Storage hub safety and emergency management planning

Pathways CO_2 Transportation Network and Storage Hub project

On behalf of Pathways Alliance, Canadian Natural is proposing to construct and operate the Pathways CO_2 Transportation Network and Storage Hub project (the "Project”). When operational, this Project would have the capacity to transport captured carbon dioxide (CO_2) from multiple oil sands facilities to a capped sandstone formation in the Cold Lake area of Alberta for underground storage.

The safety of communities, infrastructure and workers is a critical component of the Project design and is important to all Pathways Alliance members. Our approach to emergency management planning is to focus on proactive risk identification, prevention, preparedness and response planning, while adhering to industry standards and regulations.

Communities, Indigenous groups and other parties have expressed interest in emergency planning for the Project. This fact sheet is intended to provide information on emergency management planning related to the Storage Hub.

What is the Pathways Storage Hub?

As a part of the proposed Project, CO_2 would be stored underground in a geological formation called the Basal Cambrian Sandstone (BCS). Located in the Cold Lake area, the Storage Hub would consist of this underground BCS formation, the associated injection wells and tie-in piping to the CO_2 Transportation Network. The BCS is a porous rock (sandstone) that contains small spaces, similar to a sponge, that can be filled with CO_2. It is located 1,000 to 2,000 metres below the surface with an average thickness of approximately 80 metres.

Above the porous rock lie thick layers of salt rock formations. Unlike the BCS, these salt rock formations are not porous, meaning fluids cannot pass through them. Referred to as the cap rock, the salt rock formations act as an impermeable barrier—a natural seal to keep the stored CO_2 from migrating upwards.

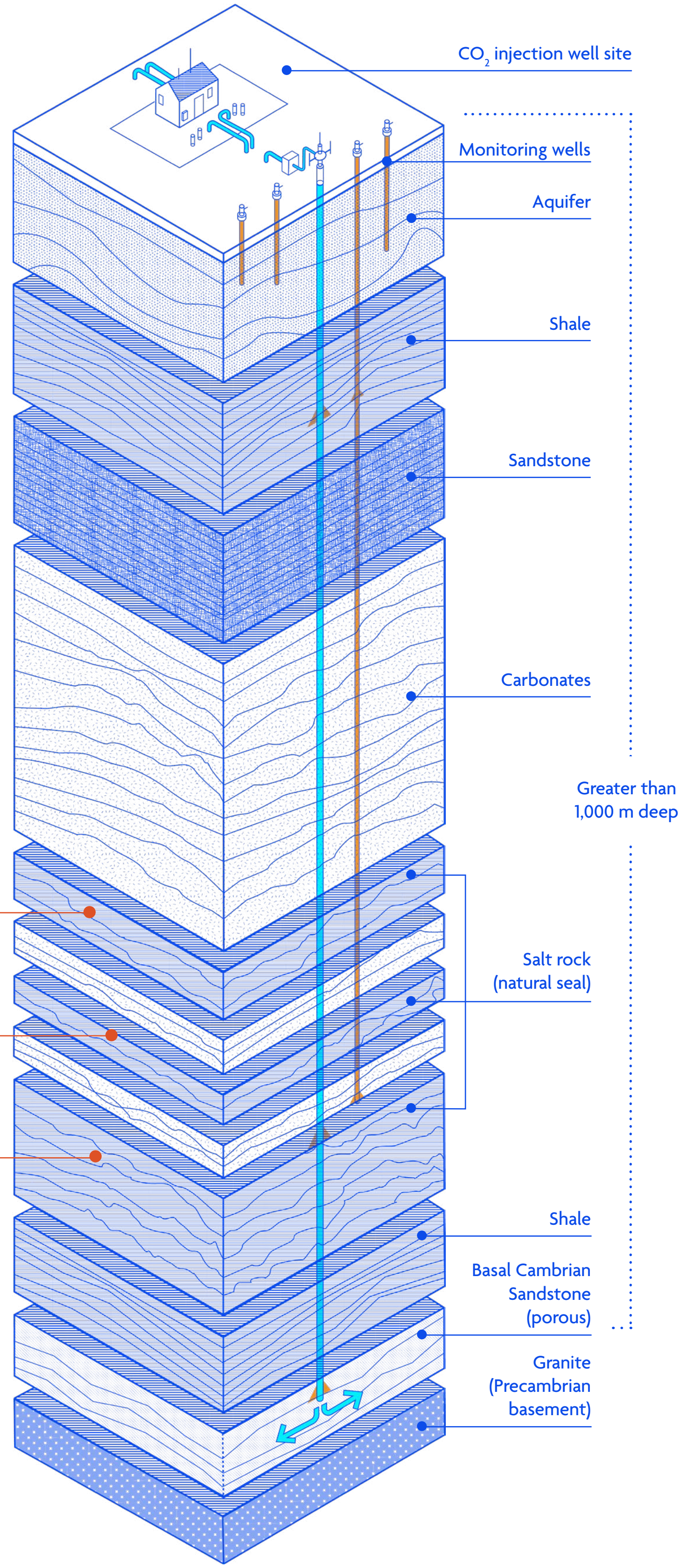
Salt rock formations:

