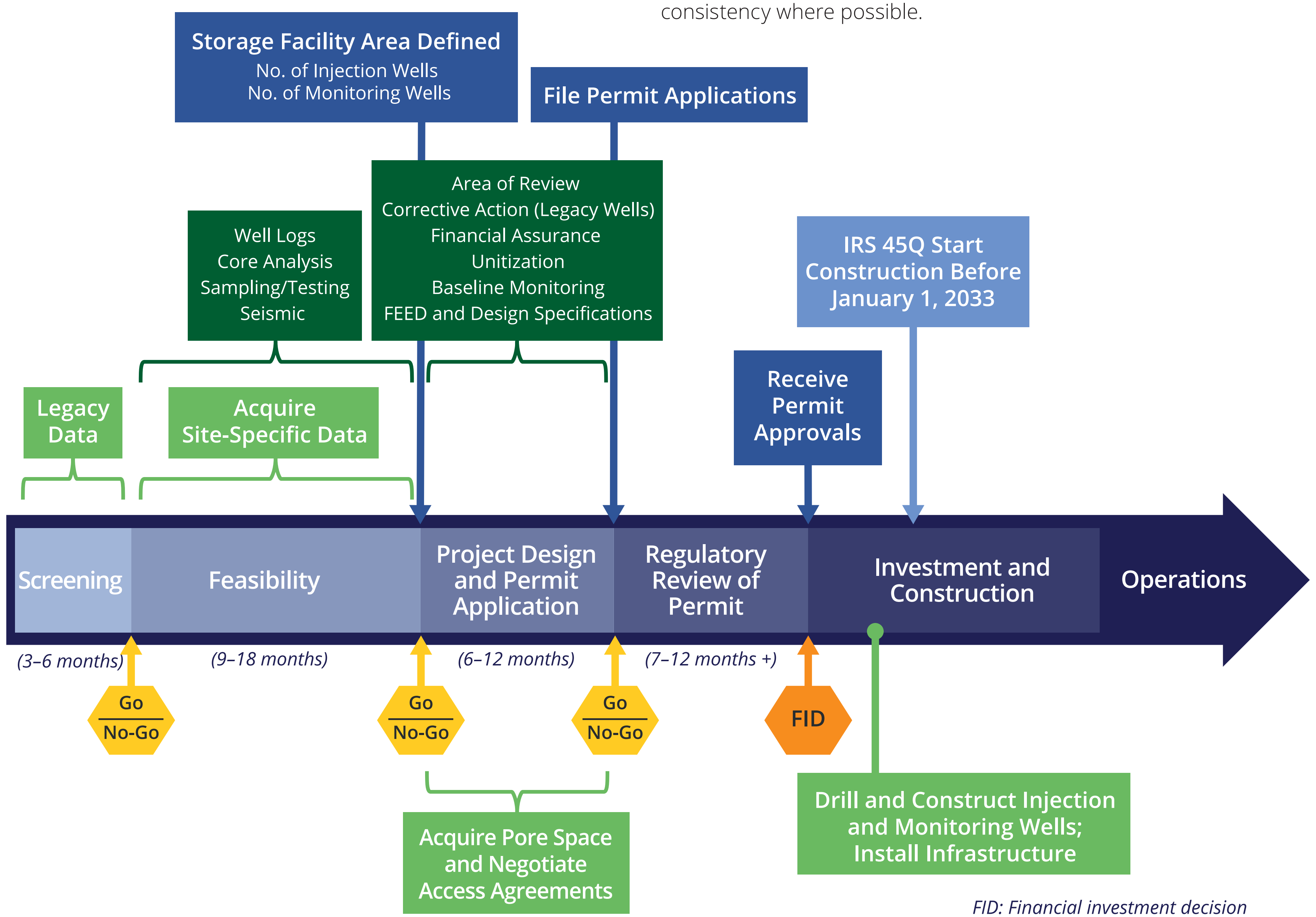
- Fox Hills Groundwater Wells
- Groundwater Wells
- Surface Water
- Soil Gas Profile Stations
- Soil Gas Probes
- Production and Injection Rates
- Wellhead Pressure Monitoring
- Temperature PDM*
- Pressure PDM
- 3D Time-Lapse VSP**
- 3D Time-Lapse Seismic
- Passive Seismic Monitoring
- Neutron Logging
- InSAR***

* Permanent downhole monitoring.
** Vertical seismic profile.
*** Interferometric synthetic aperture radar.

