Technological Prospects for Reducing the Environmental Footprint of Canadian Oil Sands

Executive Summary

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

TECHNOLOGICAL PROSPECTS FOR REDUCING THE ENVIRONMENTAL FOOTPRINT OF CANADIAN OIL SANDS

The Expert Panel on the Potential for New and Emerging Technologies to Reduce the Environmental Impacts of Oil Sands Development

THE COUNCIL OF CANADIAN ACADEMIES
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The Expert Panel on the Potential for New and Emerging Technologies to Reduce the Environmental Impacts of Oil Sands Development

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The Council also recognizes the contribution of Marlo Raynolds, Vice President, Market Development, BluEarth Renewables Inc. (Calgary, AB), to this assessment.

Message from the Co-Chairs

This Expert Panel came together in the context of a wider debate about the role of Canada's oil sands in a carbon-constrained world. A key question is whether proven and emerging technologies have the capability to significantly reduce the environmental footprint of the oil sands. That has been the charge of the Panel.

The oil sands have always been highly dependent on technology. Evaluating the extent to which existing and emerging technologies are capable of reducing the environmental footprint of all aspects of oil sands operations is a fundamental challenge.

However urgent this task, it is analytically challenging. Fundamental uncertainties temper our ability today to anticipate the future performance of emerging technologies, the future levels of ambition of carbon and other environmental policies, as well as the uncertainty inherent in forecasting the extent of technological innovation in an industry where investment priorities are strongly influenced by changing oil prices. What we do know today, however, is that a clear roadmap is needed to show how to reduce the environmental footprint of the oil sands.

By bringing together a wide range of expertise and evidence, the Panel believes that this report makes an important contribution in setting out what is known about the environmental footprint of the oil sands and the range of technological opportunities to reduce it, together with their associated risks and uncertainties. It hopes that this report will prove useful for government and industry alike as they make decisions on the best way forward.

As Chairs, we are indebted to our colleagues on the Panel who contributed their time, effort, and considerable expertise to ensure the breadth, depth, and overall quality of the report. Deliberations proved insightful and constructive for all involved.

On behalf of the Expert Panel, we thank Natural Resources Canada and Environment Canada for asking the Council to undertake this assessment, and the expert peer reviewers who set aside the time to critique the report and help ensure its comprehensiveness, accuracy, and balance. We would also like to thank the professionals at Cenovus, Syncrude, and Wood Buffalo Environmental Association for their informative and insightful tours of their facilities and Canada's Oil Sands Innovation Alliance for providing input to the Panel's deliberations. Finally, we are very grateful to the Council's project team for its outstanding research, rigour, and objectivity throughout the assessment.

Eric Newell, O.C., FCAE, A.O.E., Co-Chair

Scott Vaughan, Co-Chair

The Expert Panel on the Potential for New and Emerging Technologies to Reduce the Environmental Impacts of Oil Sands Development

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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations. The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

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The report review procedure was monitored on behalf of the Council's Board of Governors and Scientific Advisory Committee by **Murray S. Campbell**, Senior Manager, AI and Optimization, IBM T.J. Watson Research Center. The role of the report review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the report reviewers. The Board of Governors of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Dr. Campbell for his diligent contribution as report review monitor.

Janet W. Bax, Interim President
Council of Canadian Academies

Executive Summary

The oil sands of northern Alberta contain an estimated 169 billion barrels of recoverable bitumen and span an area larger than Canada's three Maritime provinces combined (142,000 km^2). Their development through surface mining and in situ methods is expected to play a growing role in global oil supplies. Bitumen production, however, is resource intensive and generates a significant environmental footprint that is forecasted to grow alongside the growth in bitumen production if current methods of extraction and upgrading are used. And though recent oil price volatility will have implications for the rate of production growth, in the longer term production is expected to double with consequent environmental impacts on air, water, and land.

