Long-Dated Environmental Liabilities in the Canadian Oil Sands

Financial Sensitivity, Risk Perception, and Information Value

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Prepared by: Max Zhang
xmaxzhang@gmail.com

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Haskayne
School of Business

Executive Summary

This report evaluates the economic relevance of oil sands tailings management technologies in a regulatory environment where tailings treatment and discharge are not yet operationally required. Based on 2024 annual disclosures, major oil sands producers report tens of billions of dollars in discounted asset retirement and decommissioning liabilities, with tailings-related obligations representing a material but variably disclosed component. These liabilities are long-dated (typically 30–60 years) and discounted at approximately 3–6 percent, making reported values highly sensitive to assumptions despite settlement occurring decades in the future.

Reported tailings-related liabilities vary by as much as 30–40 percent between major operators, driven primarily by differences in (i) effective closure and monitoring duration, (ii) uncertainty embedded in long-term remediation estimates, and (iii) discount rates reflecting perceived execution and technology risk. Illustrative sensitivity analysis shows that a one-year reduction in effective monitoring or closure duration can increase the present value of a single operator's tailings ARO by approximately CAD $90–100 million, while sub-year reductions still generate impacts in the tens of millions. Even small reductions in expected long-term costs (approximately 0.25–1.0 percent) translate into multi-million-dollar changes per operator, and differences in discount rates alone can shift reported liabilities by several hundred million dollars (for example, applying a 6.0 percent discount rate rather than 4.8 percent reduces the present value of CNRL's oil sands ARO by roughly CAD $500 million, holding other assumptions constant).

Normalizing discounted tailings liabilities to production scale yields an indicative exposure of approximately CAD $3–4 per barrel of bitumen produced. This is not an operating cost or cash outflow, but an illustrative measure of long-run financial exposure that remains largely invisible in day-to-day operating metrics.

Because these obligations reside on the balance sheet rather than in current operating expenses, the near-term economic opportunity lies in information and risk reduction rather than cost savings. A limited, paid pilot of Luminous Biosolutions' biosensor technology represents a low-cost option to generate validated monitoring data. Even a marginal improvement in liability confidence, on the order of 1 percent, would correspond to a CAD $200–300 million shift in reported balance-sheet exposure across the industry, supporting disciplined experimentation rather than immediate procurement or deployment.

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1. Regulatory and Operational Context

Key takeaway

- Oil sands tailings are legally binding but operationally deferred, creating long-dated balance-sheet exposure without near-term operating costs or discharge requirements.

Oil sands tailings management presents a distinctive economic challenge because the largest financial obligations associated with tailings arise from long-duration closure, reclamation, and post-closure monitoring requirements rather than from present-day operating activities.

Under Alberta's current regulatory framework, tailings water from oil sands mining is not permitted to be discharged to the environment and is instead required to be contained within engineered tailings facilities.[1] Regulation is governed primarily through the Alberta Energy Regulator's Fluid Tailings Management regime, including Directive 085, which focuses on containment profiles, reporting, and long-term management planning rather than active treatment or release.[2] While operators must prepare Tailings Management Plans and submit annual reports, these requirements do not establish discharge criteria or near-term treatment obligations.[3]

At the same time, oil sands operators are subject to binding legal obligations to decommission mining infrastructure, permanently stabilize tailings facilities, and restore disturbed lands to an equivalent land capability. These obligations remain in force until reclamation certification is achieved and are not satisfied by indefinite containment alone. There is no automatic release from liability based on the passage of time, and a provincial Oil Sands Mine Water Steering Committee has been established, signaling the initiation of regulatory review and rule-development processes related to future water management and release frameworks.[4]

This creates a structural mismatch between operational practice and economic exposure. Tailings-related costs are deferred, long-dated, and highly sensitive to assumptions about future remediation methods, monitoring duration, and closure performance. As a result, they are not reflected in current operating costs or standard cost curves, but instead appear as long-term environmental liabilities on corporate balance sheets.

[1] Alberta Energy Regulator, Direct 085 Fluid Tailings Management for Oil Sands Mining Project, 2022 https://static.aer.ca/prd/documents/directives/Directive085.pdf
[2] Ibid.
[3] Alberta Energy Regulator, Tailings Management, n.d. https://www.aer.ca/understanding-resource-development/resource-development-topics/tailings/tailings-management
[4] Alberta Energy Regulator, Oil Sands Mine Water Steering Committee Recommendations, 2025 https://www.alberta.ca/oil-sands-mine-water-steering-committee-recommendations#jumplinks-0

Because current operations do not involve discharge and future closure pathways remain uncertain, the economic relevance of tailings-related technologies cannot be evaluated through existing treatment costs. Meaningful financial analysis must instead focus on how improved information, monitoring, or risk management could affect the duration, uncertainty, or measurement of obligations that already exist under current law.

