EMISSIONS IMPACT & STRATEGIC FEASIBILITY ANALYSIS Calgary-Edmonton Passenger Rail Service

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EXECUTIVE SUMMARY

Purpose

To provide Alberta Regional Rail with an independent, data-driven recommendation on the optimal propulsion technology for the new Calgary-Edmonton passenger rail service, balancing environmental requirements and financial realities.

Situation

The Calgary-Edmonton corridor is the economic backbone of Alberta, connecting over 3 million people. Transportation is currently 99.7% dependent on personal vehicles, which generates a significant environmental liability of 1,628 KT of CO2e annually. A passenger rail service has been identified as a provincial priority to address unsustainable congestion and inefficiency.

Complication

Full electrification to support green rail requires an upfront capital expenditure (CAPEX) exceeding $1.1 billion USD, which is currently a prohibitive barrier to entry. In addition, Alberta's electricity grid is currently high-carbon, meaning immediate full electrification would not yield a "net-zero" benefit, yet federal regulations require a path to net-zero by 2035-2050. Therefore, selecting the wrong technology could result in stranded assets or a failed launch due to high costs.

Question

Which propulsion technology offers the optimal balance of immediate environmental impact, financial feasibility, and strategic flexibility for the Calgary-Edmonton corridor?

Recommendation

Select Dual Power (Diesel-Electric) locomotives as the primary propulsion technology.
This technology operates as an electric train in urban centers and a diesel train in rural segments, uniquely bridging the gap between affordability and sustainability, meaning it satisfies the need for immediate operations without waiting for full grid decarbonization.

Benefit

Enables Zero-Emission Quiet-Zones in downtown Calgary and Edmonton immediately, securing necessary municipal support and social license, while defers over $1 billion USD in rural infrastructure costs by avoiding full electrification on Day 1. The fleet is a dynamic asset; its emissions profile automatically improves as the Alberta grid adds renewable capacity, ensuring compliance with Net-Zero 2050 without mid-life fleet replacement.

Call to action

Adopt the Phased Rollout Roadmap to align capital spend with ridership growth:
Phase 1 (Years 1-5): Electrify only 3-5 km of track at urban terminuses to establish city-center quiet zones.
Phase 2 (Years 5-10): Extend electrification to commuter hubs (Airdrie & Leduc) as revenue stabilizes.
Phase 3 (Year 20+): Transition to a fully Net-Zero Corridor via full electrification or alternative fuels once the grid matures.

INTRODUCTION

The Calgary-Edmonton corridor – Highways 2 and 2A - is one of the most congested vehicular links in Alberta, connecting a population of over 3 million people, yet it currently faces a critical sustainability challenge due to a near-total reliance on personal vehicle travel. Transportation in this region generates a huge environmental liability of 1,628 KT of CO2e every year (Sun, 2024), driven by a 99.7% dependence on cars, and the establishment of a passenger rail service has been identified as a provincial priority to address unsustainable congestion and inefficiency. This report provides Alberta Regional Rail with an independent, data-driven assessment designed to determine the optimal propulsion technology for this service, by assessing seven types of passenger rail propulsion technologies: Modern Diesel, Diesel Electric Hybrid, Natural Gas, Natural Gas Hybrid, Dual Power (ALP-45A), Hydrogen Electric and Sole Battery Electric, balancing the urgent need for emissions reduction against the financial and contextual realities of the province.

However, global solutions are not in sync with contextual realities. Full electrification, while environmentally is the ideal solution, requires an upfront capital expenditure (CAPEX) exceeding $1.1 billion USD, creating a prohibitive entry barrier. In addition, because Alberta's electricity grid remains high-carbon, immediate full electrification would not result in a net-zero benefit, creating a conflict with federal regulations that mandate a path to net-zero by 2035–2050. This complexity means that selecting the wrong technology could result in stranded assets or a failed launch due to high costs.

In order to resolve these conflicting pressures, this analysis addresses the core strategic question: Which propulsion technology offers the optimal balance of immediate environmental impact, financial feasibility, and strategic flexibility for the Calgary-Edmonton corridor?. The study employs a methodology that integrates a quantitative Life-Cycle Assessment [LCA] to measure true Well-to-Wheel [WTW] emissions and a Comparative CAPEX model to assess financial feasibility. This is supported by a qualitative PESTEL analysis (Political, Economic, Social, Technological, Environmental, Legal), ensuring that the final recommendation accounts for critical non-financial risks to operate.

