

CREATING VALUE THROUGH TECHNOLOGY AND INNOVATION

2020 CASE STUDIES



Canadian Natural

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 guidance provided throughout the Company's 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 Oil Sands ("Horizon"), the Athabasca Oil Sands Project ("AOSP"), Primrose thermal projects, the Pelican Lake water and polymer flood project, the Kirby Thermal Oil Sands Project, the Jackfish Thermal Oil Sands Project, 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, natural gas liquids ("NGLs") or synthetic crude oil ("SCO") that the Company may be reliant upon to transport its products to market, and the development and deployment of technology and technological innovations 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.

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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 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 the Organization of the Petroleum Exporting Countries ("OPEC") and non-OPEC countries) 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 and non-OPEC countries taken in response to COVID-19 or otherwise; fluctuations in currency and interest rates; assumptions on which the Company's current guidance is 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; 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 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 adequacy of the Company's provision for taxes; the continued availability of the Canada Emergency Wage Subsidy ("CEWS") or other subsidies; 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 the Company's 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 the Company's 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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Bitumen Beyond Combustion

Creating value through technology and innovation: Our journey to net zero

Over Canadian Natural's long history, our strong culture and strategy have ensured continuous value, growth and sustainable operations. A commitment to innovation and continuous improvement delivered by our dedicated teams is at the foundation of our culture. Our commitment is constant and is a source of pride for our employees.

Throughout this booklet are projects poised to deliver everything from small, incremental greenhouse gas (GHG) reductions to potentially game-changing results. With the help of entrepreneurs, industry, academia, and government we are continuing to leverage our investments and move technologies at all levels of readiness toward commercialization. These technologies are an integral part of our journey to net zero emissions in the oil sands.

Canadian leadership in responsible energy production

Canada's crude oil and natural gas industry is delivering leading Environmental, Social, Governance (ESG) performance amongst the top crude oil exporting countries, including transparency in its operations, compliance with the most stringent regulatory and reporting requirements in the world, and leading innovation and cleantech investment.

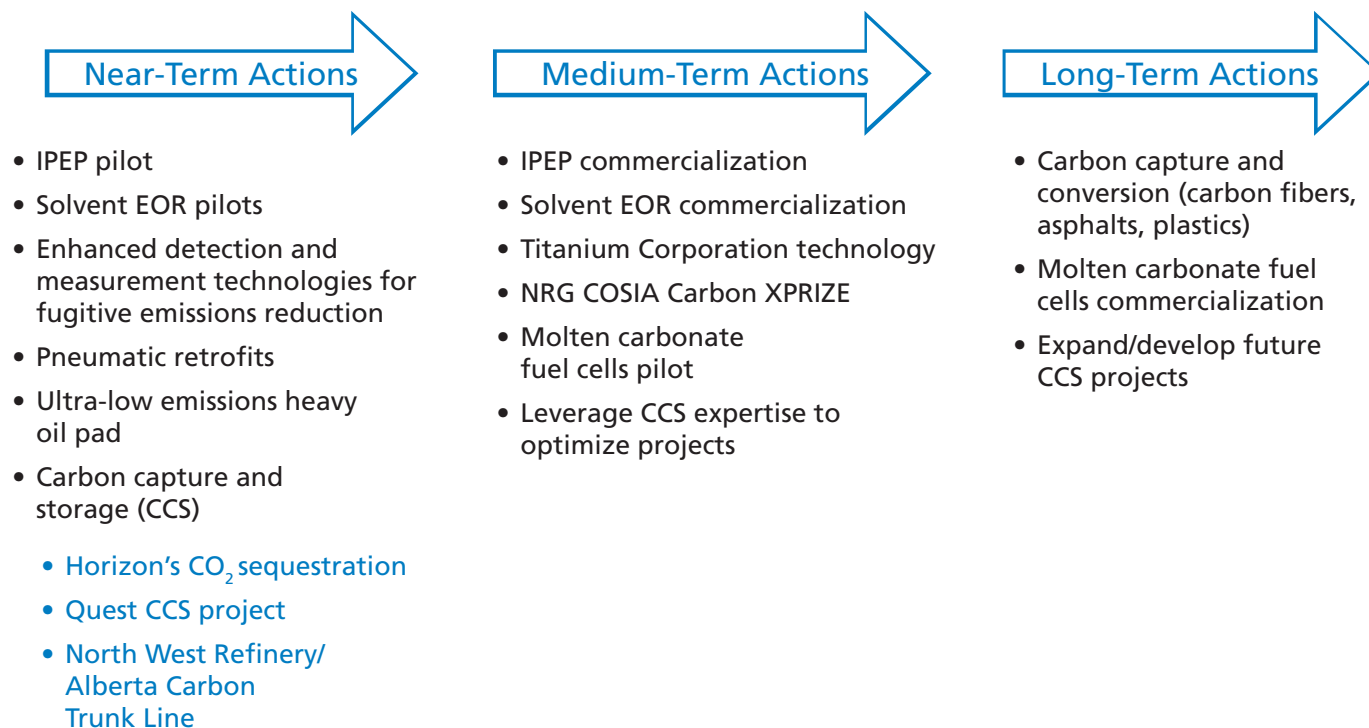
The Canadian crude oil and natural gas industry is strongly committed to doing our part to lower GHG emissions intensities, and helping to position Canada as the supplier of choice for safe, secure, affordable, reliable, socially and environmentally responsible energy the world needs.

With a well-established track record of safe and responsible development, industry is delivering impressive results, including a 20% reduction in GHG intensity by Canadian oil sands projects from 2009 levels (IHS Market Canadian Oil Sands Report, July 2020). We are on a path to ongoing improvements in performance and are strongly positioned to be resilient in a lower carbon emissions intensity economy.



Technology to deliver GHG emissions reductions

Every day, Canadian Natural employees are pushing the boundaries of technology to advance Canadian Natural's aspirational goal of reaching net zero emissions in the oil sands. This is a lofty goal and our plan is to leverage technology and innovation to reduce emissions to net zero. The case studies in this booklet showcase many examples of how we plan to get there.



Our defined pathway to drive long-term GHG emissions reduction and improve efficiencies is anchored in the development and adoption of technology. With \$3.7 billion invested in research and development (R&D) over the last decade, leveraging technology and innovation are key elements in our long-term plan and to achieving our targets.

We are seeing meaningful results today and will continue to create long-term value on our journey to net zero through a comprehensive strategy and investments in technology and innovation. Our integrated GHG reduction strategy includes:

1. Integrating emission reduction in project planning and operations;
2. Leveraging technology to create value and enhance performance;
3. Investing in research and development and supporting collaboration;
4. Focusing on continuous improvement to drive long-term emissions reductions;
5. Leading in carbon capture and sequestration/storage;
6. Engaging proactively in policy and regulation, including trading capacity and offsetting emissions; and
7. Considering and developing new business opportunities and trends.

