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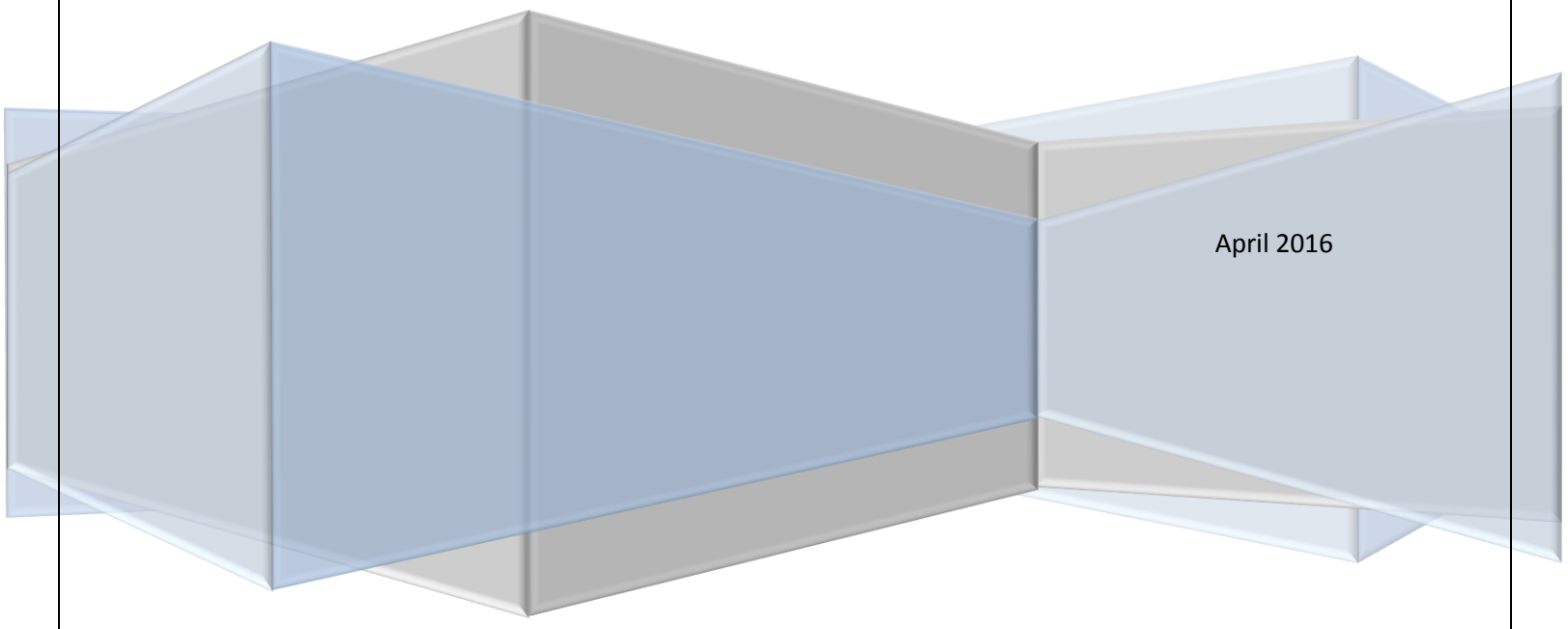
Scenario Planning

Adaptive Pathways to 2025

This document presents potential scenarios that Alberta could face over the next ten years given different developments in its oil sector. These scenarios are not intended to be predictive, but rather help identify what the Government of Alberta may need to do to effectively respond and adapt to future uncertainty.



April 2016

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Introduction

Alberta is at a crossroad. The recent decline in the price of crude oil highlights the critical importance of the oil sector for the province –and exposes Alberta's vulnerability should this sector experience additional threats or shocks. At this time of uncertainty, it is important to look forward and explore the challenges and opportunities that may lie ahead, so that we may be better prepared to meet them.

This report provides a glimpse into challenging futures that Alberta could face over the next ten years, by painting four different scenarios (**Figure 1**):

- **Prairie**: a business-as-usual scenario where Alberta's oil sector continues to grow on the back of a price rebound and access to new markets by 2020.
- **Plateau**: a potential scenario in which Alberta's oil production comes to a standstill in 2018 due to export constraints, persistently low prices, and the mass sale of electric cars world-wide.
- **Lagoon**: a potential scenario where Alberta's integrated producers remain profitable despite low prices, thanks to high margins in their refining operations; and yet, Alberta is largely unable to share in industry profitability.
- **Delta:** a potential scenario where Alberta' oil sands companies have to innovate to survive and grow in an increasingly carbon-constrained world.

These four scenarios are not meant to be predictive, nor do they cover the full gamut of futures that Alberta could face. Rather, they are intended to support discussions on emerging, high-impact developments and generate insights on how to adapt to such developments.

How to read this document

This report is organized in three main sections:

I. **Looking Back**: an overview of developments in Alberta's oil sector over the last decade, highlighting the gradual emergence of the oil sands as the lifeline to Alberta's economy and government finances (away from natural gas);

II. **Looking Ahead**: this section first outlines a business-as-usual scenario over the next ten years (Prairie), and then applies a set of "what-if" questions to the assumptions underlying Prairie to generate alternative futures (namely, Plateau, Lagoon, and Delta).

III. **Appendix:** a table comparing the key assumptions underlying the four different scenarios presented in this report, alongside a glossary of key terms.

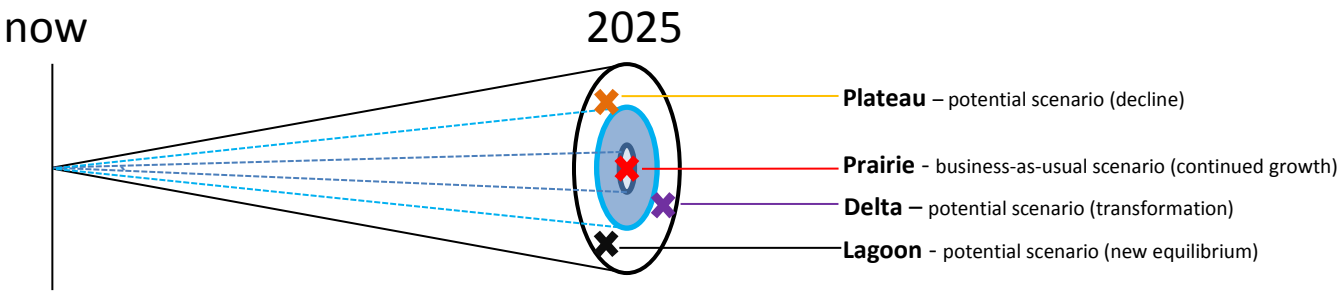


Figure 1: Viewing the future: The cone of plausibility.

Alberta's Energy Landscape – A Rolling Tide

Fifteen years ago, natural gas made up the lion's share of Alberta's resource revenues and exports. In 2005, Alberta's natural gas sector began to contract due to resource depletion and increasing competition from the U.S.[1] While natural gas prices struggled to pick up, high demand for crude oil and concerns around dwindling oil deposits spurred investment in higher cost technologies and fields around the world.[2]

In a peak oil world rife with supply disruptions, the oil sands appeared to be one of the few sources of ample, reliable, and economic oil supplies. As investors flocked to the oil sands, many refineries in the U.S. undertook expensive modifications to be able to receive bitumen –a very heavy oil that requires additional processing compared to light oil.[3] Conversely, the construction of upgraders in Alberta enabled the conversion of a portion of bitumen into higher-priced synthetic oil that could be processed in light oil refineries.

The U.S. Midwest became Alberta's main market, thanks to proximity, heavy oil processing capacity, and pipeline connections.[4] Due to its lower quality and distance from major demand centres, Alberta's bitumen tended to sell at a discount relative to the North American (West Texas Intermediate) and international (Brent) benchmarks. As oil sands production grew rapidly, pipeline bottlenecks south of the border created a supply glut that led to deeper discounts for Alberta's bitumen.[5] In addition, resurgent light oil production in the U.S. started to compete with Alberta's oil for space in light oil refineries and pipelines.[6] Crude-by-rail grew as a stop-gap measure to access alternative markets.

To shift Alberta's dependency away from the Midwest, several pipeline proposals started down the time-intensive regulatory process required by Canadian and U.S. jurisdictions.[7] By 2015, continental pipeline expansions and reversals had by and large removed bottlenecks from the Midwest to the Gulf Coast and enabled Alberta's oil to reach Quebec (through the Mid-West).[8] However, other proposals linking Alberta directly both to tidewater and the Gulf Coast remained mired in regulatory uncertainty or received outright rejections.

The relatively fast and large scale of resource development over the past ten years brought the oil sands to the forefront of the public forum. While many recognized the economic potential of the oil sands, the social and environmental impacts of resource development became deeply divisive issues. Land disturbance, rising greenhouse gas emissions, local pollution, and First Nations' protests all attracted intense scrutiny, tarnishing public perceptions around Alberta's oil sands.[9]

In November 2015, Alberta's efforts to reposition itself as a responsible producer culminated in the Climate Leadership Plan, which sets out a 100 megatons ceiling on oil sand emissions and an increase in the carbon levy to $30/tonne by 2018.[10] In February 2016, Alberta also announced changes to its royalty system, to encourage producers to reduce costs and incentivize partial upgrading in the oil sands.

Amidst these regulatory changes, the price of crude oil collapsed in the latter half of 2014 due to increasing supply from non-OPEC countries, OPEC's decision to abandon its strategy of price defense, and weak growth in worldwide crude oil demand. The magnitude and scope of this ongoing market correction remains an important uncertainty for Alberta's higher-cost, land-locked resources.

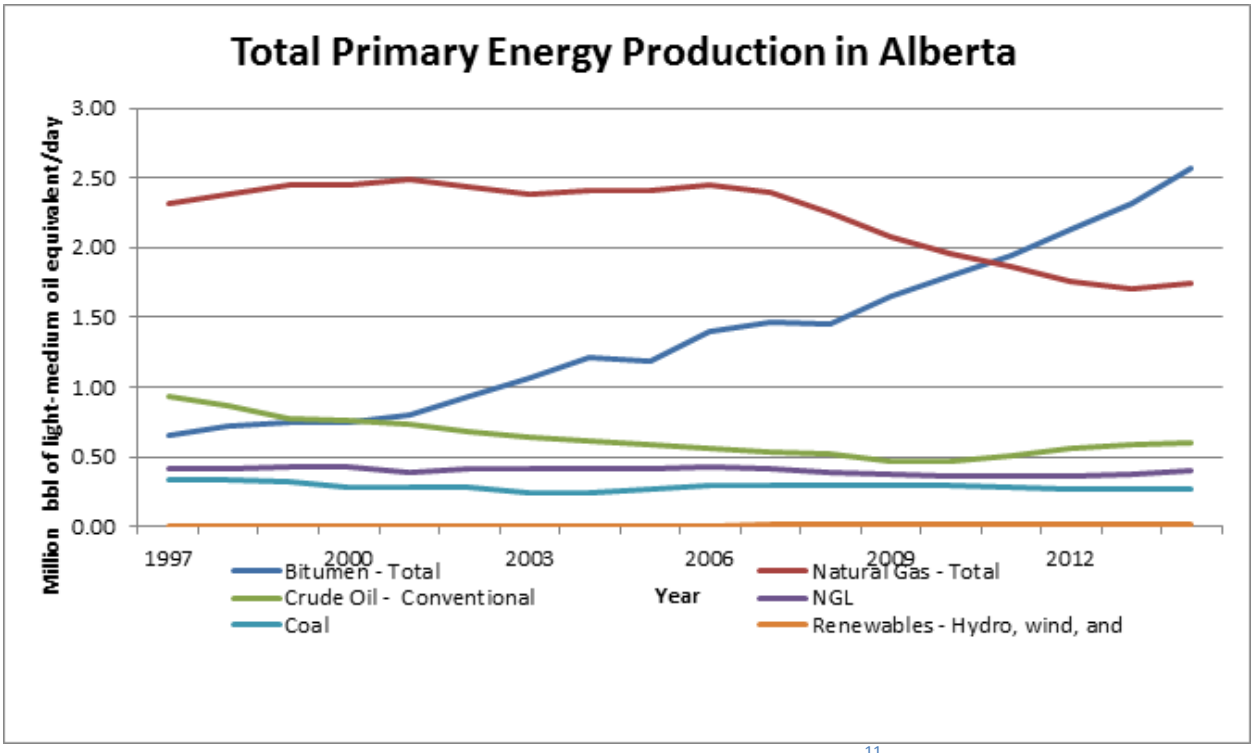


Figure 2: Total primary production in Alberta.[11]