2. Balance-Sheet Recognition of Tailings Related Liabilities

Key takeaways

- Oil sands tailings obligations are already legally enforceable and financially recognized under current law. Recognition is triggered by existing approvals and environmental legislation, not by future discharge requirements or finalized closure pathways.
- All major oil sands operators recognize tailings-related obligations within their asset retirement or decommissioning liabilities, even where disclosures do not explicitly isolate tailings as a standalone category. Differences across companies reflect disclosure structure and measurement assumptions, not the absence of obligation.
- CNRL provides the most explicit and granular disclosure, clearly identifying an Oil Sands Mining and Upgrading asset retirement obligation and explicitly linking recognition to existing legal requirements rather than future regulatory developments.
- Uncertainty affects how these liabilities are measured, not whether they exist. Across all operators, uncertainty related to timing, remediation methods, monitoring duration, and regulatory interpretation is incorporated into discounting and estimation, rather than deferring recognition.

Although oil sands tailings water is not currently subject to discharge requirements, the long-term obligations associated with tailings management are already recognized and quantified by operators under existing accounting and regulatory frameworks. These obligations arise from legally binding requirements to decommission infrastructure and achieve reclamation certification, not from near-term operating activities.

This section examines how major oil sands producers translate these obligations into asset retirement and decommissioning liabilities on their balance sheets. By reviewing disclosures across the largest operators, this section establishes three foundational points:

(i) tailings-related obligations are recognized based on existing law, not future regulation;
(ii) the resulting liabilities are long-dated and assumption-driven; and
(iii) uncertainty affects *measurement* and re-estimation, not the existence of the obligation itself.

Together, these points provide the accounting and financial foundation for the economic analysis developed in Section 3.

2.1. Legal and Accounting Basis for Recognition of Tailings-Related Liabilities

Under applicable accounting standards, oil sands operators are required to recognize environmental and closure-related liabilities once a present legal obligation exists, future cash outflows are probable, and associated costs can be reasonably estimated. Importantly, recognition does not depend on the existence of a finalized technical closure pathway or a current regulatory requirement to discharge tailings water. Rather, it is triggered by legally enforceable obligations arising from enacted laws, regulatory approvals, and binding project conditions.

In the context of oil sands mining, these obligations arise from project-specific approvals and environmental legislation administered by the Alberta Energy Regulator. Operators are legally required to decommission mining infrastructure, permanently stabilize tailings facilities, and restore disturbed lands to an equivalent land capability. These obligations remain in force until reclamation certification is achieved and are not satisfied by indefinite containment or the passage of time alone. As a result, tailings-related obligations constitute present legal obligations under accounting standards, even though the precise timing, duration, and technical methods of closure remain uncertain.

Canadian Natural Resources Limited (CNRL)

This principle is reflected clearly in CNRL's financial disclosures. CNRL explicitly states that it:

> "is required to recognize a liability for ARO associated with its property, plant and equipment, including property, plant and equipment for which underlying reserves have been de-booked, and the carrying value of the asset has been fully depleted."[5]

CNRL further clarifies that asset retirement obligations are recognized to the extent of a legal obligation resulting from existing or enacted laws, statutes, ordinances, contracts, or by legal construction. This confirms that recognition is driven by current legal obligations rather than future regulatory developments, discretionary closure strategies, or the timing of tailings water release.

Suncor Energy Inc.

Suncor applies the same recognition logic, disclosing that:

> "Decommissioning and restoration provisions are associated with the retirement of Property, Plant and Equity and Exploration and Evaluation assets. The total undiscounted

[5] Canadian Natural Resource Limited (CNRL), 2024 Annual Report, 2025 at p. 43 https://www.cnrl.com/content/uploads/2025/05/CNQ-2024-Annual-Report_Teams_W.pdf

> and uninflated amount of estimated future cash flows required to settle the obligation December 31, 2024 was approximately $21.5 billion."[6]

Suncor measures these obligations at the present value of management's best estimate of future cash flows required to settle the obligation, emphasizing that uncertainty regarding reclamation methods, regulatory interpretation, and timing affects "measurement and re-estimation" rather than initial recognition. Compared to CNRL, Suncor's disclosures place greater emphasis on uncertainty and variability as drivers of liability valuation, while maintaining the same underlying recognition principle.

Imperial Oil Limited.