Bitumen production is also technology intensive with current and forecasted levels only now possible because of important innovations implemented over the past few decades. Given the importance of technology, the Government of Canada, through Natural Resources Canada (the Sponsor), with support from Environment Canada, asked the Council of Canadian Academies (the Council) to undertake an assessment of how new and existing technology can reduce the environmental footprint of oil sands development.

The Sponsor posed the following question:

> *How could new and existing technologies be used to reduce the environmental footprint of oil sands development on air, water and land?*

The charge included three sub-questions:

- *Using the latest deployed technologies and processes as a baseline, what are the potential environmental footprints of new oil sands projects, both mining and in situ?*

- *Using publicly available information, what extraction, processing and mitigation technologies are currently being researched, developed and demonstrated by the public and private sectors, and how could they reduce or further mitigate the environmental footprint of development on a project or per-barrel basis?*

- *What are the impediments (i.e., economic, regulatory, etc.) to the deployment, on an accelerated basis, of the most promising technologies?*

To address the charge, the Council assembled an independent, multidisciplinary panel of 12 experts (the Panel) from Canada and abroad. The Panel's composition reflected a balance of expertise and experience in bitumen extraction and processing methods and in relevant environmental impact areas.

Scope of the Assessment

Given the wide range of technologies that underpin oil sands operations, the Panel prioritized those with the greatest potential to reduce the environmental footprint in the next 15 years. Technologies related to surface mining and in situ methods were considered along with those related to bitumen upgrading, which applies to about half the bitumen produced today. Technologies at a very early stage of development were acknowledged but not evaluated. Finally, the Panel did not consider broader questions such as the pace of oil sands development, the impact of different oil price scenarios, and the rate of technology deployment needed to maintain ecosystem sustainability.

TOWARDS A SIGNIFICANT REDUCTION OF THE ENVIRONMENTAL FOOTPRINT

The evidence reviewed by the Panel points to the need for Canada to accelerate the pace of oil sands technology development to reduce the environmental footprint of bitumen and synthetic crude oil production in northern Alberta. Impacts on the region's air, water, and land, as well as contributions to global greenhouse gas (GHG) emissions, are forecast to grow as bitumen production doubles over the coming decades. Improvements in environmental performance are not keeping pace with understanding of impacts or, indeed, the growth of the industry.

The analyses indicate that reductions in the environmental footprint are achievable in each of the areas considered. Continuous improvement in the use of energy, water, and land on a per barrel of bitumen basis is necessary but insufficient to reduce the total footprint. New transformative technologies developed and commercialized over the next decade will be needed to extract this resource while also protecting the environment. Strong leadership, investment in new ways of bringing technologies from the lab into commercial application, and removal of barriers to implementation are required. Industry, government, academia, Aboriginal peoples, and other stakeholders all have key roles to play.

The oil sands have always had a deeply embedded culture of applied research and development (R&D). A century ago, a government chemist, Dr. Karl Clark, developed a method of liberating the bitumen from the sands. Pilot plants demonstrated and improved this technology and successful commercial production started close to 50 years ago with surface mining and upgrading of bitumen at Great Canadian Oil Sands (now Suncor Energy Inc.).

To unlock deeper oil sands deposits, the Alberta government formed AOSTRA (the Alberta Oil Sands Technology and Research Authority) in 1974, which led the way to the development of today's in situ production, which now surpasses output from surface mining. Along the way, thousands of innovations, large and small, have overcome the tremendous technical challenges associated with oil sands production. With the use of such technologies, over 2 million barrels per day of bitumen are now produced in the region.

Today, there are dozens of initiatives under way to improve process efficiency and environmental performance in the oil sands. There is also an environmental monitoring system operating in the region that is currently undergoing major enhancements. Billions of dollars in R&D and commercialization are being spent every year.

