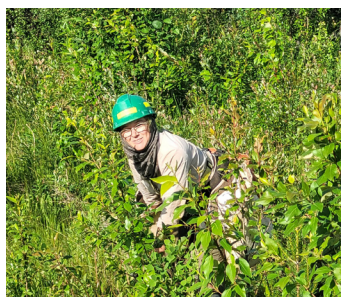


# CREATING VALUE THROUGH TECHNOLOGY AND INNOVATION

# 2022

## CASE STUDIES





# Forward Looking Statements

Certain statements relating to Canadian Natural Resources Limited (the “Company”) in this document or documents incorporated herein by reference constitute forward-looking statements or information (collectively referred to herein as “forward-looking statements”) within the meaning of applicable securities legislation. Forward-looking statements can be identified by the words “believe”, “anticipate”, “expect”, “plan”, “estimate”, “target”, “continue”, “could”, “intend”, “may”, “potential”, “predict”, “should”, “will”, “objective”, “project”, “forecast”, “goal”, “guidance”, “outlook”, “effort”, “seeks”, “schedule”, “proposed”, “aspiration” or expressions of a similar nature suggesting future outcome or statements regarding an outlook. Disclosure related to expected future commodity pricing, forecast or anticipated production volumes, royalties, production expenses, capital expenditures, income tax expenses and other targets provided throughout this Management’s Discussion and Analysis (“MD&A”) of the financial condition and results of operations of the Company, constitute forward-looking statements. Disclosure of plans relating to and expected results of existing and future developments, including, without limitation, those in relation to: the Company’s assets at Horizon, AOSP, the Primrose thermal oil projects, the Pelican Lake water and polymer flood projects, the Kirby Thermal Oil Sands Project, the Jackfish Thermal Oil Sands Project and the North West Redwater bitumen upgrader and refinery; construction by third parties of new, or expansion of existing, pipeline capacity or other means of transportation of bitumen, crude oil, natural gas, NGLs or SCO that the Company may be reliant upon to transport its products to market, the development and deployment of technology and technological innovations; the financial capacity of the Company to complete its growth projects and responsibly and sustainably grow in the long-term; and the “Outlook” section of this MD&A, particularly in reference to the 2022 targets provided with respect to budgeted capital expenditures, and the timing and impact of the Oil Sands Pathways to Net Zero (“Pathways”) initiative, government support for Pathways and the ability to achieve net zero emissions from oil production, also constitute forward-looking statements. These forward-looking statements are based on annual budgets and multi-year forecasts, and are reviewed and revised throughout the year as necessary in the context of targeted financial ratios, project returns, product pricing expectations and balance in project risk and time horizons. These statements are not guarantees of future performance and are subject to certain risks. The reader should not place undue reliance on these forward-looking statements as there can be no assurances that the plans, initiatives or expectations upon which they are based will occur.

In addition, statements relating to “reserves” are deemed to be forward-looking statements as they involve the implied assessment based on certain estimates and assumptions that the reserves described can be profitably produced in the future. There are numerous uncertainties inherent in estimating quantities of proved and proved plus probable crude oil, natural gas and NGLs reserves and in projecting future rates of production and the timing of development expenditures. The total amount or timing of actual future production may vary significantly from reserves and production estimates.

The forward-looking statements are based on current expectations, estimates and projections about the Company and the industry in which the Company operates, which speak only as of the earlier of the date such statements were made or as of the date of the report or document in which they are contained, and are subject to known and unknown risks and uncertainties that could cause the actual results, performance or achievements of the Company to be materially different from any future results, performance or achievements expressed or implied by such forward-looking statements. Such risks and uncertainties include, among others: general economic and business conditions (including as a result of effects of the novel coronavirus (“COVID-19”) pandemic and the actions of OPEC+) which may impact, among other things, demand and supply for and market prices of the Company’s products, and the availability and cost of resources required by the Company’s operations; volatility of and assumptions regarding crude oil and natural gas and NGLs prices including due to actions of OPEC+ taken in response to COVID-19 or otherwise; fluctuations in currency and interest rates; assumptions on which the Company’s current targets are based; economic conditions in the countries and regions in which the Company conducts business; political uncertainty, including actions of or against terrorists, insurgent groups or other conflict including conflict between states; industry capacity; ability of the Company to implement its business strategy, including exploration and development activities; impact of competition; the Company’s defense of lawsuits; availability and cost of seismic, drilling and other equipment; ability of the Company and its subsidiaries to complete capital programs; the Company’s and its subsidiaries’ ability to secure adequate transportation for its products; unexpected disruptions or delays in the mining, extracting or upgrading of the Company’s bitumen products; potential delays or changes in plans with respect to exploration or development projects or capital expenditures; ability of the Company to attract the necessary labour required to build, maintain, and operate its thermal and oil sands mining projects; operating hazards and other difficulties inherent in the exploration for and production and sale of crude oil and natural gas and in mining, extracting or upgrading the Company’s bitumen products; availability and cost of financing; the Company’s and its subsidiaries’ success of exploration and development activities and its ability to replace and expand crude oil and natural gas reserves; the Company’s ability to meet its targeted production levels; timing and success of integrating the business and operations of acquired companies and assets; production levels; imprecision of reserves estimates and estimates of recoverable quantities of crude oil, natural gas and NGLs not currently classified as proved; actions by governmental authorities (including any production curtailments mandated by the Government of Alberta); government regulations and the expenditures required to comply with them (especially safety and environmental laws and regulations and the impact of climate change initiatives on capital expenditures and production expenses); asset retirement obligations; the sufficiency of the Company’s liquidity to support its growth strategy and to sustain its operations in the short, medium, and Canadian Natural 2021 Annual Report 12 long-term; the strength of the Company’s balance sheet; the flexibility of the Company’s capital structure; the adequacy of the Company’s provision for taxes; and other circumstances affecting revenues and expenses.

The Company’s operations have been, and in the future may be, affected by political developments and by national, federal, provincial, state and local laws and regulations such as restrictions on production, changes in taxes, royalties and other amounts payable to governments or governmental agencies, price or gathering rate controls and environmental protection regulations. Should one or more of these risks or uncertainties materialize, or should any of the Company’s assumptions prove incorrect, actual results may vary in material respects from those projected in the forward-looking statements. The impact of any one factor on a particular forward-looking statement is not determinable with certainty as such factors are dependent upon other factors, and the Company’s course of action would depend upon its assessment of the future considering all information then available.

Readers are cautioned that the foregoing list of factors is not exhaustive. Unpredictable or unknown factors not discussed in this MD&A could also have adverse effects on forward-looking statements. Although the Company believes that the expectations conveyed by the forward-looking statements are reasonable based on information available to it on the date such forward-looking statements are made, no assurances can be given as to future results, levels of activity and achievements. All subsequent forward-looking statements, whether written or oral, attributable to the Company or persons acting on its behalf are expressly qualified in their entirety by these cautionary statements. Except as required by applicable law, the Company assumes no obligation to update forward-looking statements in this MD&A, whether as a result of new information, future events or other factors, or the foregoing factors affecting this information, should circumstances or the Company’s estimates or opinions change.

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# Creating Value Through Technology and Innovation

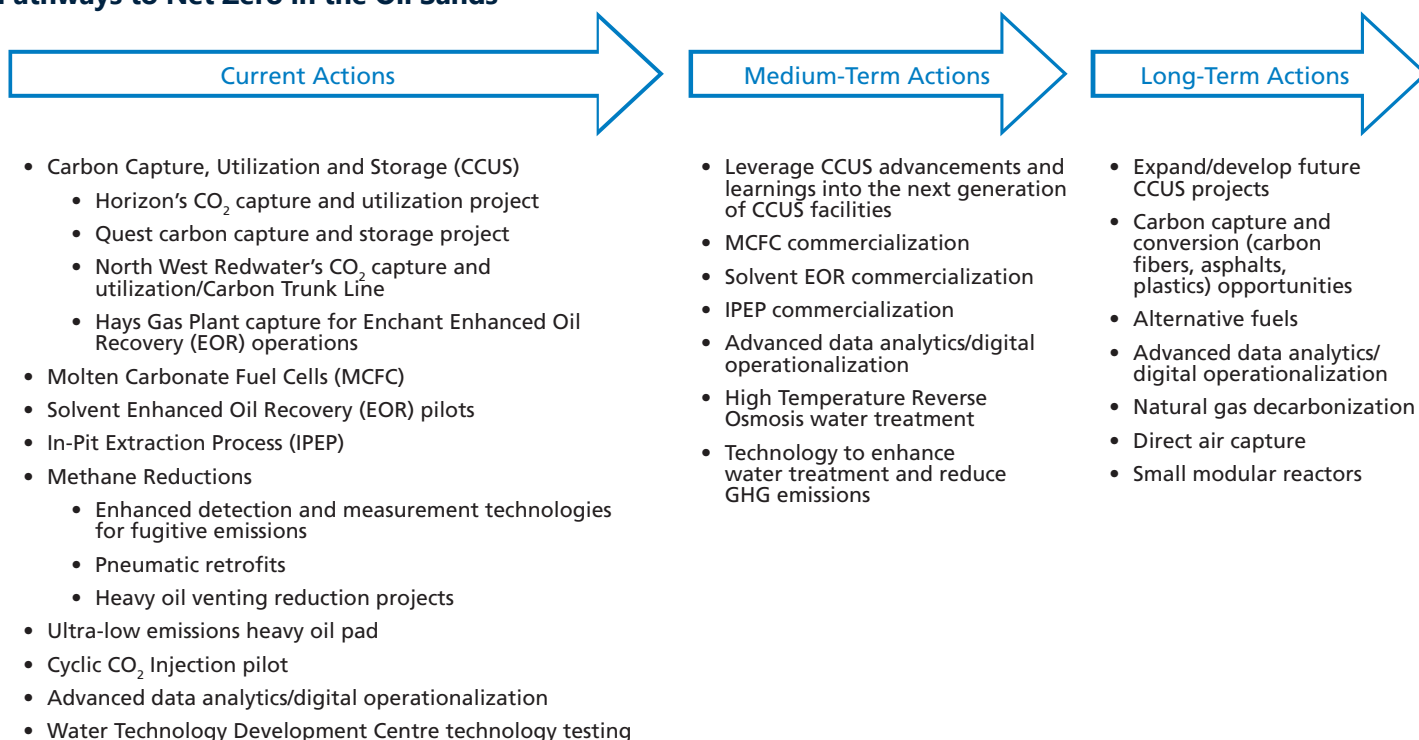
Canadian Natural is a safe, effective and efficient producer of crude oil and natural gas, meeting and exceeding regulatory standards. Canada's significant long life oil sands resources with manufacturing-like operations represent one of the clearest routes to net zero emissions of any global crude oil asset, providing the opportunity for investments in innovation to achieve net zero from oil sands operations.