A PERMITTING PROCESS

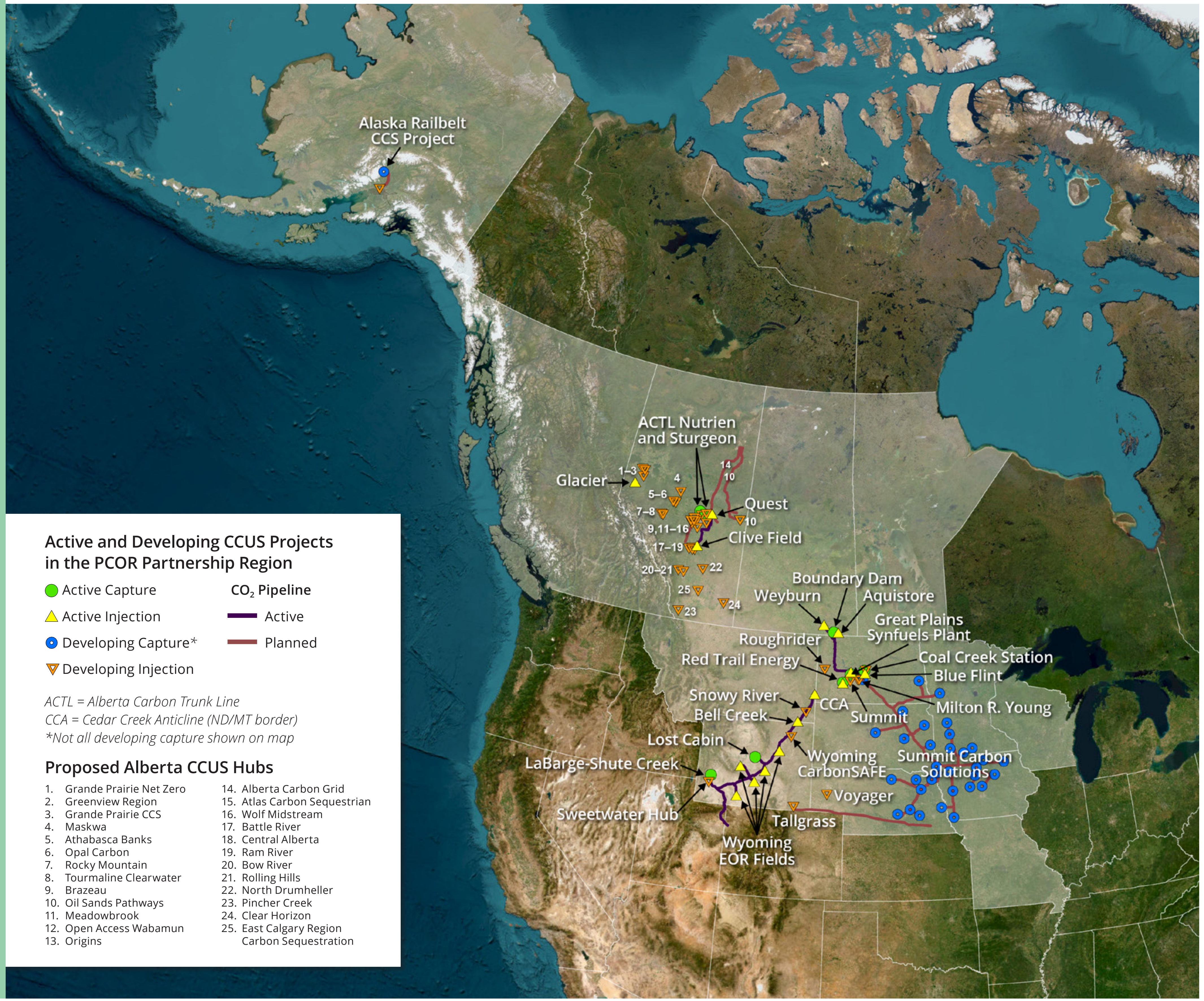
Permitting considerations for a CO_2 storage project are important, even at the earliest stages of project development. Data and information about project feasibility and geologic suitability of the potential storage site(s) will eventually be used to support the permits needed to store CO_2. The figure below shows the CCUS project development and permitting process for North Dakota, which begins with gathering of any existing data in or near the site(s) of interest.

Although this figure is specific to North Dakota, the general progression of the process, as well as the geologic and project data required, is commensurate with other jurisdictions. Reducing the time to develop CCUS permit applications, length of time for regulatory review, and issuance of a final decision will help accelerate commercial deployment of CCUS. The PCOR Partnership is engaging with regulators and project developers throughout the region and beyond to support the permitting process and find ways to promote permit application consistency where possible.