We are a proud, resilient company that uses creativity and innovation to solve our challenges. By working together and doing it right, we are confident that we will continue to innovate and thrive through periods of growth and downturns. The case studies highlighted in this booklet showcase a sample of the new technologies and continuous improvement opportunities being evaluated, piloted and/or implemented at Canadian Natural and within the industry to move us forward on the journey to net zero in the oil sands.

Advancing carbon capture and reclamation in tailings



BENEFITS

GHG

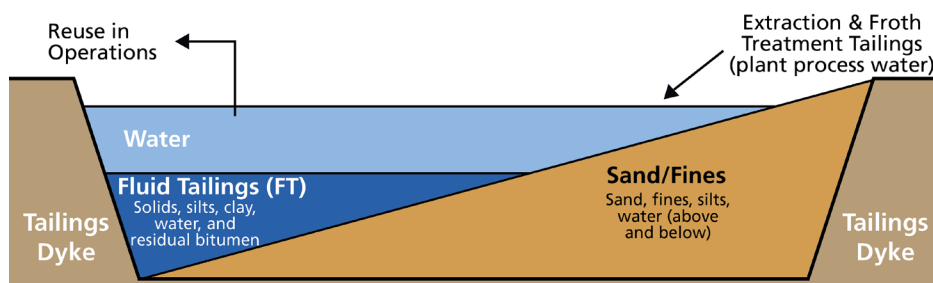
WATER

LAND

Canadian Natural has invested almost \$3.8 billion to date in extensive tailings research, technologies and project construction.

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. The graphic below depicts a typical tailings pond.



At Horizon Oil Sands, a Non-Segregating Tailings (NST) process dewateres the tailings by using 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. The warm water recovered is re-used in production. Carbon dioxide (CO₂) from Horizon's capture plant is injected and sequestered in the tailings. The addition of CO₂ to NST further enhances fines capture and accelerates dewatering. A fluid tailings (FT) plant was commissioned in 2019 to combine NST with legacy FT and enhance the fines capture process, increasing the amount of fines captured and further reducing fluid fines generation from the outset.

At the Athabasca Oil Sands Project (AOSP), we combine the use of thickeners and centrifugation technologies to help separate and remove the water from the FT. At the Jackpine Mine, an Atmospheric Fines Drying (AFD) technology helps settle out solids in the FT, while at the Muskeg River Mine we have composite tailings. Canadian Natural tested a filter press technology that uses a mechanical filter to press FT, producing water for recycling and dewatered solids suitable for reclamation material in only a few hours.

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 so industry peers can complete tailings research with samples from their own operations, working together with academia and government.

DEPLOY



Business Benefits

- Reduce operating costs from smaller tailings footprint and use less natural gas.
- Increase operational efficiency from shared industry knowledge, tailings processes and treatments.



Environmental Benefits

- Reduce GHG emissions through less natural gas consumption due to warm process water recycled without being reheated.
- 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.

Collaboration: These tailings management projects are led by Canadian Natural and shared through [Canada's Oil Sands Innovation Alliance \(COSIA\)](#).



Reducing our environmental footprint in the oil sands



BENEFITS

GHG

LAND

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 is underway 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 right in the mine pit.

IPEP reduces materials transportation by truck, pipeline length and the energy needed to pump material. This process also produces stackable dry tailings, potentially eliminating the need for future fluid tailings ponds.



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.

DEPLOY



Business Benefits

- Potential to reduce production costs by approximately \$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.
- Reduce footprint of mining operations by eliminating the need for constructing new central ore processing facilities.
- 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 [Canada's Oil Sands Innovation Alliance \(COSIA\)](#) for more rapid industry-wide adoption. IPEP was developed with broad stakeholder support, including support from the Governments of Canada and Alberta.



Canadian Natural

Recovering valuable commodities and reducing emissions



BENEFITS

GHG

WATER

LAND

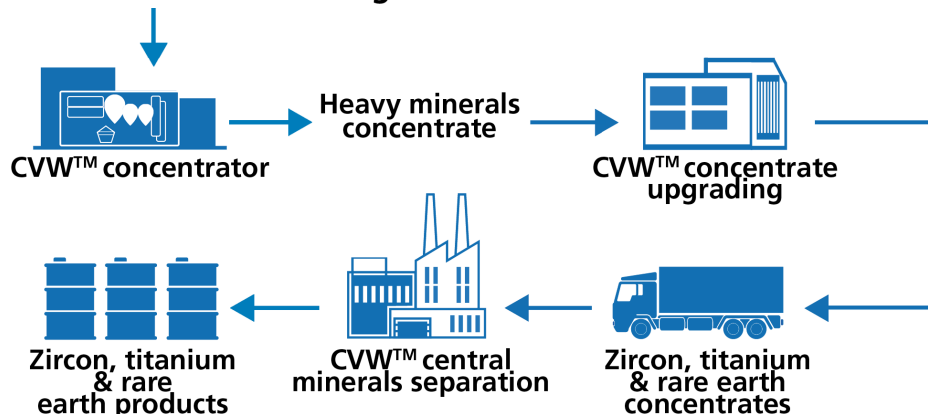
Canadian Natural and Titanium Corporation worked together to develop a design for the first commercial scale plant for Titanium's patented CVW™ (Creating Value from Waste) technology that recovers valuable products from tailings while reducing environmental footprint.

Creating Value From Froth Treatment Tailings

CVW™ is a suite of froth treatment tailings remediation technologies designed to reduce the environmental footprint of tailings ponds while recovering valuable products that would otherwise be lost in tailings ponds. These technologies recover bitumen, solvents, heavy minerals and rare earths from froth treatment tailings, preventing these commodities from entering tailings ponds and the atmosphere.

Industry-wide implementation of CVW™ could have a large impact on future greenhouse gas (GHG) emissions from tailings ponds and the extraction of heavy minerals.

Froth treatment tailings



Froth Treatment Tailings contain ~2-3% bitumen, ~15-20% solids (up to 50% of solids can be fines), solvent (~0.2-0.4%) with the balance ~80% being water.

Collaboration: [Titanium Corporation's CVW™](#) technology has been developed with broad stakeholder support, including the Governments of Canada and Alberta, and collaboration from Canadian Natural and other oil sands operators that provided tailings samples, technical input and project reviews over the last five years. The Front-End Engineering Design (FEED) study received funding from [Emissions Reduction Alberta](#).

Other collaborators include [Canada's Oil Sands Innovation Alliance \(COSIA\)](#), Alberta Energy, Sustainable Development Technology Canada, National Research Council (NRC), and Industrial Research Assistance Program (IRAP).

DEPLOY



Business Benefits

- Potentially create a new minerals industry for Alberta and Canada that could translate into economic growth, jobs, diversification and potential exports.
- Recover up to 100,000 tonnes per year of valuable minerals (zircon and titanium-bearing HiTi).



