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ESTIMATED COST OF CLEANING CANADA'S ORPHAN OIL AND GAS WELLS

OFFICE OF THE PARLIAMENTARY BUDGET OFFICER
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The Parliamentary Budget Officer (PBO) supports Parliament by providing economic and financial analysis for the purposes of raising the quality of parliamentary debate and promoting greater budget transparency and accountability.

This report provides an independent estimate of the cost of cleaning Canada's orphan oil and gas wells.

Lead Analysts:
Jamie Forsyth, Analyst
Nora Nahornick, Senior Analyst

This report was prepared under the direction of:
Trevor Shaw, Director of Fiscal Analysis
Xiaoyi Yan, Director of Budgetary Analysis

Nancy Beauchamp, Marie-Eve Hamel Laberge, Martine Perreault and Rémy Vanherweghem assisted with the preparation of the report for publication.

For further information, please contact pbo-dpb@parl.gc.ca

Yves Giroux
Parliamentary Budget Officer

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Executive Summary

Canada's conventional onshore oil and gas wells are mainly located in Alberta and Saskatchewan. Combined, the two provinces represent 91 per cent of onshore conventional oil and gas production in Canada, hosting a total of approximately 600,000 wells.[1]

Over the past decade, there has been a marked increase in inactive and plugged wells in Alberta and Saskatchewan. Currently, only 35 per cent of all wells in Alberta and 39 per cent of all wells in Saskatchewan are active, the lowest share in recorded history.

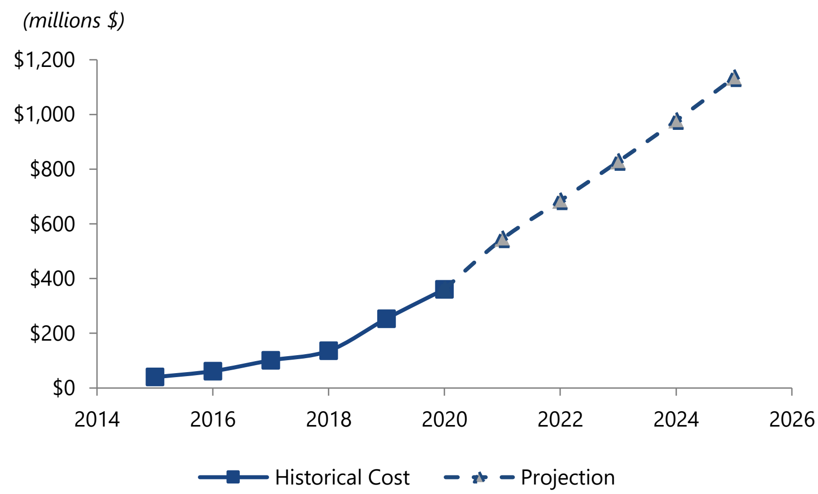
Provincial regulators require oil and natural gas companies to close inactive well sites. In the case where there is no known, financially viable operator capable of addressing the environmental liabilities associated with closing their wells, the wells under the company are deemed orphaned. In Alberta, the total number of orphaned wells have increased from roughly 700 in 2010 to 8,600 in 2020. Similarly, in Saskatchewan it has increased from roughly 300 wells in 2015 to 1,500 in 2020. As the number of orphan wells increases, so does the expected cost for cleaning up environmental liabilities. This rising cost poses a risk to not only provincial but also federal fiscal balances.

In 2020, the federal government provided $1.7 billion to the governments of Alberta, Saskatchewan, and British Columbia to fund the clean-up of inactive oil and gas wells as part of the COVID-19 Economic Response. As the number of orphan wells rise, it is likely that the cost will have to be funded through a mixture of industry, provincial and federal sources.

PBO estimates the cost for orphan well clean-up, on a national level, to be $361 million as of 2020. This cumulative cost is forecasted to rise to $1.1 billion by 2025. The estimate pertains only to onshore conventional oil and gas production and does not include potential clean-up costs of oil sands.

Summary Figure 1

Total Cost of Cleaning Orphan Wells, 2015 to 2025



Sources: Alberta Energy Regulator (AER), Orphan Well Association (OWA), Government of Saskatchewan, Capital IQ and PBO calculations.

Notes: 2020 represents actuals for the number of orphan wells. 2021 onwards is an estimate. The total cost is calculated by taking the number of orphan wells multiplied by the expected cost of clean-up in Alberta and Saskatchewan, grossed up on a national level.

In attempts to manage environmental costs, regulators in Canada have implemented a liability management program which requires a refundable security deposit to cover decommissioning and reclamation costs. As of October 2021, the security deposit on hand in Alberta is $237 million, whereas the PBO estimates that the total cost of clean-up is $415 million in 2021. This results in an estimated gap in funds of $178 million by the end of 2021 and grows to $642 million by 2025 if no additional funds are secured.

This cost estimate does not account for existing wells that could be orphaned after 2025. Most notably, the estimate excludes the roughly 7,400 wells as of 2020 that currently do not have a solvent owner and require clean-up in the form of either plugging and/or reclamation but have yet to transition to orphan status. These wells, which PBO refers to as abandoned, represent a deferred liability, and contribute to the expected clean-up cost to be borne over the next five years.

As of 2020, the number of orphaned and abandoned wells in Alberta and Saskatchewan totaled roughly 10,100 and 7,400 wells, respectively, of which 15,700 of these wells require clean-up in the form of either plugging and/or reclamation. If all abandoned wells were to enter the orphan inventory, the cost would rise from $361 million in 2020 to $801 million.