## Innovation for a Lower Carbon Emissions Future

At Canadian Natural, technology and innovation are keys to success in a lower carbon emissions future. We invest in a range of technology projects, such as carbon capture, utilization and storage (CCUS), molten carbonate fuel cells, solvent enhanced steam assisted gravity drainage (SAGD), and expanding non-combustion uses for bitumen. We understand that helping to address the challenge of climate change requires significant collaboration between industry and governments, including investing together in the research, development, scaling, and deployment of new and emerging technologies.

Throughout this booklet are projects poised to deliver incremental greenhouse gas (GHG) reductions to potentially game-changing results. Supporting innovation and leveraging technology are key to reducing our company's risk and creating value. New technology takes time to test and commercialize. By working together, coordinating efforts and collaborating, we are advancing our technologies to commercialization faster.

## Pathways to Net Zero in the Oil Sands



“ We are focused on being strategic and intentional in our decisions. We are prioritizing where we can make significant reductions in GHG emissions. ”

Canadian Natural is committed to working with industry partners and governments to help meet Canada's climate and economic objectives.

Dean Halewich,  
Senior Vice-President,  
Safety, Risk Management and Innovation



### \$450 MILLION INVESTED

in technology development and deployment in 2021<sup>1</sup>



### \$84 MILLION INVESTED

in technology development and implementation to reduce GHG emissions in 2021



### R&D INVESTMENT LEADER

in the Canadian oil and natural gas industry<sup>2</sup>

1. Technology development includes R&D with academic institutions, eligible Scientific Research and Experimental Development claims for Canadian income tax purposes, and other activities that create or deploy new technology, or improve existing technology.
2. Research InfoSource, Canada's Top 100 Corporate R&D Spenders 2021.



# Leading in Carbon Capture, Utilization and Storage (CCUS)



## TECHNOLOGY STAGE:

## DEPLOY

**Canadian Natural's long-term aspiration is a journey to net zero emissions in our oil sands operations by advancing technologies and ongoing investment in carbon capture initiatives.**

Canadian Natural is leading the oil and natural gas industry in CCUS initiatives. Our projects make us the largest owner of carbon capture capacity in Canada, based on data from the Global CCS Institute, with a combined capture capacity of ~2.7 million tonnes (Mt) of carbon dioxide equivalent (CO<sub>2</sub>e) per year.

### Quest Carbon Capture and Storage (CCS) Project

The Quest CCS facility is located at the Scotford Upgrader and is part of the Athabasca Oil Sands Project (AOSP), of which Canadian Natural has a 70% ownership interest. The Quest CCS facility has safely captured and permanently stored ~7 Mt CO<sub>2</sub>e at the end of 2021.

	Capture Capacity (Tonnes Per Year)
Horizon	~0.4 million
Quest <sup>(1)</sup>	~1.1 million
NWR <sup>(2)</sup>	~1.2 million
	~2.7 million

Equivalent to removing  
~576,000 cars off the  
road annually

(1) Canadian Natural has a 70% ownership interest in Quest.

(2) On stream in 2020. Canadian Natural is a 50% owner in NWR.

### CO<sub>2</sub> Injection in Tailings

At Horizon Oil Sands, we add captured CO<sub>2</sub> to tailings to accelerate tailings readiness for closure and reclamation. Our CO<sub>2</sub> recovery plant is designed to capture up to 50 tonnes/hour of CO<sub>2</sub> from the hydrogen plant and inject it into the tailings. The plant has a capture capacity of ~400,000 tonnes of CO<sub>2</sub> annually.

### Enhanced Oil Recovery (EOR)

Canadian Natural is a 50% partner in the North West Redwater (NWR) Sturgeon Refinery, which supplies CO<sub>2</sub> to the Alberta Carbon Trunk Line (ACTL), an integrated system that can transport and store 14.6 Mt CO<sub>2</sub>/year for enhanced oil recovery (EOR). At full capacity, the ACTL is the largest carbon capture, transportation, utilization and storage system (CCUS) in the world using captured industrial CO<sub>2</sub>. At our Hays Gas Plant, we also capture ~16,000 tonnes of CO<sub>2</sub> per year for re-use/sequestration in our nearby Enchant EOR operations.



### Business Benefits

- Research and development, and applied technology and innovation, lead to step change improvement in operational efficiencies.
- Create long-term value for the sustainability of our industry and will ensure we remain competitive with other energy producing jurisdictions around the world.
- Reducing oil viscosity and improving overall fluid mobility in the reservoir.



### Environmental Benefits

- ~7 Mt CO<sub>2</sub>e has been captured and safely stored at Quest since 2015, where CO<sub>2</sub> is captured from the Scotford Upgrader. Quest and the upgrader are part of the Athabasca Oil Sands Project, of which Canadian Natural has a 70% ownership interest.
- Canadian Natural has a total carbon capture capacity of ~2.7 Mt CO<sub>2</sub>e/year – equivalent to removing ~576,000 passenger vehicles off the road annually.
- Permanently store CO<sub>2</sub> following EOR use.



Canadian Natural

# Working together to achieve net zero oil sands emissions



TECHNOLOGY STAGE:

DEVELOPMENT

In 2021, Canadian Natural, along with Canada's other largest oil sands producers (representing 95% of Canada's oil sands production), formed the Pathways Alliance. Pathways members are working collectively with the Federal and Alberta governments to achieve net zero greenhouse gas (GHG) emissions from oil sands operations by 2050 to help Canada meet its climate goals.

Achieving net zero emissions will require multiple pathways. Currently there are more than 200 engineers and technical experts from Pathways Alliance companies that are developing applications for underground storage space, improving carbon capture technology, and developing state-of-the-art emissions reduction technology.

Pathways phase 1 plan is targeted to reduce GHG emissions by ~22 million tonnes (Mt) of carbon dioxide equivalent (CO<sub>2</sub>e) per year by 2030. Emission reductions will come from carbon capture and storage technologies, as well as other decarbonization projects such as the use of solvents, energy efficiency, cogeneration and electrification.

## Pathways Foundational Project

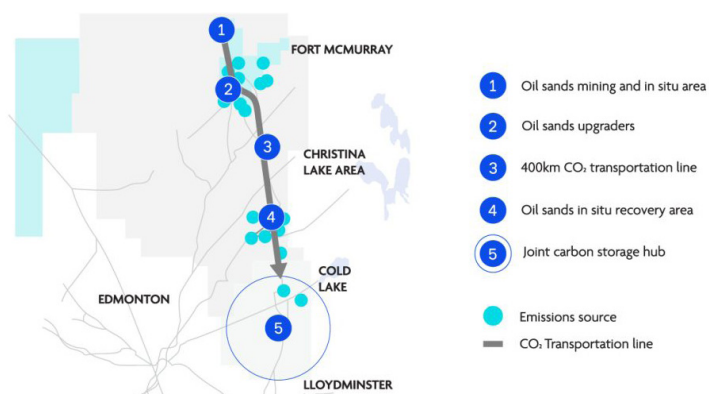
The Pathways vision is anchored by a major carbon capture and storage (CCS) system and transportation line connecting oil sands facilities in the Fort McMurray, Christina Lake and Cold Lake regions to a carbon storage hub near Cold Lake. The line follows more than 95% of existing rights-of-way.

The foundational project will capture and store ~10 Mt CO<sub>2</sub>e/year by 2030.



## Business Benefits

- Create long-term value for the sustainability of our industry and will ensure we remain competitive with other energy producing jurisdictions around the world.
- Pathways projects will create ~35,000 direct, indirect and induced jobs.
- Enables technology development to lower the cost of carbon capture projects.
- Accelerates opportunities to deploy innovative capture solutions and positions Canada to export this technology and expertise.