As impressive as these efforts are, they are not enough. This assessment of the evidence finds that most of the required challenges and solutions are multidisciplinary and have wide-ranging implications in highly integrated industrial and ecological ecosystems. The financial risks of implementing costly new technologies at the scale required are also immense. Moreover, despite a half-century of development, many seemingly intractable problems remain: what to do with tailings, how to treat and discharge water safely, how to reduce the amount of GHGs, and how to reduce the footprint on the land and wildlife caused by mining and in situ production. There are few simple solutions remaining to implement and no off-the-shelf technology.

Building on the past century of innovation, it may be expected that timely solutions can be found and implemented. But changing the pace of technology deployment will not occur without strong leadership, continued investment, and risk-taking by all. This report identifies the opportunities and the major barriers to overcome, highlighting the need for more rapid development and commercialization of promising technologies, and the opportunity for more truly collaborative approaches to solving these important issues.

DEFINING AND MEASURING THE ENVIRONMENTAL FOOTPRINT OF THE OIL SANDS

The Panel, for the purpose of this report, defined the environmental footprint primarily in terms of emissions from oil sands operations and related resource use. The footprint includes (i) GHG emissions; (ii) air pollutants (including sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions, fugitive emissions of organic chemicals, and particulate emissions); (iii) water withdrawal and the release of process-affected water (intentional and unintentional); (iv) disposal of tailings, a residual by-product of water-based bitumen extraction by surface mining; and (v) physical land disturbance, including habitat fragmentation and the stockpiling of solid by-products such as sulphur and coke.

The Panel's characterization of the environmental footprint did not consider specific thresholds. Instead, it took the broadest view of cumulative changes to the environment caused by oil sands activities and looked for technologies and strategies that could be employed to reduce the footprint both on an incremental and cumulative basis. What follows are the main findings associated with the environmental footprint of oil sands.

The environmental footprint of oil sands operations on air, water, and land is wide-ranging, significant, and cumulative, and will grow as production using current methods increases.

Assuming the use of current technology in oil sands development, emissions and use of resources will increase significantly in several areas as oil sands production expands. The effects are not always linear, nor are they necessarily limited to the oil sands region. GHG emissions, which include carbon dioxide (CO_2) and methane, for example, differ from other aspects of the environmental footprint of oil sands production in that their impact is global rather than local or regional.

Under current trends, GHG emissions and tailings disposal and related land disturbance are the most significant contributions to the environmental footprint.

GHG emissions from oil sands production using current technologies correspond closely to production levels, and could double over the next decade. Based on 2014 production forecasts, this would result in GHG emissions increasing from 76 megatonnes (Mt) of CO_2 equivalent (CO_2e) per year in 2013 to 156 Mt CO_2e per year in 2025 and to 182 Mt CO_2e per year in 2030. The growth in GHG emissions will be primarily driven by the increase of in situ production, which is much more energy intensive than surface mining. Improvements in GHG production intensity on a per barrel of bitumen basis have stagnated recently due to higher levels of in situ production. These intensities are projected to increase again in the absence of new technology and anticipated declines in reservoir quality.

The environmental footprint of tailings stems from the need to construct and maintain large ponds that can store fluid tailings for several decades or more before they can be reclaimed. These tailings ponds, which are some of the largest tailings facilities in the world (U.S. Department of the Interior, 2012), are both a legacy problem from past production and an essential part of current and new surface mining projects. While fluid tailings production intensity (the volume of fluid tailings per barrel of bitumen) is expected to decrease with the use of new technologies to meet provincial regulatory requirements (i.e., the Alberta Government's Tailings Management Framework for the Mineable Athabasca Oil Sands), total volumes are expected to increase over the next several years and then decrease well below Directive 074 levels. The resulting environmental footprint from tailings is multifaceted and includes the large areas of land disturbed; seepage of process-affected water into groundwater; the quantity, quality, and fate of process-affected water in the tailings pores; off-gassing of various chemical substances of concern (e.g., polycyclic aromatic compounds (PAHs), volatile organic compounds (VOCs) including benzene and methane); windblown fugitive dust from tailings sand beaches that contain chemicals of concern; risk of an accidental dam breach; and long-term reclamation of tailings ponds, which remains a significant technological, economic, and environmental challenge.