Summary Table 1 Estimated Cost of Orphan Well Clean-up and the Current Federal and Regulatory Funding

($ millions)	Covid Relief Funding	Security on Hand	2021 Cost	2025 Cost
Alberta	1,000	237	415	878
Saskatchewan	400	171	81	154
AB & SK Total	1,400	408	496	1,032
National Gross-up	1,720	-	545	1,134

Sources: AER, OWA, Government of Saskatchewan, Government of British Columbia, PBO calculations.

Notes: 2021 and 2025 cost are PBO's projection of the clean-up cost. Of the $1.7 billion in funding, $215 million has been disbursed thus far, as a grant, to pay for the clean-up of oil sites that require 100% of provincial funding and/or orphan wells.[2] The $200 million to the Orphan Well Association is not included as it is in the form of a loan.

At face value, the $1.7 billion allocated by the federal government to clean-up inactive oil and gas wells exceed the estimated liability over the next five years. However, thus far, nearly half the funding in Alberta has been disbursed to firms that are viable based on PBO's calculations. Therefore, there is an outstanding risk in the medium-term that the unfunded liability could persist if the remaining funding is not allocated to firms with an acute financial risk.

1. Introduction

In Canada, proven reserves of crude oil total 171 billion barrels, of which conventional oil makes up 5.7 billion barrels.[3] However, in 2019 for example, conventional oil accounted for approximately 37% of crude oil production. Most of Canada's onshore conventional oil and natural gas production is in Alberta and Saskatchewan. This report focuses on the estimated cost of cleaning up deserted onshore conventional oil and gas wells in those provinces. It does not include the potential costs associated with oil sands.

Life Cycle and Categorization of Wells

The lifecycle of a well can be simplified into four main categories: active, inactive, plugged, and reclaimed.

- Active wells are those that are actively producing oil or natural gas.
- Inactive wells are those that have not produced oil or natural gas within the last 6 or 12 months, depending on the risk classification of the well.[4] After this period, an inactive well must be suspended and can remain suspended indeterminately.[5,6]
- Plugged wells are filled with cement and have had their wellhead removed and capped according to provincial requirements.
- Reclaimed wells are those where the land has been returned to a state comparable with that prior to development. This includes remediation where wells have had adjacent contaminants managed and removed.

Orphan wells: a growing liability

Based on "the polluter pays" principle, oil and natural gas companies are required to fund the cost of well clean-up. In the case of insolvency or bankruptcy, it is required that a company address environmental liabilities before paying back creditors. When there is no known, financially viable operator capable of cleaning and closing a well, it is considered an orphan well.

In Alberta, the number of orphaned wells has increased from 700 to more than 8,600 over the last 10 years. Most of this growth occurred in the last 5 years and was likely driven by decreasing oil prices since 2014 and the industry downturn.

The growing inventory of orphan, inactive, and plugged wells constitutes a fiscal risk due to the rising costs associated with clean-up, insufficient amounts of security being held to cover closure expenses, and a growing number of companies with a lack of financial capacity to meet closure obligations.

Box 1-1 Environmental Costs of Orphan Wells

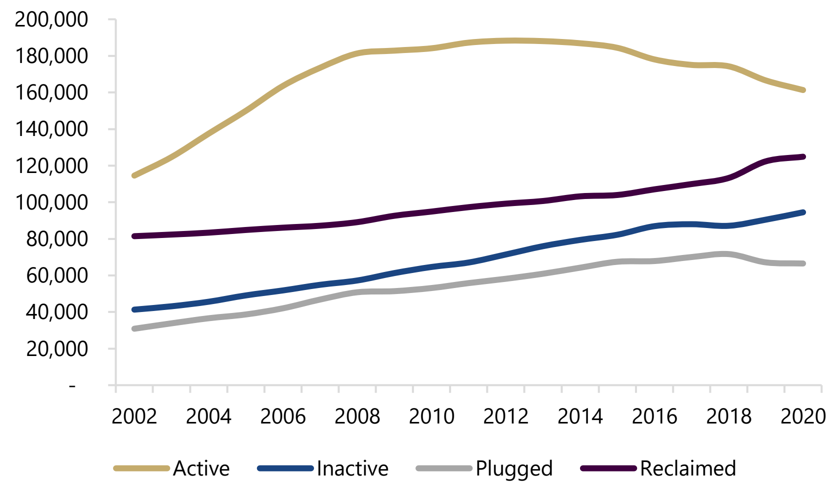
Orphan wells carry a potential environmental cost. One of the main reasons that a well is plugged is to isolate subsurface formations penetrated by the well.[7] In other words, an unplugged well can result in contamination and leakage, and it is critical that these wells be properly plugged to protect underground and surface waters. Additionally, wells that are not properly plugged can leak methane into the air.[8]

In addition to the environmental costs, there exists an opportunity cost. There is no economic gain to these wells as the land remains unusable until they are properly reclaimed and remediated. This prevents the land from being utilized for other productive uses such as agriculture or urban/suburban development.

2. Current State of Wells

There were roughly 460,000 wells in Alberta and 140,000 wells in Saskatchewan as of 2020.[9] Roughly 36 per cent of all wells are currently active, the lowest share in recorded history. There are approximately 225,000 inactive and plugged wells in Alberta and Saskatchewan, making up roughly 37 per cent of all wells.

Figure 2-1 **Number of Wells by Lifecycle Status in Alberta, 2002 to 2020**



Sources: AER, PBO calculations.
Notes: Figure 2-1 demonstrates the number of wells, categorized into 4 categories: active, inactive, plugged and reclaimed in Alberta between 2002 and 2020. In our dataset, inactive well counts include both inactive and suspended wells.