FID: Financial investment decision
FEED: Front-end engineering and design

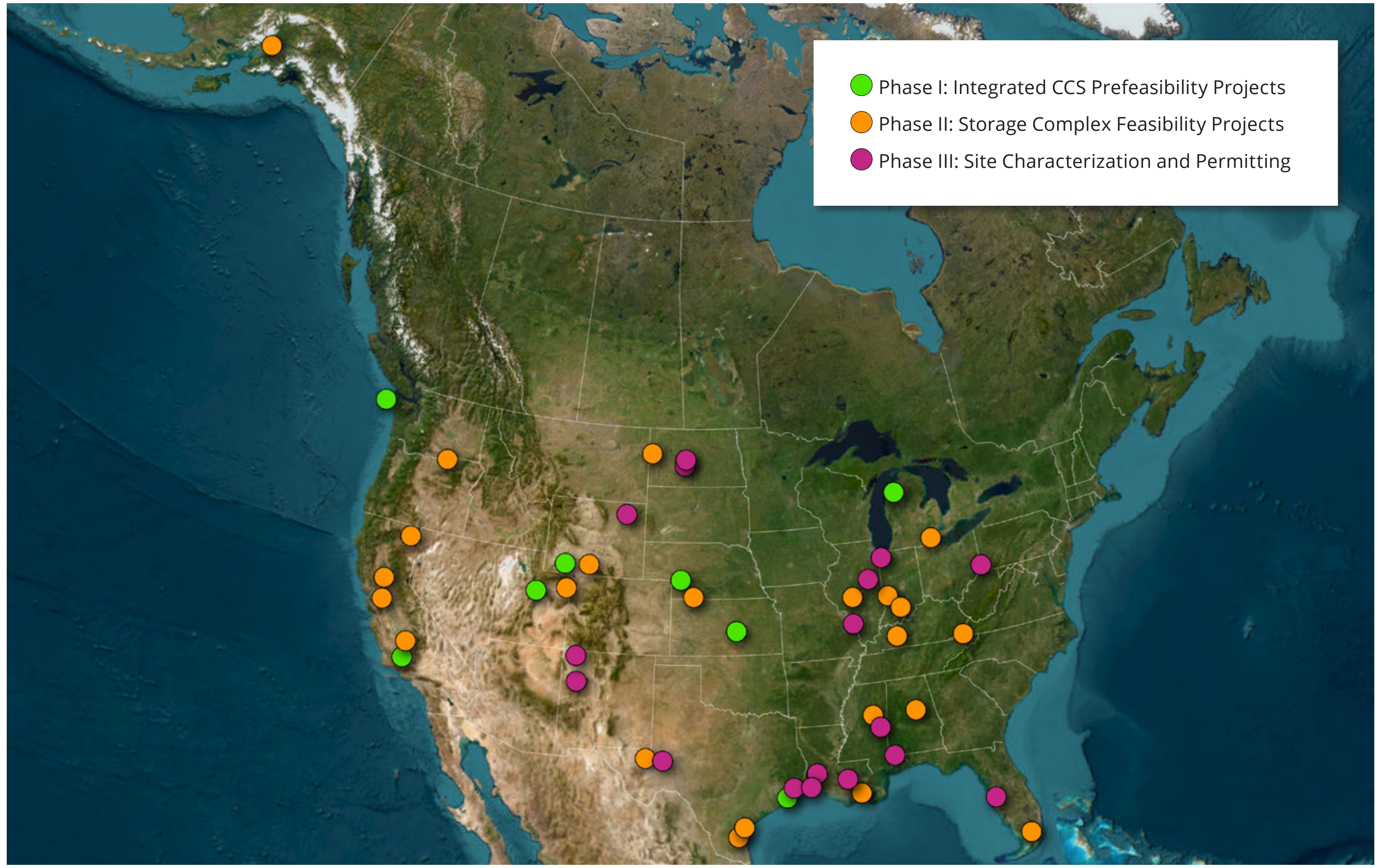
ACTIVE AND DEVELOPING CCUS PROJECTS



CARBONSAFE PROJECTS ACROSS THE UNITED STATES

The CarbonSAFE Initiative began in 2016 with the goal of addressing the key gaps on the critical path toward CCUS deployment. Building upon the knowledge and experience of RCSP efforts, this initiative is performing identification and detailed characterization of geologic storage sites. The vision of CarbonSAFE is to understand the development of a CCUS storage complex from the feasibility study until the point of injection through the following phases of project progress: integrated CCUS prefeasibility, storage complex feasibility, site characterization and permitting, and construction. CarbonSAFE will reduce technical risk, uncertainty, and the cost of commercial-scale saline storage projects. Results will improve the understanding of project screening, site selection, characterization, baseline MVA procedures, and information necessary to submit appropriate permit applications for such projects.

The CarbonSAFE effort contributes to furthering the development and refinement of technologies and techniques critical to the characterization of potential storage complexes over 50 million metric tons. Project research will provide insight into the integration of site characterization information into reservoir simulations and design of injection and monitoring strategies. The progress made by CarbonSAFE will instill greater confidence that commercial-scale CCUS projects can be integrated in a technically and economically feasible manner.[45]

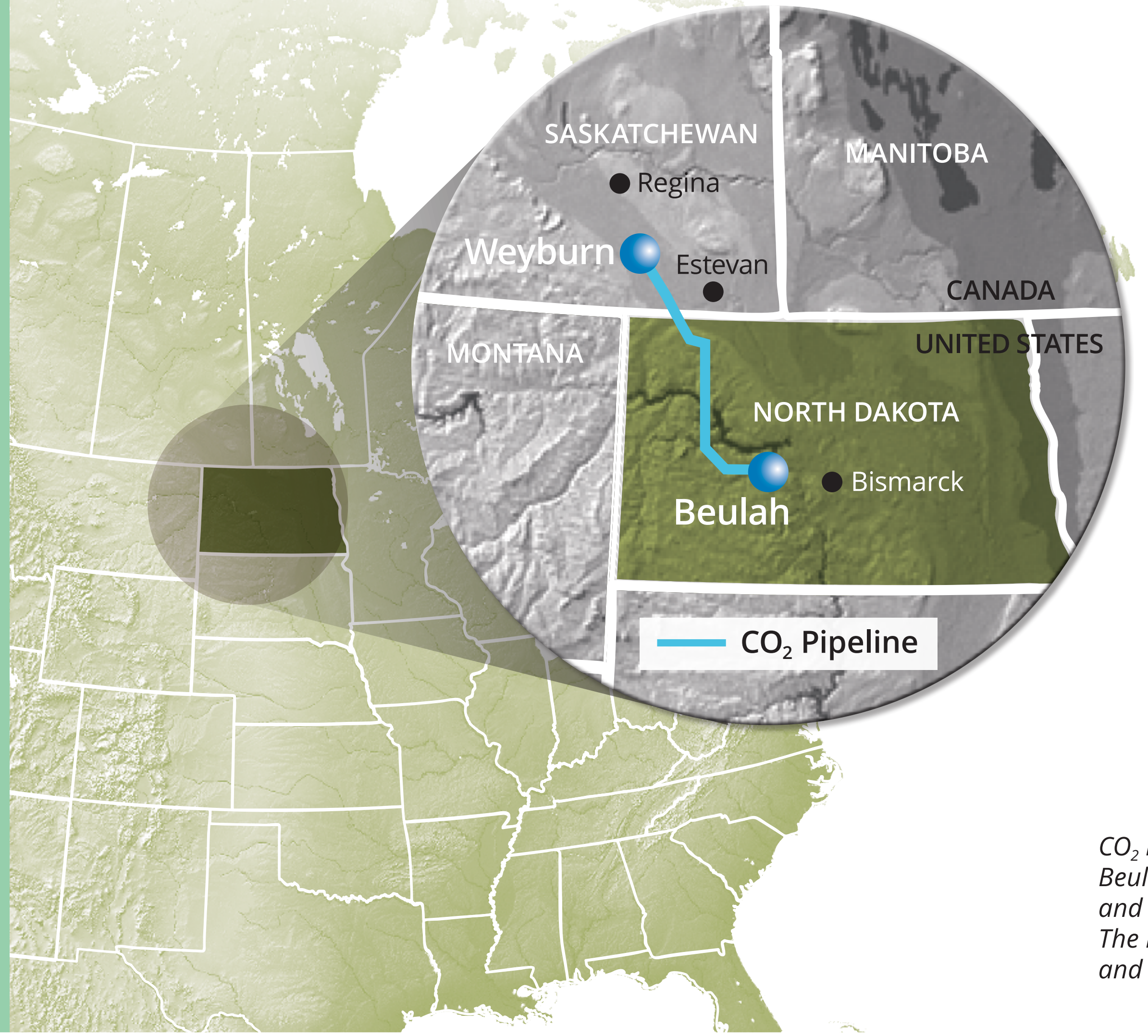


CO_2 CAPTURE AT GREAT PLAINS SYNFUELS PLANT

The majority of the CO_2 used in the Weyburn–Midale EOR project comes from Dakota Gasification Company's (DGC's) Great Plains Synfuels Plant, the only commercial-scale coal-to-natural gas facility in the United States. In November 2020, the synfuels plant reached a milestone: capturing 40 million metric tons of CO_2 since 2000. Approximately 2 million metric tons of CO_2 is captured each year, making it one of the largest carbon capture facilities in the world.[46]