## Environmental Benefits

- Through the Pathways Alliance, we will meaningfully reduce emissions from oil sands operations by ~22 Mt CO<sub>2</sub>e/year by 2030 using CCS and other emissions reduction projects.
- Pathways projects will help Canada meet its net zero climate goals by 2050.

**Collaboration:** To help Canada meet its climate goals, oil sands producers are working together with governments through [the Pathways Alliance](#) on an ambitious and actionable plan.



Canadian Natural



# Reducing the energy required to produce a barrel of oil



TECHNOLOGY STAGE:

DEPLOY

**Canadian Natural is piloting using solvent for enhanced oil recovery. When used in combination with heat, solvent technology will increase oil recovery, improve steam efficiency and reduce operating expenses to achieve reductions in greenhouse gas (GHG) emissions, water use, and land footprint.**

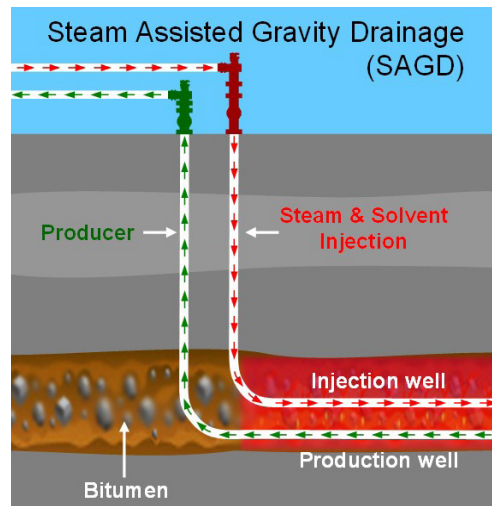
## Solvent Enhanced Oil Recovery

Solvent technologies will play a significant role in creating value across all of our thermal operations on our journey to net zero emissions. In typical thermal oil sands operations, water is heated to create steam that mixes with bitumen and reduces its viscosity so it can be pumped to the surface. When solvent is added, the process requires less steam and operates at a lower temperature – letting heat do half of the job to improve bitumen viscosity, with solvent doing the other half.

As a result, the steam-to-oil ratio (SOR) and the amount of water needed overall is significantly reduced, leading to lower operating expenses for steam and water treatment. In addition to the enhanced project economics, solvent EOR can achieve important environmental performance improvements with up to 50% lower GHG emissions intensity and improved water use intensity.

Our pilot at Kirby South tested solvent effectiveness to improve oil recovery in a steam assisted gravity drainage (SAGD) process, showing SOR and GHG intensity reductions of 45% through the pilot process, as well as solvent recoveries of approximately 85%. Canadian Natural is now progressing with engineering and design of a commercial-scale pilot SAGD pad development at Kirby North, targeting first solvent injection in early 2024.

At Primrose, in the steam flood area, a solvent injection pilot commenced in Q4 2021. This pilot consists of nine net wells (five producers and four injectors) and is targeted to operate for two years, with targeted SOR and GHG intensity reductions of 40% to 45% and solvent recoveries of greater than 70%.



*In typical SAGD oil production, water is heated to create steam that mixes with the bitumen and improves its viscosity so it can be pumped to the surface. When solvent is added, the SOR is significantly decreased.*



## Business Benefits

- Significantly improve resource recovery while reducing the steam needed and the amount of energy required to produce it.
- ~\$1.00/barrel operating cost savings.
- Reduce steam-to-oil ratio by up to 50%.
- Increase production with existing steam generation and water treatment facilities.



## Environmental Benefits

- Reduce GHG emissions intensity by up to 50% by reducing steam usage.
- Reduce the amount of steam needed, resulting in less water used in the production process.



Canadian Natural

# Targeting zero emissions in heavy oil



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural is continuously leveraging technology to develop the most efficient, environmentally sustainable methods for resource recovery while moving us further along the journey to net zero emissions.**

## Ultra-Low Emissions Primary Heavy Oil Pad Sites

In our primary heavy oil operations, Canadian Natural is piloting ultra-low emissions pad sites from reservoir to storage tank. This first of its kind pilot is testing how a typical heavy oil pad site would operate when most emissions are captured or reduced. In a typical heavy oil pad site, pumps powered by natural gas engines are used to transport oil from the reservoir to a storage tank. Once in the tank, the emulsion must be heated. This normally requires using the energy from burning solution gas.

At the ultra-low emissions site, heat generated from burning the solution gas is replaced with electricity that has renewable potential. When heavy oil is produced, solution gas is normally consumed as fuel to power the engine and heat the tank. However, Canadian Natural's ultra-low emissions site conserves the produced solution gas through on-site compression and a vapour recovery unit, reducing natural gas consumption by up to 40%. The conserved solution gas is then sent to sales to be consumed elsewhere. The pilot pad, targeted to be online in Q1 2023, will allow us to operate and make improvements on cost-effective technologies that result in ultra-low emissions.

## Cyclic CO<sub>2</sub> Injection

Canadian Natural's Cold Heavy Oil Production with Sand (CHOPS) assets in the Bonnyville/Lloydminster area typically have a primary oil recovery factor of approximately 10%. To access the remaining oil, Canadian Natural is exploring an enhanced oil recovery (EOR) process.

Over 200 million barrels of incremental oil could be recovered from Canadian Natural-owned CHOPS areas using cyclic carbon dioxide (CO<sub>2</sub>) injection. This process involves injecting CO<sub>2</sub> into a depleted reservoir to re-energize the oil, lower its viscosity and build pressure. During production, the dissolved gas gradually comes out of solution, creating foamy oil, which enhances flow rates and helps preserve the reservoir pressure. Produced CO<sub>2</sub> is captured and re-injected on the next injection cycle. On completion of injection/production cycles, the CO<sub>2</sub> remains permanently sequestered in the reservoir.



### Business Benefits

- Improve oil recovery in target wells in the Bonnyville/Lloydminster area.
- Extend the life of CHOPS heavy crude oil assets.
- Cost-effective processes that reduce emissions and operating costs associated with heating.



### Environmental Benefits

- Open possibilities for future carbon capture projects.
- Opportunity to sequester CO<sub>2</sub> in CHOPS reservoirs.
- Leverage existing pads rather than creating new ones, reducing footprint.
- Reducing natural gas consumption by up to 40%, which when applied to hundreds of heavy oil sites, can significantly reduce fuel emissions.



# Capturing CO<sub>2</sub> for electricity generation



TECHNOLOGY STAGE:

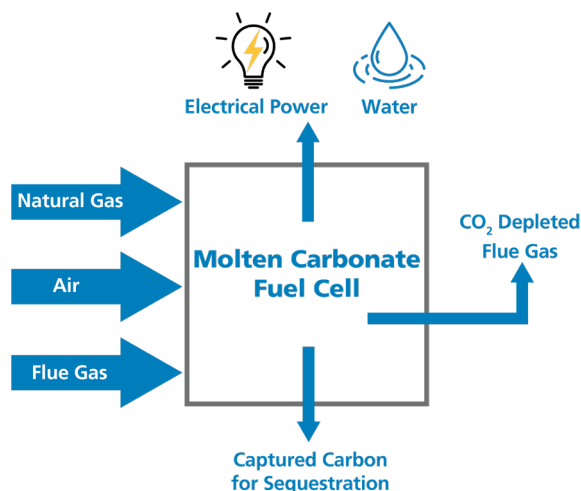
DESIGN

Canadian Natural is identifying ways to reduce greenhouse gas (GHG) emissions intensity by exploring different technologies, including novel projects with the potential to create breakthrough technologies and help move Canadian Natural closer to net zero emissions in oil sands.

## Molten Carbonate Fuel Cells (MCFC)

A typical fuel cell converts chemical energy from a fuel into electricity. MCFCs are a type of fuel cell that operate at high temperatures to produce electricity, heat and water that can be adapted to capture carbon dioxide (CO<sub>2</sub>). This technology combines capturing CO<sub>2</sub> with the generation of low GHG-intensity electricity that could be used on site or sold back to the power grid. A feasibility study funded by industry members and Alberta Innovates - Energy Environment Solutions found using MCFC technology to capture CO<sub>2</sub> promising.

This led to a preliminary front-end engineering design (pre-FEED) study to evaluate the cost of piloting a 1.4 megawatt power generation project at the Scotford Upgrader, part of the Athabasca Oil Sands Project (AOSP). The project would be partially funded by Emissions Reduction Alberta (\$15 million) and the Clean Resource Innovation Network (\$6.8 million), with front-end engineering and design (FEED) started in 2022.



An MCFC captures the CO<sub>2</sub> from flue gas as a storage-ready CO<sub>2</sub> stream, and generates low GHG-intensity electricity and water.



## Business Benefits

- Electricity for on-site use or export to the Alberta grid can provide a revenue stream to offset the costs associated with carbon capture.
- Captured CO<sub>2</sub> can be used at EOR operations to increase resource recovery.
- Potential to generate carbon credits, further enhancing economic viability of this technology.



## Environmental Benefits

- Reduce GHGs by capturing CO<sub>2</sub> to generate electricity.
- Potential zero emissions option for electricity generation.
- Water produced from the process can be captured and used at oil sands facilities, displacing other make-up water sources.