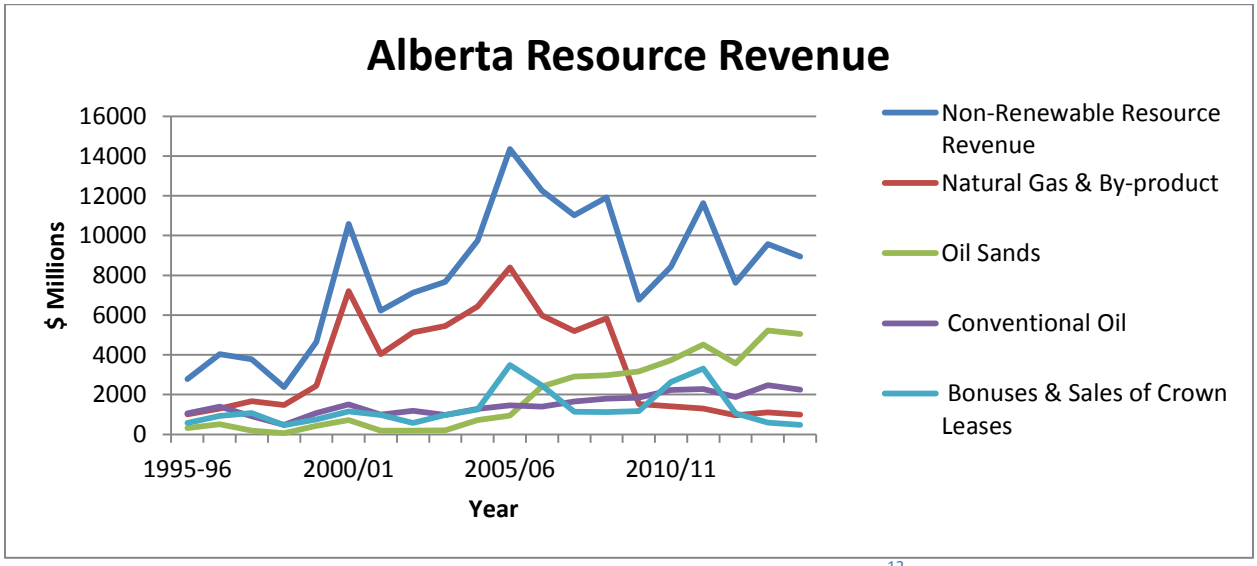


Figure 3: Alberta Resource Revenue (1995-2014).[12]

Prairie (business-as-usual scenario)

Overview

By the end of the decade, the pain borne by Alberta's oil sector in 2014-15 had given way to cautious optimism. Rising prices and pipeline expansions spurred moderate increases in capital expenditures starting in 2017. Oil sand production continued to grow well into the mid-2020s, although at a slower pace relative to the boom years of 2005-15.

Potential Pathway

2015-2020

Alberta's oil industry faced a couple of challenging years after the price collapse in late 2014. A number of smaller operators divested or went bankrupt on the back of unsustainable debts, leaving behind a trail of wells to be reclaimed.[13] By contrast, integrated operators remained profitable by offsetting lower revenues in production with higher profits in their refining and retail operations.[14]

While companies deferred or cancelled long-term plans for expansion during the downturn, the near-term impact of low prices on production was limited. Given the long lead times and capital intensity of oil sands projects, established integrated companies preferred to ride out low prices instead of compromising projects already underway .[15] Therefore, bitumen production continued to post strong gains. Conventional production, on the other hand, declined slightly due to investment cuts and resource depletion.[16]

By 2017, world-wide investment cuts had led to a slower pace of supply that was more in line with global demand levels.[17] As the price of oil started to rebound, Alberta's oil sector returned to healthy levels of profitability. Capital spending began increasing again[18] –if cautiously, in light of both increasing prices and promising steps on a number of pipeline proposals.

One such step was the favourable reception that Alberta's Climate Leadership Plan received across Canada and beyond. In the past, discussions around pipelines had been closely linked to concerns about greenhouse gas emissions from oil sands developments. As Alberta proceeded with the implementation of its Plan, some of these concerns were laid to rest.[19] While opposition to pipelines remained alive, negotiations became less polarizing.

On the back of this shift in public perception, Alberta and B.C. hammered a deal to swap pipeline access for electricity in 2017. This deal paved the way for Transmountain expansion, which began supplying California and some Asian markets in 2019.[20] Similarly, progressive additions to the Enbridge system enabled more Alberta oil to reach the Gulf Coast.[21] Besides providing access to new markets, these pipeline expansions reduced the need to move their crude by rail, thereby narrowing the discount Alberta's producers got for their crude.

2020-2025

After 2020, resurgent demand from emerging economies pushed Brent prices above US $80/barrel. Alberta's oil sector continued to attract a steady stream of investments –which, however, remained well below their pre-2015 level.[22] Rising investments in conventional oil managed to stabilize previously declining production. Bitumen production, on the other hand, continued to grow, although at a slower pace relative to the boom years of 2005/2015.

This slower pace was partly the lag effect of project deferrals and cancellations during the 2014-15 downturn. Also, higher production levels required more maintenance spending, leaving relatively smaller amount of capital available for new projects.[23] As a result, new oil sands developments focused

on smaller scale, faster pay-back steam-injection operations, instead of capital-intensive megaprojects with long pay-back.[24]

While steam injection required less water and produced less land disturbance relative to mining, increasing production deepened the cumulative impacts of extraction on the local environment. These impacts prompted increased scrutiny from a number of First Nations and environmental groups, leading to a streak of court challenges that delayed (but did not stop) projects coming online.[25] Furthermore, the carbon intensity of Alberta's oil sector failed to improve significantly, as the increasing use of more energy-intensive extraction techniques offset incremental process improvements.[26]

As prices inched higher, abundant production in the U.S. released larger quantities of light oil in the market, making new upgraders in Alberta uneconomic.[27] With now new upgrading capacity added since 2017, the heavy refining complexes in the U.S. Gulf Coast, the U.S. West Coast, and Asia became key destinations for Alberta's new heavy barrels. By 2023, however, lack of progress on new pipeline projects and increasing oil sands production had precipitated a new shortage in pipeline capacity, leading to increasing uptake of crude-by-rail.

Challenges and opportunities

Greening and decarbonizing oil sands extraction – The growing impacts of resource development on the local environment would need to be monitored and mitigated, to ensure ecological sustainability and protect the health of resource-heavy communities. Furthermore, while Alberta's producers would still have some room to grow before hitting the 100 megatons cap, far-reaching improvements in carbon intensity would be needed to support long-term resource development.

Pipeline crunch – A shortage of pipeline capacity would increase transportation costs and therefore, widen the discount Alberta's oil would receive relative to the North American benchmark. Lack of progress on new pipelines could deter new investments by undercutting project profitability.

Containing inflationary pressures – Factors like lower reservoir quality, increasing diluent and natural gas costs, and wage inflation due to talent shortages are set to push costs for new developments higher. Alberta's operators would need to contain these inflationary pressures to remain competitive and attract new investments.

Managing the social impacts of development and First Nation relations – As resource development continues, resource-heavy areas are set to face pressures regarding affordable housing, regional traffic, and services like health care and education. Consultations with First Nations would need to address the impact of expanding extractive activity on their traditional way of life, land, and treaty rights.

Ensuring an appropriate supply of labour – Alberta is unlikely to see the labour shortage experienced during the boom years of 2005-15, but high turnover due to cyclicality of commodity market and geographic distance could limit the supply of skilled labour.

Signposts (indications that this scenario is emerging)

- Brent progressively inches higher to US $80/barrel in 2020 and US $90/barrels in 2025.
- Cross-border pipeline additions (Line 3 replacement) and Transmountain expansion begin construction in 2017.
- Oil sands investments rebound in 2017, increasing to $20.4 billion in 2020 and $21.6 billion in 2025. Conventional oil and gas investment follows a similar trajectory, reaching $14.1 billion in 2020.
- Oil sands production grows to 3.3 million barrels/day in 2020 and 3.8 million in 2025.
- Average emission intensity of oil sands production remains constant.
- No new upgraders are built in Alberta or coker units added to U.S. refineries after 2017.

Alberta's petroleum production in *Prairie*

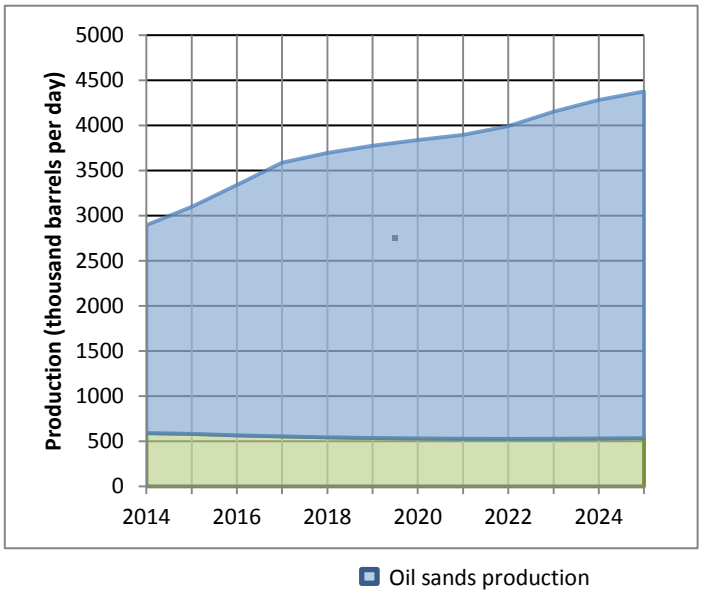


Figure 4: National Energy Board projection.[28]