ASSESSING THE POTENTIAL OF TECHNOLOGIES TO REDUCE THE ENVIRONMENTAL FOOTPRINT

Opportunities to reduce GHG emissions lie primarily with in situ operations.

In situ operations, which are set to account for much of the new growth in production, are a major source of GHG emissions. This stems from use of natural gas to produce steam that is injected underground to mobilize bitumen for extraction. Under 2014 projections, GHG emissions from in situ operations are set to rise by 300% by 2030, in contrast to an 85% rise in those from surface mining. Upgrading emissions are expected to remain stable. This makes in situ operations an important focus for efforts to reduce GHG emissions. Because they are energy intensive, operators have been experimenting with technologies to reduce the amount of water that must be vaporized into steam to extract bitumen. These technologies include the use of solvents, alternative sources of thermal energy such as electricity, and modifications to the wells that involve, for example, vacuum insulated tubing and flow control devices.

Improvements in environmental performance are, however, likely to be incremental rather than transformative in the near to midterm. The use of solvent-assisted technology, now being piloted, suggests that energy use reductions of 10 to 30% on a per barrel basis are possible, which, combined with other measures to increase energy efficiency, could reduce GHG emissions by 15 to 35%. Several operators are experimenting with solvent-based technologies that do not require steam, which could potentially reduce GHGs related to energy use by 90% and bring per barrel emissions ($KgCO_2e$) to well below the level of U.S. average crude and other international sources. Their commercialization will be affected, however, by heterogeneous reservoir quality and by uncertainty about cost, solvent recovery, and potential risks of groundwater contamination, which may vary depending on the type of solvent used.

There are few technologies that can significantly reduce GHGs from surface mining. The use of mobile mining (mobile crushing units and at-face slurrying and digestion of the oil sands ore) is the most promising. For bitumen upgrading, industry is exploring several options to improve process yields but most of these technologies offer little potential to reduce GHG emissions. Operators are also commercializing a variety of partial upgrading technologies, which share the advantage of greatly reducing or eliminating the need for diluent in bitumen transport.

Key air pollutants from oil sands operations can be reduced through the use of existing and new technology, if widely adopted.

There are existing technologies to reduce air pollutants, many of which are already employed in the industry or are planned to be phased in. For example, emissions from surface mining will be reduced as operators phase in retrofits to existing fleets or upgrade to U.S. EPA Tier 2 haul trucks to meet reduced NO_x emission standards. Tier 2 haul trucks are expected to bring reductions in NO_x of between 30 to 50%. Another “quick win” for reducing air pollutants is the use of existing dust suppression technology in mining operations for haul roads and tailings beaches, which can keep pollutants largely contained or nearby to the mine site. Dust is an important vector for the local and regional distribution of pollutants such as some trace elements and PAHs. Flue-gas desulphurization technology has been installed in upgraders to substantially reduce sulphur compounds from upgrading stacks, while selective catalytic reduction can be used to reduce NO_x emissions from truck fleets. Air pollutants arising from decomposition of residual hydrocarbons in tailings ponds can be reduced by keeping froth treatment tailings, the major source of such contaminants (e.g., solvents, VOCs), out of the tailings ponds and treating them separately.

Although no single technology has been identified to solve the issue of fluid tailings reclamation, a suite of technologies may offer an overall solution that could provide the path to acceptable reclamation.

There is no single "silver bullet" technology that can significantly reduce the volume of tailings and significantly increase consolidation of the fluid fine tailings to make them reclaimable. Operators are, however, piloting and commercializing a range of technologies that, if used together and tailored for particular geological and geotechnical conditions, may constitute a "silver suite" of tailings management solutions that could provide the path to acceptable and timely reclamation.