**Collaboration:** This concept is funded by the Athabasca Oil Sands Project (majority ownership by Canadian Natural 70%, Chevron Canada 20% and Shell Canada 10%), and Suncor as part of COSIA, the innovation arm of the [Pathways Alliance](#). It also has funding through [Emissions Reduction Alberta](#) and the [Clean Resource Innovation Network \(CRIN\)](#).



Canadian Natural

# Creating a hydrogen-rich fuel and valuable new products



TECHNOLOGY STAGE:

DESIGN

**On the journey to net zero emissions in the oil sands, Canadian Natural is researching transformational, creative solutions to reduce greenhouse gas (GHG) emissions.**

## Natural Gas Decarbonization

Canadian Natural is exploring how to decrease emissions resulting from in situ operations that require burning natural gas to produce steam. The Canadian Natural-led study, "Natural Gas Decarbonization Global Technology Scan and Evaluation", looked at technologies and solutions available around the world to convert natural gas into a hydrogen-rich fuel and a carbon rich co-product. The hydrogen-rich fuel has a lower carbon content, emitting less carbon dioxide (CO<sub>2</sub>) when burned, and the carbon-rich co-product can be used in oil sands extraction and production processes, or sold to offset costs.

With the support of Emissions Reduction Alberta (ERA) and the Natural Gas Innovation Fund (NGIF), we partnered with other natural gas producers to invest in novel natural gas decarbonization technologies, to help accelerate development and commercialization, including:

- technology that separates methane molecules into a hydrogen-rich fuel (for use as a replacement for diesel or natural gas) and valuable carbon nanotubes, which can then be sold as separate products;
- a system to generate hydrogen and solid carbon that could be used to generate electricity;
- a wave rotor to decompose thermal methane into hydrogen and carbon;
- microwave-based decomposition of methane to produce hydrogen and solid carbon with no direct CO<sub>2</sub> emissions; and
- a small field-scale unit using alloy as a catalyst for methane decomposition to produce CO<sub>2</sub>-free hydrogen and solid carbon.

## Alberta Carbon Conversion Technology Centre (ACCTC)

A world leading technology centre, the ACCTC is specially designed for innovators to test and advance carbon conversion and capture technologies. Innovators can evaluate new carbon capture and utilization technologies at demonstration scale using flue gas from a gas turbine or concentrated CO<sub>2</sub> from an on-site CO<sub>2</sub> capture unit. Innovators are encouraged to consider using the ACCTC to de-risk their technologies.



### Business Benefits

- Create valuable co-products that could be sold to offset costs.
- Reduce costs by decreasing CO<sub>2</sub> emissions.
- Act as a catalyst to attract new and fresh ideas from around the world, to accelerate technology innovation in CO<sub>2</sub> conversion.
- Create opportunities to develop relationships and partnerships with global innovators that could lead to more technology development.



### Environmental Benefits

- Reduce CO<sub>2</sub> emissions through the use of carbon conversion technologies.
- Convert the carbon in methane to a valuable co-product, thus preventing its release as CO<sub>2</sub>.
- Reduce net emissions of CO<sub>2</sub> from operating facilities.
- Accelerate CO<sub>2</sub> reuse technology development by attracting more resources (intellectual and financial) to address excess CO<sub>2</sub> emissions.

**Collaboration:** The technology scan was conducted through COSIA, the innovation arm of the [Pathways Alliance](#), led by Canadian Natural with participation by Suncor and Imperial, in partnership with the Gas Technology Institute (GTI). Canadian Natural is working with industry on many of these technologies through the [Natural Gas Innovation Fund \(NGIF\)](#). In addition to Canadian Natural's support through Pathways Alliance member companies, the ACCTC is funded by Natural Resources Canada and Innotech Alberta.



Canadian Natural



# Executing on our strategy to reduce methane emissions



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural is focused on operational practices and innovative technologies to reduce methane emissions.**

Canadian Natural's methane emissions reduction plan, led by our Conventional Greenhouse Gas (GHG) Steering Committee of senior leaders and technical experts, focuses on methane emissions arising from venting (controlled release of gases) and pneumatic devices (that control natural gas pressure/flow).

## Reducing Heavy Oil Venting

For almost two decades, Canadian Natural has been investing in natural gas conservation projects to reduce venting in our heavy oil operations. Our projects include:

- efficient management of more than 1,375 compressor units used for gas conservation;
- proactive tie-in of wells and multi-well pads where solution gas is conserved; and
- continuous improvement in facility design to reduce vented gas.

We also expanded our use of vapour combustor technology to convert methane to carbon dioxide (CO<sub>2</sub>) at our heavy oil operations when methane cannot be conserved, resulting in less carbon dioxide equivalent (CO<sub>2</sub>e) emissions. In 2021, over 138,700 tCO<sub>2</sub>e of methane was converted to CO<sub>2</sub> using this technology, reducing GHG emissions by more than 85% when compared to venting.

## Reducing Emissions from Pneumatic Devices

Pneumatic devices use pressurized natural gas to function, some of which release low volumes of natural gas as part of their normal operation. We continue to reduce emissions through our pneumatic retrofit program. Since 2018, we have completed over 6,400 pneumatic retrofits and removals resulting in a cumulative CO<sub>2</sub>e reduction from our operations of approximately 640,000 tonnes.

In 2022, Canadian Natural launched a multi-year project to convert approximately 3,800 pneumatic injection pumps in our Alberta and British Columbia conventional areas to solar configurations. This project will help us reduce methane emissions by up to an additional 361,000 tCO<sub>2</sub>e/year.

## Fugitive Emissions - Leak Detection and Repair

Our robust fugitive emissions management program is led by a team of 14 technical experts. As part of continuous improvement, we conducted over 3,000 comprehensive fugitive emission surveys using 12 optical gas imaging cameras and conducted screenings at over 21,000 wells across our conventional operations. This technology has led to a 29% decrease in the frequency of leaks detected in the surveys from 2020 to 2021.



### Business Benefits

- Reduce costs by decreasing GHG emissions, including methane and CO<sub>2</sub>.
- Gain carbon offsets through methane reduction, which can be applied to GHG compliance costs at our facilities.
- Improved precision of chemical injection on solar injection pumps, optimizing operating costs.
- Capturing natural gas from pneumatic pumps to sell to the market.



### Environmental Benefits

- From 2018 to 2021, our pneumatic retrofits and removals reduced 640,000 tonnes of CO<sub>2</sub>e.
- In 2022, approximately 54,000 tCO<sub>2</sub>e/year of methane was eliminated via pneumatic to solar injection pump conversions, resulting in fewer CO<sub>2</sub> equivalent emissions.
- Reduce methane emissions by up to 361,000 tCO<sub>2</sub>e/year once the multi-year pneumatic to solar pump conversion project is complete.



**Canadian Natural**

# Enhanced detection of fugitive methane emissions



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural is exploring methods to enhance the accuracy of greenhouse gas (GHG) emissions measurements from our conventional and oil sands assets. Canadian Natural has the largest Alternative Fugitive Emissions Management program in Alberta.**

## Alternative Fugitive Emissions Management

In 2021, Canadian Natural implemented two-year Alternative Fugitive Emissions Management Program (FEMP) pilots under the jurisdiction of the Alberta Energy Regulator (AER) in our conventional operations. The program is testing truck-based sensors and manned, aircraft-based methane sensing technology. The data will then be used in a modelling software to design a go-forward program with equivalent outcomes to the existing FEMP program. This includes using generated data to prioritize survey follow-ups, which will improve fugitive emissions findings and eliminations.

With the support of Emissions Reduction Alberta (ERA), these pilots are deploying emerging technologies across 1,500 facilities in our conventional operations to evaluate technology performance and validate forecasted emission and cost reductions. Commercialization of technologies that offer accelerated detection and accurate characterization of methane emissions will assist industry in continuous improvement of leak detection and repair efficiencies to reduce emissions.

## Methane Detection via Mobile Robots

At our Horizon operations, we are exploring the viability of using agile mobile robots to identify fugitive emissions in our plants. Using acoustic leak detection cameras and standard gas sniffing detectors mounted on the end of a robotic arm, the mobile robot can detect sounds associated with emissions leaks that are undetectable to the human ear and can “smell” the most minuscule leaks. The mobile robot can do this more regularly and efficiently than humans, and can predict where maintenance should occur. In the first six months of activity, these mobile robots have been systematically deployed in hard-to-reach areas with no new leaks being identified. Review of this technology is currently underway, with two agile mobile robots in operation.

Canadian Natural is also exploring the use of drone technology to detect fugitive emissions on select sites.



### Business Benefits

- Improve quantification of GHG emissions to help develop and deploy cost-effective solutions to reduce emissions.
- Apply learnings to thermal in situ operations.
- Potentially reduce methane fugitive emissions and reduce operating expenses by up to 86%.
- Identify almost undetectable emissions leaks before they grow, resulting in lower maintenance costs and fewer unplanned production losses.



### Environmental Benefits

- Reduce fugitive methane emissions through faster detection and repairs.
- Improve our understanding of methane and carbon dioxide emissions in terms of absolute volumes, seasonal and day/night variations.
- Help us develop technologies to better characterize fugitive emissions to support the development of appropriate mitigation strategies.

**Collaboration:** The Alternative Fugitive Emissions Management Program is funded by Canadian Natural and [Emissions Reduction Alberta](#).