Environmental Benefits

- Potentially reduce net GHG emissions by approximately 570 ktCO₂e per year.
- Recover process water, bitumen, and provide cleaner tailings, thereby accelerating reclamation.
- Reduce and avoid future fugitive emissions from tailings ponds.
- Improve tailings water quality for recycling.
- Provide a lower GHG extraction process for heavy minerals.



Canadian Natural

Carbon capture, sequestration or storage, and utilization (CCSU)



BENEFIT

GHG

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.

Leading in CCSU Initiatives

Canadian Natural is leading the oil and natural gas industry in CCSU initiatives. Our projects make Canadian Natural the sixth largest industry owner of CCS capacity in the world, and the largest in Canada, based on data from the Global Carbon Capture and Storage Institute. A portion of the carbon dioxide (CO₂) for the initiatives listed below is captured from the hydrogen plants at our operations. The hydrogen from these plants can also be called "blue hydrogen" or hydrogen with reduced greenhouse gas (GHG) emissions associated with the production process.

CO₂ Sequestration in Tailings

At Horizon Oil Sands, we add carbon dioxide (CO₂) to tailings to enhance tailings performance, reduce our footprint and sequester CO₂ in the process. Our CO₂ recovery plant captures up to 50 tonnes/hour of CO₂ from the hydrogen plant, where it is then injected into the tailings. The plant has a capture capacity of 438,000 tonnes of CO₂ annually.

Quest CCS Project

The Quest Carbon Capture and Storage 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 captured and permanently stored five million tonnes of CO₂ as of 2020.

Enhanced Oil Recovery (EOR)

Canadian Natural is a 50% partner in the North West Redwater (NWR) Sturgeon Refinery. NWR is part of a new system built to safely transport and permanently store CO₂ in Alberta. CO₂ captured from the refinery serves as an anchor supply to the Alberta Carbon Trunk Line (ACTL) where it is used for enhanced oil recovery (EOR). At full capacity, the ACTL is the largest carbon capture, transportation, utilization and storage system in the world that exclusively uses captured industrial CO₂. The system is designed to transport up to 14.6 million tonnes of CO₂ per year, equal to the impact of capturing the CO₂ from approximately 3.2 million cars. At our Hays Gas Plant in Taber, Alberta, we also capture up to 12,000 tonnes of CO₂ per year for re-use/sequestration in our nearby Enchant EOR operations.

	Capture Capacity (Tonnes Per Year)
Horizon	0.4 million
Quest ⁽¹⁾	1.1 million
NWR ⁽²⁾	1.2 million
	2.7 million

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

(1) Canadian Natural is a 70% working interest owner in Quest.

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

DEPLOY



Business Benefits

- Research and development, and applied technology and innovation, lead to step change improvement in operational efficiencies.



Environmental Benefits

- Canadian Natural's CCS projects at major facilities target capture of 2.7 million tonnes/year of CO₂ – equivalent to removing ~576,000 passenger vehicles off the road annually.



Canadian Natural

Reducing GHG emissions through steam efficiencies



BENEFITS

GHG

WATER

LAND

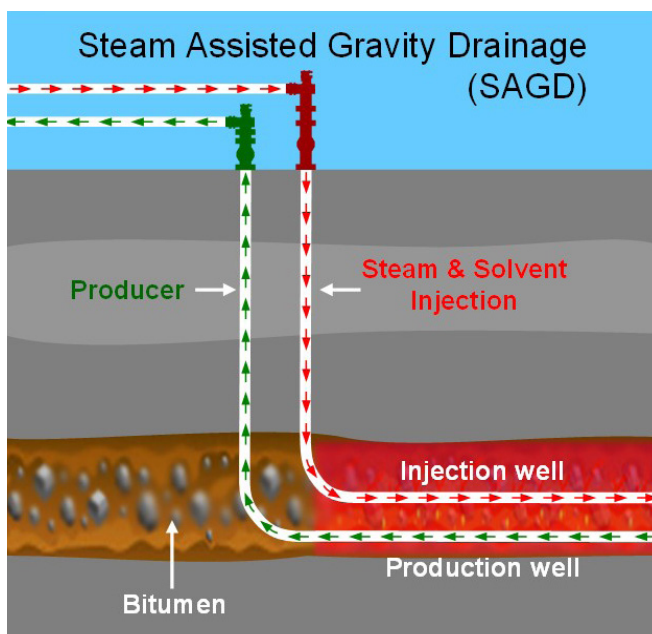
Canadian Natural is piloting using solvent for enhanced oil recovery. When used in combination with heat, solvent technology will increase oil recovery, improve steam efficiency and reduce operating expenses to achieve environmental benefits including reductions in greenhouse gas (GHG) emissions, water 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 the 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, we achieve important environmental performance improvements with up to 50% lower GHG emissions intensity and improved water use intensity.

Our pilot at Kirby South is testing solvent effectiveness to improve oil recovery in a steam-assisted gravity drainage (SAGD) process. To date, we've seen an increase in oil production, significantly lower SOR, and high solvent recovery. Canadian Natural is planning a pad scale demonstration test to verify the commercial rates of recovery at Primrose and Wolf Lake, as well as further application throughout our extensive thermal in situ asset base.



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.

DEPLOY



Business Benefits

- Significantly improve resource recovery while reducing the steam needed and the amount of energy required to produce it.
- 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

Treating process water during reclamation



BENEFITS

GHG

WATER

LAND

Water used in the oil sands production process contains compounds that require treatment prior to release. Through Canada's Oil Sands Innovation Alliance (COSIA) and independent research, industry is investigating new and better methods for treating process-affected water as part of reclamation plans.

H2nanO

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 treatment, called Solar Pass, uses tiny particles that when mixed with water and activated by sunlight, continuously treat and eliminate organics. Work is ongoing to validate the results of a demonstration pilot to assess the viability of treating oil sands process-affected water.

Demonstration Pit Lakes

Canadian Natural is among the participants in Syncrude's Base Mine Lake — the first commercial scale demonstration pit lake designed to treat process-affected water, sequester mature fine tailings as they settle, and act as a sustainable landscape component. Through COSIA, Canadian Natural contributes funds and provides technical input in the Research and Monitoring Program of this project.

We're also involved in a collaborative project with oil sands operators and InnoTech to evaluate the effects of tailings materials from different operators on water chemistry and aquatic biota. The experiments are conducted in Vegreville, AB, in an outdoor array of mesocosms or small-scale experimental columns. We are scheduled to conduct experimental trials in 2021.

Engineered Wetlands

Canadian Natural has been investigating the potential efficacy of a soil-based, reed bed treatment wetland system technology to treat oil sands process-affected water. Treatment is achieved through the action of naturally occurring soil microbes, which break down particles in the wastewater. The technology has been used with great success worldwide and may offer a cost-effective, bio-treatment process for tailings water. Canadian Natural is currently working with the technology provider to de-risk the site-based demonstration unit.