DGC and its Canadian subsidiary, Souris Valley Pipeline Ltd., operate a 205-mile pipeline to transport the CO_2 from the synfuels plant in Beulah, North Dakota, to the Weyburn and Midale oil fields in southeasern Saskatchewan for EOR. CO_2 EOR at Weyburn has stored 36 million metric tons of CO_2 to date.[47]

In July 2020, during the COVID-19 pandemic, DGC shipped its first beverage-grade CO_2 captured from the Great Plains Synfuels Plant's ammonia production facility; the shipment was for the commercial food and beverage industry. The first load was used to help balance pH levels in the water at water treatment plants in North Dakota. In December 2020, DGC worked with the North Dakota Department of Health to provide beverage-grade liquefied CO_2 to aid in keeping the COVID-19 vaccine at the recommended storage temperature.[46]



CO_2 is captured from DGC's Great Plains Synfuels Plant in Beulah, North Dakota, and piped 330 km into the Weyburn and Midale oil fields in Saskatchewan, Canada, for EOR. The injection location covers an area of 21,000 hectares and produces 23,000 barrels of oil a day.[47]

CO_2 MONITORING AND STORAGE PROJECT

Injection of CO_2 for EOR purposes began in the Weyburn oil field in 2000 and at the Midale oil field in 2005. The Weyburn Field was operated by Cenovus Energy until 2017, when it sold its majority stake in the project to Whitecap Resources.[48] Since inception, CO_2 injection into the Weyburn Field has averaged 1.7 million tonnes of CO_2, with more than 36 million tonnes of CO_2 stored[47] mainly sourced from the Great Plains Synfuels Plant but with an additional supply of CO_2 from Boundary Dam since 2014.[49]

The Midale Field was operated by Apache Canada until it was sold to Cardinal Energy Ltd. in 2017.[50] In 2020, approximately 188,000 tonnes of CO_2 was injected in the Midale unit. Since 2005, nearly 5 million tonnes of CO_2 has been injected.[51] As of 2023, the sale of CO_2 from DGC to Whitecap Resources and Cardinal Energy Ltd. represents the only instances of large quantities of captured CO_2 being traded across an international border.

> Supplies from Great Plains to Weyburn and Midale represent the first case of CO_2 being traded between two countries.

CO_2 CAPTURE AT BOUNDARY DAM

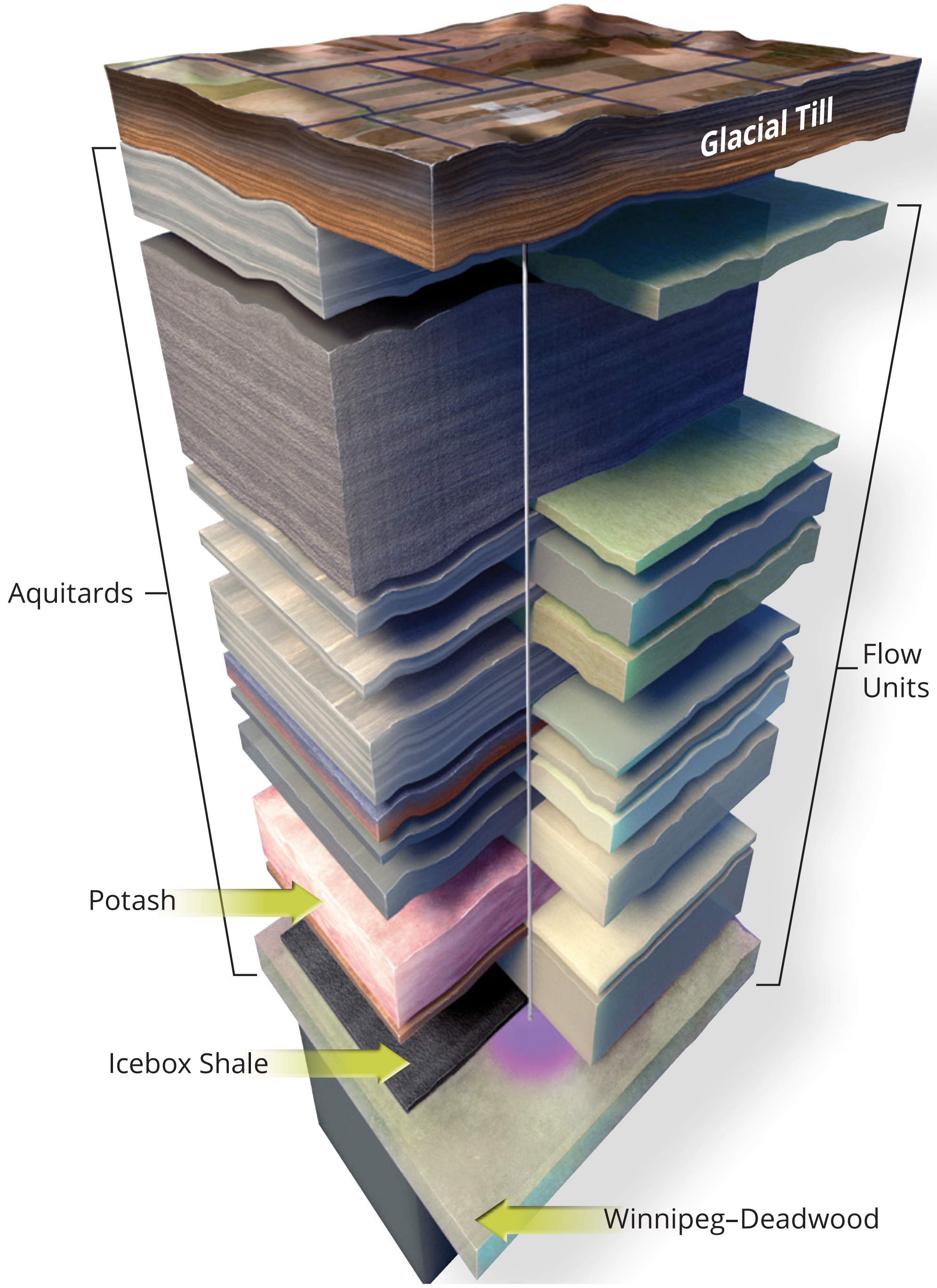
The Boundary Dam Carbon Capture Project is the world's first commercial-scale, fully integrated CCUS project at a coal-fired power station, with postcombustion capture of CO_2 from the rebuilt Unit 3. The capital cost of Can$1.2 billion was supported by funding from the provincial government of Saskatchewan and the federal government of Canada. Operated by the government-owned utility SaskPower, the project is designed to capture up to 1 MMt of CO_2 per year; between the commencement of operations in October 2014 and January 2023, SaskPower reports that over 5 million metric tons of CO_2 was captured.[52]