Imperial Oil similarly recognizes asset retirement and environmental liabilities when a legal obligation exists and records those obligations on a discounted basis using assumptions about timing, settlement costs, discount rates, and inflation. Imperial states that it:

> "accrues environmental liabilities when it is probable that obligations have been incurred and the amount can be reasonably estimated. Provisions for environmental liabilities are determined based on engineering estimated costs, taking into account the anticipated method and extent of remediation consistent with legal requirements, current technology and the possible use of location"[7]

Imperial explicitly acknowledges that changes in environmental legislation, including regulations related to mine tailings, affect the estimation of compliance costs. Unlike CNRL and Suncor, Imperial's disclosures place stronger emphasis on engineering judgment, technology assumptions, and execution feasibility as determinants of liability measurement.[8]

Cenovus Energy Inc.

Cenovus follows the same accounting framework, recognizing decommissioning liabilities when a present legal or constructive obligation arises from past events and discounting expected future cash flows using a credit-adjusted risk-free rate.[9] Cenovus explicitly acknowledges that many of these obligations will not be settled for decades, underscoring that long settlement horizons and

[6] Suncor, 2024 Annual Report, 2025 at p. 100 https://www.suncor.com/-/media/project/suncor/files/investor-centre/annual-report-2024/2024-annual-report-en.pdf?modified=20250310191514&created=20250225185554
[7] Imperial Oil 2024 Annual Report 10k Form, 2025 at p. 83. https://www.imperialoil.ca/-/media/imperial/files/annual-and-quarterly-reports/form-10-k-annual-report-2024.pdf
[8] Ibid at pp. 25-26.
[9] Cenovus, 2024 Annual Report at p. 123 https://www.cenovus.com/-/media/Project/WWW/docs/investors/2024/2024-Annual-Consolidated-Financial-Statements.pdf?sc_lang=en&hash=5FDC6C709B64AA0ED80232E24861CF79

technical uncertainty are intrinsic features of tailings-related liabilities rather than barriers to recognition.

Relevance

Across all four operators, the accounting conclusion is consistent and unambiguous: oil sands tailings-related obligations must be recognized once the legal obligation to retire, reclaim, and restore affected assets exists. Uncertainty regarding closure pathways, monitoring duration, or future discharge standards does not defer recognition; instead, it is incorporated into liability estimation, discounting, and periodic re-measurement over time.

This distinction is critical for financial analysis. Asset retirement and decommissioning liabilities represent unavoidable economic burdens already embedded in corporate balance sheets under current law. While reported values are sensitive to assumptions about timing, discount rates, and future costs, their existence is not contingent on future regulatory tightening or the adoption of specific tailings treatment technologies.

2.2. Measurement of Environmental Liabilities: Discounting, Timing, and Assumptions

While Section 2.1 establishes why tailings-related liabilities must be recognized, this section explains how those liabilities are measured in practice. This distinction is central to the economic analysis that follows.

Across major oil sands operators, asset retirement and decommissioning liabilities are measured using discounted cash flow methodologies that rely on long-dated assumptions regarding closure timing, remediation methods, monitoring duration, inflation, and discount rates. These assumptions materially influence reported liability values and create the primary mechanism through which uncertainty, information quality, and perceived execution risk affect financial outcomes.

Importantly, the economic relevance of tailings-related technologies does not arise from altering the existence of the obligation itself, but from influencing the assumptions used to estimate its magnitude and present value. This measurement framework creates a clear analytical entry point for evaluating how improved monitoring, data quality, or technical confidence could affect long-term liability estimates under existing accounting standards.

2.3. Comparative Disclosure Overview

Table 1. Comparative ARO / Decommissioning Liability Measurement

Company	Reported Liability (Discounted)	Undiscounted Future Cash Flow	Settlement Horizon	Discount Rate	Explicit Tailings Reference	Key Measurement Emphasis
CNRL	$1.9B (Oil Sands Mining & Upgrading)[10]	Not disclosed by asset class	60 years[11]	4.8% credit-adjusted risk-free[12]	Yes (included in Oil Sands Mining & Upgrading)	Legal obligation certainty; long-dated cost assumptions
Suncor	$12.3B (Decommissioning & Restoration)[13]	$21.5B total[14]	> 50 years[15]	4.8% credit-adjusted risk-free[16]	Implicit (oil sands mining included)	Uncertainty in timing, scope, and method of reclamation[17]
Imperial	$2.6B (ARO & Environmental Liabilities)[18]	Not fully disclosed	Not fully disclosed	6.0%[19]	Implicit (*see* 2.1)	Engineering estimates; regulatory and technology assumptions (*see* 2.1)
Cenovus	$4.5B Decommissioning Liabilities[20]	$15.6B total[21]	Decades	5.2%[22]	No explicit tailings segmentation	Long timing horizons; sensitivity to assumptions

Sources: Company 2024 annual reports, audited financial statements, Form 10-K (Imperial), and MD&A Disclosures

[10] CNRL 2024 Annual Report p. 40.
[11] Ibid.
[12] Ibid.
[13] Suncor 2024 Annual Report p. 40 (includes full corporate decommissioning & restoration).
[14] Ibid.
[15] Ibid at 100.
[16] Ibid.
[17] Ibid.
[18] Imperial 2024 10K p. 94.
[19] Ibid.
[20] Cenovus 2024 Annual Report p. 101
[21] Ibid.
[22] Ibid.