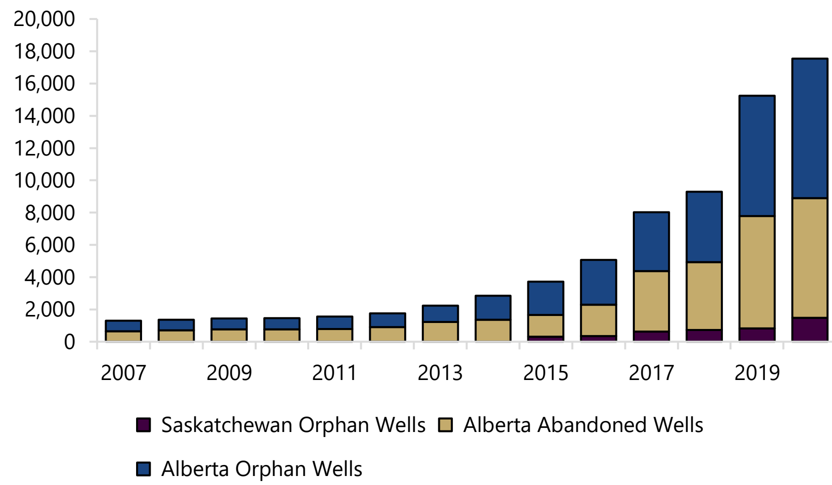
Over the past five years, the number of orphaned wells in Alberta and Saskatchewan has increased significantly, with an average growth rate of 35 per cent per year. Part of the rise in orphan wells can be explained by reduced profitability resulting from declines in oil and gas prices.

It can take years for a company to unwind its assets and for the company's wells to transition to orphan status. As a company liquidates, a portion of their inactive and plugged wells may be sold off, closed by a working interest participant, or eventually deemed orphaned.[10]

Data shows that in certain cases the wells of an insolvent company may slowly enter the orphan well inventory over multiple years. The PBO refers to these wells as abandoned, which are defined as either inactive or plugged wells owned by an insolvent company.[11]

In recent years, the number of abandoned wells has also grown exponentially (Figure 2-2). As of 2020, orphaned and abandoned wells totaled 17,543 in Alberta and Saskatchewan. Of these wells, 15,682 required either plugging and/or reclamation.

Figure 2-2 **Orphaned and Abandoned Wells, 2007 to 2020**



Sources: AER, OWA and PBO calculations.

Notes: PBO refers to an abandoned well as an inactive or plugged well that is not yet designated as an orphan well and is owned by a company that is not financially viable. A company is considered to not be financially viable if it has at least one well that has been officially deemed orphaned

Orphaned wells are those currently under the OWA inventory in Alberta or managed by the Government of Saskatchewan in Saskatchewan.

3. Outlook and Estimated Cost

3.1. Forecasting the number of orphan wells

To estimate the likelihood of well orphanhood in the short term, PBO estimated oil and gas operator insolvencies using the Kealhofer McQuown Vasicek (KMV) model.[12] The KMV model uses up-to-date stock price information of a company and accounts for market expectations to estimate the probability of default. Appendix C contains the detailed methodology.

After determining the probability of default for each company, the PBO estimated the number of inactive and plugged wells associated with each company to get the expected number of wells that are at risk of becoming orphaned in the short term.[13]

For the medium-term projection, the PBO's economic projections for West Texas Intermediate (WTI) and Gross Domestic Product (GDP) were used in linear regressions to project forward the number of wells expected to enter the Alberta and Saskatchewan orphanhood inventory.

3.2. Cost of clean-up

The main costs for total site clean-up include plugging and/or reclamation. However, reclamation can be broken down further into a two-step process where:

- Remediation – Contaminants are managed and removed; the contaminated soil is then replaced with clean soil.
- Reclamation – the land is returned to its former, pre-development state (including recontouring and re-vegetation)

Remediation cost data is sparse and highly variable as it depends on the extent of contamination.[14] Due to this variability, the cost estimates include only the costs of plugging and reclamation. As a result, the per-well clean-up cost could be understated. (Box 3-1).

The assumptions used for plugging and reclamation costs were based on the AER's Directive 011 by region. We adjusted the cost data to account for the incidence of surface casing vent flow (SCVF) and gas migration (GM).[15]

The PBO estimates that, on average, it would cost $58,000 and $28,000 to plug and reclaim a well, respectively. In addition, not all wells in the inventory require both procedures.[16] Appendix A contains a sensitivity analysis comparing different cost estimates.

Box 3-1 Total Cost of Proper Well Clean-up

The exclusion of remediation will understate the total cost of well clean-up. To illustrate, below are two examples of recent bankruptcies in the oil and gas sector and the related clean-up costs.

In 2019 both Houston Oil & Gas Ltd. and Wolf Coulee Resources Inc. went bankrupt. As of 2019, Houston Oil & Gas and Wolf Coulee Resources had 1,422 and 177 wells that were not fully cleaned, respectively.

The plugging and reclamation obligations are estimated to be $16.4 million for Wolf Coulee Resources, or equivalently $93,000 per well on average.[17] For Houston Oil & Gas, the clean-up obligations are estimated to cost $81.5 million, or $57,000 per well on average.[18]

3.3. Results

The total cost was calculated by multiplying the total number of orphan wells, broken down by the clean-up work required, by the average cost of clean-up.