Unit 3 provides 115 MW of power. In addition to reducing CO_2 emissions from Unit 3 by up to 90%, the capture process removes 100% of SO_2 emissions, which are converted to sulfuric acid for industrial use.

The main destination for captured CO_2 is the Weyburn oil field, with Whitecap Resources transporting the purchased CO_2 via a 66-km pipeline. A branch of the pipeline in close proximity to the power station feeds the Aquistore Project, which is designed to provide dedicated storage for unsold CO_2.

THE AQUISTORE PROJECT

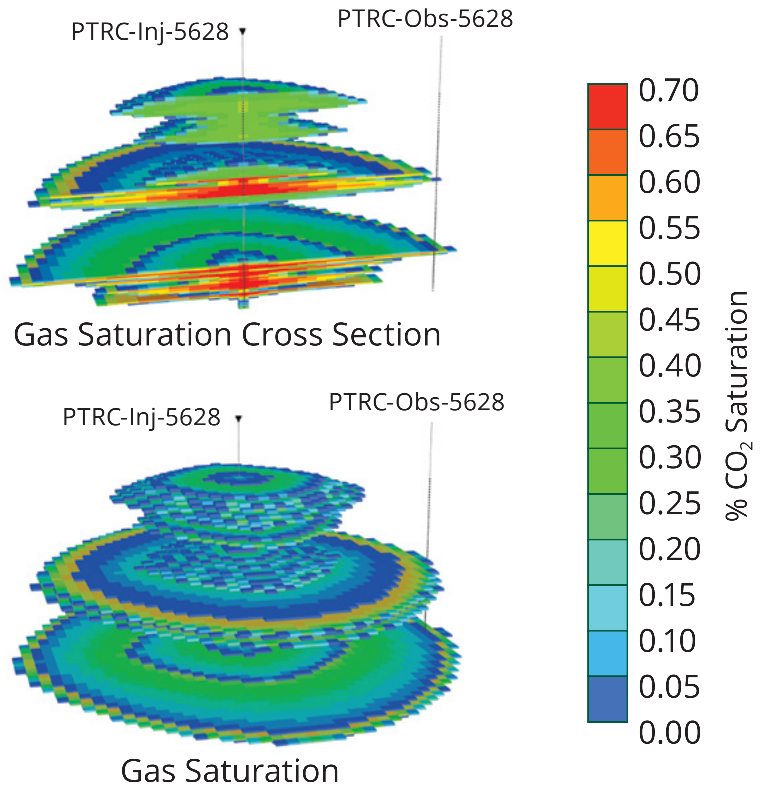
Aquistore is a dual-purpose project.[53] From a commercial perspective, Aquistore provides a dedicated storage option for unsold CO_2 from Boundary Dam—in effect providing buffer storage to prevent any need for SaskPower to vent CO_2 from capture operations. Injection commenced in April 2015, making Aquistore the first dedicated storage project to operate in Canada. As of February 2023, over 500,000 tonnes of CO_2 had been injected.[54]



Injection of CO_2 at Aquistore is via a single vertical well into the Winnipeg and Deadwood Formations at a depth of approximately 3.4 km below ground level.[53]

Monitoring of the Aquistore site is managed by Petroleum Technology Research Centre (PTRC), which installed the injection well plus an observation well and other monitoring infrastructure through funding by federal and provincial government agencies and private industry. In addition to providing monitoring data for the regulator in accordance with permitting of the storage site, Aquistore is run as a collaborative PTRC research project that aims to demonstrate that dedicated storage in a DSF is a safe and workable solution to reduce GHG emissions.

Established and novel technologies are under evaluation at Aquistore. These include cost-effective repeat 3D seismic surveys facilitated by a permanent array of 650 surface geophones, passive seismic monitoring, and downhole monitoring, including fiber-optic cables.[55]



Carbon dioxide saturation within the injection plume resulting from a simulated 50-year injection scenario (37 MMt) at the PTRC Aquistore site. The model grid is nearly square, with sides approximately 5.6 km in length.