3. Economic Interpretation of Long-Dated Tailings Liabilities

Sections 1 and 2 establish two critical facts. First, oil sands tailings obligations are legally unavoidable and already recognized on corporate balance sheets. Second, the reported magnitude of these liabilities is not fixed, but highly sensitive to assumptions regarding timing, discount rates, monitoring duration, and remediation uncertainty.

This section explains why small operational or informational improvements—such as those potentially enabled by Luminous's biosensor technology—can have immediate and outsized financial relevance, even though the underlying obligations extend decades into the future.

Across the four major oil sands operators, tailings-related liabilities are valued using discounted cash flow methodologies that rely on a small set of core assumptions:

- Discount rate (typically a credit-adjusted risk-free rate)
- Expected duration of closure and post-closure obligations (often 50–60+ years)
- Timing and profile of future cash outflows
- Degree of uncertainty embedded in monitoring, remediation, and closure assumptions

Because these liabilities are discounted over very long horizons, modest changes in any of these inputs—particularly time and uncertainty—can materially change their present value today. This creates a clear analytical pathway for evaluating the potential economic contribution of technologies that improve information quality, monitoring efficiency, or risk management, even in the absence of regulatory change or near-term discharge requirements.

The subsections that follow isolate three mechanisms through which value can be created:

- Changes in effective duration (time compression)
- Changes in uncertainty embedded in liability estimates
- Changes in discounting assumptions driven by perceived risk

Each mechanism is evaluated using simplified, transparent financial modeling grounded in publicly disclosed data.

3.1. Time Compression Effects on Long-Dated Liabilities (CNRL)

Key takeaway – Time

- Tailings liabilities are discounted over **~50–60 years**, making present values **highly sensitive to time assumptions**.
- For CNRL, a **1-year reduction** in effective closure or monitoring duration increases ARO present value by **~CAD $90–100M**.
- Sub-year reductions are still material: **~3 months ≈ $20–25M**; **~6 months ≈ $45–50M**.
- These impacts reflect **earlier realization of existing legal obligations**, not operating cost savings or accelerated spending.

Canadian Natural Resources Limited (CNRL) is the most suitable primary reference case for time-based modeling for three reasons.

First, CNRL explicitly discloses an Asset Retirement Obligation for Oil Sands Mining and Upgrading as a distinct asset category. This is the only major operator that clearly confirms tailings are included within a specifically identified oil sands ARO balance, rather than embedded implicitly within broader upstream or corporate provisions.

Second, CNRL provides unusually clear disclosure regarding the expected settlement horizon of its ARO, stating that obligations are expected to be settled over approximately 60 years. This explicit duration assumption is essential for time-based sensitivity analysis.

Third, CNRL applies a disclosed credit-adjusted risk-free discount rate of approximately 4.8%, which is consistent with peers and allows direct comparison without introducing firm-specific capital structure effects.

For clarity and conservatism, the quantitative illustrations below use CNRL as the base case.

3.1.1 Valuation Framework and Base Assumptions

All four operators implicitly rely on standard discounted cash flow mechanics when measuring asset retirement and decommissioning obligations. In simplified form, the present value of a long-dated liability can be expressed as:

$$PV = \frac{FV}{(1+r)^n}$$

Where:

- PV = present value of the liability
- FV = undiscounted future cash flows
- r = discount rate

- n = time until settlement (years)

The analysis does not attempt to re-engineer company models. Instead, it applies sensitivity analysis around disclosed assumptions.

Base-case inputs (CNRL illustrative):

- Reported ARO (Oil Sands Mining & Upgrading): $1.9 billion
- Discount rate: 4.8%
- Settlement horizon: 60 years

3.1.2 Sensitivity to Changes in Duration (Years)

Holding all other assumptions constant, reducing the effective duration of the liability—through earlier stabilization, reduced long-term monitoring, or faster confidence accumulation—changes the present value today.

This can be approximated as:

$$PV_{adjusted} \approx PV_{reported} * (1 + r)^{d}$$

Where, d is the reduction in effective duration.