Operator submissions, showing how the now suspended AER Directive 074 requirements (for reducing fluid tailings through fines capture and accelerating reclamation of tailings disposal areas) would have been met, imply that the total volume of tailings could be potentially stabilized at a level slightly higher than today, followed by a gradual decline as new treatment and reclamation technologies are deployed. However, no operator was able to meet the Directive's timeframes to achieve a fines capture of 50% (in addition to that captured in hydraulically placed dykes and beaches).

The current policy of zero water discharge and the absence of water treatment standards mean that, even if water recycling rates increase, tailings ponds will continue to exist and grow as bitumen production increases. A decline in ore quality as operators open new mines may also lead to an increase in fluid fine tailings production per barrel. Preliminary evidence suggests that water treatment technologies, if scaled up, have the potential to treat process-affected water for discharge. This lack of regulatory criteria for treatment and discharge of process-affected water is considered by the Panel a major impediment to both water and tailings management in the region.

While the Panel did not have the opportunity to assess the implications of the new Tailings Management Framework that replaced Directive 074 as of March 2015, it does note two important departures from Directive 074: a recognition of the potential need to consider the regulated release of process-affected water to the environment, and separate requirements for legacy tailings volume reduction.

Some 30 end-pit lakes are planned for the region, half of which will use water-capped fluid fine tailings as a reclamation strategy. A full-scale commercial demonstration of water capping is under way but it will take at least a decade of monitoring to demonstrate whether this technology can be effective in producing safe, ecologically productive lakes that do not require perpetual care and maintenance. Risks of groundwater seepage and contamination and breaches remain, and public acceptance of water-capped tailings technology is not assured.

Keeping separate the more toxic froth treatment tailings from the other more voluminous tailings streams, and effectively treating these streams for return to the mine, would address two important tailings problems. It would reduce fugitive emissions and toxicity that remains in froth tailings after treatment and avoid expensive reclamation issues unique to this material. It could also allow for the recovery of bitumen and metals.

Freshwater withdrawals, which are to increase mainly with growth in surface mining production, can be reduced through greater efficiency and water recycling. Solvent technologies have the greatest potential to reduce freshwater withdrawals.

While operators continue to improve their water recycling rates, much greater reductions could be realized with the use of solvent technologies. For surface mining operations, which are bigger users of fresh water, solvent-based extraction technologies could replace water in the removal of bitumen from the sand, potentially eliminating the production of fluid fine tailings. These technologies, however, are in an early stage of development, with little to no information available on performance in large-scale operations, costs, or environmental impacts from solvent release. For in situ operators, reduction in water intensity is being achieved on an experimental basis through the use of solvent-assisted technologies; longer-term solvent-based technologies would further reduce the use of fresh water.

For some substrates and some important land uses, reclamation technologies are unproven. To help maximize the reduction of land impacts, technologies need to be complemented by management-based approaches.

Provincial regulations require lands disturbed by oil sands operations to be reclaimed to equivalent land use that existed prior to disturbance. While mine reclamation for upland uses is a mature technology, lake, wetland, and riparian reclamation technologies are still under development. Technologies to enhance reclamation for wildlife habitat and traditional land uses by First Nations, such as the reclaimed grasslands that now provide habitat for bison at the Beaver Creek Wood Bison Ranch (overseen by the Fort McKay First Nation), are limited.

Ultimately, the greatest reduction in the land footprint will come with management-based approaches that complement the most promising technologies. For surface mining, for example, land impacts can be reduced by treating process-affected water for discharge and employing new tailings disposal technologies, which together can reduce the size of ponds and improve the consolidation of tailings, thereby reducing related land disturbance and ultimately speeding reclamation.

