CREATING VALUE THROUGH TECHNOLOGY AND INNOVATION

CASE STUDIES
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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 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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The world needs more Canadian Energy

Canada’s crude oil and natural gas industry has been safely and responsibly developed for over a century. When it comes to environmental performance, Canadian Natural has a success story that all Canadians can be proud of. Canada’s industry has taken what was branded as a high-intensity oil in 2009, and transformed it into one of the premium oils on the global stage. For instance, Canadian Natural has reduced its emissions intensity at Horizon Oil Sands by 37% from 2012 to 2018, in addition to lowering primary heavy oil venting emissions by 78%, and we are the fifth largest capturer and sequester of carbon dioxide (CO₂) in the oil and gas sector globally. In just these three areas, Canadian Natural has taken the equivalent of more than two million cars off the road over this time period. And the success story is just getting started.

Every day, 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 book showcase many examples of how we plan to get there.

Canadian oil is one of the world’s premium products. Delivering Canada’s oil and natural gas to global markets needs to be a climate change priority if the world is going to reduce its global greenhouse gas (GHG) emissions.

Canadian Natural believes achieving net zero GHG emissions in our oil sands operations is possible by leveraging technology and Canadian ingenuity. This approach applies new technologies and processes throughout the production cycle: from designing facilities to avoid emissions in the first place, to reworking existing processes to reduce emissions, to storing and/or converting or utilizing the remaining emissions.
The case studies 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.

Our collaboration with entrepreneurs, industry, academia, and government helps us to leverage our investments and move technologies at all levels of readiness toward commercialization faster.

The State of Technologies refers to the current readiness stage of the technology in the development cycle, as opposed to the level of implementation within Canadian Natural’s operations, which varies from project to project.

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The projects above are focused on the following strategic areas:

- Alternative extraction
- Carbon capture and utilization
- Carbon conversion
- Digital technology
- Emissions measurement
- Energy efficiency
- New product utilization
- Pipeline technology
- Reclamation and biodiversity
- Tailings management
- Value from waste
- Water efficiency
Advancing carbon capture and reclamation in tailings

Tailings Management

When we begin a project, we always have a vision and a proactive plan for the landscape, including comprehensive land-use planning that considers the end of mine life and tailings reclamation. The graphic below depicts a typical tailings pond at Canadian Natural.

At Horizon, a Non-Segregating Tailings (NST) process dewatering 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.

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 fluid tailings (FT). In 2018, several technologies were piloted, including filter bags and a filter press to treat fines, centrifuge optimization trials (for long-term consolidation of treated fines) and enhancements to the Atmospheric Fines Drying technology to help settle out solids in the 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 so industry peers can complete tailings research with samples from their own operations, working together with academia and government.

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

Canadian Natural has invested more than $3.5 billion to date in extensive tailings research, technologies and project construction.

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 forest ecosystems.
Eliminating tailing ponds and reducing emissions

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, 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, eliminating tailings ponds.

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.

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 also one of nine projects selected for government funding through the Oil Sands Innovation Challenge by Emissions Reduction Alberta.

D4 - 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 and reduce and avoid fugitive emissions through the production of “dry” stackable tailings.
Recovering valuable commodities and reducing emissions

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.

Collaboration:

Titanium Corporation 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, technical input and project reviews over the last five years. The 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).

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) as well as approximately two million barrels of hydrocarbons (bitumen and diluent).

Environmental Benefits

- Potentially reduce net GHG emissions by approximately 570 ktCO₂e per year.
- Recover process water and provide cleaner tailings, thereby accelerating reclamation.
- Reduce and avoid future fugitive emissions from tailings ponds.
- Improve tailings water quality for recycling.
- Offers a lower GHG extraction process for heavy minerals.
Carbon capture, sequestration or storage, and utilization (CCSU)

Leading in CCSU Initiatives

Canadian Natural is leading the oil and natural gas industry in CCSU initiatives. Our projects (listed below) make Canadian Natural the fifth 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.

CO₂ Sequestration in Tailings

At Horizon, we have been adding carbon dioxide (CO₂) to tailings since 2009 to enhance tailings performance, reduce our footprint and sequester CO₂ in the process. Over 260,600 tonnes of CO₂ have been injected from 2009 to Q3 2019.

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 officially reached a new milestone, with four million tonnes of CO₂ permanently captured and stored from 2015 to 2019.

Enhanced Oil Recovery (EOR)

At our Hays Gas Plant in Taber, Alberta, we capture up to 12,000 tonnes of CO₂ per year for re-use/sequestration in our nearby Enchant EOR operations.

Canadian Natural is a 50% partner in the North West Redwater (NWR) Sturgeon Refinery, expected to capture 1.2 million tonnes of CO₂ annually for EOR when fully online.