DEPLOY



Business Benefits

- Demonstration pit lakes and engineered wetlands have the potential to reduce operational costs and provide an environmentally effective long-term solution.



Environmental Benefits

- Data collected will provide operators with information to use for designing pit lakes and wetlands.
- Innovative water treatment processes have lower energy requirements and the potential to mitigate greenhouse gas generation. They have the dual benefit of being an operational management tool and a final reclamation and closure outcome.
- Process water treated through engineered wetlands could become a key piece of the final reclamation landscape and support biodiversity.



Leveraging digital technology for safety and environmental performance



BENEFIT

SAFETY

Canadian Natural is leveraging three dimensional (3-D) digital models, virtual reality (VR) and augmented reality (AR) technologies in innovative ways to make employees safer, improve operational efficiencies, implement new technologies and improve cost effectiveness.

Major Canadian Natural facilities have been designed for a number of years with a series of 3-D models using the Smart Plant Review (SPR) software. Teams can view and perform 'virtual walkthroughs' of the models on their desktop computers to identify potential hazards and optimize project planning. SPR is used by close to 1,500 employees to gain efficiencies and lower operational costs through plant planning activities, particularly during turnarounds and other maintenance periods, facility design changes and orientation/training.

Safety is a core value at Canadian Natural and digital technologies allow us to develop enhanced employee training and onboarding of new site personnel.

Virtual Reality

The VR plant is spatially identical to the actual Horizon plant with every single vessel, valve, pump and other component in its correct location and colour-coded, providing engineering believability. Employees can train on equipment and in computer generated scenarios (e.g. emergency incidents) that would otherwise be impossible.

Canadian Natural is currently looking at combining the Operator Training Simulator with the VR environment. This technology would allow operators to experience operating scenarios like maintenance lock out or a plant emergency, in the VR environment to gain experience quickly.

To help ensure our knowledge and resources are used effectively and efficiently to add value, our cross-corporate Digital Optimization Working Group ensures Canadian Natural is leveraging innovative digital technologies — including 3-D modelling, VR and AR — across the Company.

Artificial Intelligence

Canadian Natural is also using data analytics on Horizon Oil Sands' multi-year data set to maximize the operation's uptime. For example, analyzing our industry-leading data set for patterns has enabled us to predict when Horizon's carbon dioxide compressors could go offline. Using artificial intelligence, we have put mitigations in place to proactively prevent failures and ensure steady production. We are also using this technology to predict pipeline corrosion and transmitter outages.



Canadian Natural Board Member, Annette Verschuren, tests a VR headset and digitally walks around the Horizon Oil Sands plant.

DEPLOY



Business Benefits

- Maintain safe operations while reducing operating costs by gaining efficiencies in training, plant planning activities, and applying new technologies.
- A similar SPR model is being developed for AOSP and opportunities are being investigated to use 3-D models in other areas of the Company to improve drilling methods and resource capture.
- Accurately predict production upsets and issues to help ensure efficient, safe and steady production.



Environmental Benefits

- Improve response time to operational upsets and incident response, thereby reducing potential impact.
- Reduce unplanned environmental events due to predictive analysis.



Canadian Natural

A collaborative approach to quantifying emissions



BENEFIT

GHG

Canadian Natural is exploring methods to enhance the accuracy of greenhouse gas (GHG) emissions measurements from large industrial area sources, including open pit mines and tailings ponds.

Area Fugitive Emissions Measurement

Canadian Natural's research helps address the challenge of quantifying rates of methane and carbon dioxide (CO₂) emissions from non-point sources. Continuous improvement in the consistency and accuracy of measurement techniques will allow us to fine tune our strategies to reduce emissions.

At Horizon Oil Sands, we're incorporating multiple layers of collaborative research to provide a more complete picture of how emissions are generated and influenced by the atmosphere. Work is underway to evaluate emissions profiles through a range of methods:

- Probes installed in the tailings pond to determine how changes in water temperature affect the emissions generated from the pond.
- Ground-based sensors to measure methane and CO₂ emissions around the tailings pond and mine.
- Drones to measure emissions from the ground to 500 ft high.
- Aircraft to measure emissions from 500 to 3,000 ft.

Canadian Natural is evaluating a series of advanced sensors, laser and fiber optic technology, meteorological data, as well as computer modelling techniques. Data collection and analysis is occurring on four discrete field seasonal campaigns. Environment and Climate Change Canada's fixed wing aircraft measurements are also coordinated to coincide with field measurements.

DEPLOY



Business Benefits

- Improve quantification of GHG emissions to help develop and deploy cost-effective solutions to reduce emissions.
- Apply learnings from this project to conventional and thermal in situ operations.



Environmental Benefits

- Quantify methane and CO₂ emissions through all seasons to allow for quicker identification and implementation of mitigation strategies. In turn, this will lead to development of technologies that more effectively reduce emissions from area fugitive sources.
- Transferable technology for other industrial sectors, increasing the opportunity to reduce overall emissions in Canada and globally.

Collaboration: Industry partners on this project include innovators (vendors) and academic institutions: the [Petroleum Technology Alliance Canada](#), [Boreal Laser](#), University of Guelph, University of Alberta, University of British Columbia, [RWDI Air](#), SAIT and the [NASA Jet Propulsion Laboratory](#).

This project is funded by [Emissions Reduction Alberta](#) and through [Canada's Oil Sands Innovation Alliance \(COSIA\)](#) with other industry partners.



Executing on our strategy to reduce methane emissions



BENEFIT

GHG

Canadian Natural is focused on operational practices and innovative technologies to reduce methane emissions on our journey to net zero emissions in the oil sands.

Methane is a greenhouse gas (GHG) that is the main component of natural gas. In the upstream oil and natural gas industry, methane emissions are typically from venting (controlled release of gases) and pneumatic devices (that control natural gas pressure/flow). These sources are the focus of Canadian Natural's methane emissions reduction plan and our Methane Steering Committee of senior leaders and technical experts.

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 1,000 compressor units used for gas conservation.
- Proactive tie-in of wells and multi-well pads where solution gas is conserved.
- Continuous improvement in facility design to reduce vented gas.

We also expanded our use of vapour combustor technology to convert methane to carbon dioxide (CO₂) at our heavy oil operations when methane cannot be conserved, resulting in less CO₂ equivalent emissions. In 2019, over 13,000 e³m³ of methane was converted to CO₂ 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. From 2018-2020, nearly 5,000 high-emitting pneumatic controllers were removed or converted to low-emitting ones.

Measuring Fugitive Methane Emissions

We are working with the Petroleum Technology Alliance Canada (PTAC) and other partners on a multi-year Alternative Fugitive Emissions Measurement Program (Alt-FEMP) to develop more accurate systems and technologies for accelerating methane leak detection and repair (LDAR), enabling us to find, repair and eliminate unintentional methane venting while continuing to meet regulatory requirements.