Prairie Evaporite Formation
~145 m thick
~850 m deep

Cold Lake Formation
~40 m thick
~1,050 m deep

Lotsberg Formation
~220 m thick
~1,150 m deep

Combined salt thickness (all 3 salts):
>350 m



ABOVE: These multiple overlying layers of impermeable rock formations act as a natural seal, which can safely and permanently store CO_2. For illustrative purposes only, not to scale.

CO_2 injection path

Monitoring system

Multi-Layered Safety and Risk Management System: Storage Hub

The proposed Pathways Storage Hub would have a multi-layered risk management system based on decades of technical experience and scientific research. These layers are broadly categorized as prevention, detection and response.

Layer 1: Prevention

The first layer of the system is identifying and mitigating risks. Risk management begins at the design stage and continues throughout development and operations of the Project. Engineers and other experts must incorporate multiple safety measures into the design and development of the Project, including, but not limited to, the following:

Selecting a suitable geological formation
Alberta's BCS formation is well suited to CO_2 storage. The formation is located 1,000 to 2,000 metres below the surface and is under three layers of thick salt rock formations (or cap rock) that act as natural seals by preventing the CO_2 from moving upward.

The BCS is a porous rock formation that can trap CO_2 molecules within small spaces in the rock. The CO_2 would be injected into the formation as a fluid, which is less mobile than gas. Over time, the injected CO_2 and the fluids and minerals already in the BCS formation would react, resulting in some of the CO_2 becoming solid or dissolving into the fluid. The injected CO_2 is not expected to affect the integrity of the storage or cap rock formations. The distribution of the three salt formations varies with a minimum thickness of 150 m to upwards of 400 m of total salt thickness, located well below any groundwater source. These salt formations are self-sealing, meaning they can slowly change shape over time to repair small cracks, making them effective layers for containing CO_2.[1]

Determining a safe injection pressure
During the Project-planning stage, geologists and engineers determine the pressure at which the CO_2 would be injected at based on data collected from wells in the area. The injection pressure must maintain the integrity of the storage and cap rock layers, and it must meet regulatory standards.

[1] Costin, L.S. and Wawersik, W.R. "Creep Healing of Fractures in Rock Salt." United States Department of Energy, August 1980. osti.gov/servlets.purl/5021049.

Layer 2: Detection

The second layer in the system is the comprehensive, continuous and consistent monitoring of the underground formations to detect changes in activity. The proposed Project would have multiple monitoring points. Instrumentation would be placed at the CO_2 injection site and down into the underground formations in the Storage Hub. Additionally, sampling programs and regular field monitoring would be established as part of operations. Activity outside typical operating parameters would trigger a response. Further, monitoring programs for the Storage Hub must comply with the Measurement, Monitoring and Verification (MMV) Plans under the Alberta Energy Regulator's (AER) Directive 065 and must be evaluated and approved prior to operations or CO_2 injection. Examples of the types of monitoring technologies and systems that are planned are outlined below.