### Capture Capacity (Tonnes Per Year)

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<td>Horizon</td>
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<td>Quest(1)</td>
<td>1.1 million</td>
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<td>NWR(2)</td>
<td>1.2 million</td>
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<td>2.7 million</td>
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(1) Canadian Natural is a 70% working interest owner in Quest.
(2) On stream in 2020. Canadian Natural is a 50% owner in NWR.

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

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.
Reducing the energy required to produce a barrel of oil

Canadian Natural is piloting using solvent for 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 have the potential to create value across all of our thermal operations on our journey to net zero emissions.

In typical in situ oil sands production, water is heated to create steam that mixes with the bitumen and improves its viscosity so it can move to the surface. When solvent is added, the process requires less steam and 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 increase oil recovery in a steam-assisted gravity drainage (SAGD) reservoir. To date, we’ve seen an increase in oil production, 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 with execution details being refined through 2020 and project execution in 2021. If successful, there is the potential for application throughout our extensive thermal asset base.

Business Benefits

- Significantly improve resource recovery while reducing operating expenses through reduced energy use for steam creation.
- Reduce steam-to-oil ratio by up to 50%.
- Leverage existing pads and avoid construction costs.

Environmental Benefits

- Increase efficiencies to reduce steam, translating into up to 50% reduced GHG emissions intensity.
- Reduce the amount of pad development needed, thus reducing our land footprint.
- Reduce the amount of water used in the production process.
Process water treatment during reclamation activities

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

H2nan0

Canadian Natural and other oil sands producers are working with water treatment company H2nan0 and researchers at the University of Toronto on a sunlight-activated, reusable treatment process for process-affected water. This treatment, called SolarPass, 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 partners involved with 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. The fluid tailings (FT) will de-water and densify at the bottom over time, while overall water quality is improving every year so the lake will be a functioning aquatic ecosystem in the final reclaimed landscape.

Other research includes small-scale experimental field trials (or mesocosms) that replicate natural ecosystems and allow for controlled laboratory conditions in a field setting. The first study was initiated in 2017, with 30 in-ground walled aquatic test sites, filled with process-affected water and treated FT, to assess the biological process of tailings water improvements in natural conditions.

Engineered Wetlands

Canadian Natural is participating in the Process Water Wetlands Treatment Study, which uses engineered wetlands to treat tailings water. Researchers are: identifying the chemical composition of the water, determining environmentally acceptable levels of non-carbon based (inorganic) materials, and engineering a constructed wetland treatment system that uses plants and soil to trap, transfer and transform these inorganic elements found in the water.

The project leverages the natural biological processes occurring within wetlands. For example, wetlands sequester carbon dioxide (CO₂) through the growth of plants and algae, which eventually sinks to the bottom and accumulates through time without being released back into the atmosphere. Our goal is to understand how constructed wetlands respond to environmental stresses and can be used to improve water quality.

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 to determine the ecological development of these features under a variety of input conditions.
- Innovative water treatment processes have lower energy requirements and the potential to reduce greenhouse gas (GHG) emissions. 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

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 three-dimensional 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 now 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 also allow us to develop enhanced employee training/onboarding of new employees and contractors at site.

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.

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.

Business Benefits

- Maintain safe operations while reducing operating costs by gaining efficiencies in training, plant planning activities, particularly during turnaround and other maintenance periods, and applying new technologies.
- SPR is used by close to 1,500 employees. A similar 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.

Environmental Benefits

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

A VR headset allows employees to digitally walk around the Horizon plant.
A collaborative approach to quantifying emissions

Canadian Natural is exploring how 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 (CO$_2$) 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, we’re incorporating multiple layers of collaborative research to have 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.
- Thermal imaging to determine ground temperatures, how they affect wind flows and their impact on emissions.
- Ground-based sensors to measure methane and CO$_2$ 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. Satellite-based monitoring by GHGSat and Environment and Climate Change Canada’s fixed wing aircraft measurements are also coordinated to coincide with field measurements.

Collaboration:

Industry partners on this project include innovators (vendors) and academic institutions: the Petroleum Technology Alliance Canada, Luxmux Technology Corporation, Agar Corporation, 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.

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 CO$_2$ 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.

D4 - DEPLOY
A achieving methane emissions reductions

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.

Reduction 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 in Alberta. 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 are also using 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. Vapor combustors burn excess methane gas in an enclosed unit while keeping the equipment temperature cool. The lower temperature allows combustors to be installed near the wellhead, reducing surface disturbance.

Reducing Emissions from Pneumatic Devices

We continue to reduce emissions through our pneumatic retrofit program. Pneumatic devices use pressurized natural gas to function and some will release small amounts of natural gas as part of their normal operation. Canadian Natural is removing or converting high-emitting pneumatic controllers to low-emitting ones.