**Canadian Natural**



# Advancing technologies to reduce methane emissions



TECHNOLOGY STAGE:

DEPLOY

**Canadian Natural is working to reduce methane emissions in our conventional operations. Led by our internal Conventional GHG Steering Committee, we are advancing technologies that will help us meet our absolute methane emissions reduction target of 50% from a 2016 baseline by 2030 in our North America Exploration and Production operations.**

## Catalytic Conversion for Methane Venting

As part of our focus on using innovative technologies to be more effective and efficient, Canadian Natural is working with Metan, a technology company, to field-test a device that helps reduce emissions between the time a well becomes inactive and is shut-in, until the time we are ready to commence abandonment and/or remediation activities.

Metan's device uses a catalytic oxidizer to convert methane into lower-intensity carbon dioxide (CO<sub>2</sub>) in situations where gas may be migrating from the casing of an inactive well. The device is mounted in a weatherproof enclosure and is an effective solution to temporarily reduce methane emissions, at a tenth of the cost of other options. This allows teams to plan and coordinate when well integrity mitigation will take place. Canadian Natural worked with the Saskatchewan Research Council (SRC) to test the Metan unit in its laboratory in 2021 and in field locations in 2022. The field test results were positive. Work is now ongoing to incorporate final design changes before implementation.

## Cement Alternatives for Well Decommissioning and Remediation

Well integrity is the key focus of well remediation activities when dealing with fugitive methane emissions. Canadian Natural is working within a consortium of operators to further enhance our well decommissioning and remediation efforts by testing different cement alternatives for use in well abandonment operations. Many technologies do not currently have the field performance data needed to satisfy expectations of operators or regulators. This project takes cement alternatives from laboratory verification to multiple field trials for each technology. By leveraging partner investment, we aim to accelerate the development of commercial alternatives to current cement applications.

Five technologies will be selected for trial in Alberta, beginning in 2023. The project is partially funded by the Clean Resource Innovation Network (CRIN) and the Net Zero Technology Centre.



*Reclaimed well site. Canadian Natural has abandoned over 3,000 wells in our North America Exploration and Production operations in 2021.*



### Business Benefits

- Convert methane into CO<sub>2</sub> so it could be potentially stored or used in enhanced oil recovery efforts.
- Enhance worker productivity through reduced decommissioned well visits.



### Environmental Benefits

- Convert over 95% of methane vented from conventional wells into less-intense CO<sub>2</sub>.
- Reduce or eliminate fugitive methane emissions resulting from well decommissioning and remediation.
- Accelerate the development of technologies to reduce fugitive emissions from well decommissioning and remediation.



Canadian Natural

# Leveraging digital technology for safety and environmental performance



TECHNOLOGY STAGE:

DEPLOY

**Canadian Natural is leveraging three dimensional (3-D) digital models, virtual reality (VR) and augmented reality (AR) technologies in innovative ways to benefit the company.**

For a number of years, major Canadian Natural facilities have been designed with a series of 3-D models using the Smart Plant Review (SPR) software. Using this software, teams can perform 'virtual walkthroughs' of the models on their computers to identify potential hazards and optimize project planning. SPR is used by close to 1,800 employees to gain efficiencies and lower operational costs in plant planning activities, particularly during turnarounds and other maintenance periods, facility design changes and orientation/training.

## Virtual Reality (VR)

The VR Digital Triplet is spatially identical to the actual Horizon Oil Sands facility and created from our 3-D engineering models. It contains every single vessel, valve, pump and other components in their exact location. Using VR, employees can train on equipment, operational procedures, orientation, and emergency response in the specific plant location. This allows a level of training that would otherwise be impossible in an operating plant. 3-D models are in use at our UK platforms (Ninian Central, Ninian South and Tiffany). The three locations are fully scanned and 3-D models are available to all employees and contractors for easy access to centralized data for project planning, facility design changes and risk assessments.

Similar 3-D and Laser Scan models are in development for our Albion mine and opportunities are being investigated to use 3-D models in other areas to improve drilling methods and resource capture.



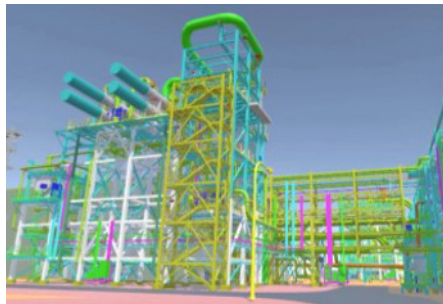
## Business Benefits

- Maintain safe operations while reducing operating costs by gaining efficiencies in training, plant planning activities and applying new technologies.
- Reduced need for personnel travelling offshore to conduct surveys, minimizing risks and improving safety, while allowing teams to work together and connect across a number of remote locations.



## Environmental Benefits

- Improve response time to operational upsets and incident response, thereby reducing potential impact.



*Examples of the 3-D engineered model of the Horizon Oil Sands Facility.*



Canadian Natural



# Deploying data analytics for environmental performance



TECHNOLOGY STAGE:

DEPLOY

Canadian Natural is leveraging artificial intelligence and machine learning to enhance our operational systems and further refine our processes to deliver reliable production.

## Artificial Intelligence

Canadian Natural is using data analytics to enhance and refine our operations. Here are some projects we are working on:

- **Jackfish Hot Lime Softener (HLS) Data Science Project** – Our specially designed programs are helping us improve chemical efficiencies and steam throughput, while enhancing performance of the hot lime softener at our Jackfish operations. The software applies advanced analytics and data science to proactively enhance reliability and water treatment performance - removing hardness, minerals and solids from produced water.
- **Steam Quality Control Algorithm** – Our advanced algorithm is contributing to reduced variations in steam quality by optimizing the fuel gas supply to our once through steam generators (OTSGs) at our Primrose operations. Trials have shown the potential to increase steam quality from 80% to 83%, with no significant increase in scale deposits and erosion. This results in a 0.5% - 1% reduction in GHG emissions intensity.
- **Horizon Predictive Analytics Models on Carbon Dioxide (CO<sub>2</sub>) Compressors** – Using machine learning and Horizon's industry-leading dataset, we developed predictive models to detect anomalies on Horizon's CO<sub>2</sub> compressors, helping the reliability team increase the compressor uptime from 85% to 95%.
- **Horizon Thickeners Water Clarity Prediction** – Using machine learning, operational data and lab samples, we are developing a model to predict water clarity in thickeners. Once complete, we will be able to continuously estimate the amount of water clarity chemicals needed for optimum thickener operation. This will result in considerable chemical cost savings.
- **Improving Uptime to Reduce Emissions** – In our International operations, we are using a suite of artificial intelligence tools to benchmark our daily emissions data against a baseline. This data allows us to identify production anomalies in real-time that could be causing emissions fluctuations. As a result, we are able to find and address instances of excess GHG emissions when they occur.



Hot lime softener at Jackfish.



## Business Benefits

- Reduce chemical and water recycling costs at our thermal operations.
- Extend time between hot lime softener cleanings, maximizing uptime and reducing costs.
- Accurately predict production issues, allowing us to take proactive, planned measures and improve uptime and operating efficiencies.



## Environmental Benefits

- Reduce GHG emissions through enhanced, steady water treatment.
- Reduce unplanned environmental events due to predictive analysis.
- Enhance water treatment, reducing the amount of chemical use.
- Reduce greenhouse gas emissions using data inputs to show production anomalies.



Canadian Natural



# Developing technologies to further decrease water use



TECHNOLOGY STAGE:

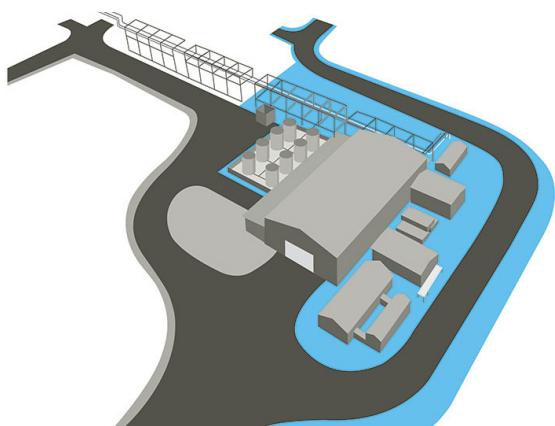
DEPLOY

Effective and efficient water treatment is a priority for all of Canadian Natural's operations. We are always looking for innovative ways to enhance our processes and reduce our fresh water use. In collaboration with industry, we continue to improve water use through best practices, innovation and shared results.

## The Water Technology Development Centre (WTDC)

About 80% of Alberta's oil sands reserves can be recovered through in situ extraction technology. In situ operations use water to produce high temperature steam that is injected into the reservoir to heat the bitumen. The water is recovered, treated and used again. In situ operators have established a world-class water technology development centre at an operating oil sands facility to conduct collaborative research to reduce the cost of water recycling, improve the reliability and efficiency of recycling technology and reduce the environmental footprint of facilities.

The WTDC is a dedicated facility to test new technologies on 'live' process fluids in real-world conditions. Its unique design allows operators to share risks and costs so they can drive the development of more technologies than they could on their own. The test centre will speed technology development and implementation, shortening the current timeframe required to field test technologies and move them to commercial application, leading to an accelerated return on investment.



A 3-D model of the WTDC at Suncor's Firebag plant.