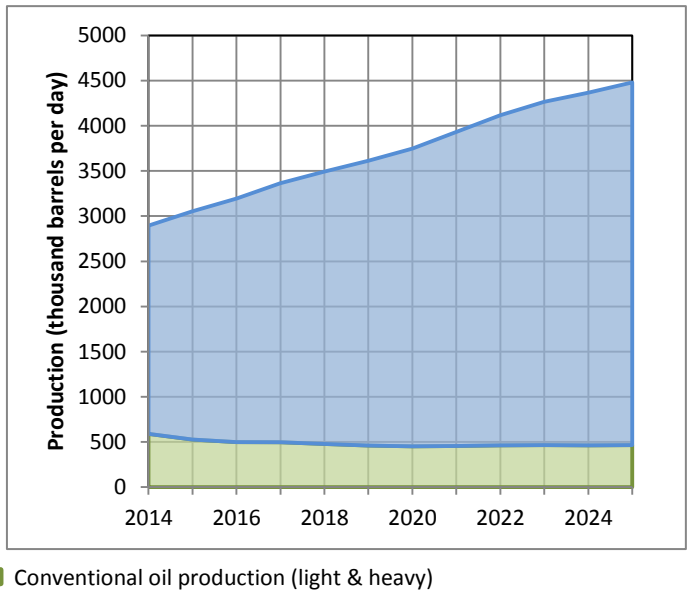


Figure 5: Alberta Energy Regulator projection.[29]

Indicative of capital expenditures in Alberta in *Prairie*

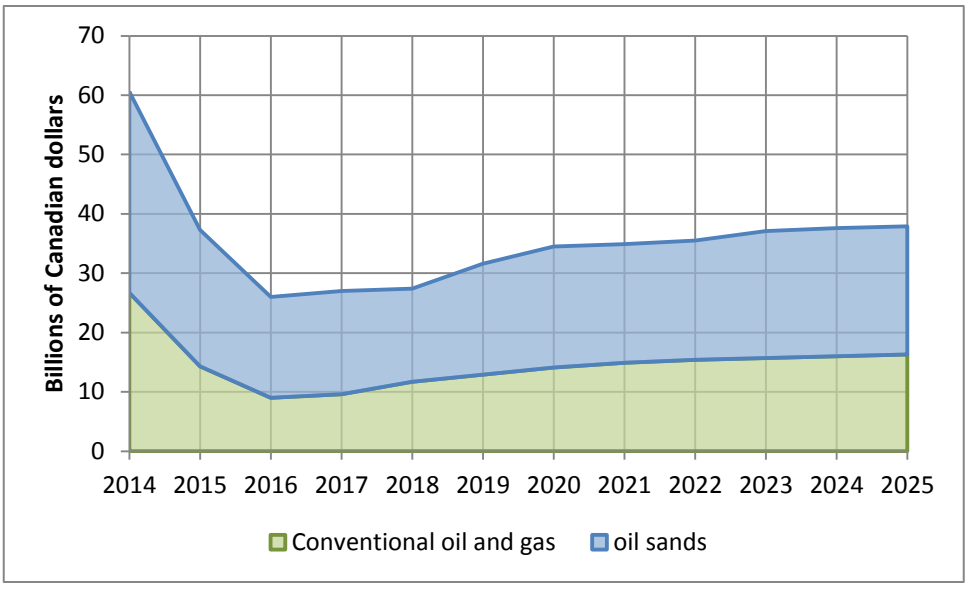


Figure 6: Alberta Energy Regulator projection.[30]

Plateau (potential scenario)

Overview

Gripped by low prices and no new export infrastructure, Alberta's oil production growth had come to a standstill by 2018. Long gone were the days where oil hovered around $100/barrel U.S., Chinese and U.S. thirst for crude oil seemed unstoppable, and experts warned against peak oil. In a peak demand world, Alberta's higher-cost, land-locked oil resources were unable to attract new investment, and therefore could no longer be relied upon to be the economic and fiscal lifeline they once were.

Potential Pathway

2015-2020

By 2020, the world oil market had struggled to absorb the excess supply that sent prices tumbling in late 2014. On the demand side, weak growth from industrializing countries, China's re-orientation towards a service economy, and efficiency gains in industrialized countries had limited increases in world consumption.[31] Supply had also remained relatively plentiful, due to high inventory levels, unexpectedly robust U.S. production, and OPEC's continued strategy to pursue market share.[32] As a result, prices failed to rebound significantly, stabilizing around US $50-60/barrel (Brent) between 2016 and 2020.

In Alberta, low prices took their toll on industry profitability, as many companies operated at or even below break-evens.[33] However, not all companies were affected equally. Established integrated operators were somewhat able to offset low revenues or losses in production with higher margins in their refining operations.[34] By contrast, many non-integrated companies faced unsustainable losses, as they operated below or near break-even costs. Mergers and acquisition intensified on the back of companies looking to gain economies of scale and growth through acquisition.

As Alberta's oil sector sought to adjust to lower-for-longer prices, operational efficiency became an imperative. Companies shed jobs, reduced salaries, and put pressure on their suppliers to decrease costs.[35] Research and development budgets ended up on the chopping block, prompting a focus on incremental improvements that could deliver cost savings instead of transformative technologies.[36]

Alberta's oil industry also drastically scaled down its prospects for expansion, as investment capital shifted away from capital intense, long pay-back oil sands projects, towards less costly oil developments with faster returns in other parts of the world.[37] Despite Alberta's Climate Leadership Plan, lack of progress on pipelines also became a liability for oil sands investors and producers. With pipeline capacity maxed out in 2017,[38] companies had no other option but to resort to rail –which squeezed the profitability of projects due to higher transportation costs.[39]

By 2019, a series of high-profile derailments had prompted regulators to introduce more stringent safety measures, making crude-by-rail cost-prohibitive for most oil companies. Amidst no new pipelines, limited use of rail, and low returns, project cancellations led to no new production growth after 2018.

2020-2025

As the new decade started, low prices had only gone so far in boosting economic growth and lifting oil demand world-wide. After more than a decade of high oil prices in the 2000s, the world economy had become much less oil intensive due to efficiency gains and fuel switching out of oil, particularly in the power sector of the emerging economies.[40] In the 2020s, fuel switching accelerated as a result of the drastic reduction in the cost of batteries and renewable energy technologies, which enabled the rapid electrification of transportation.[41]

Following the success that Tesla had achieved in 2015, several carmakers and technology companies had invested billions on both new pug-in models and the mass production of batteries. With battery costs rapidly falling, unsubsidized plug-in cars became cost-competitive with their internal-combustion

counterparts in the early 2020s. Furthermore, as wind and solar technologies became cheaper and more widely available, electric cars helped store intermittent power, creating a mutually reinforcing circle.[42]

In 2022, world-wide sales of electric vehicles lifted off.[43] The United States, Europe, Japan, and China emerged as the fastest markets for electric vehicles, thanks to incentives[44] and restrictions on vehicle purchases.[45] The market liftoff of plug-in cars ate away at demand for transportation fuels, removing 1 million barrels of crude oil a day off the global market by 2023 and 2 million by 2025.[46] While trucking, aviation, and ships remained dominated by petroleum fuels, sluggish world-wide economic growth and efficiency gains in commercial transportation failed to outweigh the impact of electric cars.

As oil prices plummeted to historic lows, Alberta's oil sector found itself in another, deeper crisis. Ten years before, non-integrated producers had born most of the brunt of low prices. By contrast, integrated operators had been able to shield themselves through higher profits in refining. This time, even integrated operators were affected, as lower demand for gasoline squeezed the profitability of refining.

The oil crisis triggered a new, more dramatic wave of consolidation around a small number of well-capitalized companies. Plans for the expansion of the oil sands were put on hold indefinitely, leaving much of Alberta's oil in the ground. Every year that followed brought more electric cars around the world, and less demand for oil[47] –only partially offset by rallying oil demand for commercial transportation. As one of the cheapest oils to buy and most expensive to produce in the world,[48] Alberta's bitumen was unable to compete for investments in a peak demand world.

Drastic cuts to maintenance spending in Alberta resulted in shut-ins of higher-cost oil sands projects, where companies were not able to recover operating costs at low prices. Amongst these projects were the most carbon intensive operations, which faced higher costs due to an increase of the carbon levy. Periodic rounds of salary reductions and job losses became the norm, as producers sought to contain losses.

Challenges and opportunities

Managing the economic and fiscal transition – The province and communities in resource-heavy areas would need to find new ways to sustain their economy and finances. As part of this effort, Alberta would need to manage its investment reputation.

Managing reclamation liability – Unsustainable financial pressures on Alberta's oil sector could leave the provincial government on the hook for decommissioning stranded oil production.[49]

Ensuring market optionality – Even with the prospect of flat or declining demand for oil in the transportation sector globally, lack of direct access to tidewater would hurt Alberta's producers by limiting options to reach markets where the electrification of transportation is slower.

Leveraging petroleum for alternative uses –Alberta could research and develop non-transportation uses for its oil or means to convert it into energy in forms other than oil (such as hydrogen or methane).[50]

Signposts (indications that this scenario is emerging)

- Brent stabilizes around US $50-60/barrel by 2020.
- Pipelines projects are set back by regulatory delays and polarized negotiations.
- World-wide sales of electric cars increase by an average of 45 per cent per year.
- Plans for oil sands expansions beyond 2018 are cancelled or deferred – production peaks in 2018 at 2.7 million barrels/day.
- Alberta's operators increasingly invest in cheaper-to-produce oil assets outside of the province.
- There is a year-to-year increase in abandoned and orphaned wells.

Alberta's petroleum production in *Plateau*

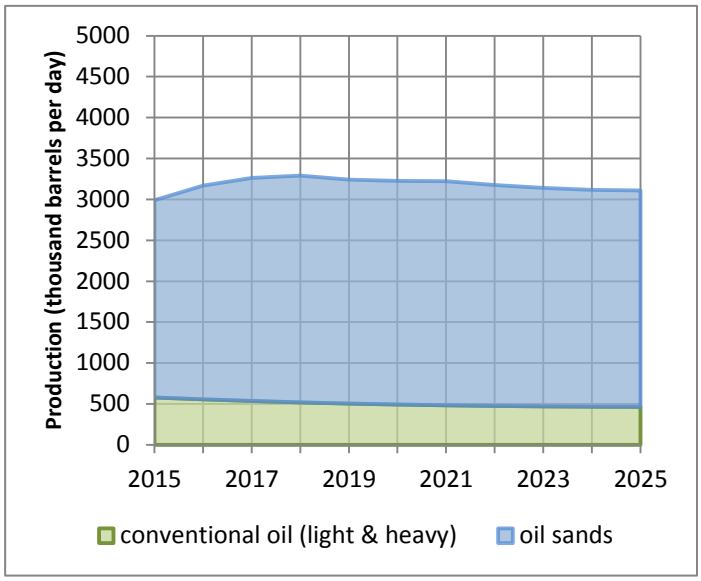


Figure 7: Indicative of Alberta oil production in *Plateau.*[51]