Measuring Fugitive Methane Emissions

By enhancing understanding of fugitive methane emission sources, we can improve operational efficiencies, reduce emissions and support the development of best practices. Canadian Natural is working with industry, the Petroleum Technology Alliance Canada (PTAC) and other partners to develop more accurate systems and technologies for quantifying fugitive emissions, accelerating leak detection and repair, and reducing venting. Emissions Reduction Alberta is partially funding the oil sands research on fugitive emissions.

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

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.

Environmental Benefits

- 16.8 million tonnes of CO₂ equivalent has been conserved in Canadian Natural’s heavy oil operations between 2014 and 2018 — the same as removing 3.6 million passenger vehicles from the road over five years.
- With 4,000 controller retrofits in 2018 and 2019, we are targeting reductions of up to 400,000 tonnes of CO₂ equivalent/year.
- Venting volumes have decreased by 72% at our Alberta heavy oil assets between 2014 and 2018, due to mainly natural gas conservation projects that significantly reduce methane emissions.
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 in 2019 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.

**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.

**Business Benefits**

- Reduce the risk of pipeline failures on six of our more complex systems of pipelines 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

Canadian Natural’s land management practices include reducing our impact through 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.

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.

Acoustic Recording Units for Monitoring Biodiversity

Acoustic recording units (ARUs) are commonly used throughout the oil sands to improve our monitoring and documenting of rare species. ARUs record vocalizations, while innovative software analyzes the recordings to determine the presence of rare or hard-to-detect species. In a project convened at Canada’s Oil Sands Innovation Alliance (COSIA), a centralized hub was created to house and share the data collected. Use of this technology increases data reliability, reduces safety risks and costs associated with performing field surveys, and allows ongoing wildlife monitoring in remote and difficult terrain.

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 50 species, almost 11,000 litres of fruit/seed, and 231 million seeds for approximately 31.6 million seedlings.

Business Benefits

- Reduce ground disturbance activities, reducing the reclamation required and further accelerating the rate of liability reduction.
- Reduce cost and safety risks associated with performing field surveys by using ARUs.

Environmental Benefits

- Reduce re-vegetation timelines from three to five years, to two to four years through the area-based reclamation approach.
- Reduce impacts to rare species through an increased understanding of their behaviour.
- 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 Acoustic Wildlife Data Research and Development COSIA joint industry project includes the University of Alberta, ConocoPhillips Canada and Suncor. The OSVC is a COSIA environmental priority area-led study that includes all COSIA members.
Capturing CO₂ for electricity generation

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 operates 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 series of COSIA joint industry projects: a preliminary front-end engineering design (pre-FEED) on installing and operating a 200-kilowatt pilot project, followed by the potential for a larger scale pre-FEED evaluating the cost of piloting a 1.4 megawatt power generation project at the Scotford Upgrader, part of the Athabasca Oil Sands Project (AOSP).

**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 was initially undertaken by a collaboration of COSIA members and Alberta Innovates. Canadian Natural (majority owner of the AOSP) and Shell Canada are currently looking for additional participants for the 1.4 MW unit to pilot. The project will be partially funded by Emissions Reduction Alberta.
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.

Targeting zero emissions in heavy oil

Zero Emissions Primary Heavy Oil Pad Site
In our primary heavy oil operations, Canadian Natural is piloting a zero 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 all 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 needs to be heated. Heat for the storage tank and energy for the pump would normally come from burning solution gas.

In the case of the zero emissions site, solution gas is replaced with energy sources – electricity – that has renewable potential. The production of heavy oil results in a secondary process where solution gas is liberated in the well and the storage tank. The liberated solution gas has the potential to be vented into the atmosphere, but in the case of the zero emissions site the solution gas is conserved through on-site compression and a vapour recovery unit. The conserved solution gas is 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 zero emissions. If the pilot results in a more effective and efficient approach, it could be expanded across our heavy oil operations in the future.

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.
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 2020.

World Leading Technology Centre

The Alberta Carbon Conversion Technology Centre (ACCTC) is a specially designed facility 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.

Funded by Natural Resources Canada and the Alberta Ministry of Economic Development and Trade, the ACCTC provides technology developers with the facilities for testing and refining their technologies using real-life flue gas from natural gas combustion. Other partners and collaborators include: Canada’s Oil Sands Innovation Alliance (COSIA) project member companies, and Shepard Energy Centre, a joint venture between Enmax Generation Portfolio Inc. and Capital Power (Alberta) Limited Partnership. InnoTech owns and operates the ACCTC, which opened in May 2018.

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.

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.
Increasing water recycling efficiency

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.