In 2020, with the approval of the Alberta Energy Regulator and funding from Emissions Reduction Alberta, we launched a pilot program to determine if a combination of methane detection technologies can perform as well or better than prescribed regulatory programs to find and mitigate methane emissions while reducing overall LDAR operating costs. If successful, the new Alt-FEMP could reduce our operating costs for methane LDAR by up to 85%.

DEPLOY



Business Benefits

- Reduce costs by decreasing GHG emissions, including methane and CO₂.
- Gain carbon offsets through methane reduction, which can be applied to compliance costs at our larger emitting projects.
- Potentially reduce methane leak detection and repair operating expenses by up to 85%.



Environmental Benefits

- 14.7 million tonnes of CO₂ equivalent has been conserved in Canadian Natural's heavy oil since 2015 — the same as removing approximately 625,000 passenger vehicles from the road annually over the same period.
- From 2018 to 2020, our pneumatic retrofit program reduced 500,000 tonnes of CO₂e/yr, or the equivalent of removing 108,000 cars from the road per year.
- Reduce methane fugitive emissions through faster detection and repairs.
- 13,000 e³m³ of methane was converted, resulting in less CO₂ equivalent emissions.



Canadian Natural

Proactive pipeline integrity management



BENEFITS

SAFETY

LAND

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.

Real-Time Pipeline Data Comparison

Canadian Natural adopted PipeWISE, a cost effective real-time software that uses current pipeline meter data to determine if the pressure and flow of the line has deviated from previously recorded norms. The technology is sensitive, allowing us to detect smaller leaks well in advance.

Fiber Optic Sensing for New Pipelines

In 2018, the Leak Detection group also started testing fiber optic technology at our facilities for the purpose of detecting smaller, previously undetectable leaks. Based on the positive results achieved, we've installed the first commercial fiber optic sensing for leak detection in the Swan Hills, Alberta area. This technology also senses geotechnical ground movement in real time, effectively allowing us to proactively respond.



Testing the integrity of fiber optic conduit (pressure test).

Monitoring Changing Internal Pipeline Fluid Dynamics

Atmos is a software model that uses changing internal pipeline fluid dynamics to determine the exact location and size of a potential failure. It is a proven technology, used primarily on large transmission pipeline systems throughout North America. By trialing and then adopting Atmos, Canadian Natural has proactively reduced our risk on six of our more complex systems of pipelines.

DEPLOY



Business Benefits

- Reduce the risk of pipeline failures on six of our more complex pipeline systems and on many of our pipeline systems throughout Canada.
- Advanced data management leading to improved operational efficiency along with detection reliability.



Environmental Benefits

- Reduce leak consequence by increasing the detection of smaller leaks.
- Increase proactive response time by measuring the geotechnical ground movement.



Accelerating the pace of reclamation and protecting biodiversity



BENEFIT

LAND

Canadian Natural's land management practices include reducing our impact by progressively reclaiming large contiguous areas of land more efficiently and cost effectively. We incorporate long-term biodiversity and reclamation planning into our programs to maintain the characteristics of each ecosystem and reduce impacts on wildlife.

Area-Based Abandonment and Reclamation

In our conventional operations, Canadian Natural's industry-leading area-based closure program is accelerating the pace of well abandonment and site reclamation in innovative and cost-effective ways, advancing environmental closure obligations. We continue to geographically group well and pipeline abandonments, reclamation and remediation activities to take sites out of service in a safe and environmentally sound manner. These activities have reduced the time to reclamation certification from three to five years, to two to four years, and reduced costs.

Canadian Natural is working with industry and regulators through the [Petroleum Technology Alliance Canada \(PTAC\)](#) on outcome-based remediation targets that reduce excavation and disposal, allowing for faster re-vegetation of sites while protecting biodiversity.

Early Successional Wildlife Dynamics

Successfully reclaiming oil sands operations is an important part of our commitment to reducing our environmental impact. The Early Successional Wildlife Dynamics Program, a [Canada's Oil Sands Industry Alliance \(COSIA\)](#) Joint Industry Project led by Canadian Natural, is a robust monitoring initiative to help measure the success of reclamation across multiple oil sands operations. Since its inception in 2016, the program has shown that a diversity of species typically found in mature boreal forests are returning to and re-establishing on older reclaimed sites (greater than 20 years), including insects, small mammals, amphibians and birds.

Seed Collection and Research

The [COSIA Oil Sands Vegetation Cooperative \(OSVC\)](#) works to harvest and bank seeds from a wide variety of species, and to promote knowledge development for improved collection, handling, storage and eventual deployment of that seed into seedling and outplanting on reclaimed land. Beyond operational collections, the OSVC is active in identifying research gaps in the areas of seed collection, seed storage, and plant production to improve reclamation outcomes. To date, the OSVC has banked 51 species, almost 11,000 litres of fruit/seed, and 240 million seeds for approximately 33 million seedlings.

DEPLOY



Business Benefits

- Reduce ground disturbance activities, reducing the reclamation required and further accelerating the rate of liability reduction.
- Reduce the frequency and intensity of sampling through the development of the Rapid Assessment Method (RAM).



Environmental Benefits

- Reduce re-vegetation timelines from three to five years, to two to four years through the area-based reclamation approach.
- Contribute to the state of knowledge regarding the efficacy of upland reclamation in the Athabasca Oil Sands Region as it pertains to wildlife.
- Improve reclamation outcomes and ensure native species thrive on reclaimed sites.

Collaboration: Canadian Natural is working with the [Petroleum Technology Alliance Canada](#) to advance area-based reclamation. The Early Successional Wildlife Dynamics COSIA Joint Industry Project includes Canadian Natural, Imperial and Suncor. The OSVC is a COSIA environmental priority area-led study that includes all COSIA members.