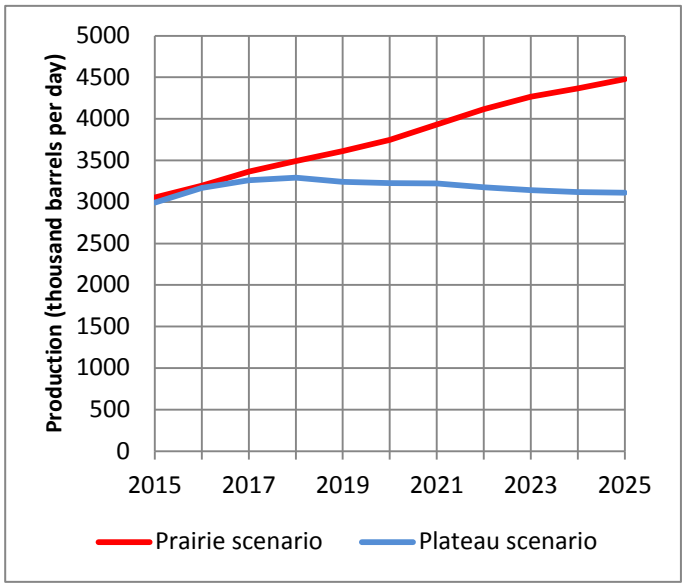
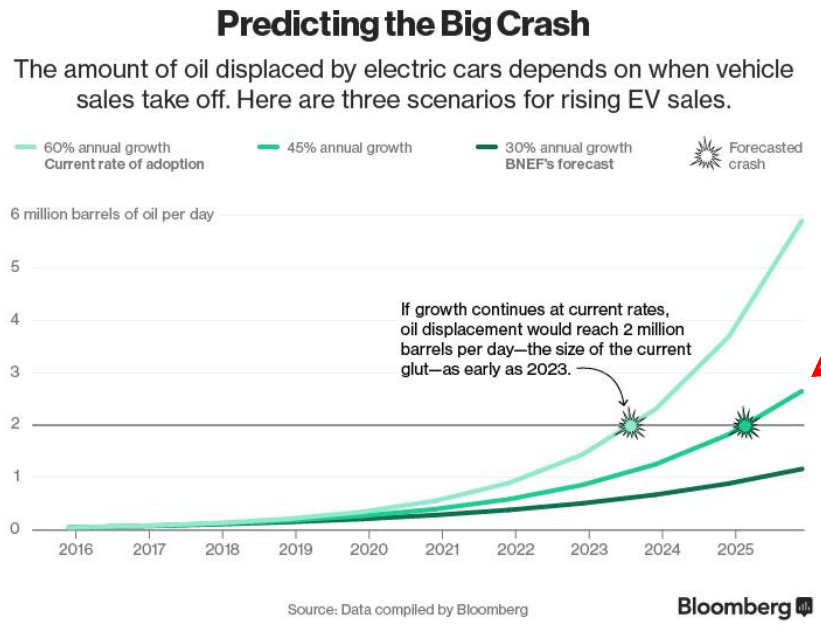


Figure 8: Total Alberta oil production in Prairie vs Plateau.

World-wide growth in electric car sales and displaced oil barrels[52]



World-wide growth of electric car sales assumed in Plateau

Lagoon (potential scenario)

Overview

By 2025, persistently low prices had taken a toll on Alberta's finances. By contrast, Alberta's integrated companies had maintained strong profits by leveraging cheap crude feedstock and relatively higher prices for transportation fuels. Cross-border pipeline expansions enabled these companies to direct additional volumes of crude to affiliated refineries in the Gulf Coast. However, these expansions were insufficient to substantively increase returns for the province or reduce Alberta's reliance on the North American market.

Potential Pathway

2015-2020

After the 2014 price collapse, a new market equilibrium emerged at $50/barrel (Brent) as a result of unexpectedly robust supply and sluggish demand growth from industrializing countries. By 2020, low prices had gradually boosted global demand, by diminishing the case for efficiency investments and stimulating the use of cars in both industrialized and emerging economics. However, high inventory levels, a long-lasting shift in OPEC's strategy away from price defense, decreasing supply disruptions in oil-producing regions, and the stronger resilience of U.S. tight oil helped keep prices in check.[53]

Low crude prices benefitted refineries in North America, which were able to buy cheap oil feedstock and sell refined products at a relatively higher price[54] to serve a growing transportation market, both domestically and abroad.[55] Heavy oil refineries benefitted the most, since their configuration enabled them to maximize the yield of transportation fuels from heavy oil.

As one of the cheapest oils in the world, Alberta bitumen offered U.S. and Canadian refineries some of the most attractive refinery margins in the world.[56] Such high margins represented a great opportunity for Alberta's integrated companies, as refining enabled these companies to remain profitable despite lower revenues or losses in production.[57] By contrast, many of Alberta's non-integrated companies either went bankrupt or became targets for take-over by integrated producers.

By 2018, integrated companies had brought online new bitumen production, to serve demand in the U.S. Gulf Coast in light of declining Mexican and Venezuelan production. As Alberta's new barrels filled existing pipeline capacity, operators increasingly relied on crude-by-rail. This translated into billions of dollars of foregone resource revenues for the provincial government. Furthermore, Alberta was largely unable to share in industry profitability, as most of industry profits were realized and subject to taxation in the U.S., where refineries were located.

In an effort to raise revenues and win support for pipelines to tidewater, the provincial government pushed forward on its Climate Leadership Plan, including the introduction of more stringent measures on greenhouse gas emissions reduction. These measures increased compliance costs for Alberta's producers, many of which already operated near break-even costs. Despite strong profits in refining by integrated producers, Alberta's oil industry tried to contain cost pressures by focusing on operational efficiency and capital discipline. After 2018, investments in new production centered mostly on incremental expansions and debottlenecking of existing projects.

By 2020, the Climate Leadership Plan had failed to win Alberta access to tidewater. Negotiations on inter-provincial pipelines had remained polarized and set back by regulatory delays. However, pipeline access to the U.S. increased with the replacement of Line 3 in 2019, further cementing Alberta's bitumen capture within the North American refining market.

2020-2025

In the new decade, companies continued to push their refining units as hard as possible, using them to cushion the impact of low oil prices. As the transportation fuel market in North America started to saturate, integrated producers faced diminishing returns from refining.[58] Also, investment cuts in oil production world-wide slowly brought supply more in line with global demand, increasing crude feedstock prices to $U.S. 70/barrel (Brent) by mid-decade.

To ensure their viability given these changing market dynamics, Alberta's oil companies doubled down on their efforts to maintain capital discipline. Companies continued to put pressure on their suppliers to reduce input costs for existing projects. Research and development budgets were slashed, as operators shifted their focus from expensive game-changers to incremental improvements.

While recovering oil prices showed promise for small-scale projects in Alberta, relatively high break-even costs for new projects and more stringent environmental regulations became a liability for producers. Furthermore, diminishing returns in refining made integrated producers more cautious about investments in new oil sands projects. As a result, investment shifted mostly towards the effective maintenance of current projects. At the same time, new production slowed down markedly, driven by more cost-effective "brownfield" expansions instead of stand-alone or "greenfield" projects.[59]

As resource development lost steam, labour pressures moderated, keeping labour costs in check. Communities in resource-heavy areas came to grips with reduced need for skilled labour and losses in municipal revenues. At the same time, "brownfield" expansions of the oil sands intensified the impacts of resource extraction on water and land in areas already affected by development. This prompted a streak of legal action from affected First Nations that delayed projects and added unforeseen costs.[60]

Challenges and opportunities

Capturing more value from bitumen in the refined products market– Low crude oil prices and high refining margins present Alberta with the opportunity to incentivize or otherwise capture more value from the processing of its resources to serve the transportation fuel market.

Capturing rent – Low crude prices hurt the provincial government, but benefit integrated producers (as long as transportation fuel prices are relatively high). Strong industry performance despite (or perhaps, because of) low crude prices could be a catalyst for the provincial government to explore new ways to capture rent, potentially with a focus on the downstream sector.

Ensuring investment attraction and retention – Slowing oil sands activity highlights the importance of attracting and retaining new investment to sustain the oil sands as a driver of employment and economic growth.

Driving down production costs – In a low price environment, Alberta's producers would need to innovate to drive down production costs and remain competitive. The provincial government would need to explore ways to enable innovation to support continued activity in the oil sands.

Managing relations with First Nations – Consultations with First Nations would need to address the impacts of "brownfield" expansions on their traditional way of life, land, and treaty rights.

Signposts (indications that this scenario is emerging)

- On average, refining margins remain high, but start to decline after 2020.
- Brent averages $50-60/barrel to 2020, increasing to $70/barrel in 2025.
- Oil sands production increases to 2.8 million barrels/day in 2018 and 3 million barrels/day in 2020.
- Industry consolidates around well capitalized, integrated producers.
- Exports of gasoline and diesel from the U.S. Gulf Coast to other markets increase.

Alberta's petroleum production in *Lagoon*

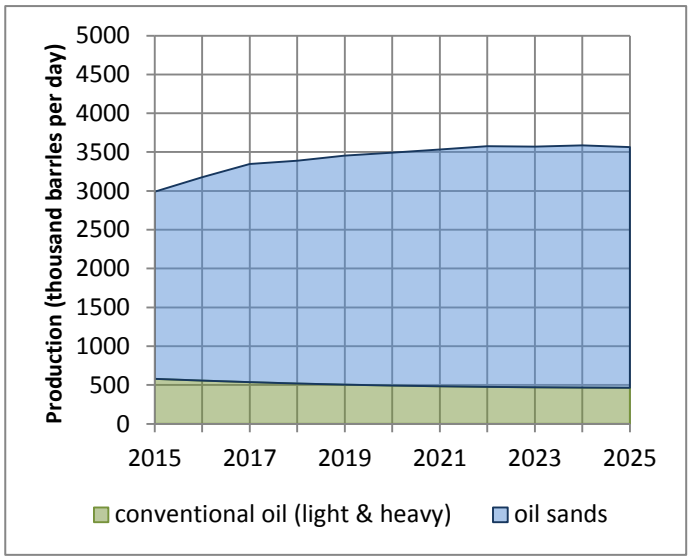


Figure 9: Indicative of Alberta oil production in *Lagoon*.[61]