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 $140 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. Suncor is leading the WTDC initiative, which includes the following project partners: Canadian Natural, CNOOC and Husky Energy.
Developing new ways to treat recycled water and lower emissions

High Temperature Reverse Osmosis

As part of in situ oil sands development, the steam-assisted gravity drainage (SAGD) process is commonly used to recover bitumen from the reservoirs beneath the surface. Natural gas is used to heat water and produce steam, which is injected into the reservoir. In a typical SAGD facility, recycled water that is used to generate steam is cooled and heated as part of the treatment process. The cooling and heating process requires additional equipment and energy. If our operations can be redesigned to keep the water hot throughout the recycling process, significant cost savings, and reductions in GHG emissions and 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 SAGD 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 planned for 2021 at the Water Technology Development Centre. Funding support for this project is being provided by Emissions Reduction Alberta.

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.

Business Benefits

• Significantly reduce the capital cost of new SAGD facilities.

Environmental Benefits

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

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.
Recovering usable chemicals from saline water

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

Mangrove Water Technologies for Saline Water Treatment

Horizon 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, 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 launched at Horizon in 2021.

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

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).
Using algae to convert CO₂ into valuable products

On our journey to net zero emissions Canadian Natural is exploring many different technologies to turn carbon dioxide (CO₂) into valuable products.

Algae Project

Canadian Natural is exploring how we can convert algae and CO₂ into bio-oil and bio-materials through the Algal Carbon Conversion Project (Algae Project).

The National Research Council of Canada (NRC), Pond Technologies and St. Marys Cement Canada used an earlier study to launch a pilot-scale bio-refinery in 2016 at St. Marys Cement plant in Ontario. The pilot project captures CO₂ from the cement plant operations and places it in large tanks with algae to promote photosynthesis using strong LED lights. Algae are then pressed to release bio-oil. The process sees algae multiply at much faster rates than normal, while at the same time consuming large quantities of greenhouse gases (GHGs).

When applied to oil sands operations, the algae process could produce bio-materials, such as nutraceuticals, fertilizers and animal feed. Canadian Natural participated in the pilot results as an observer and is evaluating the results for later potential deployment.

Each tonne of algae can reduce CO₂ emissions by 1.8 tonnes while yielding biofuel, useful products and oxygen. Overall, the potential reduction at an oil sands facility would be over 1.5 million tonnes of CO₂ equivalent emissions.

Business Benefits

- This technology holds potential for a reduction in operational costs and an increase in plant efficiencies.
- Potential revenues from sale of bio-materials.

Environmental Benefits

- If successfully applied on a commercial scale, the potential reduction at an oil sands facility would be over 1.5 million tonnes of CO₂ equivalent emissions, which is like removing 300,000 vehicles off the road.

Collaboration:

This project began as a collaboration between Canadian Natural, the NRC and Pond Technologies, an algae technology company based in Ontario, Canada.
Reducing emissions through carbon conversion

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

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 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 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 (CO$_2$) emissions and yield co-products to use in the oil sands extraction and production processes, or to sell to offset costs.

The results of the research led to the development of the ARCTIC Innovation Challenge — a challenge that identified a number of decarbonization technologies.

Two technologies were then selected from the challenge for a techno-economic study and testing is planned for 2020. Both of the successful technologies make a carbon co-product that can be produced at different grades, each with different uses.

Canadian Natural is participating in a study to understand more about the potential markets for the different grades of carbon. We are also looking at the technology available to upgrade carbon for more relevant markets.

Business Benefits

- Create valuable co-products that could be sold or used to offset costs.
- Reduce costs by a potential $150 million/year based on the sale of co-products.

Environmental Benefits

- Convert the carbon in methane to a valuable co-product, thus preventing its release as CO$_2$.
- Reduce net emissions of CO$_2$ from operating facilities.

Collaboration:

The Study 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.
Uncovering new, high-value uses for bitumen

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.

<table>
<thead>
<tr>
<th>Carbon Fibers and Combination Products (Including Graphene)</th>
<th>Asphalts</th>
<th>Plastics or Polymers</th>
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</thead>
<tbody>
<tr>
<td>Used in steel, cement and wood</td>
<td>High quality asphalts for roads</td>
<td>Polymers that are compostable and biodegradable</td>
</tr>
<tr>
<td></td>
<td>Asphaltenes for carbon fiber feedstock</td>
<td>Vanadium flow batteries</td>
</tr>
</tbody>
</table>

Source: Canada’s Oil Sands Innovation Alliance (COSIA.ca)

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.
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.

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. Along with other large producers, we share research information and technologies through an unprecedented collaborative industry effort. 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 Clean Resource Innovation Network (CRIN) is an industry-led network launched in 2017 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.

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.

PTAC supports collaborative networks to advance innovative research and technology development projects that address pertinent industry challenges through activities which reduce costs, improve operational efficiencies, enhance environmental stewardship, and advance regulatory development. Canadian Natural is an active participant in a number of PTAC projects.