Monitoring systems

Control room operators would monitor the injection monitoring systems 24/7 for changes outside normal operating parameters.

Managing pressure in the Storage Hub

The proposed Storage Hub would be connected to multiple injection wells that are capable of real-time pressure monitoring. This helps monitor and track injection pressure in the BCS formation. Additionally, monitoring wells would be used in the area to observe conditions in the geosphere and hydrosphere.

Using seismic imaging

Seismic imaging is a method that uses sound waves to create pictures of what's beneath the Earth's surface and is commonly used to inform oil and gas development. By sending sound waves into the ground and measuring how they bounce back, geophysicists can see and study layers of rock or gas such as CO_2 deep underground. Once CO_2 is injected underground, seismic imaging can show how it's distributed through the BCS formation. Time-lapse seismic imaging can also be used to track how the CO_2 spreads over time to compare it to predicted expectations or behaviour. This technology can help verify that the CO_2 remains contained in the Storage Hub.

Layer 3: Response

The final layer of the system is emergency response planning in the unlikely event an incident occurs. Detailed response plans are required and regulated by the AER and set out actions to mitigate the effects of an incident. Below are examples of the system procedures and emergency response planning that would be used.

Isolating the system

A subsurface safety valve would be installed deep underground in each CO_2 injection well, typically near the bottom of the well. Its primary function is to automatically shut off the flow of CO_2 if there's an issue, such as a sudden pressure increase or a mechanical failure. For example, if the pressure in the well becomes too high or if the system detects any unexpected changes, the valve can close automatically, stopping the injection of CO_2. This allows the unexpected condition to be investigated while ensuring that the stored CO_2 remains contained underground.

The valve can be remotely controlled to open or close based on real-time monitoring, offering an added layer of control for operators. It's a key safety feature that helps keep the process safe and controlled.

Responding to an incident

Prior to starting operations, Pathways Alliance would develop a comprehensive Emergency Response Plan (ERP) in close cooperation with local and regional authorities. It would outline the actions required to respond quickly and effectively to an incident involving a CO_2 release at a surface location such as the well site. Local residents and communities would be contacted directly to share their views and provide input for consideration in the preparation and finalization of an ERP.

An ERP is designed to protect people, facilities, the public and the environment in case of an emergency. Its intent is to make sure the right actions are in place to quickly and effectively respond to an incident and minimize potential impacts.

An ERP outlines all the steps needed to handle an emergency, including how to mobilize response teams, notify people who may be affected and inform government or health agencies. It also defines roles and responsibilities, how decisions will be made, what resources will be used, how information will be shared and what to do if evacuation is necessary. Before starting CO_2 injection operations, the Pathways ERP would be reviewed and approved by the appropriate regulators in accordance with AER's Directive 071.

What is Monitoring, Measurement and Verification (MMV)?

Monitoring, Measurement and Verification (MMV) activities are a fundamental component of a CO_2 sequestration project, providing assurance that sequestered CO_2 is contained. The MMV Plan sets out monitoring objectives, thresholds and interpretations for CO_2 sequestration.

Monitoring refers to the surveillance and observation of CO_2 storage operations. A robust monitoring network provides assurance of the continued storage of CO_2. Monitoring activities occur at all stages of a project, including pre-development, injection operations and closure periods.

Measurement refers to CO_2 injection rates, which are fundamental for quantifying the amount of CO_2 sequestered.