### Business Benefits

- Accelerate the development and commercialization of new water treatment technologies, while shortening the time required to field test.
- Increase the number of technologies tested, while collaboratively managing the risks, leveraging multi-company expertise and lowering the costs of technology development.
- Reduce the costs of commercial facility development.



### Environmental Benefits

- Lower GHG emissions and land footprint through improved water recycling technologies.
- Improve technologies and practices for managing the waste products from water recycling.

**Collaboration:** The \$143 million Water Technology Development Centre (WTDC) is one of the Joint Industry Projects being convened under COSIA, the innovation arm of the [Pathways Alliance](#), with funding support from [Alberta Innovates](#). The WTDC is attached to Suncor Energy's Firebag in situ facility.



Canadian Natural

# Developing new ways to treat recycled water and lower emissions



TECHNOLOGY STAGE:

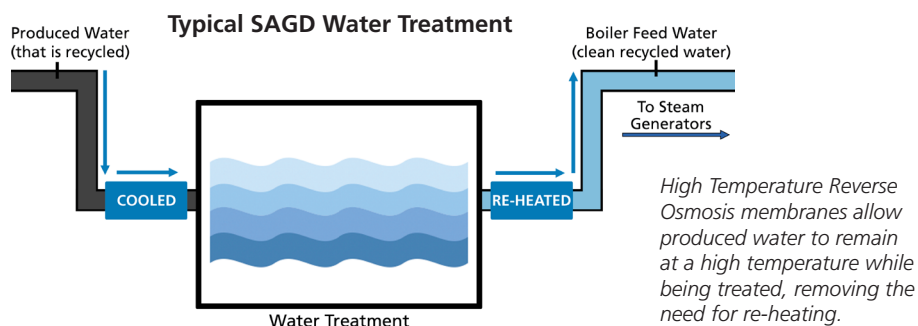
DEVELOPMENT

Canadian Natural is continuously looking for ways to improve operational efficiencies and reduce our greenhouse gas (GHG) emissions. Effective water management is integral to lowering our GHG emission intensity across all projects.

## High Temperature Reverse Osmosis (HTRO)

As part of in situ oil sands development, steam is injected into the reservoir to recover bitumen from the reservoirs beneath the surface. Natural gas is used to heat water and produce steam. In a typical in situ oil sands facility, recycled water used to generate steam is cooled and heated as part of the treatment process requiring additional equipment. If our facilities can be redesigned to keep the water hot throughout the treatment process, significant cost savings and reductions in land footprint could be realized.

Canadian Natural, in partnership with Suncor and Suez Water Technologies, is developing HTRO membranes to enable the in situ oil sands water treatment process to operate at higher temperatures, thus eliminating the need for cooling and re-heating the water. The HTRO project is breaking new ground by developing commercial reverse osmosis membranes to treat produced/recycled water and operate above 100°C. Bench-scale testing is currently underway with a larger pilot planned for 2023 at the Water Technology Development Centre.



### Business Benefits

- Reduce the capital cost of new steam assisted gravity drainage (SAGD) facilities.
- Reduce natural gas consumption, reducing fuel costs.
- Reduce impacts to thermal surface facilities and improve well productivity.



### Environmental Benefits

- Reduce GHG emissions by 5%-10% by efficiently producing high quality water that enables the use of high efficiency steam generators.
- Reduce fresh water use.

## Conventional Reverse Osmosis to Further Reduce Fresh Water Use

At our Primrose and Wolf Lake operations, we are also deploying conventional reverse osmosis technology for saline water treatment. The higher quality, treated water will be used as make-up boiler feed water, reducing impacts to surface facilities and improving well productivity. This project, which will continue to help us reduce fresh water use at the plant, is targeted to be commissioned by the end of 2022.

**Collaboration:** The High Temperature Reverse Osmosis (HTRO) project was convened under COSIA, the innovation arm of the [Pathways Alliance](#), with funding support provided by [Emissions Reduction Alberta](#).



Canadian Natural

# Enhancing water treatment and lowering emissions



**TECHNOLOGY STAGE:**

**DEVELOPMENT**

**Canadian Natural is continuously looking for ways to improve operational efficiencies and reduce our greenhouse gas (GHG) emissions. Effective water management is an integral piece of lowering our GHG emission intensity across all our projects.**

## H2nanO

Water used in oil sands production contains compounds that require treatment prior to release. Canadian Natural and other oil sands producers are working with water treatment company H2nanO and researchers at the University of Toronto on a sunlight-activated, reusable treatment process for process-affected water. This technology, called Solar Pass, uses small, floating particles that when mixed with water and sunlight, activate a high-strength chemical reaction to continuously treat the process-affected water, improving its support of healthy aquatic life.

In 2022, H2nanO demonstrated that within a week of treatment on a process-affected water sample, treated water was safer for aquatic life. Our joint industry project through COSIA, the innovation arm of the Pathways Alliance, has proven the technology works and Canadian Natural is now working with H2nanO to refine the technology to add it to our water treatment options.

## Zero Lime Softening for Water Treatment in Thermal Operations

In a typical steam assisted gravity drainage (SAGD) water treatment process, silica is removed via a lime softening process before it is sent to the once through steam generators (OTSGs) to create steam for use in the reservoir. In the zero lime softening treatment, silica removal is not required for OTSG operation if hardness in the boiler feed water is reduced to very low levels. The zero lime softening process therefore requires less equipment - the lime softener and associated downstream filtration can be eliminated. Canadian Natural is engaged with industry partners in a pilot of the technology at one of the partner's SAGD facilities. The pilot is expected to be completed in 2023.



### Business Benefits

- Accelerate water treatment at the end of mine life when an oil sands facility is decommissioned and during progressive mine reclamation.
- Reduce the capital cost of water treatment in new SAGD facilities.
- Reduce chemical and power handling costs.



### Environmental Benefits

- Treat process-affected water without the use of additive chemicals, absorbents or electricity, as well as without wastes, reducing the carbon footprint of water treatment.
- Reduce the footprint of water treatment in new SAGD facilities.



# Creating value-added products



## TECHNOLOGY STAGE:

## DISCOVERY

**Canadian Natural is collaborating with industry, entrepreneurs, academics, and funders to uncover new uses and methods of utilizing bitumen to reduce potential downstream greenhouse gas (GHG) emissions intensity.**

### Assessing the Viability of Non-Combustion Products

Most bitumen produced from Alberta's oil sands, like other types of petroleum, is primarily used for making combustion products like fuels, such as gasoline, diesel and heating oil.

Canadian Natural and industry continue to look for opportunities and ways to incorporate solutions to become more effective and efficient and find new markets for our products. Some opportunities we are currently exploring include:

- **Bitumen Beyond Combustion (BBC)** – Led by Alberta Innovates, the BBC program explores alternative, non-combustion uses for bitumen. Canadian Natural provided industrial samples to the Carbon Fibre Grand Challenge, a \$15 million competition designed to accelerate the development of carbon fibre from bitumen-derived asphaltenes.
- **Converting Bitumen into Valuable Products** – Work is ongoing with vendors to develop technology to convert bitumen, particularly the heaviest part of the bitumen, into activated carbon, graphene, graphite, and carbon fibre.
- **Converting Petroleum Coke into Solid Carbon** – We are exploring methods of converting petroleum coke, a byproduct from our upgrading process, into various forms of solid carbon (activated carbon, graphene and graphite) that can be input into applications like water treatment and energy storage/battery manufacturing.

### Converting Carbon Dioxide (CO<sub>2</sub>) to Calcium Carbonate

Canadian Natural is also investigating using novel technology to capture CO<sub>2</sub> from flue gas and convert it to carbonates such as high purity calcium carbonates. The versatile high purity calcium carbonates could then be sold for use in the production of paints, plastics, rubbers, ceramics, etc. Canadian Natural is partnering with companies through the Natural Gas Innovation Fund to explore the potential development of a small-scale laboratory test, followed by a field test in Alberta.

**Collaboration:** Canadian Natural is part of the Strategic Advisory Committee in Bitumen Beyond Combustion, led by [Alberta Innovates](#). The project includes partners like BASF Canada, Bowman Centre for Sustainable Energy, Canmet ENERGY Devon Lab of Natural Resources Canada, oil sands producers and others, including academics from the University of Alberta. The flue gas conversion project was convened under the [Natural Gas Innovation Fund](#).



### Business Benefits

- Diversify the use of oil sands components resulting in high-value products that can be made by, or in partnership with, Alberta's oil sands industry.
- Accommodate increased oil sands production in Alberta by creating new and/or expanded markets for oil sands components and their derived products.
- Potential to extend long-term value of reserves.
- Potential to find additional revenue streams that can be realized based on the existing process of mining or in situ extraction of bitumen.



### Environmental Benefits

- Reduce life-cycle GHG emissions intensity by producing new products derived from oil sands that will not be combusted as fuel.
- Reduce CO<sub>2</sub> emissions by capturing and converting CO<sub>2</sub> from flue gas.



**Canadian Natural**

# Creating value-added opportunities



## TECHNOLOGY STAGE:

## DISCOVERY

**Canadian Natural's energy requirements are diverse among our facilities. Currently, some of our projects in British Columbia use hydroelectricity from the grid, and we are exploring unique ways to meet our power and fuel needs while reducing greenhouse gas (GHG) emissions.**

### Alternative Fuels

Canadian Natural is exploring using hydrogen to offset some of the diesel fuel used in combustion engines. Hydrogen is a cleaner burning fuel, and when combined with diesel, it has been found to reduce emissions by up to 25%. We worked with industry peers to test this technology and improve its economics at the Southwest Research Institute (SWRI).