Current Liability

The PBO estimates the combined liability in Alberta and Saskatchewan to be approximately $329 million as of 2020. At a national level, the estimated cost of cleaning up the orphan well inventory is $361 million as of 2020.

Box 3-2 National Cost Adjustment

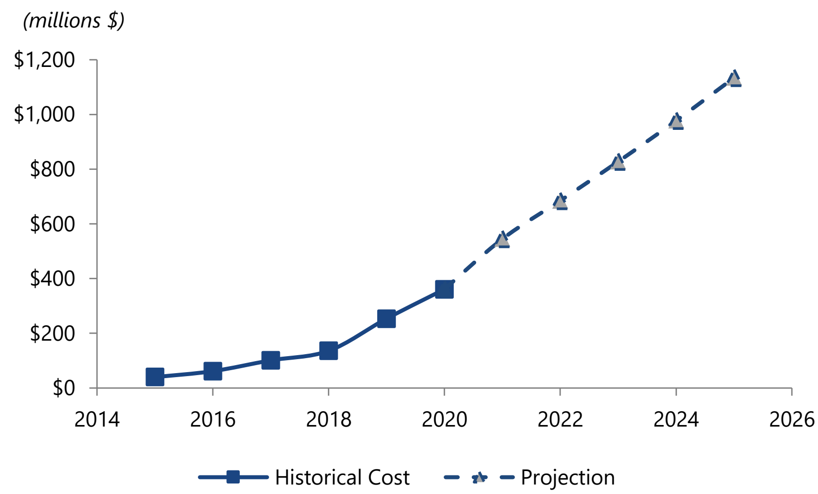
According to Natural Resources Canada, Alberta makes up the highest amount of crude oil production in Canada, representing 80.5 per cent of production in Canada. Saskatchewan was the second highest producer, representing 10.5 per cent of total crude oil production. Together, these two provinces represented approximately 91 per cent of Canada's crude oil production. Using this ratio, the cost in Alberta and Saskatchewan is grossed-up to the national level to arrive at the cost of cleaning up all orphan oil wells in Canada.

If the entire subset of roughly 7,400 abandoned wells in Alberta is included in the cost, rather than only those that are already in the orphan inventory, the contingent liability could be as high as $801 million as of 2020.[19]

Future Liability

The PBO estimated the 5-year cost of well clean-up for the OWA and the Government of Saskatchewan. By 2025, the PBO estimates that 10,113 wells could transition to orphan status, resulting in a total of 18,383 wells that would require plugging and/or reclamation. This translates to an estimated cumulative liability of $1 billion by 2025. (Figure 3-1).

Figure 3-1 Projected Cost of Cleaning Orphan Wells, 2015 to 2025



Sources: AER, OWA, Government of Saskatchewan, Capital IQ, PBO calculations.

Notes: 2020 represents actuals for the number of orphan wells. 2021 onwards is an estimate. Figure 3-1 represents the total cost on a national level.

The projected cost is driven by companies whose wells enter the orphan well inventory for the first time and the stream of abandoned wells that transition to orphan status.

Table 3-1 shows the cost between 2021 to 2025 to clean-up the wells projected to enter the orphan well inventory. PBO estimates the cumulative cost for orphan well clean-up, on a national level, to reach $361 million in 2020. This cost is expected to rise to $1.1 billion by 2025.

Table 3-1 Estimated Annual Cost for Orphan Well Clean-up, 2021 to 2025

($ millions)	**2021 - 2022**	**2022 - 2023**	**2023 - 2024**	**2024 - 2025**	**2025 - 2026**	**5-Year Total**	**Cumulative Total**
Alberta	140	110	113	118	123	604	878
Saskatchewan	27	17	17	18	20	99	154
AB & SK Total	167	127	130	136	143	703	1,032
National Gross-up	184	140	143	149	157	773	1,134

Sources: AER, OWA, Government of Saskatchewan, Capital IQ, PBO calculations.

Notes: 2020 represents actuals for the number of orphan wells. 2021 is the PBO's projection. The yearly cost of clean-up is estimated by multiplying the average cost of clean-up by the forecasted number of inactive and plugged wells expected to enter the orphan well inventory.[20]

The increase in the cost of clean-up in 2021-22 is mainly driven by increased uncertainty due to the pandemic and low oil prices in 2021 resulting in a rise in the number of bankruptcies. From 2022 onwards, the increase in the number of wells projected to become orphaned are driven by the entry of abandoned wells into the orphan well inventory.

3.4. Emissions of unplugged oil and gas wells

Unplugged inactive oil and gas wells impose heavy environmental costs, risks to local environments, and public safety concerns.

Oil and gas wells emit methane. Per ton, methane can have 34 times the global warming potential of carbon dioxide over a 100-year period and 86 times the impact over a 20-year period.[21]

The United States Environmental Protection Agency (EPA) estimates that on average, each unplugged inactive oil and gas well emits 0.13 metric tons of methane annually.[22] With roughly 120,000 unplugged inactive wells in Alberta and Saskatchewan, this would equate to over 16,000 metric tons of methane being released annually, equivalent to 545,000 metric tons of carbon dioxide per year over a 100-year period.[23,24]

4. Legislation and Liability Management

When a company doesn’t have sufficient funds to address their environmental liabilities, the wells become a liability of the province.[25]

Alberta’s Orphan Well Association (OWA) is funded primarily by the Orphan Fund Levy, First Time Licensee and Regulator Directed Transfer Fees, and loans from the Government of Alberta.[26] The Orphan Fund Levy is funded by industry through the Liability Management Framework.[27]

In Saskatchewan, the Orphan Fund Procurement Program is responsible for identifying orphaned oil and gas sites and is funded through the Saskatchewan Oil and Gas Orphan Fund (SOGOF). The SOGOF is funded by industry through the Licensee Liability Rating Program.[28]

As of October 2021, the total liability security held by the AER and the Government of Saskatchewan was $237 million and $171 million, respectively. This compares to $265 million held by the AER and $132 million held by the Government of Saskatchewan in 2017.