There are three significant opportunities to reduce mine sprawl and decrease the amount of disturbed land at any given time. First, a full integration of mine and tailings planning with reclamation and closure planning will allow for easier, faster, better, and more efficient reclamation. This requires both the development of regional closure planning to meet regional goals, as outlined in the Lower Athabasca Regional Plan, and planning that relies on true collaboration between individual mines, First Nations, regulators, and other stakeholders including in situ operations. Second, tailings technology development needs to have a much stronger focus on creating reclamation-ready tailings that have strengths sufficient for reclamation using the mine fleet, allow for better control and quality of seepage waters, and allow permanent reclamation and dam de-commissioning/de-licensing within a few years of deposition. The third approach is to be more assertive with tailings ponds closure. At present, many tailings ponds that are near capacity remain open, providing operators with an outlet for tailings should mine plans change and/or a risk insurance should issues arise with other tailings ponds. This, however, results in more active tailings ponds than necessary, an expanded size of the mine sprawl, and delayed reclamation.

Many of the technologies reviewed could reduce the environmental footprint of oil sands operations on an intensity (per barrel) basis. To reduce the footprint on an absolute basis at projected growth rates requires wide adoption of longer-term transformative approaches.

The Panel found no suite of technologies deployable in the near to midterm that would achieve an absolute reduction in the environmental footprint. This is due to a range of reasons including the rapid forecasted growth rate of bitumen production, the time needed to prove technologies in the field, significant technical challenges associated with tailings, the lower quality of new reserves, and the technologies' economic viability. Some promising technologies create environmental trade-offs such as increasing energy use. As a result, if bitumen production were to grow as forecasted in mid-2014, the environmental footprint in 2025 would still be higher than today's baseline even with widespread adoption of the most promising near to midterm technologies including water treatment technologies, new tailings technologies and land management approaches for surface mining, solvent-assisted technologies for in situ production, and carbon capture and storage (CCS) for upgrading.

To achieve absolute reductions, transformative approaches and technologies will be required to supplement the many important but incremental technologies that can achieve reductions on an intensity basis. These include the use of solvent-based technologies for in situ extraction that substitute water for solvent, and which could bring GHG emissions (CO_2e) from production below that of other crudes, including U.S. average crude oil. They also include substituting natural gas with alternative low carbon sources of energy, such as hydro, geothermal, or nuclear. Although theoretically able to reduce the GHG footprint significantly, these sources are a decade or more away from wide adoption, requiring significant investment to solve technical challenges or build the necessary infrastructure. Low carbon electricity sources would also support the deployment of electricity-based technologies, such as electromagnetic heating for in situ recovery. These technologies are not currently competitive with the use of natural gas.

Alternative low carbon energy sources that can be used in combination with the best new technologies and CCS, especially in the context of upgrading, should be given additional consideration. CCS offers a feasible set of technologies already being deployed in the oil sands and elsewhere in the world. The costs and risks associated with large-scale implementation, however, render CCS largely commercially unattractive for wide adoption in the oil sands. These costs vary substantially depending on the industrial process producing the carbon to be captured. Because they emit concentrated streams of CO_2, upgraders are the most likely candidates for current carbon capture technology. Practical considerations in retrofitting existing upgraders, however, likely limit carbon capture to 20 to 40% of their carbon stream. Wider adoption of CCS technologies will depend on further investment in R&D, as well as measures that make CCS applications more economic, such as a higher carbon price. As carbon prices rise, however, other alternative low carbon energy sources are likely to become competitive before CCS can be applied to all major sources of GHG emissions from the oil sands.

ACCELERATING THE DEVELOPMENT AND ADOPTION OF OIL SANDS TECHNOLOGY

Impediments to the accelerated adoption of the most promising technologies relate to the resources used, business decisions, and government policies.

For technologies to reduce the environmental footprint of oil sands development, the most efficient must be widely adopted across the industry. Impediments to such adoption include resource input factors (e.g., different reservoir characteristics, natural gas prices); business factors (e.g., scale of investment, development time, investment cycle); and policy factors (e.g., regulation, taxation, public investment in technology development).

Reservoir characteristics present a basic challenge to technology adoption. Since oil sands deposits are heterogeneous, varying in quality and viscosity, production techniques that are effective in one place may not be in another. This can limit the diffusion of specific innovations across the oil sands region. As for resource inputs, natural gas, one of the most important inputs in oil sands operations, is widely used to generate steam, electricity, and hydrogen (in upgrading). Low gas prices, however, discourage investments in, for example, solvent-assisted in situ recovery, use of alternative sources of power like hydro, and improvements in energy efficiency, all of which would reduce GHG emissions.