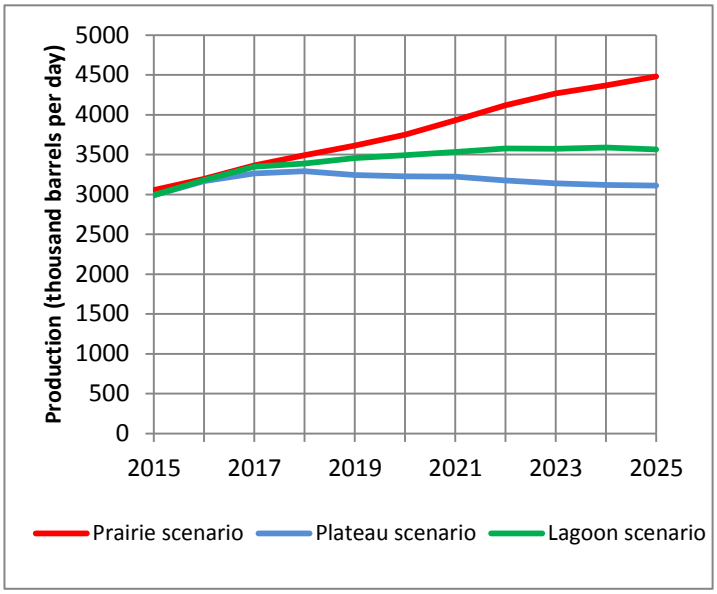


Figure 10: Total Alberta oil production in Prairie, Plateau, Lagoon

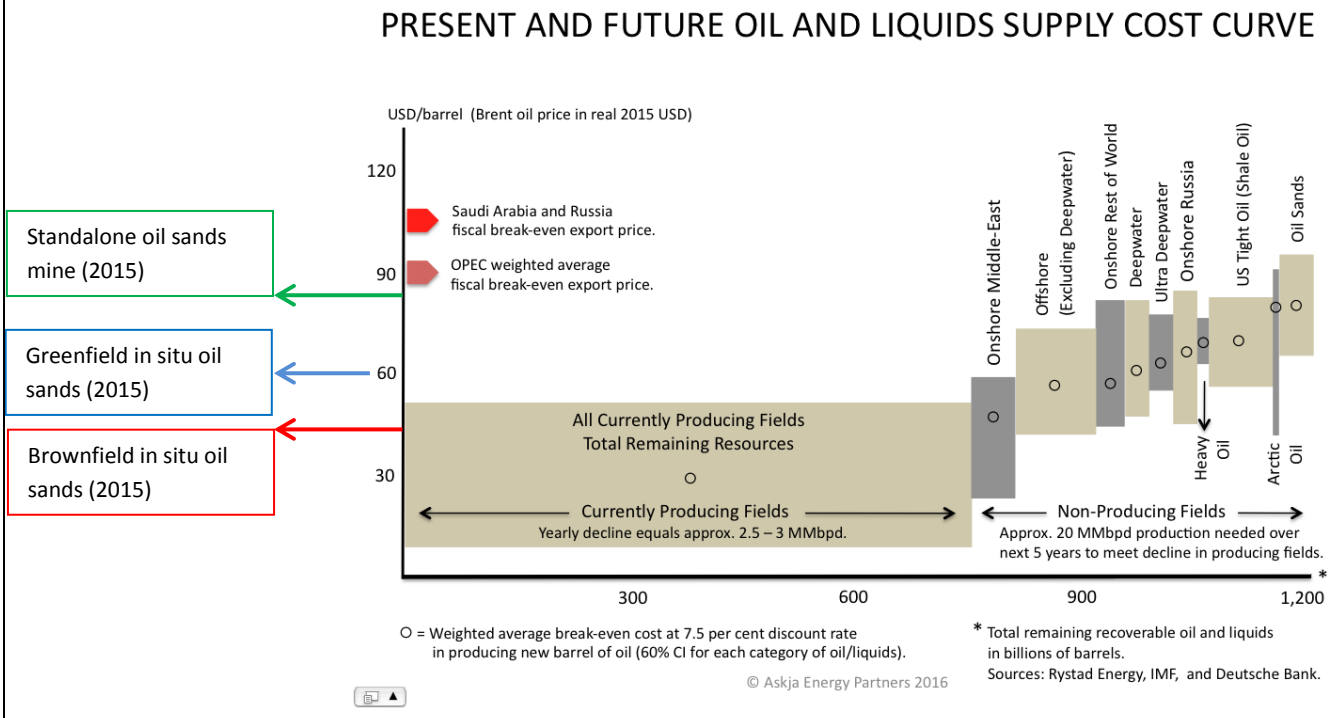


Figure 11: Present and future oil and liquids supply cost curve.[62]

Delta (potential scenario)

Overview

By 2025, aggressive action on emissions world-wide had accelerated the transition towards a lower-carbon economy. Given their higher cost and carbon intensity,[63] Alberta' oil sands companies had to innovate to survive and grow in an increasingly carbon-constrained world. This imperative accelerated the adoption of game-changing technologies by well-capitalized companies. As Alberta's oil started to shed its traditional "dirty" label, access to tidewater enabled Alberta's producers to start expanding production to serve new markets.

Potential Pathway

2015-2020

After the 2015 Paris Agreement, climate change remained at the forefront of the political agenda internationally. Extreme weather and draughts became more frequent world-wide,[64] causing billions of dollars in damages and forcing millions of people from their homes. In emerging economies, worsening air quality led to an epidemic of respiratory diseases,[65] which quickly became the leading cause of death and lower productivity in cities.[66]

While the impacts of climate change strengthened governments' resolve to curb emissions, multi-lateral agreements on strict carbon budgets remained elusive. Instead, countries and regional blocs pushed forward their own initiatives to fit local circumstances. Led by China, industrializing countries started to turn on the coal industry.[67] By contrast, several industrialized economies implemented aggressive emission curbs on transportation.[68]

In line with these developments, in 2017 the United States announced the introduction of a national fuel standard effective in 2020. Similar to initiatives implemented in the E.U.[69] and California,[70] the U.S. standard mandated a reduction in the lifecycle carbon intensity of transportation fuels by 6% by 2025. Fuels that failed to comply with baseline targets incurred higher taxes or emission permit costs, with federally-mandated price caps on fuels to protect customers.[71]

In preparation for this standard to come into effect, U.S. refineries started to track information and discriminate between different crudes based on their carbon lifecycle emissions.[72] Carbon intensive crudes like bitumen became subject to a "carbon discount", as U.S. refineries hedged against future penalties for higher-emitting refined products. On the other hand, crudes with lower-than-average carbon intensity started to command a "carbon premium" in the U.S. market.[73]

Meanwhile in Canada, pipeline projects showed no sign of progress to shift Alberta's dependency away from the U.S market. As a result, Alberta's bitumen and synthetic oil became subject to steep discounts. Furthermore, sluggish growth in fuel transportation demand in North America kept refining margins low, precluding Alberta's integrated companies from offsetting lower revenues in production.

Surviving in an increasingly carbon-competitive U.S. market made innovation an imperative for Alberta's oil sands companies. Operators re-oriented their business models away from new production volumes, towards the decarbonization of their production. To this end, well-capitalized companies partnered with small firms and academia to accelerate the development and commercial adoption of game-changing technologies, investing billions in innovation.

By 2020, these investments had shown that significant carbon reductions were within reach. Successful innovations included solvents to reduce natural gas use in extraction;[74] molten carbonate fuel cells to capture carbon emissions while producing electricity;[75] and finally, electro-reduction[76] and bio-reactors[77] to convert carbon dioxide into biofuels and nanotubes.[78] Crucially, these innovations opened up new revenue-generating streams (e.g., sale of excess electricity and carbon products), which companies used to offset higher production costs. Looking ahead, the challenge was to scale up these innovations from a small number of projects, to encompass most oil sands production.

2020-2025

By the new decade, zero-emission vehicles were still many years away from mass adoption, due mostly to high battery costs. As transportation remained dominated by oil, increasingly stringent curbs on transportation emissions became more widely adopted world-wide. These measures partly offset the effects of population growth and increasing standards in developing countries, leading to slow increases in world demand for crude.

Confronting major deficits, the Canadian government awoke to the economic importance of the oil sands,[79] while recognizing the significant decarbonization effort under way. To help promote economic growth, in 2021 the federal government brokered a grand bargain to push forward the Eagle Spirit pipeline from Alberta to the B.C coast. The bargain made the pipeline contingent on a national fuel quality standard and carbon taxes on imported oil, to accelerate innovation in the oil sands. Completed in 2023, the pipeline enabled Alberta's oil to reach some Asian markets and the U.S. West Coast.

As international (Brent) crude prices recovered to $75 due to supply disruptions in the Middle East, Alberta's conventional oil producers leveraged premium prices in the U.S. market to expand production. Additions to the Alberta Carbon Trunk Line in 2022 enabled increasing quantities of captured carbon to be used for enhanced oil recovery in conventional production. Oil sands production picked up too after a no-growth period, to serve mostly Asian markets that were yet to adopt fuel standards.

Efforts to drastically lower the emission intensity of oil sands production continued, as well-capitalized companies kept retrofitting a larger number of operations with carbon-reducing technology. Production of lower carbon-emitting crude enabled these companies to offset discounts for their more carbon-intensive production. Furthermore, revenues from related business areas such as carbon products helped these operators sustain further decarbonization. Investments in new technologies and processes continued, as companies sought to lower costs and find a use for captured carbon.[80]

By 2025, about 15 % of Alberta's bitumen and synthetic oil production was less carbon intensive than the U.S. baseline, and an additional 40 % was equal to the baseline. Industry increasingly consolidated around large companies that leveraged innovation to decarbonize some of their production while diversifying into complementary businesses like biofuels. A number of smaller operators emerged at the fringes, focusing exclusively either on higher-cost production for premium markets or lower-cost, carbon-undifferentiated production for markets with no fuel quality standards.

Challenges and opportunities

Enhancing carbon and cost competitiveness – competing in an increasingly carbon-constrained world requires an accelerated pace of innovation able to achieve significant cost and emission reductions.

Using CO_2 for value creation – decarbonization challenges the oil industry with finding uses for captured emissions. Conversely, turning carbon emissions from waste to a monetizeable asset can help sustain decarbonization, creating a mutually sustaining cycle.

Enhancing the reputation of Alberta's oil – innovation could help shift the reputation of Alberta's oil sands industry, promoting investment attraction.

Promoting alternative oil uses – Alberta could sustain activity in the oil sands by promoting the development of end-use, value-added products from oil like carbon fibers.

Signposts (indications that this scenario is emerging)

- U.S. (or U.S. and Canadian markets served by Alberta) adopts fuel quality standards.
- Technology that contributes to significant (75-90%) emission reductions is commercialized in Alberta.
- Crudes face carbon premiums or discounts based on their lifecycle carbon emissions.

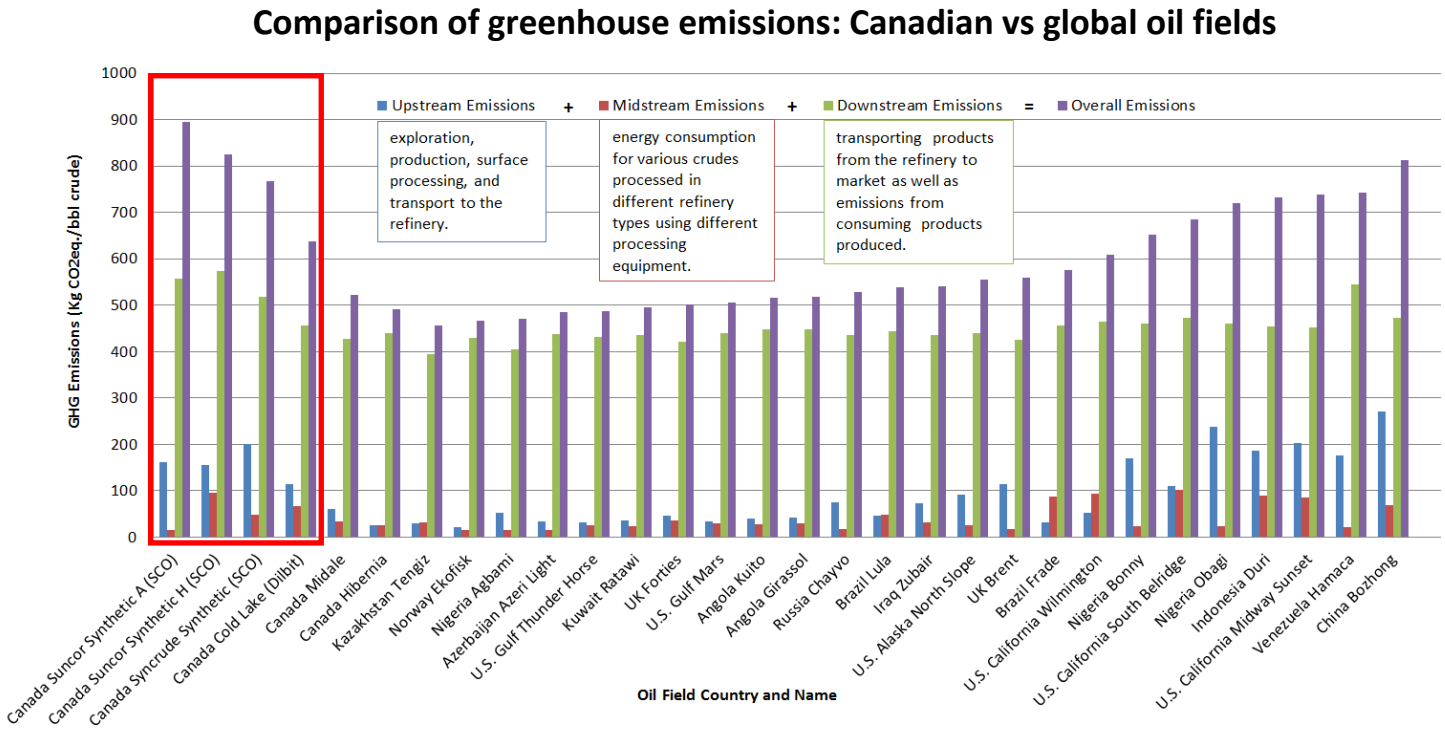


Figure 12: Lifecycle emissions estimates of Canadian vs global crudes.[81]