4.1. Estimating solvency

Wells belonging to insolvent owners are more likely to become provincial responsibility. Provincial regulators in Alberta and Saskatchewan monitor the financial health of each company. Companies with low solvency ratios, as approximated by corporate assets-to-liabilities ratios, are required to provide a security deposit against their potential plugging, remediation, and reclamation obligations. [29,30]

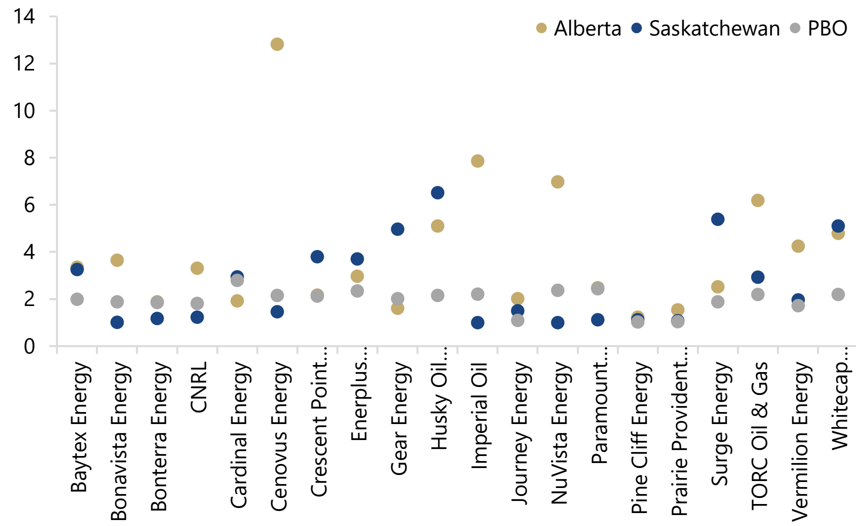
Prior to the introduction of Alberta’s Licensee Life-Cycle Management Program (Directive 088), Alberta and Saskatchewan had very similar methods in estimating the liability rating of a company.[31,32] The liability rating for a corporation was determined by dividing deemed assets by deemed liabilities. A licensee’s deemed asset value was measured in terms of their net production value, and the deemed liability is based on the future cost to fully plug and reclaim the well site.[33,34]

The parameters used by Alberta and Saskatchewan to calculate deemed assets differed – particularly the value on production (industry netback). In 2016, Alberta used $237/m^{3}OE, compared to Saskatchewan who used $149/m^{3}OE. Saskatchewan uses the same value as of 2020.[35] Therefore, a company’s regulatory solvency score in Alberta may not equal that in Saskatchewan.

The PBO calculated liability ratings for publicly traded oil and gas operators in Alberta and Saskatchewan using data from recent annual or quarterly financial statements, acquired through S&P Capital IQ.

Figure 4-1 shows how the liability ratings differ across provinces when using the liability ratings from provincial regulators, and when using information from financial statements instead.

Figure 4-1 Liability Ratings Across Alberta and Saskatchewan, 2019



Sources: AER, OWA, Government of Saskatchewan, Capital IQ and PBO calculations.

Notes: This graph includes the 20 largest well owning public companies in both Alberta and Saskatchewan that also has an assigned liability rating that exists in both provinces. This figure demonstrates the different liability ratings across Alberta and Saskatchewan for the same company. A higher score implies that the company is more solvent, that is a higher ratio of assets-to-liabilities.

The solvency ratios calculated for the purposes of provincial energy regulation tend to overstate the financial well-being of publicly traded oil and gas operators based on public financial statements. The pattern is particularly evident for the largest operators in Alberta. The top 20 publicly traded companies had an average liability rating of 4.26 and 2.51 in Alberta and Saskatchewan, respectively.[36] (Figure 4-1). This compares to the PBO's solvency score of 1.96 for the same companies.[37]

By examining the industry average, this disparity is consistent and becomes particularly evident when looking at the top 10 companies that exist in both Alberta and Saskatchewan.[38] (Table 4-1).

Table 4-1

Estimated solvency of oil and gas operators, 2019

	PBO	Alberta	Saskatchewan
Industry Average	2.25	3.48	2.75
Top 10 Companies	1.98	4.74	2.66

Sources: AER, OWA, Government of Saskatchewan, Capital IQ and PBO calculations.

Notes: A higher score means more solvent, that is a higher ratio of assets-to-liabilities. Table 4-1 includes only public companies with an assigned liability rating that exist in both Alberta and Saskatchewan.[39] Top 10 is based on total number of wells.

4.2. Security on hand

Regulators in Canada have implemented a liability management program which requires a refundable security deposit to cover decommissioning and reclamation costs. Companies must pay into this if their rating goes below a specified threshold. In Alberta, if a company's liability management ratio falls below 1, then the company must post a security deposit with the AER.

As of October 2021, Alberta had a total security on hand (SOH) of $237 million and Saskatchewan had a total SOH of $171 million. (Table 4-2).