Capturing CO₂ for electricity generation

BENEFITS

GHG

WATER



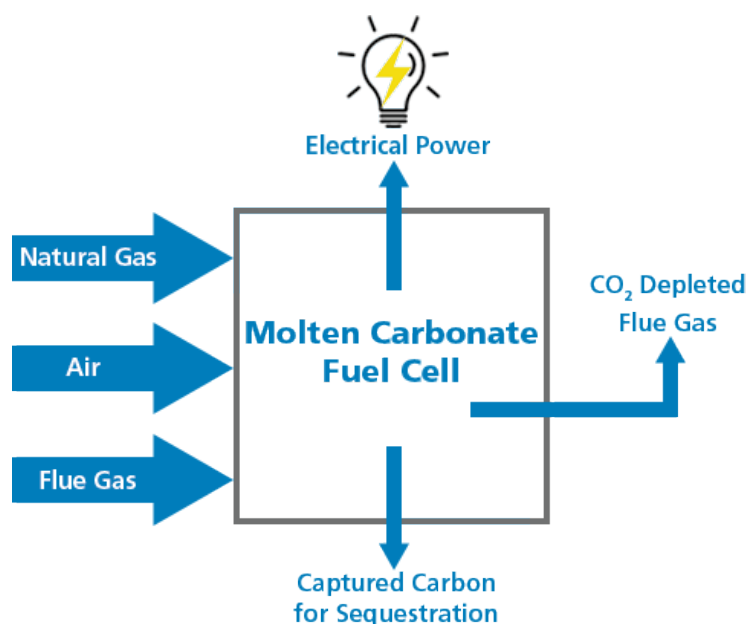
Canada's Oil Sands Innovation Alliance's (COSIA) members are identifying ways to reduce greenhouse gas (GHG) emissions intensity by exploring different technologies, including unconventional projects with the potential to create breakthrough technologies and help move Canadian Natural closer to net zero emissions.

Molten Carbonate Fuel Cells (MCFC)

A typical fuel cell converts chemical energy from a fuel into electricity. MCFCs are one type of fuel cell that operate at high temperatures to produce electricity, heat, and water that can be adapted to capture carbon dioxide (CO₂). This technology combines capturing CO₂ with generating low GHG-intensity electricity that could be sold back to a power grid.

A feasibility study funded by industry members and Alberta Innovates - Energy Environment Solutions found that MCFC technology to capture CO₂ was 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).

As a result of this study, Canadian Natural (majority owner of the AOSP) is leading a COSIA Joint Industry Project to pilot a 1.4 megawatt MCFC at the Scotford Upgrader. The project will be funded (40%) by Emissions Reduction Alberta and is targeted to start-up in 2022.



An MCFC captures the CO₂ from flue gas as a sequestration-ready CO₂ stream, and generates low GHG-intensity electricity and water.

DEVELOPMENT



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 CO₂ 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 CO₂ to generate electricity which could be applied to other industries.
- Potential zero emissions option for electricity generation.
- Water from combustion can be captured and used at oil sands facilities, displacing other make-up water sources.

Collaboration: This project is a collaboration of [COSIA members](#) and [Alberta Innovates](#). The project will be partially funded by [Emissions Reduction Alberta](#).



Canadian Natural

Reducing emissions in heavy oil



BENEFITS

GHG

LAND

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

Ultra-Low Emissions Primary Heavy Oil Pad Site

In our primary heavy oil operations, Canadian Natural is planning an ultra-low emissions pad site from reservoir to storage tank. This first of its kind pilot will test what a typical heavy oil pad site would look like when most emissions are captured or reduced. In a typical heavy oil pad site, pumps powered by natural gas 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.

In the case of the ultra-low emissions site, solution gas is replaced with electricity that has renewable potential. When heavy oil is produced, solution gas, that could be vented into the atmosphere, is released into the well and the storage tank. Canadian Natural's ultra-low emissions site conserves this liberated gas through on-site compression and a vapour recovery unit. The conserved solution gas is then sent to sales to be consumed elsewhere. Once in place, the test pad will allow us to operate and make improvements on cost-effective technologies that result in ultra-low emissions.

Canadian Natural is also planning another type of ultra-low emissions site where the waste heat generated by an engine skid that runs the wellhead equipment is redirected to heat the emulsion tank on site through an exchange process. This heating process is typically done with natural gas and burners. Construction is underway with completion targeted for 2021.

Cyclic CO₂ Injection

Canadian Natural's Cold Heavy Oil Production with Sand (CHOPS) assets in the Bonnyville/Lloydminster area typically have a primary recovery factor of 8%-10%. To access the up to 90% 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 CO₂ Injection. This process involves injecting gaseous carbon dioxide (CO₂) 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 CO₂ is captured and re-injected on the next injection cycle. On completion of injection/production cycles, the CO₂ remains permanently sequestered in the reservoir.

Canadian Natural is working closely with industry partners and the Government of Saskatchewan through the [Petroleum Technology Research Centre \(PTRC\)](#) to advance our knowledge in this area. We are now exploring a potential pilot, which includes evaluating CO₂ sources.

DEVELOPMENT



Business Benefits

- Improve oil recovery in target wells in the Bonnyville/Lloydminster area.
- Extend the life of CHOPS heavy oil assets.
- Create synergies with other business units (i.e. thermal, mining and/or downstream).
- Add economic value to the existing assets.



Environmental Benefits

- Open possibilities for future carbon capture projects.
- Opportunity to sequester CO₂ in CHOPS reservoirs.
- Leverage existing pads rather than creating new ones, reducing footprint.



Canadian Natural

Improving production and reducing environmental impact



BENEFITS

GHG

WATER

LAND

Canadian Natural is continuously exploring technologies with the potential to make a significant difference in emissions reductions. Our applied technologies and day-to-day operational efficiencies are also increasing productivity and reducing greenhouse gas (GHG) emissions.

Optimizing Multi-laterals to Enhance Productivity

In 2017, Canadian Natural piloted a multi-lateral horizontal technique to increase reservoir contact, improve productivity and unlock reserves in conventional heavy oil areas where Cold Heavy Oil Production with Sand (CHOPS) wells were unsuccessful. Multi-lateral horizontal wells had proven successful and effective in unlocking reserves in other areas, so we adapted the process to the unique geological parameters and production characteristics of primary heavy oil areas.



Multi-lateral horizontal wells increase reservoir contact, adding reserves without drilling and completing new wells.

The first horizontal well had 400 to 800 metres of reservoir contact, increasing to 2,000 to 4,000 metres of contact in 2017/2018. In 2019, our teams scaled it up to 10,000 metres. With this new approach, Canadian Natural is seeing improved productivity and recovery. We're also able to reduce our surface/land area with pad drilling while increasing location inventory in our heavy oil assets.

Horizontal designs (multi-lateral horizontals and fishbone wells) are now a part of our suite of drilling methods along with CHOPS wells.

Liquids Enhancement and Gas Storage (LEGS)

Optimizing recovery efficiency is key to maximizing the value of an asset. In 2020, the Liquids Enhancement and Gas Storage pilot at Septimus, in British Columbia, was successfully completed. The pilot used cyclic natural gas re-injection to re-vaporize and re-mobilize stranded liquids in a tight Montney reservoir, allowing them to flow readily to the well.

To accomplish this, produced field gas was captured and re-injected into the wellbore during injection cycles and produced back with incremental liquids volumes. Success of the LEGS pilot demonstrated the potential of the technology to add capital efficient reserves on existing and future developments, with the added potential to improve liquid sales rates by removing gas market/transportation limitations. As a result, the Company is targeting two additional pilots in the Greater Wembley area.