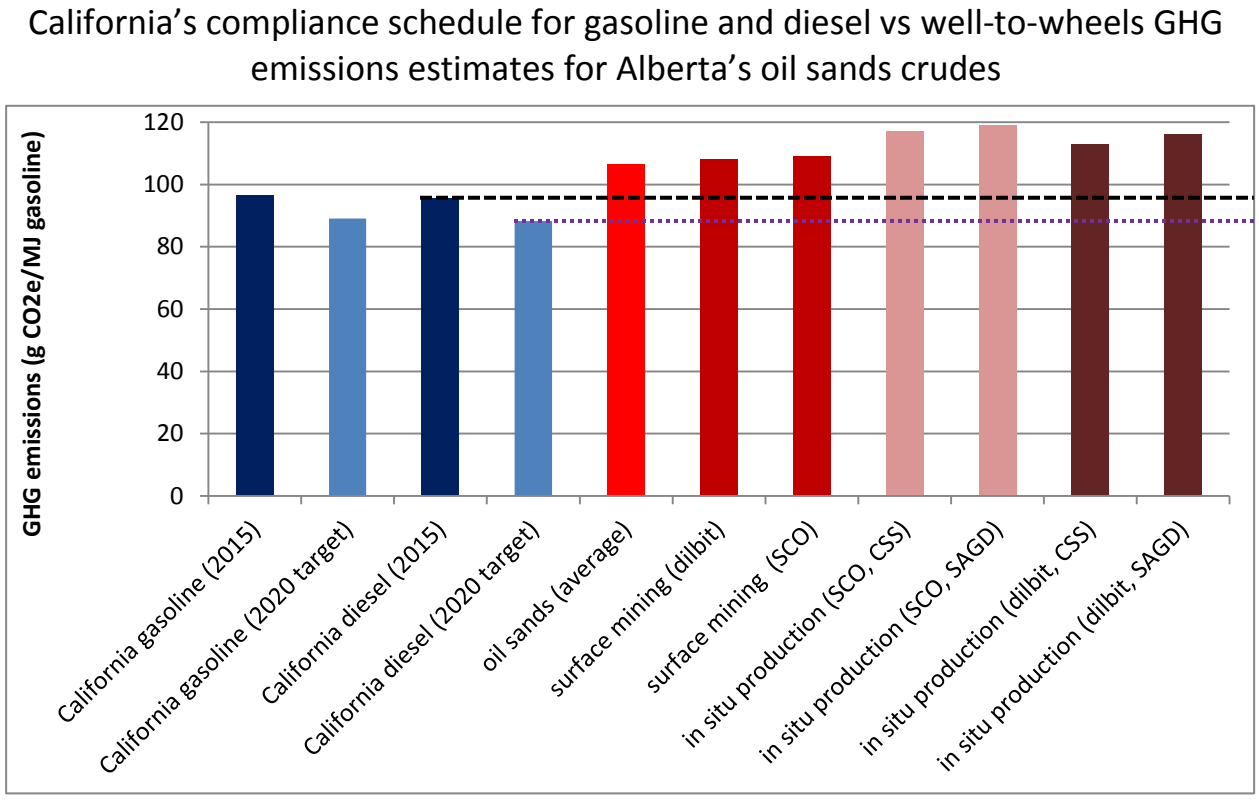


Figure 13: This graph uses California's compliance targets for transportations fuels as an illustration of the GHG emission reductions required for oil sands companies to remain competitive if similar fuel quality standards were to be introduced in the U.S. and Canada.[82]

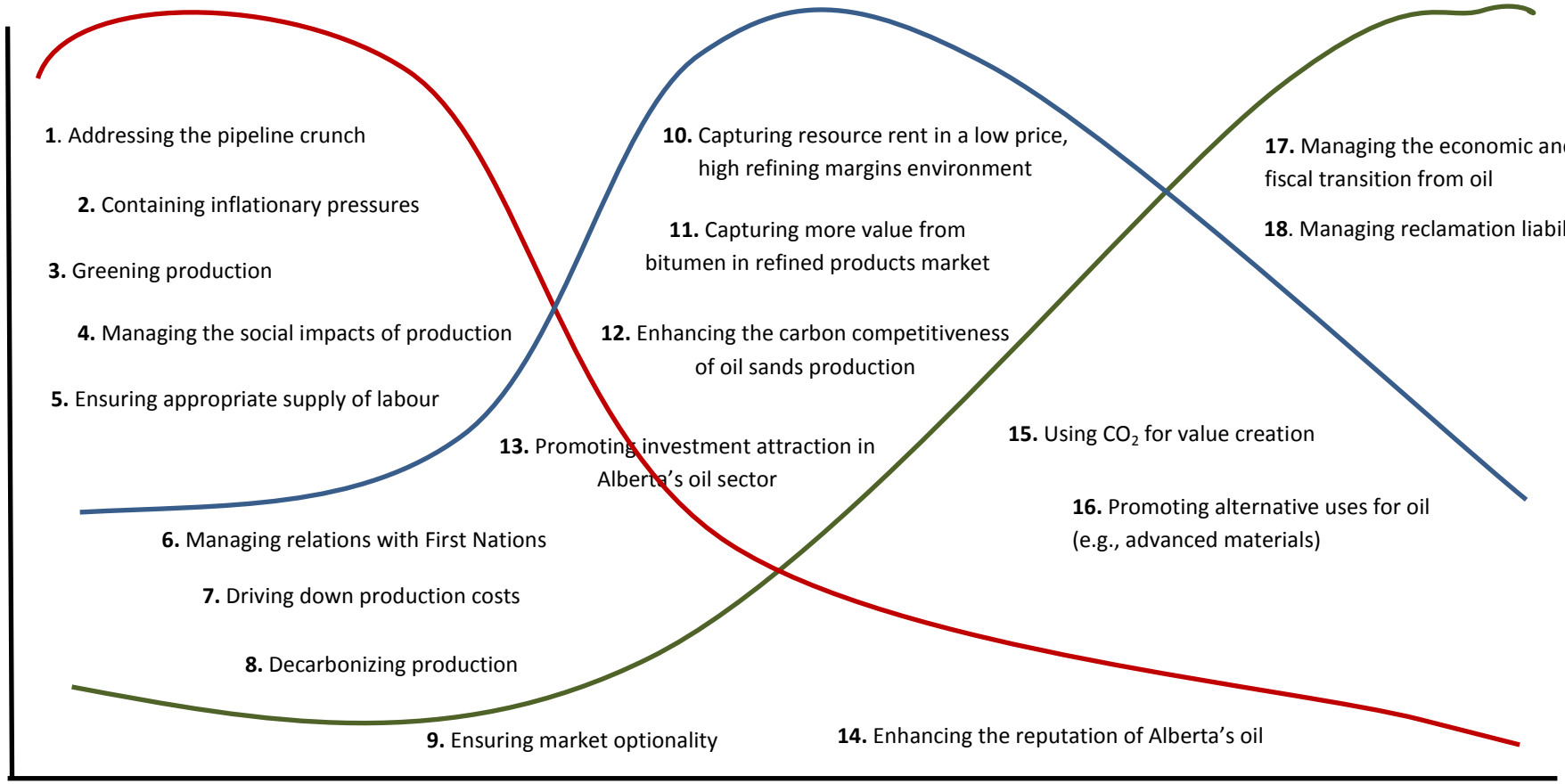
Appendix

Scenario Overview

	Prairie	Plateau	Lagoon	Delta
Crude demand from emerging economies	Resurgent due to rising population, standards of living, and economic activity.	Weak due to slow economic growth and increasing diffusion of electric cars with renewables.	Sluggish at first but increasingly –if slowly– boosted by low prices.	Slowing due to increasingly stringent emissions curbs on transportation after 2020.
Crude demand from mature economies	Slow decline due to diminishing oil intensity.	Substantial decline due to rapid electrification of transportation.	Low prices slow down long-term decline by boosting demand.	Moderate decline due to aggressive climate change action.
Global crude supply	Investment cuts lead to a slower pace of production.	Resilient due to high inventory levels, robust US production, and OPEC's abandonment of price defense.	Plentiful due to high inventory levels, robust US production, OPEC's abandonment of price defense, and no supply disruptions.	Disrupted by frequent outages in oil-producing regions
Global crude prices	Steadily increasing prices. Discounts for Alberta's crude widen before 2019 and after 2023, as pipelines are filled.	Persistently low prices.	Low but slowly recovering prices. Discounts for Alberta's crude widen until cross-border additions are completed in 2019.	Volatile prices. In the U.S. and Canadian markets, crudes face discounts or premiums based on their lifecycle emissions.
Energy policy and regulations from outside of Alberta	Federally-imposed tanker moratorium on Northern B.C. Coast.	New federally-imposed safety measures make crude-by-rail cost-prohibitive.	Federally-imposed tanker moratorium on Northern B.C. Coast.	U.S. mandates a 6% reduction in lifecycle fuel emissions from 2020 to 2025, followed by Canada. Aggressive but loosely coordinated climate change action world-wide.
Energy policy and regulations from within Alberta	100 Mt emissions cap on oil sands; economy-wide carbon levy; flaring reduction.	100 Mt emissions cap on oil sands; economy-wide carbon levy; flaring reduction.	100 Mt emissions cap on oil sands; economy-wide carbon levy; flaring reduction.	100 Mt emissions cap on oil sands; economy-wide carbon levy; flaring reduction.
Alberta's crude production	Robust oil sands production. Conventional production stabilizes in 2020.	Oil sands production peaks in 2018 and then slowly declines. Conventional production declines.	Oil sands production expands incrementally. Conventional production declines.	Oil sands production picks up in 2023, after a no-growth period. Conventional production expands.
Alberta's export infrastructure	Transmountain to B.C. and cross-border additions by 2019.	No new pipelines.	Cross-border Line 3 replacement by 2019.	Eagle Spirit to B.C. by 2023.
Alberta's oil industry structure and profitability	Non-integrated companies return to profitability. Integrated companies enjoy higher production revenues as refining margins ease.	Low prices drive many non-integrated companies out of business. Integrated companies take a hit as the electrification of transportation speeds up.	Integrated companies leverage low prices and high refining margins to remain profitable. Non-integrated companies suffer.	Drastic emission reductions become key to growth. Innovation opens up new revenue-generating streams like carbon conversion.
Technology focus in Alberta's oil sector	Incremental improvements.	Improvements that can deliver cost savings.	Incremental improvements.	Game-changing innovations focused on decarbonization.
Social attitudes on resource development	Alberta's Climate Leadership Plan lays to rest concerns around oil sands emissions.	Polarized and antagonistic.	Polarized.	Innovation helps the oil sands sector shed its "dirty" label.