Table 4-2

Alberta's security on hand is insufficient to meet the current clean-up liabilities

($ millions)	SOH	Estimated Clean-up	Estimated Shortfall
Alberta	237	415	178
Saskatchewan	171	81	-

Sources: AER, OWA, Government of Saskatchewan, Capital IQ and PBO calculations.

Notes: 2021 uses PBO projections for the estimated clean-up. The security on hand (SOH) represents the actuals collected from the Governments of Saskatchewan and the AER as of October 2021. Alberta is estimated to be short their total clean-up costs by $178 million in 2021 given the current SOH.

According to current projections, Saskatchewan has sufficient SOH. However, Alberta has a deficit of funds on hand when considering the 2021 estimated cost of clean-up. By 2021, it is estimated that Alberta would be $178 million short of the projected $415 million clean-up cost. If no additional SOH is invested, by 2025 this gap in funds grows to $642 million.

Additionally, this only considers the wells expected to enter the orphan well inventory. If abandoned wells are factored in, then the liability is even larger.

4.3. Grant allocations under the Site Rehabilition Program

The federal government provided up to $1.7 billion to the governments of Alberta, Saskatchewan, and British Columbia to fund the clean-up of inactive oil and gas wells as part of COVID-19 Economic Response. Of the $1.7 billion, $1 billion went to the government of Alberta for site clean-up, $200 million went to the OWA in the form of a loan to support the clean-up of orphan sites, $400 million went to the government of Saskatchewan and $120 million went to the government of British Columbia.

Thus far, $556.8 million in grant funding was approved and allocated to more than 500 Alberta based companies over 5 different grant periods.

Table 4-3 Estimated Cost of Orphan Well Clean-up and the Current Federal and Regulatory Funding

($ millions)	Covid Relief Funding	Security on Hand	2021 Cost	2025 Cost
Alberta	1,000	237	415	878
Saskatchewan	400	171	81	154
AB & SK Total	1,400	408	496	1,032
National Gross-up	1,720	-	545	1,134

Sources: AER, OWA, Government of Saskatchewan, Government of British Columbia and PBO calculations.

Notes: 2021 and 2025 cost are PBO's projection of the clean-up cost.

Of the $1.7 billion in funding, $215 million has been disbursed thus far, as a grant, to pay for the clean-up of oil sites that require 100% of provincial funding and/or orphan wells.[40] The $200 million to the Orphan Well Association is not included as it is in the form of a loan.

At face value, the $1.7 billion allocated by the federal government to clean-up inactive oil and gas wells exceed the estimated liability over the next five years. At this time, just under half of the traceable funds in Alberta went to 10 companies, who received a total of $222 million.[41] According to the PBO's model, there is a low likelihood that these 10 companies will default over the next year.

Additionally, the OWA was not eligible to receive grant funding under the SRP and received $200 million in the form of a repayable loan. Therefore, this funding is not estimated to materially reduce the liability of $361 million in 2020.

Nearly half the funding in Alberta has been disbursed thus far to firms that, based on PBO's calculations, are viable. Therefore, there is an outstanding risk in the medium-term that the unfunded liability could persist if the remaining funding is not allocated to firms with an acute financial risk.

Appendix A: Sensitivity Analysis

According to the OWA's 2020-21 annual report, the average cost of plugging a well was $23,000 and the average cost of reclaiming a site was $22,500.[42]

The Alberta Liabilities Disclosure Project estimates plugging costs between $53,118 and $84,547 per well and reclamation costs between $107,111 and $194,539 per site.[43]

Due to limited data on actual plugging and reclamation costs, PBO used estimates from Directive 011 to inform our estimate. We used plugging costs by region while accounting SCVF and GM to determine the expected value of plugging a well. This was weighted by the proportion of wells in each region to generate an average across Alberta. Similarly, for reclamation, we used the regions defined in Directive 011 to determine the average reclamation cost, weighted by the proportion of wells in each region. Using this methodology, we estimate that in 2015 the average cost of plugging and reclaiming a well was $52,525 and $25,062, respectively. This was adjusted to 2021 values using PBO economic projection of CPI.

Appendix B: Data

To construct the estimated contingent liability, the PBO created a database which consolidated the universe of oil and gas wells in Alberta and Saskatchewan.

The main sources of data used for this estimate comes from the Alberta Energy Regulator (AER), Alberta’s Orphan Well Association (OWA), and the Government of Saskatchewan.

The data received from the AER consists of a list of well licences from 2002 to 2020 with corresponding indicators for licence (lifecycle) status, company name, and company code. This data was combined with data from Alberta’s OWA to determine which well licences have become orphaned.

The licence status variable allowed us to track how each well had moved through the well life cycle over time, and to examine the state of each orphan well prior to becoming orphaned.

Similar analysis was done for Saskatchewan based on the data provided. The data received from the Government of Saskatchewan consisted of a list of well licence, company name, company code between 2015 to 2020.

Due to differing identifications across corporations in Alberta and Saskatchewan, the PBO constructed a new business identification to merge the two datasets.

S&P Capital IQ was used to obtain financial information on individual corporations. The company’s assets and liabilities were used to construct a liability ratio. Due to discrepancies in the liability ratio calculations in Alberta and Saskatchewan, Capital IQ was used to run a comparable analysis. Additionally, daily close price of stock data, liabilities, debt, and market capitalization was gathered where applicable for forecasting.

Appendix C: KMV Model

A well is considered orphaned if it is a non-producing well that has no known, financially viable operator capable of closing the well. To estimate the number of wells expected to become orphaned, the PBO forecasted corporate defaults.