On the business side, the scale and capital intensity of oil sands projects encourage a preference for proven technologies. Risk aversion may lock in existing technologies and delay deployment of environmentally superior alternatives. Another impediment is the long lead time for technology development in extractive industries such as the oil sands, which often stretches from 10 to 20 years. Also, innovation is inherently uncertain: most of the technologies now being tested may fail or not prove commercial while the remainder may take many years to move from concept to market. Collectively, these business factors have important implications for the many new projects approved or in the application stage, for which technology decisions are now being made or will be made in the near future. Finally, the time value of money incents operators to defer non-productive expenditures (e.g., reclamation) until as late as possible. In the absence of policies or regulations to the contrary, the use of net present value economics discourages both development and deployment of technological solutions in these areas.

Government policy, or lack of, can also impede rapid adoption of new technologies. While Alberta's Specified Gas Emitters Regulation does impose a carbon compliance price on large emitters (as one option should they not meet annual CO_2 emission intensity reduction targets of up to 12%), it is only a modest economic incentive for firms to invest in new technologies that reduce GHG emissions, amounting to only a few cents per barrel. Similarly, the absence of regulations setting discharge standards for treated water, thereby allowing for its release back to the environment (as is commonly done in almost all other types of mining and other industrial operations), discourages operators from investing in water treatment technology and results in the continued growth of tailings ponds. Finally, governments can also help support efforts to better design mines for closure and perhaps to provide more incentive to accelerated reclamation.

Renewed collaborative innovation efforts that focus on environmental performance can accelerate development and adoption of new technologies.

Since no single solution to the environmental challenges is available, a "business as usual" approach to innovation is insufficient. Indeed, the current style of innovation, aimed at intensity targets, will not be enough. Without agreement on the extent and breadth of environmental footprint and related targets for reduction, collective innovation efforts will continue to suffer from a lack of focus.

The current track of continuous improvement is important but unlikely to bring forward transformative technologies. For this to happen, a renewed collaborative effort will be required for technology development and demonstrations. There is an opportunity, for example, for big demonstration projects on use of solvents that look at solvent content in the rejected waste solids in the case of mining operations, and at solvent impacts on groundwater and atmospheric emissions for in situ operations. Having leadership aligned across industry, government, and public research institutes towards a major effort in developing, testing, and adopting technologies will help reduce the environmental footprint, not only on an intensity basis but also in terms of their cumulative, absolute impact. This would include emphasis on fundamental scientific research and knowledge transfer and on collaboration between academia across the country, industry, and government, where research is multidisciplinary and partnerships are fully transparent. Also important is well-timed industry investment (in addition to investment magnitude) such that technologies are developed in the appropriate sequence to create a technology platform.

The Panel also identified the importance of regulations to accelerate innovation based on performance rather than technology mandates, and involvement of stakeholders to determine environmental priorities (i.e., global and regional footprint scales). Governments can help by developing a more complete regulatory regime that places a higher value on carbon, clarifies future water treatment and discharge standards, establishes simple and clear criteria for closure and reclamation, and generally helps to create the conditions for a healthy and dynamic innovation ecosystem.

Technology can have maximum impact in reducing the environmental footprint when the pace of its development and deployment aligns with that of oil sands development.

New technologies, especially those that can potentially bring major reductions in the environmental footprint, can take 10 to 20 years or more to develop and implement. The Panel concluded that oil sands development needs to reflect this reality if technology is to have maximum effect. The current pace of development requires the most promising technologies to be ready for broad adoption in the near term to prevent the locking in of existing and less efficient technologies to the majority of new projects. This underscores the need for a major collaborative effort to accelerate the development and adoption of the most promising technologies and solutions.