Duration Reduction	Implied PV Increase
1 Year	~$91 million
2 Year	~$188 million
3 Year	~$289 million
5 Year	~$500 million

Sample Calculation:

$$FV_{60} = 1.9 \times (1.048)^{60} \approx 31.5\ billion$$

$$PV_{59} = \frac{31.5}{(1.048)^{59}}, (1.048)^{59} = \frac{(1.048)^{60}}{1.048}$$

$$PV_{59} = 1.9 \times 1.048 \approx 1.991\ billion$$

$$\Delta PV = PV_{59} - PV_{60} = 1.991 - 1.9 = 0.091\ billion$$

$$\Delta PV \approx \$91\ million$$

These figures do not represent cost savings in the conventional operating sense. They represent changes in the present value of already-recognized, legally unavoidable liabilities resulting from earlier realization of obligations that already exist, not from incremental spending or new regulatory requirements.

3.1.3 Sensitivity to Sub-Year Reduction (Monitoring Phase)

Importantly, not all duration effects operate at the scale of whole years. Monitoring, verification, and confidence-building phases often operate on monthly or quarterly timelines, even when final closure spans decades.

Modeling fractional reductions using the same framework:

$$PV_{adjusted} \approx PV_{reported} * (1 + r)^{d}$$

Where, d < 1

Effective Reduction	Implied PV Increase
3 mo.	~$23 million
6 mo.	~$46 million
9 mo.	~$69 million
12 mo.	~$91 million

This framing is particularly relevant for technologies focused on biological monitoring, early detection, or performance verification, where the primary benefit is reducing the time required to establish confidence rather than accelerating final reclamation certification.

The key insight is not the precision of any single estimate, but the scale mismatch between:

- The cost of improving monitoring or information quality, and
- The balance-sheet sensitivity of liabilities discounted over multi-decade horizons.

Even small reductions in effective duration—measured in months—can produce present-value impacts that are material relative to the order-of-magnitude cost of a paid pilot. This asymmetry provides a financially coherent justification for evaluating tailings-focused technologies based on their potential to compress time and uncertainty, rather than on immediate operating cost reductions.

3.2 Uncertainty Compression and Liability Re-Measurement

Key takeaway – Uncertainty

- Reported tailings liabilities already embed **conservative uncertainty buffers** related to remediation scope, monitoring duration, and biological performance.
- **Small reductions in uncertainty (≈0.25–1.0%)** translate into **multi-million-dollar present-value changes** per operator.
- This value is realized through **liability re-measurement under existing accounting standards**, not regulatory change or accelerated closure.
- **Information quality has financial value** because it narrows uncertainty bands applied to **long-dated obligations that already exist**.

While Section 3.1 isolates the effect of time compression, an equally important, and often larger, driver of liability valuation is uncertainty embedded in long-dated closure and monitoring assumptions.

Asset retirement and decommissioning liabilities are not point estimates. They are management estimates constructed under uncertainty regarding remediation scope, monitoring duration, biological performance, regulatory acceptance, and future intervention requirements. Under accounting standards, this uncertainty is not ignored; it is explicitly incorporated into liability measurement through conservative assumptions, contingency buffers, and periodic re-estimation.

As a result, the reported present value of a tailings-related liability reflects not only expected future costs, but also risk-weighted uncertainty about whether those costs will increase, extend, or require rework over time.

3.2.1 How Uncertainty Enters ARO Measurement

Across major oil sands operators, uncertainty affects liability measurement through several mechanisms:

- Conservative assumptions about remediation scope and duration
- Extended monitoring horizons to demonstrate long-term stability
- Contingency allowances for potential future remediation actions
- Sensitivity to regulatory review, approval, or re-assessment of closure plans

This is reflected explicitly in disclosures. Operators consistently emphasize that changes in estimated future costs, timing, technology, and regulatory interpretation can materially affect the recorded liability, even when the underlying legal obligation itself does not change.

In practice, this means that the reported liability already includes a margin for uncertainty, particularly for assets such as tailings facilities that are characterized by long durations, biological complexity, and site-specific risk.

3.2.2 Why Information Quality Has Financial Value

Technologies that improve biological monitoring, early detection, and performance verification do not eliminate tailings obligations. However, they can reduce uncertainty surrounding:

- Whether tailings systems are stabilizing as expected
- Whether biological risks (e.g., naphthenic acid impacts) are trending favorably
- Whether additional remediation or extended monitoring will be required
- Whether closure assumptions remain defensible over time

Improved information quality can therefore influence management's best estimate of future cash flows, even if total closure is still decades away.

Under accounting standards, when uncertainty is reduced, liabilities may be re-measured to reflect updated assumptions. This creates a financial pathway whereby better monitoring and risk visibility can lower the expected value of future obligations, not by changing the law, but by changing what is reasonably expected under that law.

3.2.3 Illustrative Sensitivity: Small Percentage Changes, Large Effects

Because tailings liabilities are large and long-dated, even very small changes in assumed future costs can materially affect present value.