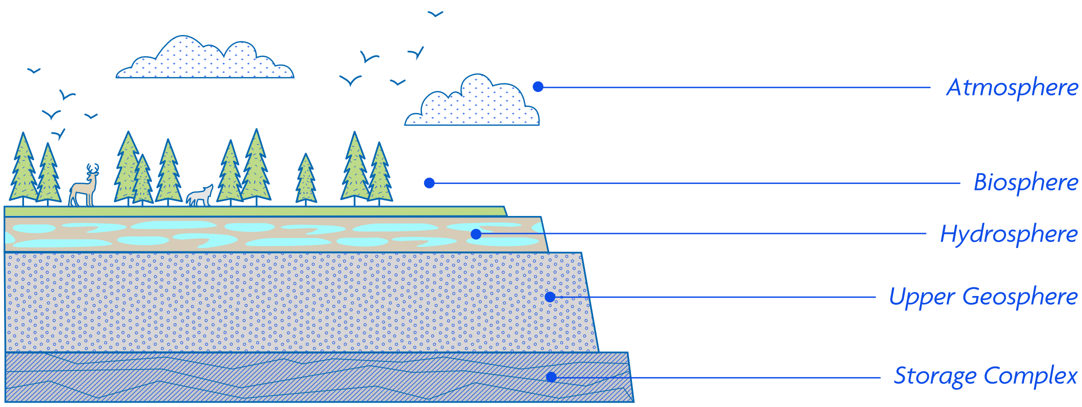
Verification is the process of comparing monitoring data of CO_2 injection with model predictions. The verification process allows model predictions to be verified and adapted over the life of a project.

MMV activities continue throughout a project and even during the post-closure period, helping to confirm that the CO_2 storage site is functioning safely and as expected.

The MMV Plan

An MMV Plan outlines the activities for monitoring, measuring and verifying to manage risks throughout a project. For the proposed Project, the MMV Plan would be prepared with reference to provincial, Canadian and international standards for safe operations over the Project life. The MMV Plan would be created to address potential risks, meet legal requirements and ensure that all conditions of Project approvals are followed. The MMV Plan would include a Risk Management Plan that contains the risk identification, assessment and management activities specific to this Project.

The subsurface and surface environments are divided into monitoring domains to ensure effective risk identification, mitigation and MMV deployment.



For illustrative purposes only, not to scale.

Atmosphere and Biosphere: Natural environments on the Earth's surface, including all living ecosystems on land and surface water.

Hydrosphere: Underground formations containing non-saline groundwater.

Upper Geosphere: Underground formations between the storage complex and the protected groundwater layers above.

Storage Complex: The underground formations that safely store CO_2, along with the formations above (the cap rock) that keep the CO_2 securely in place.

MMV technologies are chosen because they have a proven track record of quickly detecting any problems in their area of use. This allows for rapid investigation and action to address issues when necessary. MMV technology is selected to accommodate different surface conditions while minimizing environmental disturbance.

The MMV Plan would be flexible and adaptive as the CO_2 sequestration progresses. MMV activities would be updated over time based on what we learn about the site, how it's performing, new research on CO_2 storage, advances in technology and changes in regulations. This helps the CO_2 stay safely and securely contained.

Learning from incidents

A key component of any major project is mitigating risk to help protect the environment, the local communities and a company's assets. One way Pathways member companies manage risk is through continuous improvement activities, like reviewing lessons learned from historical incidents—both ours and others—and using those lessons to improve Project design and work practices to prevent similar incidents from occurring.

Case study: Illinois well pad leak

In 2024, a CO_2 leak at a CO_2 storage site in Illinois occurred due to a combination of factors: metal corrosion, placing a Monitoring, Measurement and Verification (MMV) well inside the CO_2 storage reservoir adjacent to an injector, and operator protocols. While CO_2 did not reach the surface or any protected groundwater sources, and did not affect people, it did enter a different formation than the targeted storage reservoir.

What we learned:

- For the injection well design, metallurgy of the well would be incorporated to prevent corrosion, including the use of corrosion-resistant alloys to reduce corrosion risk.
- The proposed Project design plans to situate its MMV wells above and outside of the designated Storage Hub formation when adjacent to the injection well. Regional MMV wells completed inside the storage reservoir would be strategically placed away from injection sites to monitor CO_2 storage operations. Experience has demonstrated that required MMV data adjacent to injection wells can be obtained in zones immediately above or offset from injection wells.
- Regular well-integrity assessments would also be incorporated into the operations of the injection well, including protocols for a suspected leak, reducing risk of an unlikely well failure.