Appendix

Summary of Strategic Challenges and Opportunities (Three Horizons)



	HORIZON 1	HORIZON 2	HORIZON 3
FOCUS	**Competing** within given structures	**Adapting** to an evolving environment	**Shaping** emerging businesses
INTENT	Strengthen, defend, and expand **core** business	Drive growth in areas **related** to core business	Uncover options for **new** future growth areas
SCENARIOS	**Prairie**	**Lagoon, Delta**	**Plateau**

Using Scenarios

It can be interesting to read scenarios and imagine what the future may hold. However, the real value of scenarios is in the extent to which they inform decisions and actions in the present.

Below are six scenario applications that, either individually or in combination, can help bring future insights into the present:

1. **Build partnerships**
   Scenarios can be used to facilitate discussions with other organizations around cross-cutting issues, mutual aims, and potential areas for collaboration.

2. **Stress-test current strategies**
   Scenarios can be used to test how different strategies would perform under alternative conditions. In this way, it is possible to identify and address the potential weaknesses or failure points of specific strategies, so as to improve their robustness against future uncertainty.

3. **Develop hedging strategies**
   Scenarios can help develop new strategies or contingencies that hedge against the emergence of unlikely yet disruptive developments. While certain scenarios may seem unlikely, none is impossible. Building on the opportunities and challenges presented by different scenarios can help improve adaptability to change.

4. **Be a trailblazer**
   Scenarios can help uncover currently unknown needs or weak developments that have the potential to radically transform the industry. These insights can help organizations brainstorm and experiment with innovative ideas, to gain first-mover advantage and stay ahead of the competition.

5. **Establish a vision**
   Scenarios can help kick-start a discussion around the changes different stakeholders would like to see. It is possible to create a normative scenario by taking elements that different people like best from existing scenarios and then exploring what would need to be true for this vision to happen.

6. **Establish an early warning system**
   Scenarios can help identify key events or developments that organizations can monitor to gauge which way the operating environment is headed. This monitoring can help organizations adjust course or better prepare for change.

Glossary

Break-even cost
The amount of money for which a barrel of crude oil must be sold to cover the costs of producing it (usually including a rate of return for the producer).

Benchmark price
The price per barrel of oil traded in the international marketplace. Major benchmarks include:

- *Brent*: a sweet light crude oil (low viscosity, low sulphur content) from the North Sea that serves as the international standard.
- *West Texas Intermediate (WTI)*: a sweet light grade of oil (low viscosity, low sulphur content) used as benchmark for North America.
- *Western Canadian Select (WCS)*: a heavy sour grade of oil (high viscosity, high sulphur content) used as benchmark for Alberta's bitumen.

Bitumen
Viscous mixture of hydrocarbons that contains high levels of sulphur and nitrogen compounds.

Conventional crude oil
Mixture of hydrocarbons recoverable at a well from an underground reservoir, and liquid at atmospheric pressure and temperature. Unlike bitumen, it flows through a well without stimulation and through a pipeline without processing or dilution.

Heavy crude oil
Oil with gravity below 22 degrees API (hence, the heavier, the more viscous). Heavy crudes must be blended or mixed with condensate to be shipped by pipeline.

Integrated company
A business entity that engages in the exploration, production, refining, and distribution of crude oil or gas. Typically, the various operations of an integrated company can fall into "upstream" (exploration and production), "midstream" (transportation), and "downstream" (refining and retail).

Net-back
Revenues derived from the sale of crude oil minus all costs associated with getting the oil to a market.

OPEC
An organization (the Organization of Petroleum Exporting Countries) formed in 1961 to administer a common policy for the sale of petroleum.

ENDNOTES

Alberta's Energy Landscape –A Rolling Tide

[1] Alberta Energy Regulator, (2015), *ST-98: Alberta's energy reserves and supply/demand outlook*, p. 20. Available at: http://www.aer.ca/data-and-publications/statistical-reports/st98.
[2] International Energy Agency (2014), *World energy investment outlook: Special report*, p. 52. Available at: https://www.iea.org/publications/freepublications/publication/weo-2014-special-report---investment.html.
[3] Royalty review advisory panel (2015), *Alberta at a crossroads: Royalty review advisory panel report*, p. 30. Available at: http://www.energy.alberta.ca/Org/pdfs/RoyaltyReportJan2016.pdf.
[4] Canadian Association of Petroleum Producers (2015), *Crude oil: Forecast, markets & transportation*, p. iv.
[5] Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 26-28.
[6] Royalty review advisory panel (2015), *Alberta at a crossroads: Royalty review advisory panel report*, p. 28-31 Available at: http://www.energy.alberta.ca/Org/pdfs/RoyaltyReportJan2016.pdf.
[7] Pipeline projects are designed to export Alberta crude to the US Gulf Coast (Keystone XL, Seaway, Crushing Extension, Gulf Coast), Pacific Basin (Northern Gateway, Transmountain Expansion), Atlantic Basin (Energy East, Line 9) and between US regions (Flanagan South, Southern Access Expansion and Spearhead).
[8] Canadian Association of Petroleum Producers (2015), *Crude oil: Forecast, markets & transportation*, p. 22-29.
[9] Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 10-25.
[10] Alberta government (2016), *Climate Leadership Plan*. Available at: http://www.alberta.ca/climate-leadership-plan.cfm.
[11] Alberta Energy Regulator (2015), *ST-98: Alberta's energy reserves and supply/demand outlook*. Available at: https://www2.aer.ca/t/Production/views/ExecutiveSummaryFigure3TotalprimaryenergyproductioninAlberta/Figure3TotalprimaryenergyproductioninAlberta?:embed=y&:showShareOptions=true&:display_count=no.
[12] Alberta Energy (2016), *Resource Revenue Collected*. Available at: http://www.energy.alberta.ca/About_Us/2564.asp

Prairie (business-as-usual scenario)

[13] See Johnson, Tracy (June 14, 2016), *Bankrupt energy firms add to Alberta's abandoned well problems*. CBC News. Available at: http://www.cbc.ca/news/canada/calgary/abandoned-oil-wells-in-alberta-1.3613068.
[14] Conference Board of Canada (2015), *Canada's oil extraction industry*, p. 7. See also Pittis, Don (August 21, 2015), *Big oil that's making a killing*. CBC News business. Available at: http://www.cbc.ca/news/business/big-oil-that-s-making-a-killing-don-pittis-1.3197791.
[15] National Energy Board (2016), *Canada's energy future 2016: Energy supply and demand projections to 2040*, p. 53; Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, crude bitumen production; Canadian Association of Petroleum Producers (2016), *Crude oil: Forecast, markets and transportation 2016*, p. 7.
[16] Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, crude oil production; Canadian Association of Petroleum Producers (2016), *Crude oil: Forecast, markets and transportation 2016*, p. 6.
[17] Conference Board of Canada (2015), *Canada's oil extraction industry*, p.4; International Energy Agency, (2015), *World energy outlook 2015*, p. 49.
[18] Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, capital expenditures.
[19] As a signal of this potential outcome, see: McConnell, Rick (July 19, 2016), *Alberta's climate change plan selling point for pipelines*, *Rachel Notley says*. CBC News. Available at: http://www.cbc.ca/news/canada/edmonton/alberta-s-climate-change-plan-selling-point-for-pipelines-rachel-notley-says-1.3686055.
[20] As a current signal of this development, see Bellafontaine, Michele (April 21, 2016), *Alberta explores electricity-for-pipeline access trade deal with B.C*, CBC News. Available at:

Endnotes

http://www.cbc.ca/news/canada/edmonton/alberta-explores-electricity-for-pipeline-access-trade-deal-with-b-c-1.3547565.

[21] Enbridge Mainline –Line 3 replacement.

[22] Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, capital expenditures.

[23] National Energy Board (2016), *Canada's energy future 2016: Energy supply and demand projections to 2040*, p. 52.

[24] National Energy Board (2016), *Canada's energy future 2016: Energy supply and demand projections to 2040*, p. 52; Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, crude bitumen production.

[25] Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 23.

[26] Environment Canada (2013), *Canada's emissions trends*, p. 23, 27-8. Available at: https://www.ec.gc.ca/ges-ghg/985F05FB-4744-4269-8C1A-D443F8A86814/1001-Canada's%20Emissions%20Trends%202013_e.pdf; National Energy Board (2016), *Canada's energy future 2016: Energy supply and demand projections to 2040*, p. 53; Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 21.

[27] As a signal of this development, see: Forrest, Jackie (September 12, 2012), *Why upgrading in Alberta is a non-starter*, Alberta Oil Magazine. Available at: http://www.albertaoilmagazine.com/2012/09/why-upgrading-bitumen-in-alberta-is-a-non-starter/. See also Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, crude bitumen demand; Alberta government (2015), *Upgraders and refineries: facts and stats*. Available at: http://www.energy.alberta.ca/Oil/pdfs/FSRefiningUpgrading.pdf.

[28] Alberta Energy (2016), *Canada's energy future 2016: Energy supply and demand projections to 2040,* Crude oil production (reference case). Available at: https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx.

[29] Alberta Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, crude oil production and bitumen production.

[30] Alberta Energy Regulator (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, capital expenditures.

Plateau (potential scenario)

[31] International Energy Agency (2015), *Oil medium-term market report 2015*, p. 18.

[32] International Energy Agency (2015)*, World energy outlook 2015*, p. 168.

[33] Alberta government (2016), *Budget 2016: Fiscal plan – economic outlook*, p. 76. Available at: http://finance.alberta.ca/publications/budget/budget2016/fiscal-plan-economic-outlook.pdf.

[34] Conference Board of Canada (2015), *Canada's oil extraction industry*, p. 7. See also Pittis, Don (August 21, 2015), *Big oil that's making a killing*. CBC News business. Available at: http://www.cbc.ca/news/business/big-oil-that-s-making-a-killing-don-pittis-1.3197791.

[35] As a signal of this development, see: Conference Board of Canada (2015), *Canada's oil extraction industry*, p. 2.

[36] As a signal of this development, see: Bickis, Ian (2015), *Canadian oil industry struggles to balance environmental pressures with money*, CTV news. Available at: http://www.ctvnews.ca/business/canadian-oil-industry-struggles-to-balance-environmental-pressures-with-money-1.2613485.

[37] Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 54.

[38] On when pipeline capacity is expected to be hit, see Canadian Association of Petroleum Producers (2016), *Crude oil: Forecast, markets and transportation*, p. 32; Oil Change International (2015), *Lockdown: The end of growth in the tar sands*, p. 3. Available at: http://priceofoil.org/2015/10/27/lockdown-the-end-of-growth-in-the-tar-sands/

[39] Alberta government (2016), *Budget 2016: Fiscal plan – economic outlook*, p. 76. Available at: http://finance.alberta.ca/publications/budget/budget2016/fiscal-plan-economic-outlook.pdf.

[40] This scenario assumes that the structural factors that limited demand growth in 2014 will continue to play out well into the 2020s. See International Energy Agency (2015), *Oil medium-term market report: Market analysis and forecasts to 2020*, p. 17-40.