Using CNRL's reported Oil Sands Mining & Upgrading ARO of approximately $1.9 billion as an illustrative base case for scenario analysis:

Reduction in Expected Future Cost	Approximate PV Impact
0.10%	~ $1.9 million
0.25%	~ $4.8 million
0.50%	~ $9.5 million
1.00%	~ $19.0 million

These figures are not forecasts. They simply illustrate the order-of-magnitude sensitivity of long-dated liabilities to modest changes in expected outcomes.

Crucially, these impacts arise without accelerating closure timelines and without assuming regulatory change. They result purely from narrowing uncertainty bands around already-recognized obligations.

A tailings-focused biosensor is not a remediation technology; it is an information technology applied to a biological risk domain. Its economic relevance therefore lies in its ability to:

- Reduce uncertainty earlier in the life of the liability
- Improve confidence in biological performance trends
- Support more defensible closure and monitoring assumptions
- Reduce the likelihood of conservative re-estimation driven by information gaps

From a financial perspective, this means the value of a pilot is not tied to immediate operating cost reductions. Instead, it is tied to whether improved information can collapse even a small portion of the uncertainty premium embedded in long-dated liabilities.

Given the scale of tailings-related obligations, the asymmetry is clear: the cost of testing whether uncertainty can be reduced is small relative to the potential balance-sheet sensitivity such reductions create.

3.3. Discounting and Risk Perception Effects (Imperial Oil Reference Case)

Key takeaway – Discounting

- Oil sands tailings liabilities are discounted at **~4.8% to ~6.0%** across major operators.
- **Imperial Oil applies the highest discount rate (~6.0%),** reflecting greater reliance on engineering-defined remediation pathways and lower perceived execution risk.
- Because liabilities are discounted over multi-decade horizons, small rate differences matter: a **0.25–1.0% change can shift reported liabilities by ~$100–500M for a single operator.**
- Discount rate differences reflect **risk perception and technical confidence**, not weaker legal obligations.

While Sections 3.1 and 3.2 demonstrate how time compression and uncertainty reduction can affect the present value of long-dated tailings liabilities, a third mechanism operates through the discount rate applied to those liabilities. Discount rates reflect management's assessment of timing, execution risk, and uncertainty associated with future remediation and closure activities. Because tailings obligations are discounted over horizons of 50–60+ years, even modest differences in discount rates produce large changes in reported liability values.

Importantly, this mechanism does not create value in the sense of reducing the underlying obligation. Rather, it affects how conservatively that obligation is measured today. For liabilities, a higher discount rate results in a lower reported present value, and therefore a smaller balance-sheet burden.

3.3.1 Evidence Among Corporate Disclosures

Among major oil sands operators, disclosed discount rates vary meaningfully:

- CNRL, Suncor, and (to a large extent) Cenovus (5.2%) applies a credit-adjusted risk-free discount rate of approximately 4.8%, reflecting long-dated obligations with substantial uncertainty.
- Imperial Oil applies a materially higher discount rate of approximately 6.0%, explicitly grounding its ARO and environmental liability estimates in engineering-based cost assessments and technology-related assumptions.

Imperial's disclosures state that its asset retirement and environmental liabilities are estimated using assumptions related to:

- anticipated remediation methods,
- current and expected technology,
- engineering judgments regarding execution feasibility, and

- regulatory requirements as interpreted through available technical solutions.

This is a critical distinction. Imperial's use of a higher discount rate indicates a view that remediation activities are supported by greater technical determinacy or execution confidence, allowing future cash flows to be discounted more aggressively. In accounting terms, this reflects lower perceived risk in the timing and execution of remediation, not a weaker legal obligation.

3.3.2 Discount Sensitivity (CNRL Illustrative)

Using CNRL's reported Oil Sands Mining & Upgrading ARO of approximately $1.9 billion as a base case, the sensitivity of the reported liability to changes in the discount rate is substantial:

Change in Discount Rate (%)	Approximate Impact on PV
+ 0.25%	- $110 million
+ 0.50%	- $210 million
+ 1.00%	- $420 million
+ 1.20% (to 6%)	- $520 million

As highlighted, if CNRL were able to justify discounting its tailings-related liabilities at a rate comparable to Imperial's 6.0%, the implied present value of its Oil Sands Mining & Upgrading ARO would fall by approximately $500 million, holding all other assumptions constant.

This reduction would not reflect a reduction in environmental responsibility, nor a deferral of legal obligations. It would reflect a reassessment of execution risk, technological confidence, and uncertainty surrounding future remediation activities.

3.3.3 Relevance to Tailings Monitoring and Technology

Discount rates are not chosen arbitrarily. They are grounded in management's judgment about the risk profile of future cash flows, including:

- uncertainty around remediation methods,
- likelihood of rework or extended monitoring,
- technological reliability, and
- confidence in closure performance.

Technologies that improve biological monitoring, early detection, and system understanding do not change the law. However, they can influence how confidently future remediation pathways are understood and executed. Over time, this can support a reassessment of the risk embedded in long-dated tailings obligations.