The Kealhofer Merton Vasicek (KMV) model has been widely applied in both practical and academic research and is the model chosen for the short-term forecast.[44] The KMV model is based on a structural approach to calculate the expected default probability of a single company.[45]

Default risk refers to the uncertainty surrounding a firm's ability to service its debts and obligations. Under this model, a firm will default when the firm's default point, (D) is greater than the market value of the firm's assets (V_A).

$$E(V, 0) = \max\,[0, V_A - D] \quad (1)$$

The default risk of a firm increases as the market value of its assets (V_A) approaches the value of its default point (D), until finally a default is triggered, and the market value of assets is insufficient to repay its debts. The ability for the firm to repay its debts depends on the value of the asset at the expiry date, T. If the value of the asset at time T is greater than the firm debts and obligations, $V_A > D$, then the firm will pay the promised payment.

For any publicly listed firm, the market value of debt and equity is observable. However, the underlying value of the firm (V_A) and its volatility (σ_A) is not observable.

The idea behind the KMV model is that a firm's equity can be seen as a call option on the underlying value of the firm with a strike price that is equal to the face value of the firm's debt. Therefore, the equity value can be represented by the Black-Scholes option pricing equation under the assumption that the market value of the company follows Geometric Brownian Motion (Equation 2).

According to Geometric Brownian Motion, assets are traded and follow the following equation:

$$dV_A = \mu_A V_A dt + \sigma_A V_A dW \quad (2)$$

where V_A is the value of the asset, μ_A is the firm's asset value drift rate, σ_A is the volatility of the asset, and dW represents the standard Wiener process.

Under this assumption, the company's asset value can be considered as a call option on the underlying value of the firm with a strike price equal to the company's debt.

$$V_E = V_A N(d_1) - De^{-rT} N(d_2) \quad (3)$$

Where V_E is the company's equity value, V_A is the company's total asset value, D is the company's total debts and obligations, and $N(\cdot)$ is the cumulative distribution function of a standard normal distribution. d_1 and d_2 are probability distribution functions defined as follows:

$$d_1 = \frac{\ln\left(\frac{V_A}{D}\right) + \left(r + \frac{\sigma_A}{2}\right)^2 T}{\sigma_A T}$$

$$d_2 = d_1 - \ \sigma_A\sqrt{T}$$

As mentioned, the main challenge is that one does not observe the underlying asset value of the firm (V_A) and its volatility (σ_A). Using the Black-Scholes-Merton Model, we introduce another equation about the volatility of the company's equity and the volatility of the company's asset value.

$$\sigma_E = \frac{V_A}{V_E} N(d_1)\sigma_A \qquad (4)$$

In order to find the unobservable value and volatility of the firm, one must solve the system of non-linear equations which combines equations (3) and (4):

$$f_{1(V_E,\sigma_E)} = V_A N(d_1) - \mathrm{D}e^{-\mathrm{r(T-t)}} N(d_2) - V_E = 0$$

$$f_{2(V_E,\sigma_E)} = \frac{V_A}{V_E} N(d_1)\ \sigma_A - \sigma_E = 0$$

Asset value and volatility are the only unknown variables in these relationships and therefore these two variables can be found by solving the system of equations.

At this point, the underlying value of the firm and its volatility can be estimated. The next step is to determine the distance-to-default. Default occurs when the value of the company's asset's fall below the default point, otherwise known as the value of debt. In other words, if the value of the company's assets is worth less than the promised debt repayment, then the company is said to default.

The distance-to-default is calculated as the distance between the expected value of the asset and the default point. Equation 5 represents the distance to default as the cumulative probability distribution function for a normal distribution.

$$\text{Distance-to-default} = \frac{\ln\left(\frac{V_A}{D}\right) + (\mu - \frac{1}{2}\sigma_A^2)T}{\sigma_A\sqrt{T}} \qquad (5)$$

Therefore, the probability of default is the probability that the asset value will fall below the default point. Putting this together, the probability of default is directly derived by taking the cumulative normal distribution of the negation of the distance-to-default.

$$PD(t) = P[V_A \leq D] = \cdots = \ \phi(-D\text{istance-to-default}) \qquad (6)$$

In order to use the KMV model, the PBO used Canadian treasury bill rates as a proxy for the risk-free rate.

To calculate the probability of default, the firms must be publicly traded with publicly available financial statement, market price of debt, equity and appraisals. Utilizing market prices to determine default risk strengthens the predictive power of the estimate.

S&P Capital IQ was used to obtain financial information on individual corporations. This data source compiles and standardizes information on publicly traded corporations and is continually updated. PBO matched corporations provided by the Alberta Energy Regulator and the Government of Saskatchewan using the Capital IQ identifier converter.[46]

Daily close price of stock data was used to get the returns (V_E) and volatility of equity (σ_E). Literature shows that default often occurs when the market value of a firm's assets is between the total and short-term liabilities so the PBO used short-term liabilities plus one-half of the long-term liabilities as the default point (D).

Data from Capital IQ omits private corporations and, therefore, does not reflect the complete universe. Given that many corporations that own oil wells are subsidiaries of larger corporations or are private companies, the PBO would use the parent corporation, when possible, if full financial information was not made available for the underlying company. As a result, approximately 66% of all wells had associated financial information in Alberta and 68% in Saskatchewan. To account for companies where financial information was unavailable, the PBO took the weighted average probability of default and scaled this for private corporations.

In the medium-term, the PBO used ordinary least squares (OLS) regression to predict the number of wells entering the orphanhood inventory. The PBO considered West Texas Intermediate (WTI), Gross Domestic Product (GDP) and historical trends for orphaned wells as explanatory variables.