Frequently Asked Questions

Many people have questions about the impact and safety of CO_2 storage. Because this technology has been in operation for decades, its effects are well researched[2] and documented.[3]

What's CO_2?

Carbon dioxide, or CO_2, is a colourless, odourless gas that's produced when animals (including humans) breathe, or when carbon-containing materials (including fossil fuels) are burned. CO_2 is naturally occurring in the atmosphere and essential to the photosynthesis process that sustains plant life, but it becomes hazardous in high concentrations. Risks related to CO_2 depend on the concentration upon release, duration of exposure and environmental conditions.

How is CO_2 captured?

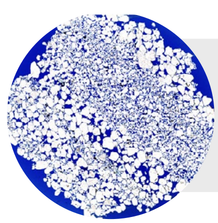
CCS has the potential to help prevent CO_2 created by industrial activities from entering the atmosphere. Typically, capture technologies are fitted to a large stationary source of CO_2 emissions (e.g. boiler or generator), which diverts the CO_2 before it reaches the atmosphere. The CO_2 is compressed and turned into liquid form, which can flow through the pipeline network to the injection wells. Then, the liquefied CO_2 is stored deep underground.

What is stored underground? Gas or liquid?

CO_2 is transported and stored as a liquid. This liquid fits into tiny spaces in the sandstone storage layer deep underground. This layer is constantly monitored to confirm that the fluid doesn't move into overlying formations. Some of the overlying formations are dense and solid, with no spaces for the CO_2 to enter. Around 10% of the stored CO_2 dissolves in the salty water that exists within the storage layer. Some stored CO_2 reacts with the sandstone and becomes a solid mineral, which doesn't move at all.

What happens to the CO_2 after it is pumped underground?

In the proposed Project, captured CO_2 would be injected into the Basal Cambrian Sandstone (BCS) formation, 1,000 to 2,000 metres below the surface. This formation is a porous rock (sandstone) that contains small spaces, similar to a sponge, that can be filled with CO_2. Currently, these spaces contain salt water. As CO_2 enters the formation, some CO_2 will dissolve into the salt water, and some will be trapped beside the salt water in the spaces within the rock. Over time, the CO_2 can even solidify, becoming part of the rock itself.[4]



A magnified image of the sand grains (white) and pore space (blue) that make up the Basal Cambrian Sandstone. The CO_2 will be injected into the pore space in this rock.

[2] "20 Years of Carbon Capture and Storage." International Energy Agency, November 2016. iea.org/reports.
[3] "CO_2 Storage Resources and Their Development." International Energy Agency, December 2022. iea.org/reports.
[4] "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda." National Academies of Sciences, Engineering and Medicine, 2019. nap.nationalacademies.org.

Could stored CO_2 affect my drinking water?

The CO_2 storage reservoir is between 1,000 and 2,000 metres below the surface, and the storage reservoir and fresh groundwater reservoirs are separated by cap rock. If any CO_2 exited the storage layer, the monitoring systems (including seismic imaging) are set up to detect it. CO_2 is unlikely to reach groundwater, which is an average of 150 m below the surface.

What prevents the CO_2 from coming back to the surface?

Above the porous BCS (sandstone) lie thick layers of salt rock formations called cap rock. Unlike the BCS, the cap rock is not porous, meaning fluids cannot pass through them. The cap rock act as a barrier to keep the stored CO_2 from moving upwards, creating a natural seal.[5]

Once the CO_2 is underground, imaging and monitoring will show how the CO_2 is distributed through the storage zone. The geological formations above the storage layer will also be monitored to confirm that CO_2 is remaining in place and not moving upwards.