In this sense, discount rate sensitivity represents a measurement channel, not an independent value lever. A biosensor does not "earn" a higher discount rate on its own. But improved technical

confidence, supported by better data and monitoring, can reduce perceived execution risk; one of the inputs that determines how aggressively liabilities are discounted.

For tailings-related liabilities:

- Higher discount rates reduce reported present value
- Lower discount rates increase reported present value

Accordingly, from a balance-sheet perspective, operators prefer lower reported liabilities, all else equal. The relevance of discount rate sensitivity in this analysis is not to suggest manipulation of assumptions, but to demonstrate how technology-driven reductions in uncertainty and execution risk can materially affect liability measurement under existing accounting frameworks.

3.4 Illustrative Normalization of Tailings Liabilities by Production Scale

Key takeaways – Scale

- When normalized to production, discounted tailings liabilities imply ~CAD $3–4 per barrel of long-run balance-sheet exposure (CNRL illustrative).
- This is **not an operating cost**, cash charge, or pricing benchmark.
- The figure exists to convey **magnitude and asymmetry**, not precision.
- Balance-sheet exposure per barrel is **orders of magnitude larger** than the cost of piloting monitoring technologies.
- Normalization explains why **small, low-cost information investments can be financially rational**, even without near-term operational impact.

Sections 3.1 through 3.3 demonstrate that tailings-related liabilities are economically meaningful, but also highlight a structural challenge in using asset retirement obligations (AROs) as a primary value lens for an early-stage technology such as Luminous Biosolutions. These liabilities are long-dated, highly assumption-driven, and recognized primarily on the balance sheet rather than through current operating expenditures. As a result, they function as value propositions rather than procurement drivers, influencing valuation, risk perception, and long-term capital allocation rather than near-term operational decisions.

In addition, tailings obligations depend on future closure pathways and regulatory endpoints that are not yet finalized, further weakening the usefulness of conventional unit economics as a direct analytical tool. The absence of current discharge requirements or active treatment regimes means that there is no observable operating cost against which a biosensor can be benchmarked today. This makes it difficult to translate the economic relevance of tailings liabilities into intuitive, operator-facing metrics without additional abstraction.

To address this limitation, this section introduces a controlled normalization of tailings-related liabilities to operational scale. The objective is not to convert AROs into actionable unit costs, but to provide an illustrative reference point that conveys magnitude, exposure, and long-run relevance in terms that are more easily understood by operators, founders, and decision-makers. This normalization is therefore contextual, not prescriptive, and is explicitly not intended to imply current per-barrel costs, pricing thresholds, or procurement justification.

3.4.1 Methodology: Illustrative Normalization of Tailings-Related Liabilities

This analysis applies a simple, transparent normalization methodology to translate long-dated tailings-related liabilities into an operational reference metric, while preserving the conceptual distinction between balance-sheet obligations and operating economics.

First, discounted asset retirement or decommissioning liabilities are taken directly from publicly disclosed financial statements of major oil sands operators. Where available, liabilities specific to oil sands mining and upgrading are used; otherwise, broader decommissioning and restoration provisions that include oil sands assets are applied with appropriate caution.

Second, these discounted liabilities are normalized using publicly disclosed operational scale metrics, including annual production volumes and proved and probable (2P) reserve estimates. This produces an indicative $/bbl figure that expresses the **r**elative magnitude of tailings-related exposure in relation to the size of the operating asset base.

Third, the resulting normalized figures are explicitly treated as exposure proxies, not operating costs. Tailings obligations are not incurred on a per-barrel basis in real time, are not reflected in operating expenses, and do not correspond to cash outflows tied to current production. The normalization therefore does not imply that operators are currently "paying" a tailings cost per barrel.

Finally, these normalized values are used solely to contextualize scale and long-run exposure, and to support qualitative discussion of why even small reductions in uncertainty, monitoring duration, or conservatism could be economically meaningful relative to the size of existing liabilities. They are not used as valuation inputs, pricing benchmarks, or procurement thresholds.

4.3.2 Results and Discussions

Canadian Natural Resources Limited (CNRL) – Production and Liability Normalization Inputs

Item	Value	Unit	Notes / Source Context
Reported Oil Sands Mining & Upgrading ARO	1.9	$ billions	Discounted liability, disclosed by asset category

Item	Value	Unit	Notes / Source Context
Average Daily Production	~1.35–1.36	MMBOE/day	Total company production, annual report
Annualized Production	~497	MMBOE/year	1.36 × 365
Settlement Horizon Assumption	~60	years	Explicitly disclosed by CNRL
Discount Rate	4.8	%	Credit-adjusted risk-free rate
Implied ARO per BOE (illustrative)	~3.8	$/BOE	1.9B ÷ 497 MMBOE

The normalization results for CNRL illustrate the scale of tailings-related exposure when translated into an operationally intelligible frame. An implied liability of approximately $3.8 per BOE highlights that, while tailings obligations are not incurred on a per-barrel basis in real time, their magnitude is material relative to the long-run economics of oil sands production. This figure should not be interpreted as a current cost or charge embedded in operations, but rather as a contextual indicator of how large the balance-sheet exposure is when viewed against the production base that ultimately gives rise to the obligation.