Notes

1 Government of Canada, Crude oil facts (nrcan.gc.ca)

2 Government of Alberta, Site Rehabilitation Program

Government of Saskatchewan, Accelerated Site Closure Program

Government of British Columbia, Dormant Sites Reclamation Program

3 Government of Canada, Crude oil facts (nrcan.gc.ca)

4 Alberta Energy Regulator, Well, What's the Difference? Orphaned, abandoned, reclaimed: understanding how wells are classed

5 Muehlenbachs, L. (2017). 80,000 Inactive Oil Wells: A Blessing or a Curse?

6 In this report, inactive wells refer to inactive and suspended wells in the Alberta and Saskatchewan inventory.

7 Alboiu, V., and Walker, T.R. (2019). Pollution, management, and mitigation of idle and orphaned oil and gas wells in Alberta, Canada

8 Kang, M., et al. (2019). Reducing methane emissions from abandoned oil and gas wells: Strategies and costs

9 Alberta Energy Regulator and Government of Saskatchewan.

10 If a company goes bankrupt before all their wells are properly decommissioned, anyone who owned part of the site, known as a "working interest participant", will be ordered to close the wells. See: Alberta Energy Regulator, Orphan Energy Sites

11 This differs from the AER's definition of an abandoned well. An abandoned well as defined by the AER is synonymous with a plugged well in this report. The PBO defines a company as not financially viable if the company has at least one well which has been officially designated as orphaned. Inactive and plugged wells under a company that is not financially viable are considered to be abandoned. Abandoned wells may eventually become orphaned, sold, or decommissioned by a working interest participant.

12 Default risk refers to the uncertainty surrounding a company's ability to pay its debts and meet its obligations. See: Modeling Default Risk

13 Active wells are excluded as it is assumed that if a well is active then it has some financial viability and would be sold during bankruptcy proceedings. This may cause an underestimation in the projected number of orphaned wells.

14 Carbon Tracker, It's Closing Time: The Huge Bill to Abandon Oilfields Comes Early

15 Alberta Energy Regulator, Directive 011.

16 Clean-up costs for plugging and reclaiming wells are assumed to be the same in Alberta and Saskatchewan.

17 Insolvency Insider, Wolf Coulee Resources

18 Insolvency Insider, Houston Oil & Gas

19 Of the abandoned wells, wells that require both plugging and reclaiming outnumber those that only require on reclamation.

20 In the projection of orphan wells, the PBO assumes only inactive and plugged wells will enter the orphan well inventory. It is assumed that wells which are active will be sold in the bankruptcy proceedings. However, this may cause an underestimation in the projected number of orphaned wells.

21 Climate Change 2013: The Physical Science Basis

22 Raimi, D., Nerurkar, N., and Bordoff, J. (2020). Green Stimulus for Oil and Gas Workers: Considering a Major Federal Effort to Plug Orphaned and Abandoned Wells.

23 This estimate has high uncertainty due to limited data.

24 Climate Change 2013: The Physical Science Basis

25 Orphan Well Association, AER-OWA Partnership

Government of Saskatchewan, Orphan Fund Procurement Program

26 Orphan Well Association, Annual Report 2019

27 Alberta Energy Regulator, Directive 006

28 Government of Saskatchewan, Licensee Liability Rating Program

29 Alberta Energy Regulator, Liability Management Rating and Reporting

30 Government of Saskatchewan, Licensee Liability Rating Program Reports

31 In Alberta, Directive 088: Licensee Life-Cycle Management will eventually replace Directive 006: Licensee Liability Rating (LLR) program. Directive 088 is being developed in phases, and elements in Directive 006 will remain in effect until complete.

32 Alberta Energy Regulator, Liability Management

33 Alberta Energy Regulator, Directive 006

34 Government of Saskatchewan, Licensee Liability Rating Program

35 Both are backward-looking and apply industry averages to profitability.

36 The average is weighted by the total number of wells a company owns in Alberta and Saskatchewan.

37 Ibid.

38 The values in Table 4-1 are simple averages, unweighted.

39 This table includes only publicly traded companies so that the PBO could create a liability rating using Capital IQ. As a result, there may be companies that own more wells that are private and do not have information on Capital IQ.

40 Government of Alberta, Site Rehabilitation Program

Government of Saskatchewan, Accelerated Site Closure Program

Government of British Columbia, Dormant Sites Reclamation Program

41 Not Well Spent: A review of $1-billion federal funding to clean up Alberta's inactive oil and gas wells | Parkland Institute

42 Orphan Well Association, Annual Report 2020/21

43 Alberta Liabilities Disclosure Project, Description of ALDP's Methodology for Completing the Alberta Energy Regulator's Internal Study of Oil and Gas Well Reclamation Costs

44 Lu Y.: *Default Forecasting in KMV*. University of Oxford, 2008.

Chen, Y., and Chu, G. (2014). Estimation of Default Risk Based on KMV Model—An Empirical Study for Chinese Real Estate Companies

45 Crosbie P., Bohn J. (2004): Modelling default risk, Published by Moody's KMV Company. Modeling Default Risk (moodysanalytics.com)

46 The Capital IQ identifier converter does not perfectly match all corporations. Mismatching can occur due to naming conventions as well as similarly named corporations in other sectors and/or countries. Given the volume of companies, it is possible that some corporations could be improperly matched with their respective capital IQ identifier. To mitigate this risk, the PBO manually reviewed cases that were not identical matches for companies that had more than 100 wells under their ownership.