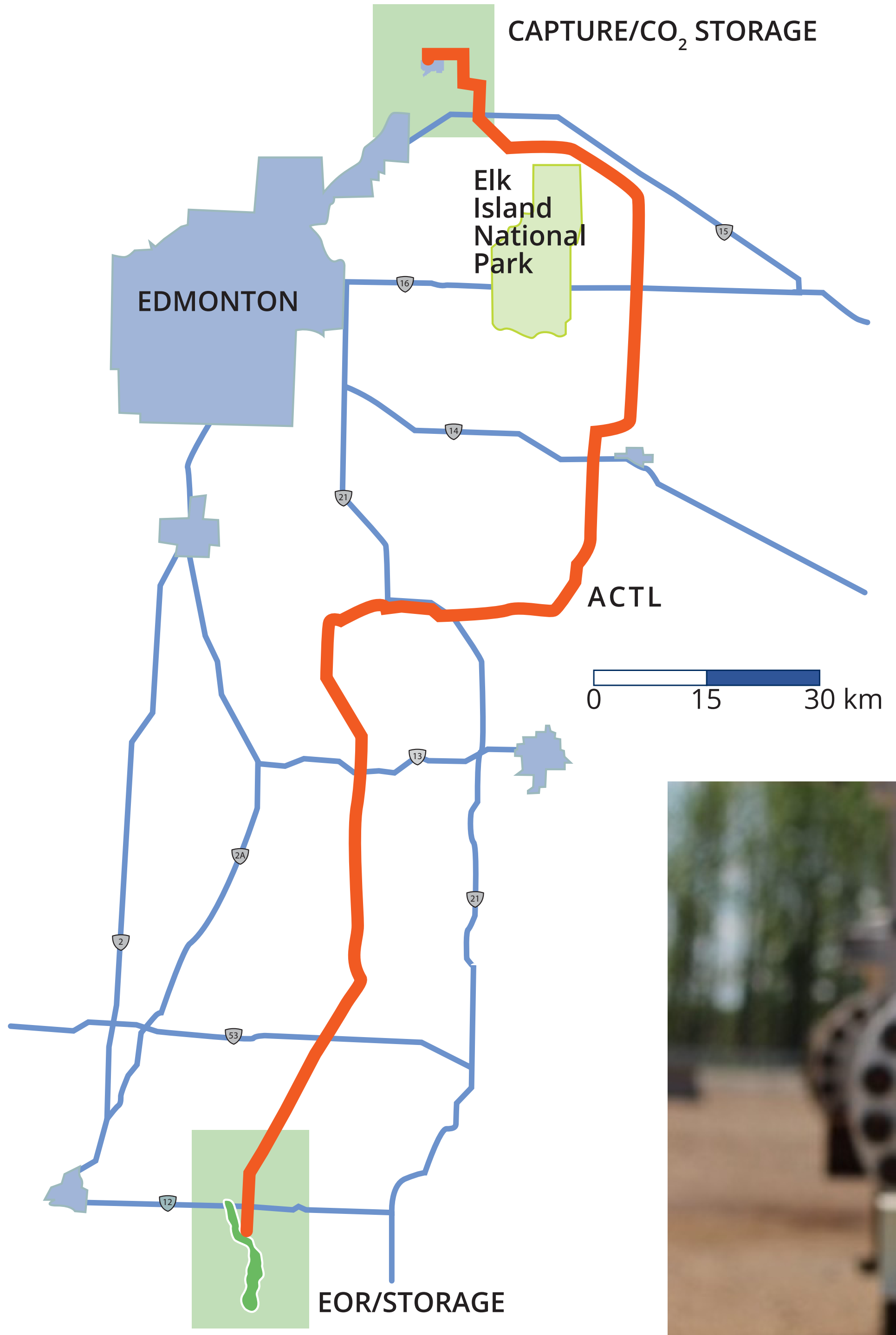
QUEST CARBON CAPTURE AND STORAGE PROJECT

Shell Canada Energy commenced operations at Quest, a fully integrated CCUS project located northeast of Edmonton, Alberta, in November 2015. As of the end of 2022, the Quest project captured and stored 7.7 million tonnes of CO_2. The cost to operate Quest is about 35% lower than what was forecast in 2015, and if Quest was built today, it would cost about 30% less thanks to capital efficiency improvements.[56]

The capture plant, located at the Scotford refinery, was built as a modification to an existing steam methane reformer that produces hydrogen for upgrading oil sands bitumen into synthetic crude oil. Licensed Shell amine technology is used in the capture process, which reduces CO_2 emissions from the upgrading operations by approximately one-third.

Captured CO_2 is transported via a 60-km pipeline to a dedicated storage site and injected into the Basal Cambrian sandstone, a DSF, at a depth of around 2 km below the surface. Infrastructure at the site includes three injection wells and a host of monitoring technologies that provide opportunities for international research collaborations. The project is expected to store at least 27 MMt of CO_2 over the anticipated 25-year life of the upgrader, although the storage reservoir has a much greater storage potential.