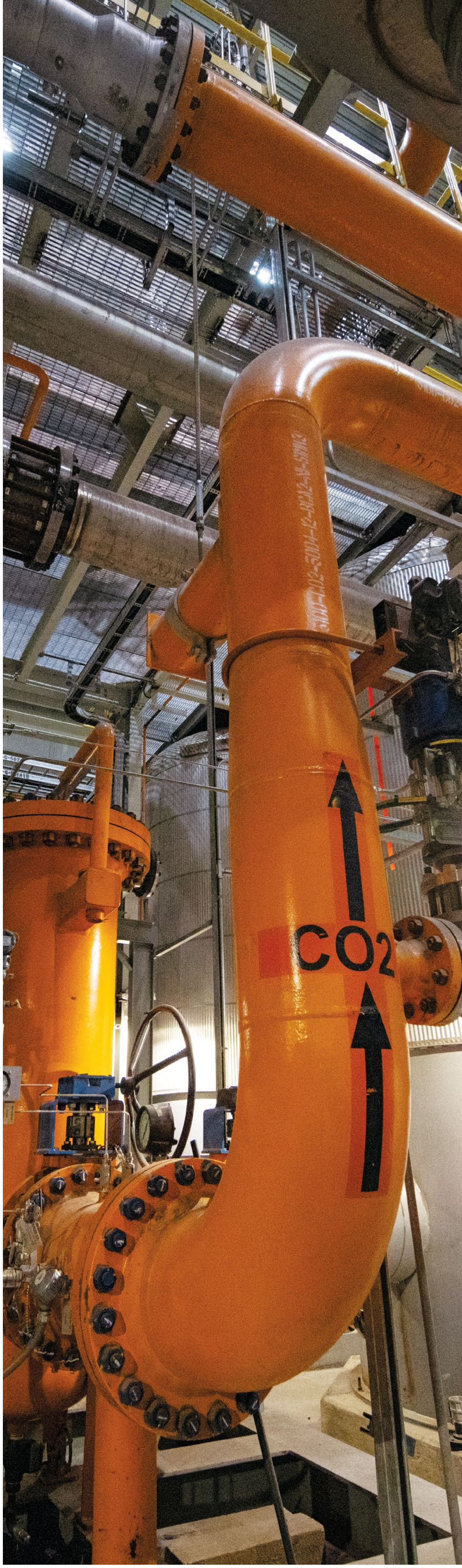
How can you be sure there are no unknown fractures in the formation?

The Pathways sequestration site, located far from the Rocky Mountains, is an area that is less prone to faulting and fracturing than much of the rest of Alberta and British Columbia. The rock layers above the storage zone contain thick salt rock formations, cap rock, known for their strength and natural malleability. The cap rock is less likely to fracture and can gradually shift and seal on its own. This self-sealing[6] property helps preserve the integrity of the storage site.

How will the CO_2 be monitored in the future?

Pathways would develop a site-specific MMV Plan in accordance with the Alberta Energy Regulator's Directive 065. The MMV Plan would include ongoing data collection, analysis and regularly scheduled reporting to support safe and secure CO_2 storage over the life of the Project.

Monitoring would be conducted prior to CO_2 injection (to provide baseline data), during CO_2 injection and for a period after CO_2 injection has finished. Monitoring technologies are likely to include measurement of CO_2 injection rates; pressure monitoring of the storage layer and formations above the cap rock; monitoring of soil, groundwater and surface water; time-lapse monitoring to detect the growth of the CO_2 plume within the storage layer; and seismicity monitoring.



[5] Masserweh, O. and Abushaikha, A.S. "CO_2 Sequestration in Subsurface Geological Formations: A Review of Trapping Mechanisms and Monitoring Techniques." Earth-Science Reviews, Volume 253, June 2024. sciencedirect.com.

[6] Costin, L.S. and Wawersik, W.R. "Creep Healing of Fractures in Rock Salt." United States Department of Energy, August 1980. osti.gov/servlets.purl/5021049.

Photo location: NAIT.

Pathways Alliance

We are Pathways Alliance, five of Canada's largest oil sands companies working together to provide the reliable energy the world needs while advancing environmental innovation. The oil sands industry creates thousands of jobs across the country and generates critical revenue for governments that help fund essential services that all Canadians rely upon. To ensure the industry continues to provide these benefits for decades to come, our members are working together to advance environmental innovation and projects like the Pathways CO_2 Transportation Network and Storage Hub.

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Learn more at PathwaysAlliance.ca or reach us at **contact@pathwaysalliance.ca.**

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