From a strategic perspective, the relevance of this normalization lies in magnitude and asymmetry rather than precision. The implied $/BOE exposure is orders of magnitude larger than the expected cost of testing or piloting improved monitoring technologies, yet it remains largely invisible in day-to-day operating metrics. This reinforces the central challenge identified earlier: tailings liabilities matter economically, but they sit outside conventional operational decision frameworks. By anchoring the discussion to a normalized reference point, the analysis clarifies why even modest improvements in information quality, monitoring confidence, or long-term performance assurance can be financially meaningful, despite having no immediate impact on operating costs or near-term cash flows.

Crucially, this framing supports evaluation at the strategic and pilot-testing level rather than at procurement or pricing thresholds. The normalized figure is best understood as a benchmark for exposure and risk concentration, providing context for why allocating limited capital to test technologies that could influence long-dated assumptions is rational, even when no regulatory trigger or operational mandate yet exists.

4. Pilot Justification and Decision Framework

The analysis in Sections 1 through 3 demonstrates that tailings-related liabilities are economically material, but not operationally actionable in the near term. As a result, the decision facing oil sands operators is not whether to adopt a tailings monitoring technology at scale today, but whether it is rational to invest modest capital to reduce uncertainty in long-dated obligations that already exist on the balance sheet.

From this perspective, the relevant decision is not a procurement decision, but a learning and risk-reduction decision. The appropriate benchmark is therefore not cost savings per barrel, but whether a limited pilot can generate information that meaningfully improves confidence in tailings performance, monitoring assumptions, or closure pathways.

4.1 Decision Logic for a Paid Pilot

A paid pilot of Luminous Biosolutions' biosensor technology can be justified under three conditions:

1. Asymmetry of cost versus exposure
   Tailings-related liabilities are measured in the billions of dollars and extend over multiple decades. By contrast, the relatively lower and temporary cost of a pilot program could yield millions if not hundreds of millions in future savings. Even if the probability of materially influencing liability assumptions is low, the payoff asymmetry strongly favors experimentation.

2. Information value over operating value
   The primary output of a pilot is not remediation or treatment, but improved information regarding biological performance, stability, and risk trajectories. This information has value precisely because current liability estimates embed conservatism driven by uncertainty and limited long-term data.

3. Optionality under regulatory uncertainty
   With future tailings water management and closure standards still under development, early data generation provides operators with strategic flexibility. Operators that build internal understanding earlier are better positioned to respond efficiently to future regulatory pathways, regardless of their ultimate form.

4.2 Recommended Pilot Structure

To ensure relevance and discipline, any pilot engagement should be structured around clearly defined learning objectives rather than performance guarantees.

Potential pilot elements could include:

- Scope: Deployment of biosensors at a limited number of tailings-relevant locations to monitor biological indicators tied to stability, toxicity trends, or remediation confidence.
- Duration: A fixed-term pilot aligned with monitoring cycles (e.g., 6–12 months), rather than full closure timelines.
- Outputs: Data focused on trend detection, early-warning capability, and confidence-building metrics rather than regulatory compliance or discharge readiness.

- Governance: Clear internal ownership within environmental, closure planning, or long-term liability management teams, rather than operations or procurement.

Success criteria should be framed around whether the pilot:

- Improves internal confidence in monitoring assumptions
- Identifies previously unobservable risk signals
- Supports refinement of long-term closure or monitoring plans
- Generates defensible data that could inform future liability re-estimation

Although tailings obligations will not be settled for decades, the assumptions used to measure them are revisited continuously and are shaped by the quality of information available today. In the absence of robust, site-specific biological monitoring data, operators default to conservative assumptions that inflate long-term liability estimates by extending monitoring horizons, embedding contingency buffers, and assuming higher execution risk. A limited, paid pilot of Luminous's biosensor technology is therefore rational not because it solves a current operational problem, but because it tests whether improved information can reduce uncertainty in long-dated obligations that already exist on the balance sheet. The cost of such a pilot is immaterial relative to the scale of tailings liabilities, yet the information generated could inform closure planning, monitoring assumptions, and future liability re-measurement. In this context, pilot funding represents a low-cost option on learning and risk reduction, rather than a procurement decision or commitment to deployment.