When used as a replacement for diesel, biodiesel can help reduce a diesel engine's overall GHG emissions. We are evaluating the use of biodiesel in our haul trucks and other facilities and investigating methods to generate our own biodiesel, either through partnerships or generation via waste streams at our facilities.

We are also continuing to work with industry peers to assess hydrogen fuel technologies for GHG emissions intensity reduction.

### Harnessing Renewable Energy Sources

At our Septimus and Noel natural gas processing plants in British Columbia, we have invested in power infrastructure to use the province's hydroelectricity to drive electric compressor motors instead of using natural gas.

Septimus has avoided approximately 624,000 tonnes CO<sub>2</sub>e since 2011 when it started operating, while Noel has avoided approximately 112,000 tCO<sub>2</sub>e since we gained ownership of the plant in 2014. We are now looking at other opportunities to leverage hydroelectrical power.

Canadian Natural is also actively evaluating opportunities to add solar and wind power generators to supplement the electrical needs of our existing and new facilities.



### Business Benefits

- Diversify energy suppliers to reduce our risk and manage costs.



### Environmental Benefits

- Reduce GHG emissions by up to 18%-25% in trucks at our mine sites.

**Collaboration:** Canadian Natural is part of a hydrogen/diesel joint industry project through COSIA, the innovation arm of the [Pathways Alliance](#), that includes Imperial and Teck Resources.



**Canadian Natural**

# Minimizing risk and improving tailings reclamation timelines



TECHNOLOGY STAGE:

DEPLOY

**Canadian Natural invests in extensive tailings research, technologies and project construction to help minimize risk and reduce our environmental footprint.**

## Proactive Tailings Management

When we begin a project, we always have a vision and a proactive plan for the landscape that considers the end of mine life and tailings reclamation.

Our Non-Segregating Tailings (NST) process at Horizon uses cyclones to separate the coarse sand and thickeners to capture fines and remove water in the tailings stream prior to being sent to the tailings pond. Carbon dioxide (CO<sub>2</sub>) from Horizon's capture plant is injected in the tailings, further enhancing fines capture and accelerating dewatering.

In 2021, we launched a pilot to send flocculent-treated fluid tailings (FT) through the NST process twice, allowing for even more fines to be captured. This retro-fit to our successful NST process has the potential to enhance reclamation times.

Since 2019, end of pipeline flocculation has been added to the NST process in order to treat the FT, allowing for even more fines to be captured. Legacy FT in the tailings ponds is also harvested and treated, with year-round operation since 2021. These additions to our successful NST process have the potential to reduce reclamation times.

At the Athabasca Oil Sands Project (AOSP), we use thickeners, centrifuges, and atmospheric fines drying to remove water from our FT.

## Applied Process Innovation Centre (APIC)

The APIC was designed and equipped at Horizon to perform a variety of tests and programs to investigate and accelerate the application of promising tailings technologies to commercial scale. It also acts as a collaboration hub allowing industry peers to complete tailings research with samples from their own operations, work together with academia, entrepreneurs and government. In 2021, we invested in a lab-scale centrifuge to allow us to further our understanding of consolidation, and speed-up settlement of tailings fines.

**Collaboration:** These tailings management projects are led by Canadian Natural and shared through COSIA, the innovation arm of the [Pathways Alliance](#).



### Business Benefits

- Reduce operating costs from smaller tailings pond footprint and reduce natural gas use through heat recovery from thickeners.
- Potential to reduce FT treatment costs without the use of a centrifuge.
- Increase operational efficiency from shared industry knowledge, tailings processes and treatments.



### Environmental Benefits

- Reduce fresh water usage and the amount of water sent to the tailings pond.
- Reduce tailings pond size through increased fines capture and decreased FT production, releasing more water for recycling and reducing water intake from the Athabasca River.
- Accelerate reclamation to create landforms that support wetlands and self-sustaining boreal forests.



Canadian Natural



# Leading industry in tailings reclamation



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural is an industry leader for abandonment, decommissioning and reclamation activities. We are continually looking for new and improved ways to manage our tailings to reduce their footprint, decrease reclamation time and reduce tailings pond stability risk.**

## Reclaiming Canadian Natural's First Tailings Facility

The South Expansion Area (SEA) at our Muskeg River Mine, part of our Albian operations, was the first tailings facility to apply for dam decommissioning and closure under Alberta's Dam and Canal Safety Directive (2018). The Directive requires the operator to present a plan and obtain authorization from the Alberta Energy Regulator for the decommissioning and closure of the facility that ensures the stability and safety of the landform. As part of the decommissioning process, the dam consequence risk was successfully reduced to the lowest category in 2021 under this more stringent Directive. Canadian Natural has transformed the site into a reclamation area that includes natural landscape features, like streams, wetlands and upland forest areas with hummocks to create natural wildlife habitat.

Canadian Natural is a leader in progressive reclamation. For our mining operations, we are reclaiming our tailings ponds and overburden waste dumps during the operating stage up to the end of life of the facilities, therefore reducing our liability and risk over time. At our external tailings facilities to date, we have reclaimed 550 ha at Horizon Mine, 154 ha at Jackpine Mine and 396 ha at Muskeg River Mine.



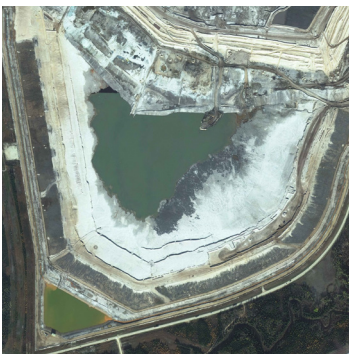
### Business Benefits

- Reduce our impact and liability by reclaiming areas in our oil sands mines to meet or exceed government requirements.



### Environmental Benefits

- Reduce our footprint by reclaiming oil sands mine areas with local vegetation that creates natural wildlife habitat.



**Active Pond**  
October 2014



**Reclaimed Area**  
August 2022

*Reclamation at Muskeg River Mine includes 290 ha at the South Expansion Area.*

# Reducing tailing ponds and emissions



TECHNOLOGY STAGE:

DESIGN

In Canadian Natural's Oil Sands Mining and Upgrading operations, reducing the need for tailings ponds and greenhouse gas (GHG) emissions are environmental priorities.

## In-Pit Extraction Process for Tailings

As part of our continuous investments in research and technology, Canadian Natural focuses on improving performance by enhancing our processes while reducing environmental impact. At Horizon Oil Sands, a field pilot was completed on an alternative bitumen extraction method — the In-Pit Extraction Process (IPEP). This involves a relocatable, modular extraction plant that processes ore and separates bitumen in the mine pit. IPEP reduces materials transportation by truck, pipeline length and energy needed to pump material. This process also produces stackable dry tailings, potentially eliminating the need for future fluid tailings ponds.

Building on the success of the field pilot, we have now completed the front-end engineering and design (FEED) of a demonstration plant.



IPEP involves a relocatable, modular extraction plant that processes ore and separates bitumen right in the mine pit at Horizon. [Watch this video](#) to learn more about IPEP.



### Business Benefits

- Potential to reduce production costs by approximately \$1 to \$2/barrel while substantially reducing tailings management costs and liabilities.



### Environmental Benefits

- Reduce GHG emissions by up to 40% in bitumen production compared to conventional oil sands mining processing plants by minimizing transportation.
- Accelerate reclamation, reduce and avoid fugitive emissions, and potentially eliminate the need for future fluid tailings ponds through the production of "dry" stackable tailings.

**Collaboration:** Canadian Natural has committed to making this technology available to oil sands mining companies through COSIA, the innovation arm of the [Pathways Alliance](#), for more rapid industry-wide adoption. IPEP was developed with broad stakeholder support, including support from the Governments of Canada and Alberta.



Canadian Natural



# Accelerating the pace of reclamation and protecting biodiversity



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural's land management strategy is to reduce our impact by progressively reclaiming large contiguous areas of land more efficiently and cost effectively. We incorporate long-term biodiversity and reclamation objectives in our programs to maintain the characteristics of each ecosystem and restore wildlife habitat.**

## Area-Based Abandonment and Reclamation

In our conventional and thermal operations, Canadian Natural's industry-leading closure program is accelerating the pace of well abandonment and site reclamation in innovative and cost-effective ways, while advancing environmental closure obligations. We group well and pipeline abandonments, reclamation and remediation activities to take sites out of service in a safe and environmentally sound manner to remove our footprint over larger areas.

These activities have reduced the average time to reclamation certification from four years to three years. Between 2016 and 2021 we have abandoned 8,649 inactive wells and submitted 5,080 reclamation certificates.

## Minimizing Seismic Footprint

In 2021, COSIA, the innovation arm of the [Pathways Alliance](#), challenged technology providers to put forward technologies and techniques with the goal of achieving zero disturbance seismic in the oil and gas industry. Innovators responded and a joint industry project was launched to investigate the viability of Eco-Seis. This technology combines new and conventional seismic sources and applies them with a unique seismic geometry with the goals of maintaining sensitive habitat and minimizing surface disturbances, continuing the high standards of safety imbedded in the industry, while at the same time acquiring the quality of data required.