DEPLOY



Business Benefits

- Increase liquid recoveries and reserves.
- Improve the economics of new field developments and drills.
- Add reserves without drilling and completing new wells.
- Unlock previously uneconomic pay zones.



Environmental Benefits

- Reduce surface footprint of operations.
- Add high value reserves without completing new wells, reducing water usage.
- Potential to reduce flared gas volumes during downstream plant outages.



Re-imagining CO₂



BENEFIT

GHG

On the journey to net zero emissions, Canadian Natural is searching for transformational, creative solutions to reduce greenhouse gas (GHG) emissions through our support of the NRG COSIA Carbon XPRIZE.

NRG COSIA Carbon XPRIZE

The US\$20 million [NRG COSIA Carbon XPRIZE](#) is a global competition challenging the brightest minds and innovators across the world to re-imagine what we can do with carbon dioxide (CO₂) emissions by advancing technology development. [Finalists have been chosen](#), representing a diversity of approaches to turn CO₂ emissions into valuable and usable products, such as enhanced concrete, plastics, liquid fuels and carbon fiber.

The competition is structured with two tracks — one focused on testing technologies at a natural gas power plant and the other on testing technologies at a coal power plant. Prizes of US\$10 million are available for each track. The grand prize will be awarded in 2021.

World Leading Technology Centre

The Alberta Carbon Conversion Technology Centre (ACCTC) is a specially designed facility that opened in 2018 for innovators around the world to test and advance carbon conversion technologies. These technologies are aimed at fast-tracking CO₂ emission reductions through the conversion of carbon into usable products.

The ACCTC, owned and operated by InnoTech Alberta Inc., is located next to the Shepard Energy Centre, an 860 megawatt (MW) natural gas-fuelled power generation facility jointly owned by ENMAX and Capital Power. Innovators have the opportunity to evaluate new carbon capture and utilization technologies at demonstration scale using flue gas from Shepard or concentrated CO₂ from the capture unit. In addition to Canadian Natural's support through [Canada's Oil Sands Innovation Alliance \(COSIA\)](#) project member companies, the ACCTC is funded by Natural Resources Canada and the Alberta Ministry of Economic Development and Trade.

DEVELOPMENT



Business Benefits

- Act as a catalyst to attract new and fresh ideas from around the world, to accelerate technology innovation in CO₂ conversion.
- Create opportunities to develop relationships and partnerships with global innovators that could lead to more technology development.



Environmental Benefits

- Reduce CO₂ emissions through the use of carbon conversion technologies.
- Accelerate CO₂ reuse technology development by attracting more resources (intellectual and financial) to address excess CO₂ emissions.

Collaboration: The NRG COSIA Carbon XPRIZE has two co-title sponsors — NRG Energy, a U.S. integrated wholesale power generation and retail electricity company, and COSIA. The COSIA sponsorship is funded by six oil sands companies as part of a joint industry project. Participants include Canadian Natural, ConocoPhillips Canada, Cenovus, Imperial, CNOOC and Suncor.



Canadian Natural

Increasing water recycling efficiency and lowering emissions

BENEFITS

GHG

WATER

LAND



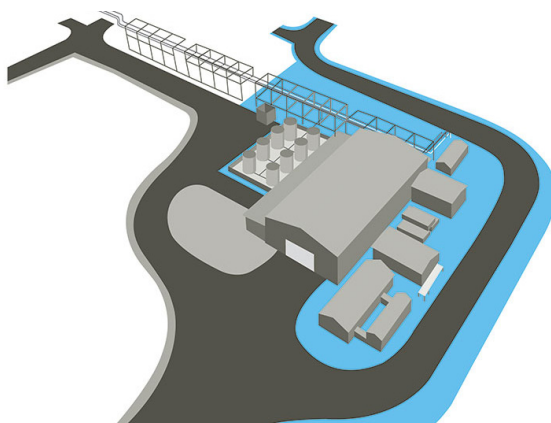
Canadian Natural is a joint industry partner in the Water Technology Development Centre (WTDC) to help reduce the cost of water recycling, improve recycling technology, and reduce the environmental footprint of facilities.

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 that could 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 eight-year 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.

Collaboration: The \$143 million Water Technology Development Centre is one of the Joint Industry Projects being convened under [Canada's Oil Sands Innovation Alliance's \(COSIA\) Water Environmental Priority Area \(EPA\)](#), with funding support from [Alberta Innovates](#). The WTDC is attached to Suncor Energy's Firebag in situ facility.

DEPLOY



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.



Canadian Natural

Developing new ways to treat recycled water and lower emissions



BENEFITS

GHG

WATER

LAND

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.

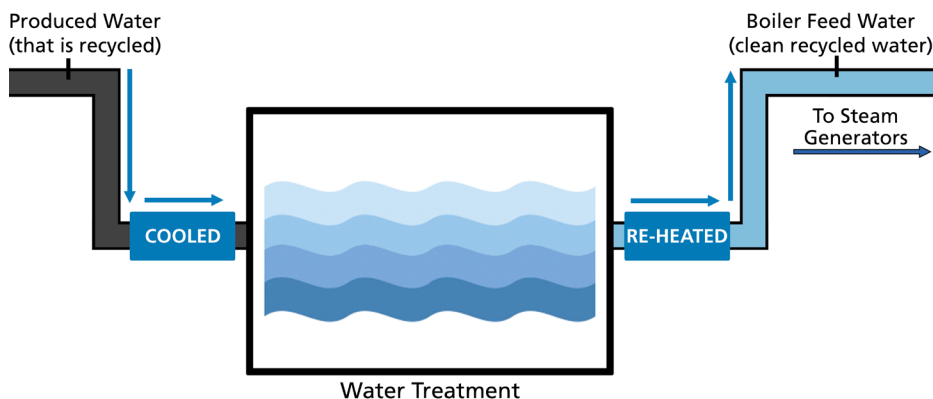
High Temperature Reverse Osmosis

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 that is used to generate steam is cooled and heated as part of the treatment process and this requires 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 High Temperature Reverse Osmosis (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. Reverse osmosis is commonly used for water treatment in other industries, but at temperatures well below 100°C.

This project is breaking new ground by developing commercial reverse osmosis membranes to operate above 100°C. Lab testing is currently underway with a demonstration scale pilot targeted for 2023 at the Water Technology Development Centre.

Typical SAGD Water Treatment



High Temperature Reverse Osmosis membranes allow produced water to remain at a high temperature while being treated, removing the need for re-heating.

DEVELOPMENT



Business Benefits

- Significantly reduce the capital cost of new SAGD facilities.
- Significantly reduce natural gas consumption, reducing fuel costs.



Environmental Benefits

- Reduce GHG emissions by 5%-10% by efficiently producing high quality water that enables the use of high efficiency steam generators.
- Reduce plant footprint by adopting membrane technology.

Collaboration: This water management project is led by Canadian Natural and shared through [Canada's Oil Sands Innovation Alliance \(COSIA\)](#). Funding support for this project is being provided by Emissions Reduction Alberta.