ALBERTA CARBON TRUNK LINE



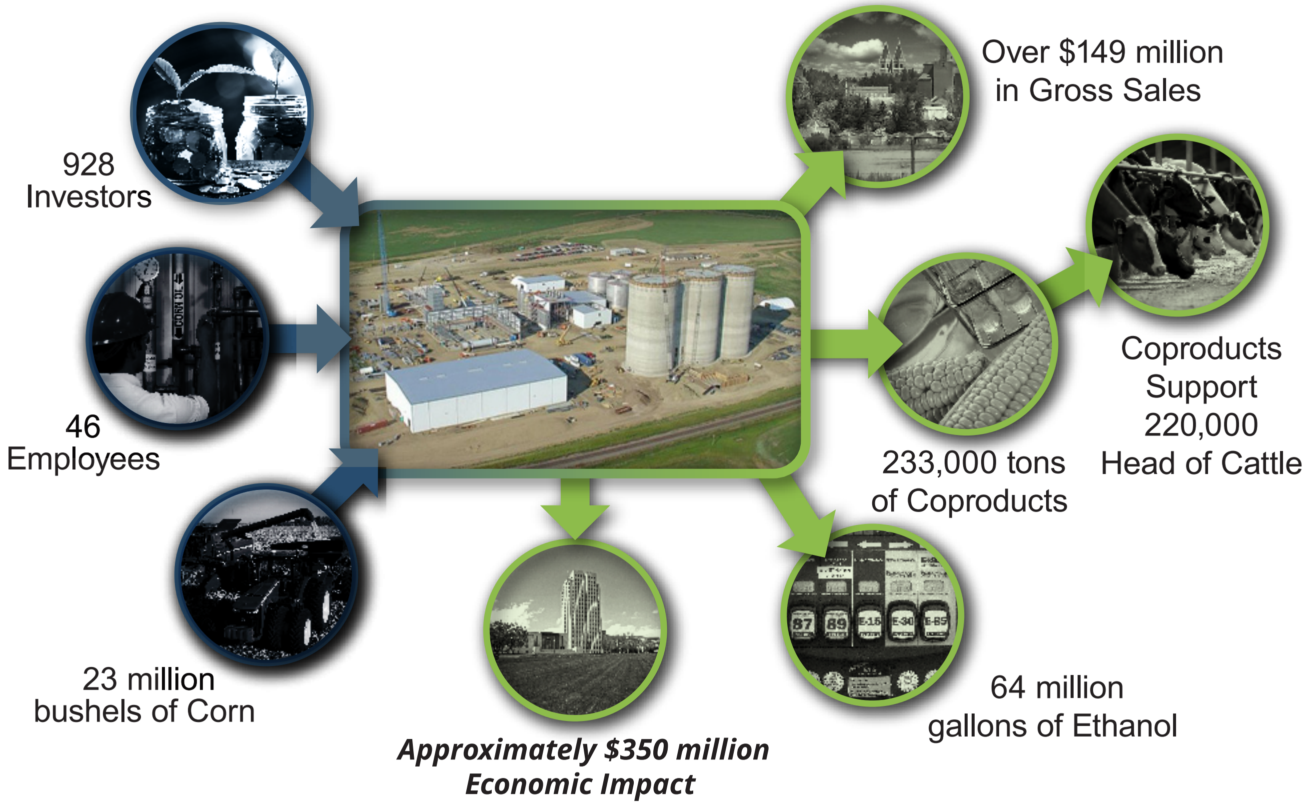
The ACTL system is the world's newest integrated, large-scale CCUS system.[57] Located in central Alberta, CO_2 captured from the NWR (North West Redwater Partnership) Sturgeon Refinery and the Nutrien Fertilizer facility is transported down a 40-cm-diameter, 240-km-long pipeline to mature oil fields near Clive, Alberta. Designed as the backbone infrastructure needed to support a lower-carbon economy in Alberta, the ACTL system captures industrial emissions and delivers the CO_2 to mature oil and gas reservoirs for use in EOR and permanent storage. The ACTL can transport up to 14.6 MMt of CO_2 per year, and as of July 2023, more than 4 million metric tons of CO_2 had been injected and stored in the Clive oil field.[58]

RED TRAIL ENERGY

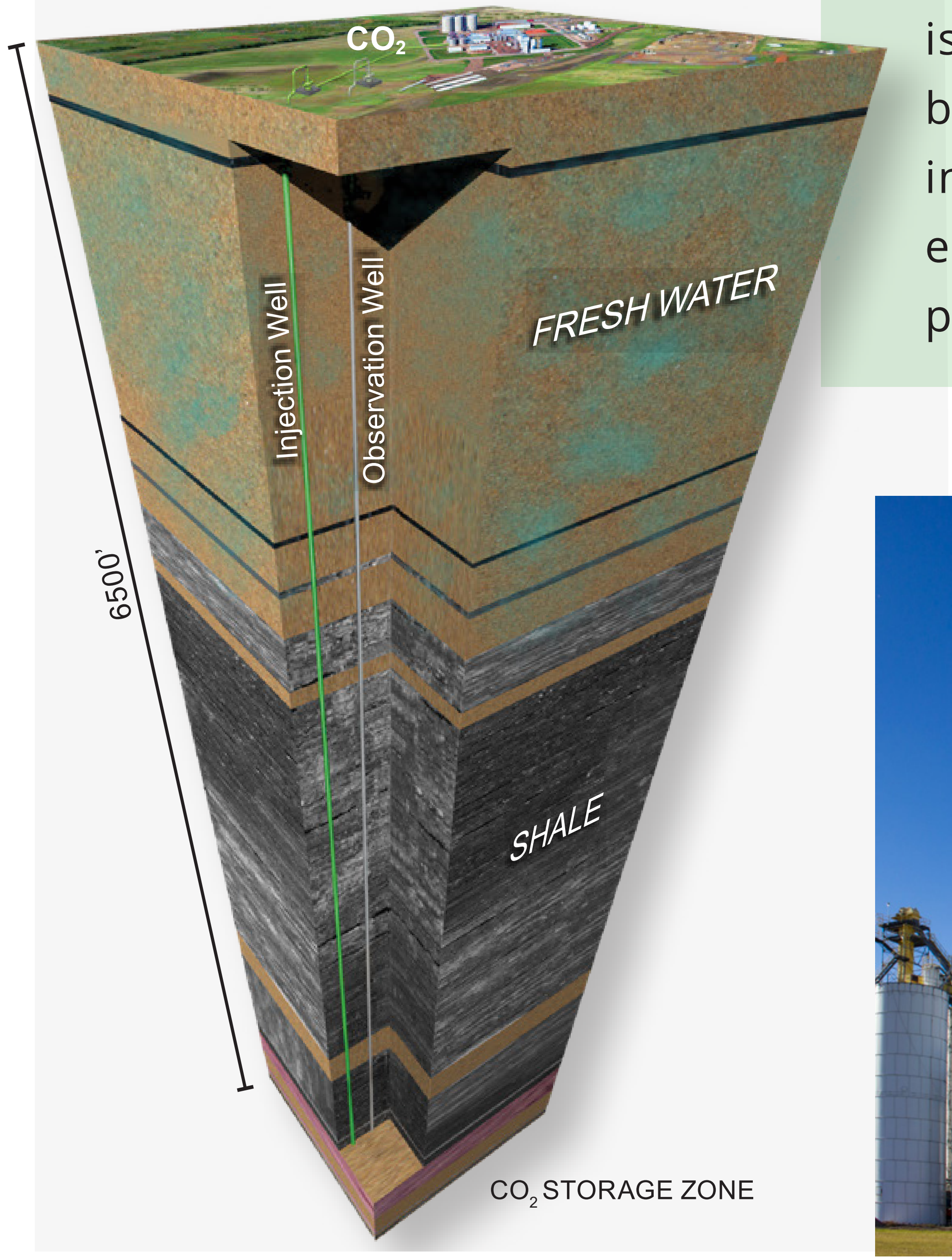
Red Trail Energy, LLC (RTE), an ethanol producer near Richardton, North Dakota, is operating a CO_2 capture facility adjacent to the RTE ethanol facility to ultimately inject about 180,000 tonnes of CO_2 annually more than a mile below RTE property for permanent storage. After a 5-year investigative period conducted by the EERC, in partnership with the NDIC Renewable Energy Program and DOE, the RTE project was determined a technically viable option for significantly reducing CO_2 emissions from ethanol production.