[41] Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/; Policy Horizons Canada (2016), *Canada in a changing global landscape*, p. 7. Available at: http://www.cbc.ca/news/canada/calgary/canada-super-power-oil-decline-renewables-policy-horizons-1.3601400.
[42] Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/.
[43] This scenario assumes that sales of plug-in vehicles sustain a trajectory of 45 per cent yearly increases since 2015 –slightly lower than the growth rate that helped the Ford Model T cruise past the horse and buggy in the 1910s. See Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/.
[44] As a signal of this development in the U.S. and China, see U.S. Department of Energy, *Federal Tax credit for all-electric and plug-in hybrid vehicles*. Available at: https://www.fueleconomy.gov/feg/taxevb.shtml; Shepherd, Christian (February 25, 2016), *China shifts gears to drive electric car development*, Financial Times. Available at: https://next.ft.com/content/a55e7d36-db8a-11e5-a72f-1e7744c66818.
[45] As a signal of this development in Canada and beyond, see Leavitt, Sarah (June 2, 2016), *Quebec plans to set minimum sale quota on electric cars*, CBC News. Available at: http://www.cbc.ca/news/canada/montreal/quebec-bill-electric-cars-quota-1.3612718; Lippert, John (August 2, 2015), *California has a plan to end the auto industry as we know it*, Bloomberg Markets. Available at: http://www.bloomberg.com/news/articles/2015-08-03/california-regulator-mary-nichols-may-transform-the-auto-industry.
[46] Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/.
[47] Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/.
[48] See Tuttle, Robert (January 13, 2015), *Mexico feels heat of Canada crude as price advantage narrows*, Bloomberg. Available at: http://www.bloomberg.com/news/articles/2015-01-13/mexico-feels-heat-of-canadian-crude-as-price-differences-narrow.
[49] Policy Horizons Canada (2016), *Canada in a changing global landscape*, p. 16. Available at: http://www.cbc.ca/news/canada/calgary/canada-super-power-oil-decline-renewables-policy-horizons-1.3601400.
[50] Policy Horizons Canada (2016), *Canada in a changing global landscape*, p. 16. Available at: http://www.cbc.ca/news/canada/calgary/canada-super-power-oil-decline-renewables-policy-horizons-1.3601400.
[51] The oil sand production forecast is consistent with low case production scenarios produced by Alberta Energy's Economic Analysis and Information. The conventional oil forecast is derived from the low price case of the National Energy Board, *Canada's Energy Future 2016: Energy supply and demand projections to 2040*, Appendix: crude oil production. Available at: https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx.
[52] Randall, Tom (February 25, 2016), *Here's how electric cars will cause the next oil crisis*, Bloomberg. Available at: http://www.bloomberg.com/features/2016-ev-oil-crisis/.

Lagoon (potential scenario)
[53] These assumptions are consistent with the International Energy Agency's low oil price scenario. See: International Energy Agency (2015), *World energy outlook 2015*, p. 155.
[54] As a signal of this development, see Johnson, Tracy (July 24, 2015), *Oil prices are down, gasoline prices are not. What gives?*, CBC News. Available at: http://www.cbc.ca/news/business/oil-prices-are-down-gasoline-prices-are-not-what-gives-1.3163008; Pittis, Don (August 21, 2015), *The Big Oil that's making a killing*, CBC News. Available at: http://www.cbc.ca/news/business/big-oil-that-s-making-a-killing-don-pittis-1.3197791.
[55] In this scenario, it is assumed that robust gasoline consumption and the rise of diesel-fueled commercial transportation in the U.S. provide refiners with space to grow at home. At the same time, U.S. exports of diesel and gasoline from the Gulf Coast grow, to capture market share in markets like Europe and Latin America. As a signal of this development, see U.S. Energy Information Administration (May 20, 2015), *Low crude oil prices, increased gasoline demand lead to higher refiner margins*. Available at: http://www.eia.gov/todayinenergy/detail.cfm?id=21312.

[56] Rubin, Jeff (2016), *The future of Canada's oil sands in a decarbonizing global economy*, CIGI papers No. 94, p. 8. Available at: https://www.cigionline.org/publications/future-of-canadas-oil-sands-decarbonizing-global-economy.
[57] According to the U.S. Energy Information Administration, favourable refining margins have kept integrated companies profitable in 2015 despite low oil prices, but they have been unable to fully offset low earnings in production. As a result, the profitability of select global integrated oil companies has dropped from $ 30-60 billion per quarter between 2011 and Q3 of 2014, to $10-20 billion per quarter between Q4 of 2014 and 2015. See U.S. Energy Information Administration (June 17, 2015), *Refiner margins unable to fully offset low upstream earnings for integrated oil companies*. Available at: https://www.eia.gov/todayinenergy/detail.cfm?id=21692.
[58] As a signal of this development, see: Blas, Javier (July 28, 2016), *Big Oil lost one engine when energy prices plunged, now the second is sputtering*, Financial Post. Available at: http://business.financialpost.com/news/energy/big-oil-lost-one-engine-when-energy-prices-plunged-now-the-second-is-sputtering?__lsa=d0b6-e1eb.
[59] As a signal of this development, see IHS Market (2015), *Turning point for oil sands costs and competitiveness*. Available at: http://press.ihs.com/press-release/energy-power-media/ihs-turning-point-oil-sands-costs-and-competitiveness.
[60] See, for example, Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 23.
[61] The oil sand production forecast is consistent with production scenarios internal to the Department of Energy. Conventional oil forecast is derived from the low price case of the National Energy Board, *Canada's Energy Future 2016: Energy supply and demand projections to 2040*, Appendix: crude oil production. Available at: https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx.
[62] Askja Energy: The independent Icelandic and northern energy portal. Available at: https://askjaenergy.com/2016/02/04/current-low-oil-prices-are-not-sustainable/. Estimates for oil sands projects (in situ brownfield, in situ greenfield, and standalone mining) are from the Alberta Energy Regulator, (2016), *ST-98 2016: Alberta's energy reserves 2015 and supply/demand outlook 2016-2025*, supply costs.

Delta (potential scenario)
[63] According to the U.S. Congressional Research Service, Canadian oil sands crudes are generally more GHG emission-intensive than other crudes as they emit an estimated 17% more GHGs on a lifecycle basis than the average barrel of crude oil refined in the U.S. See Lattanzio, Richard (2014), *Canadian oil sands: life-cycle assessments of greenhouse gas emissions*, U.S. Congressional Research Service. Available at: https://www.fas.org/sgp/crs/misc/R42537.pdf.
[64] See, for example, U.S. Environmental Protection Agency (2015), *Understanding the link between climate change and extreme weather*. Available at: https://www3.epa.gov/climatechange/science/extreme-weather.html.
[65] See, for example, Phillips, Tom (Feb. 18, 2014), *Toxic smog threatens millions of Chinese lives*, The Telegraph. Available at: http://www.telegraph.co.uk/news/worldnews/asia/china/10646593/Toxic-smog-threatens-millions-of-Chinese-lives.html.
[66] On the link between pollution and productivity, see Ferro Shane (2015), *The pollution outside your office window affects your work in a big way*, Business Insider Finance. Available at: http://www.businessinsider.com/pollution-affects-labor-productivity-2015-6.
[67] As a signal of this development, see The Economist (2015), *Coal mining: in the depths*. Available at: http://www.economist.com/news/business/21647287-more-countries-turn-against-coal-producers-face-prolonged-weakness-prices-depths.
[68] These curbs could include sstricter efficiency standards on both light- and heavy-duty vehicles, financial or non-financial incentives for zero-emission vehicles, fuel quality standards, and traffic congestion management measures in metropolitan centres.
[69] EU legislation requires a reduction of the lifecycle (well-to-wheel) greenhouse intensity of the fuels used in vehicles by 6% by 2020. See European Commission, *Climate action: Fuel quality*. Available at: http://ec.europa.eu/clima/policies/transport/fuel/index_en.htm.

[70] California's low carbon fuel standard requires a 10% reduction in the lifecycle (well-to-wheel) carbon intensity of petroleum-based fuels by 2020 (based on a 2010 baseline). See California Energy Commission, *Low-carbon fuel standard*. Available at: http://www.energy.ca.gov/low_carbon_fuel_standard/.

[71] California has implemented price caps on fuels for consumer protection. See California Environmental Protection Agency—Air Resources Board (2016), *Low-carbon fuel standard basics*. Available at: http://www.arb.ca.gov/fuels/lcfs/background/basics.htm

[72] On this potential development, see Policy Horizons Canada (2016), *Canada in a changing global energy landscape*, p. 10. Available at: http://www.horizons.gc.ca/sites/default/files/Publication-alt-format/2016-0266-eng_0.pdf.

[73] On this potential development, see Policy Horizons Canada (2016), *Canada in a changing global energy landscape*, p. 10 and 13. Available at: http://www.horizons.gc.ca/sites/default/files/Publication-alt-format/2016-0266-eng_0.pdf.

[74] Coyne, Todd (2015), *The five holy grails that will revolutionize the energy sector*, Alberta Oil Magazine. Available at: http://www.albertaoilmagazine.com/2015/03/five-areas-energy-sector-should-focus/.

[75] Canada's Oil Sands Innovation Alliance (2016), *Molten carbonate fuel cells*. Available at: http://www.cosia.ca/molten-carbonate-fuel-cells.

[76] As a signal of this development, see McSpadden, Kevin (2015), *Audi just invented fuel made from CO2 and water*, Time. Available at: http://time.com/3837814/audi-environmental-protection-green-energy-climate-change-cars/

[77] Canada's Oil Sands Innovation Alliance (2016), *The Algae project*. Available at: http://www.cosia.ca/initiatives/greenhouse_gases/the-algae-project.

[78] On the production of nanotubes from CO2, see Zyga, Lisa (2016), *Researchers assess power plants that convert all of their CO2 emissions into carbon nanotubes*, Phys.org. Available at: http://phys.org/news/2016-06-power-co2-emissions-carbon-nanotubes.html

[79] Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 60.

[80] Innovations in the oil sands include the use nanotechnology, microbiology, electrical conduction, and radio waves to extract bitumen (collectively known as oil sands 3.0). See, for example, Findlay, J. Peter (2016), *The future of the Canadian oil sands: Growth potential of a unique resource amidst regulation, egress, cost, and price uncertainty*, Oxford Institute for Energy Studies, p. 49. Research into carbon dioxide uses focuses on conversion to carbon fibers, synthetic fuels, and graphene. See, for example, Climate Change and Emissions Management (2016), *CO2 to graphene reactors*. Available at: http://ccemc.ca/project/co2-graphene-reactors/.

[81] Policy Horizons Canada (2016), *Canada in a changing global energy landscape*. Available at: http://www.horizons.gc.ca/eng/content/canada-changing-global-energy-landscape#04.

[82] On California's compliance schedule for gasoline and diesel, see TransportPolicy.net (2016), California –Fuels: low-carbon fuel standard. Available at: http://transportpolicy.net/index.php?title=California:_Fuels:_Low_Carbon_Fuel_Standard. The emissions estimates for oil sands are Natural Resources Canada's (with the exception of the oil sands average), as reported in Lattanzio, Richard (2014), *Canadian oil sands: life-cycle assessments of greenhouse gas emissions*, U.S. Congressional Research Service, p. 11. Available at: https://www.fas.org/sgp/crs/misc/R42537.pdf.