If successful, this technology could reduce line clearing on seismic programs by 30%-50%. The pilot is being funded by the Pathways Alliance (COSIA), Alberta Innovates, the Clean Resource Innovation Network, and the Petroleum Technology Alliance Canada. Eco-Seis and the Pathways partners will undertake a seismic project in the winter of 2023 to demonstrate the results of the technology.



### Business Benefits

- Less ground disturbance, while reducing the reclamation required and further accelerating the rate of liability reduction.
- Reduce the costs associated with land clearing for seismic activities.
- Increase the success of wetland reclamation to reduce closure costs.



### Environmental Benefits

- Reduce re-vegetation timelines from four years to three years through the area-based abandonment and reclamation approach.
- Reduce disturbance and maintain sensitive habitat while executing seismic activities.



# Improving reclamation and protecting biodiversity



TECHNOLOGY STAGE:

DEPLOY

**Canadian Natural develops every project with a strategic vision and plan to proactively manage impact on the land. We are committed to reclaiming all our worksites once our activities are complete — whether that is boreal forest, native prairie or farmed land. Our reclamation strategies support the establishment of healthy ecosystems, biodiversity, wildlife habitat and a range of land uses.**

## Technology for Reclamation Planning

Canadian Natural's environment teams are leveraging digital technologies to enhance our robust environmental planning and monitoring practices. Here are two examples of technologies we are using to meet our project approvals and maximize our reclamation work:

- **Drones for Reclamation Planning** – At our mine sites in northern Alberta, we conduct manual tree establishment ground surveys on reclamation areas between five to eight years old and performance surveys between 12 to 20 years. These tasks are time intensive and costly. In 2021, Canadian Natural began partnering with Natural Resources Canada in a project to determine tree establishment via drone technology. Using Light Detection and Ranging (LiDar) technology, the drones scan the same reclamation areas that were ground surveyed. The data is now being compared and analyzed in a digital model of the forest.
- **Real-Time Mobile Environmental Data Collection** – Environmental data collection has typically been conducted with pen and paper, resulting in lagging field data that is costly, time consuming, and inefficient to access. To address this challenge, we designed and implemented a real-time mobile data collection application. The enhanced system allows us to define work scopes, track project progress in real-time, observe patterns, make analysis quickly, and effectively communicate among all stakeholders.

## Reducing Bird Interactions

To enhance our robust bird detection and deterrent systems at Horizon, we are working with Environment and Climate Change Canada to identify the target signal of specific bird species. Our long range radar unit is designed to track birds up to 20 km away from our site. This allows us to detect bird flights near incoming aircraft and through the filtering of the data, detect large bodied birds when they get close to our operations. Work is ongoing to develop real-time data displays that will be used to respond to a potential landing near our operations.



### Business Benefits

- Reduce costs and safety risks associated with manual ground surveys.
- Use data to build a more complete picture of reclamation outcomes, allowing us to meet regulatory requirements more quickly.
- Provide business-useful information for quick decision-making, potentially further reducing costs.



### Environmental Benefits

- Improve reclamation outcomes and biodiversity ensuring native species thrive on reclaimed sites.
- Collect enhanced data sets allowing for real-time adjustments to reclamation programs.
- Maximize the effectiveness of our reclamation work.
- Reduce bird contact near operating facilities.



Canadian Natural

# Proactive pipeline integrity management



**TECHNOLOGY STAGE:**

**DEPLOY**

**Canadian Natural has teams of highly experienced individuals with technical expertise in pipeline integrity management. These teams drive a consistent approach to problem solving, align solutions with industry best practices and continually identify new ways to detect and reduce the potential of pipeline incidents.**

Canadian Natural has a proactive pipeline integrity management program that places a high level of focus on pipelines near moving water bodies and in geotechnically active areas. As a result, we have further strengthened our processes and tools to predict possible failure locations, along with the early detection of small leak rates, to mitigate potential environmental impacts. Some of the new technologies deployed to help us maintain safe, reliable operations of our pipeline network are shown below.

## Nanocomposite Coating for Early Leak Detection

Early leak detection is a priority for Canadian Natural's Asset Integrity teams. That's why we are exploring using an external sensor with a nanocomposite coating on our multiphase pipelines at water crossings. This unique nanocomposite is made of carbon nanotubes, graphene and polymers that will react when put into contact with liquid hydrocarbons. When the liquid hydrocarbons contact the coating, the coating expands, changing the distance between the adjacent nanotubes, causing the sensor resistance to increase, alerting our teams to the incident. Final proofing of the technology and roll-out planning is currently underway.

## X-Ray Technology for Corrosion Detection

Canadian Natural is deploying technology popular in the medical field to detect corrosion in difficult to access pipelines. Pipelines in our thermal operations are typically covered in layers of specialized insulation and are not conducive to pigging (a process where a small unit is sent through the pipeline for cleaning and to determine the pipeline's condition). Using an automated digital radiographic pipeline crawler, we are now able to scan these hard-to-access pipelines and assess the images and data generated. This technology is helping us reduce costs and the time needed to access pipelines and ensure pipeline integrity in our thermal operations.

## Better Insulation for Above-Ground Pipe

Above-ground pipelines must be insulated to prevent freezing in the cold northern winters; however, this insulation introduces the risk of stress corrosion cracking of the pipe. Canadian Natural is working with InnoTech Alberta and other industry partners to review and share knowledge and enhance the insulation system used on these pipelines. Together, we will develop enhanced inspection and monitoring, and mitigation practices for pipelines, piping and vessels already in-service, as well as for new construction.



### Business Benefits

- Reduce costs and time associated with proactive inspections on hard-to-access pipelines in our thermal operations.
- Prevent downtime on above-ground pipelines that use thermally insulated carbon steel.



### Environmental Benefits

- Detect corrosion before a leak occurs, preventing potential impact to the environment.
- Reduce leak consequence through enhanced monitoring and mitigation efforts on above-ground pipelines that use thermally insulated carbon steel.



**Canadian Natural**

# Strategic Collaborations

[Canadian Natural](#) partners with organizations that bring companies, innovators and investors together to help leverage our investments into incremental and game-changing technologies and accelerate development timelines.



Clean Resource Innovation Network

[www.cleanresourceinnovation.com](http://www.cleanresourceinnovation.com)

**The Clean Resource Innovation Network (CRIN)** is an industry-led network that leverages large-scale collaboration and aligns research and technology priorities. Canadian Natural is an active participant in the network, bringing together the oil and natural gas industry and the sectors necessary to accelerate the commercialization of new technologies (service companies, private and public innovators, think tanks, investors, policy makers and academics). CRIN's vision is for Canada to be a global leader in producing clean hydrocarbon energy from source to end use.



[www.pathwaysalliance.ca](http://www.pathwaysalliance.ca)

**The Pathways Alliance** is working together with governments on an actionable plan to reduce greenhouse gas emissions from oil sands production to net zero emissions by 2050 to help Canada meet its climate goals. Pathways represents six of Canada's largest oil sands producers and operate facilities representing ~95% of oil sands production.



[www.cosia.ca](http://www.cosia.ca)

**Canada's Oil Sands Innovation Alliance (COSIA)**, the innovation arm of Pathways, is focused on reducing industry's impacts to air, water and land, while accelerating tailings reclamation. The integrated organization leverages 10 years of collaborative success within COSIA, which has resulted in more than 1,100 environmental innovations valued at more than Cdn\$1.8 billion and adds to the industry's significant efforts to reach net zero.



[www.ptac.org](http://www.ptac.org)

**The Petroleum Technology Alliance Canada (PTAC)** is a Canadian hydrocarbon industry association that serves as a neutral non-profit facilitator of collaborative research and technology development, and operates in partnership with all industry stakeholders to transform challenges into opportunities. Canadian Natural is an active participant in a number of PTAC projects. Through PTAC, over 800 research and development projects have been facilitated to date, with a reduction of 11 Mt CO<sub>2</sub>e annual GHG emissions.



[www.ngif.ca](http://www.ngif.ca)

**The Natural Gas Innovation Fund™ (NGIF) Industry Grants** was created by the Canadian Gas Association to fill a technology development gap in the sector and invests in innovation led by cleantech start-ups and small and medium-sized enterprises, enabling natural gas solutions for current and emerging challenges facing Canada's energy system. NGIF Industry Grants plays an important role in the natural gas sector and aligns with Canadian Natural's commitment to lowering GHG emissions intensity by leveraging technology and Canadian ingenuity.



[www.ptrc.ca](http://www.ptrc.ca)

**The Petroleum Technology Research Centre (PTRC)** is a not-for-profit corporation that facilitates research and development and demonstration projects into enhanced oil recovery and carbon storage, with the goals of improving recovery rates while reducing the environmental footprint of the oil and gas industry. Canadian Natural contributes to PTRC's Heavy Oil Research Network (HORNET), a program that is focused primarily on enhanced oil recovery.





**Canadian Natural**  
**Canadian Natural Resources Limited**

2100, 855 - 2nd Street S.W.  
Calgary, AB T2P 4J8  
[www.cnrl.com](http://www.cnrl.com)

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**T** (403) 517-6700  
**F** (403) 517-7350  
**E** [public.affairs@cnrl.com](mailto:public.affairs@cnrl.com)