This project resulted in the first permitted geologic storage facility in North Dakota, Red Trail Richardton Ethanol Broom Creek Storage Facility No. 1, and was established with formal approval of RTE's North Dakota CO_2 storage facility (Class VI) permit on October 19, 2021. Major activities included drilling a stratigraphic test (coring, testing, logging) well followed by extensive laboratory analyses and evaluation, modeling and simulation of potential CO_2 injection and storage, and continued collaboration with incentive and regulatory officials.

RTE established commercial contracts for the capture facility, installation of wells and monitoring equipment, flowline, and other carbon capture system infrastructure. When injection started on June 16, 2022, RTE became the first active Class VI project in North Dakota. Over the first year and a half of operations, RTE injected nearly 250,000 metric tons, for an average of about 500 metric tons per day, essentially meeting the designed goals of the system.



Since beginning injection in June 2022, the RTE project has injected over 250,000 tonnes of CO_2, meeting designed capacities with no significant safety or operational issues, all while being within budget. Any slowdowns in CO_2 injections have only been a result of ethanol production slowdowns or project maintenance and upgrades.



RED TRAIL ENERGY
EERC
UND UNIVERSITY OF NORTH DAKOTA
renewable ENERGY PROGRAM
NORTH DAKOTA INDUSTRIAL COMMISSION
U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

PROJECT TUNDRA (CARBONSAFE NORTH DAKOTA)

Project Tundra is designed to capture 90% of the CO_2 produced at the Milton R. Young Station (about 4 million metric tons per year). This capture rate is the equivalent to taking 800,000 gasoline-fueled vehicles off the road. North Dakota-based Minnkota Power Cooperative (Minnkota) is leading the project, along with research support from the EERC through DOE's CarbonSAFE Initiative.

In the fall of 2020, the North Dakota CarbonSAFE project began Phase III of the DOE initiative, a 3-year effort building off of the success of Phase II and covering site characterization and permitting. Field activities over the project period include drilling three stratigraphic test wells and collecting nearly 20 square miles of 3D seismic data in the area around the Milton R. Young Station.

As part of the CarbonSAFE project, two North Dakota CO_2 storage facility permit applications were approved in January 2022, the second and third approved storage facility applications in the state. The project has also developed and received approval in April 2022 for an EPA-compliant MRV plan that meets the requirements of the IRS 45Q tax incentive program. Further, the project had a draft environmental assessment approved in August 2023 that has been published for public comment and, as of March 2024, is awaiting final approval.

As of March 2024, Project Tundra received approval for installation of Class VI injection wells. Minnkota is approaching a FID to begin construction of the project's capture system and injection and monitoring wells.

North Dakota CarbonSAFE is part of ongoing regional efforts to ensure reliable, affordable energy; the wise use of North Dakota's resources; and wide-scale commercial deployment of CCUS.

PROJECT TUNDRA · Minnkota Power Cooperative (A Touchstone Energy® Cooperative) · EERC, University of North Dakota · U.S. Department of Energy · National Energy Technology Laboratory · Industrial Commission of North Dakota Lignite Research, Development and Marketing Program · CMG · slb · Square Butte Electric Cooperative

January 2022	Storage Facility Permit Applications Approved
April 2022	EPA MRV Plan Approved
August 2023	Draft Environmental Assessment Approved
2027	First CO_2 Captured

DRY FORK STATION (CarbonSAFE WYOMING)

The University of Wyoming School of Energy Resources (UWY SER) leads the Wyoming CarbonSAFE project at Dry Fork Station in the Powder River Basin. Funded by DOE, Wyoming CarbonSAFE investigates the practical, secure, and permanent geologic storage of CO_2 emissions from coal-based electricity generation facilities near Gillette, Wyoming. The Wyoming CarbonSAFE team is characterizing the subsurface geology for suitability for CO_2 storage, preparing permitting documents, working to integrate CO_2 capture technologies, assessing regulatory and business issues, and helping to advance the project toward commercialization. Along with many committed industry, academic, and government partners, UWY SER has drilled a stratigraphic test well, conducted downhole petrophysical tests, analyzed core, collected and analyzed seismic data, and is committed to developing robust monitoring plans and communicating project details to the public.

INTEGRATED TEST CENTER

Dry Fork Station also houses the Integrated Test Center (ITC), which is among a select few facilities in the world that provides space for technology developers to evaluate technologies using actual coal-based flue gas from an operating coal-fired power plant. ITC is a public–private partnership—under UWY SER's supervision—fostering the next generation of energy technology. ITC allows for real-world testing at an active power plant and alleviates typical concerns of being able to transfer technology from a lab to a plant.

> Wyoming's Carbon Valley: a trifecta of private, state, and federal interests leveraging one another toward a common goal: CCUS.

Center of Excellence for Economic Geology Research, School of Energy Resources · University of Wyoming School of Energy Resources · U.S. Department of Energy · National Energy Technology Laboratory · Basin Electric Power Cooperative (A Touchstone Energy Cooperative) · EERC University of North Dakota · Enhanced Oil Recovery Institute · Carbon GeoCycle · slb · CMG · WMPA Wyoming Municipal Power Agency · Advanced Resources International, Inc.