Canadian Natural

Recovering usable chemicals from saline water

BENEFIT

WATER



Canadian Natural is continuously looking for more ways to treat the saline water recovered from mining activities at Horizon Oil Sands.

Mangrove Water Technologies for Saline Water Treatment

Horizon Oil Sands is a unique site with groundwater that's too salty to be used in the extraction process. Through regular operations, the water is being temporarily removed and stored.

In 2019, Canadian Natural partnered with Mangrove Water Technologies Ltd, a company based in Vancouver, Canada, that is focused on commercializing a technology for the conversion of brines to desalinated water and chemicals for on-site use. The technology applies an electric current to a novel electrochemical process that combines aspects of fuel cells with electrodialysis to separate the salts into different compounds. Along with the water, it produces industrial strength hydrochloric acid, commonly used for in situ extraction, and caustic acid, used in the bitumen mining process.

Canadian Natural is currently conducting a small-scale pilot to determine if it is economically and technologically feasible, and advancing the targeted environmental outcomes. If successful, a full-scale pilot could be potentially launched at Horizon in 2022.



Mangrove's technology converts saline waste water into clean water for potential reuse at the mine, along with compounds that could be sold.

DEVELOPMENT



Business Benefits

- Potential to produce hydrochloric acid used in in-situ extraction that could be sold to other companies.
- Reduce operating costs through reduced risks associated with an on-site waste stream.
- Creates a high-value water treatment process for potential application in other industrial sectors, in Canada and elsewhere in the world.



Environmental Benefits

- Reduce freshwater use by replacing it with treated saline waste water that can be immediately reused.

Collaboration: This water management project is led by Canadian Natural and shared through [Canada's Oil Sands Innovation Alliance \(COSIA\)](#).



Canadian Natural

Reducing emissions through carbon conversion



BENEFIT

GHG

Canadian Natural is always looking for new research and development opportunities for reducing greenhouse gas (GHG) emissions from our operations towards our goal of net zero emissions in the oil sands.

Natural Gas Decarbonization

Canadian Natural is exploring how to decrease emissions resulting from steam-assisted gravity drainage (SAGD) operations that require burning natural gas to produce steam.

The Canadian Natural-led [Canada's Oil Sands Innovation Alliance \(COSIA\)](#) study, "Scan and Evaluation of Natural Gas Decarbonization Technologies", sought to identify chemical pathways to convert natural gas into a hydrogen rich fuel and a valuable co-product, with the ultimate goal of reducing carbon content. This hydrogen rich fuel, when burned in the boilers, would produce less carbon dioxide (CO₂) emissions and yield co-products to use in the oil sands extraction and production processes, or to sell to offset costs.

As a result of the successful study, the [ARCTIC Innovation Challenge](#) was launched to identify potential decarbonization technologies. Of the many technologies submitted, two were selected for a techno-economic study that showed that each technology had the potential to economically produce a hydrogen rich fuel gas and a carbon by-product. With the support of Emissions Reduction Alberta and the Natural Gas Innovation Fund, we are continuing testing with one of the technologies.

Working with industry partners through COSIA, we are also investing in the development of a technology that converts natural gas into carbon fiber and a hydrogen rich by-product. A techno-economic study on this technology is planned for 2021.

DESIGN



Business Benefits

- Create valuable co-products that could be sold or used to offset costs.
- Reduce costs by decreasing CO₂ emissions.



Environmental Benefits

- Convert the carbon in methane to a valuable co-product, thus preventing its release as CO₂.
- Reduce net emissions of CO₂ from operating facilities.

Collaboration: The technology scan was conducted through COSIA, led by Canadian Natural with participation by Suncor and Imperial, in partnership with the [Gas Technology Institute \(GTI\)](#). The ARCTIC Innovation Challenge program is a partnership with British Columbia-based not-for-profit [Foresight Cleantech Accelerator Centre](#) and COSIA member companies to find and fund clean technology solutions for resource sector challenges in Western Canada.



Canadian Natural

Uncovering new, high-value uses for bitumen



BENEFIT

GHG

Canadian Natural is collaborating with industry, academics and funders to uncover new uses and methods of utilizing bitumen to reduce downstream greenhouse gas (GHG) emissions intensity and move us further on our journey to net zero emissions.

Bitumen Beyond Combustion — 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. The Bitumen Beyond Combustion (BBC) program, led by Alberta Innovates, was designed to explore alternative, non-combustion uses for bitumen. The program involves three phases:

- Identifying oil sands components and information on potential technologies (2017).
- Identifying alternate products and their market potential (2018).
- Identifying and funding projects to support work on producing technologies and identifying their challenges and potential solutions.

The funding of the final phase of BBC was completed in 2019, with seven projects receiving \$2 million each to advance their technologies. The aggregate of all product categories should utilize, by the year 2030, at least 500,000 barrels per day of bitumen.

This project brings together oil sands companies, other industries, material science companies and academic researchers to uncover new uses and methods of utilizing bitumen.

Carbon Fibers and Combination Products (Including Graphene)	Asphalts	Plastics or Polymers
<ul style="list-style-type: none">• Used in steel, cement and wood	<ul style="list-style-type: none">• High quality asphalts for roads• Asphaltenes for carbon fiber feedstock	<ul style="list-style-type: none">• Polymers that are compostable and biodegradable• Vanadium flow batteries

Source: Canada's Oil Sands Innovation Alliance ([COSIA.ca](https://cosia.ca))

Collaboration: Canadian Natural is part of the Strategic Advisory Committee in Bitumen Beyond Combustion, led by [Alberta Innovates](https://albertainnovates.ca). The project includes partners like [BASF Canada](https://basf.ca), [Bowman Centre for Sustainable Energy](https://bowmancentre.ca), [Canmet ENERGY Devon Lab](https://canmetenergydevonlab.ca) of Natural Resources Canada, oil sands producers and others, including academics from the University of Alberta.

DISCOVERY



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 new revenue streams that can be realized based on the existing process of mining or in situ extraction of bitumen.



Environmental Benefits

- Reduce GHG emissions intensity by producing new products derived from oil sands that will not be combusted as fuel.



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.



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.



Canada's Oil Sands Innovation Alliance (COSIA) is an alliance of oil sands producers focused on accelerating the pace of improvement in environmental performance in Canada's oil sands through collaborative action and innovation. Canadian Natural is a founding member and active participant in COSIA. Since its inception in 2012, COSIA members have collectively shared over 1,000 distinct technologies worth \$1.4 billion to develop, with a focus on managing greenhouse gas (GHG) emissions reductions, tailings, water and land.



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, nearly 500 R&D projects have been launched to date, with a realized value of almost \$133 million per year.



The Natural Gas Innovation Fund™ (NGIF) 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 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.



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.

NOTES

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