Based on this detailed framework, the report recommends the adoption of Dual Power (ALP-45A) locomotives as the primary propulsion technology. This solution uniquely bridges the gap between affordability and sustainability by enabling the immediate creation of Zero-Emission Quiet Zones in downtown Calgary and Edmonton, thereby securing municipal support while deferring over $1 billion USD in rural infrastructure costs. Crucially, a Dual Power fleet functions as a dynamic asset; its emissions profile will automatically improve as the Alberta grid adds renewable capacity, ensuring long-term compliance with Net-Zero 2050 mandates without requiring mid-life fleet replacement

CHAPTER 1
THE CONTEXT

The Calgary-Edmonton corridor serves as the economic backbone of Alberta, connecting a population of over 3 million via Highways 2 and 2A. However, intensifying travel demand has strained this road-based infrastructure, creating unsustainable congestion and inefficiency that necessitate immediate intervention. In response, a Rail Passenger service has emerged as a provincial priority. This independent third-party assessment, prepared for review by Alberta Regional Rail, assesses the feasibility of this transition through a data-driven Emissions Impact Analysis, benchmarked against CAPEX to identify the optimal locomotive technology. By evaluating seven propulsion systems inside Alberta's specific PESTEL context, the analysis delivers a strategic recommendation that secures both immediate cost-effectiveness and long-term adherence to net-zero mandates.

SITUATION
THE STATE OF THE CORRIDOR

The current transportation landscape in the Calgary-Edmonton corridor is characterized by a near-total dependence on personal vehicle travel, resulting in a significant and growing environmental liability.

The Demand Profile

The corridor forms part of a sophisticated ecosystem of frequent transit hubs rather than a simple linear route between destinations. The gravity model by Arduin & Fryer (2025) predict an annual demand of 5.2 million passengers, with the primary market segment consisting of short-distance commuters travelling between satellite communities such as Airdrie and Leduc and major urban centers. To support this usage pattern, the operational strategy should prioritize technology that is efficient in acceleration and deceleration to handle frequent stops, rather than focusing solely on high-speed cruising capabilities. Following Arduin & Fryer (2025) this assessment will focus on rails with an operating speed of 160 km/h.

The Environmental Baseline

Currently, personal vehicles and intercity buses provide nearly all of the corridor's traffic. A Life-Cycle Assessment [LCA] of 2023 traffic data shows that these modes (buses and personal vehicles) emit 1,628 KT of CO_2e annually (Author's Calculation based on AADT Analysis, 2025. Among those calculations, personal vehicles have the major share of footprint, accounting for 79.59 % of the total, with an emissions intensity of approximately 132.5 g CO_2e per passenger-kilometre (NRC, 2022). This data establishes a stringent performance benchmark: in order to justify the required capital investment, any chosen rail technology must demonstrate the ability to significantly outperform this baseline.

COMPLICATION

Alberta’s High-Carbon Grid

While the case for rail is strong, the path to a green railway in Alberta is still hampered by unique financial and environmental obstacles. The project faces a decarbonization dilemma, in which the most obvious solutions are currently rendered ineffective or unfeasible due to local realities.

The State of the Alberta Grid

In most jurisdictions, going electric is the automatic choice for decarbonization. However, Alberta’s electricity grid currently has a carbon intensity of 470 g CO_2e /kWh, one of the highest in Canada (Government of Alberta, 2023). Consequently, a Battery-Electric train operating on today’s grid would have a life-cycle carbon footprint of ~41.5 g/p-km, which is higher than that of a modern Diesel-Electric Hybrid (~34.0 g/p-km). This creates a conflict between the perception of green technology and the reality of emissions reductions in the short term.

The Infrastructure Barrier.

Fully electrifying the 300 km corridor to support electric or battery trains requires an immense upfront capital expenditure [CAPEX]. With heavy rail electrification costs estimated between $3.5 million and $8.5 million USD per kilometre, the infrastructure bill alone could exceed $1.1 billion USD (Levy, 2018; Caltrain, 2024). This is a prohibitive barrier to entry for a new service, potentially leaving the project financially unviable before it begins.

Regulatory Friction.

The project must go through a complicated regulatory landscape. The Clean Electricity Regulations of the Federal Government require a net-zero grid by 2035, while the provincial government targets 2050 for reliability (Government of Canada, 2024). Therefore, the chosen technology must be robust enough to operate under current conditions while remaining compliant with future net-zero requirements, to avoid becoming a “stranded asset” in a decarbonizing world.

THE CORE QUESTION

Alberta’s High-Carbon Grid

Given the high environmental cost of the status quo, the financial barrier of full electrification, and the unique constraints of Alberta’s energy grid, the central strategic question this report addresses is:

“Which propulsion technology offers the optimal balance of immediate environmental impact, financial feasibility, and strategic flexibility for the Calgary-Edmonton corridor?”

CHAPTER 2
PROBLEM SETUP & METHODOLOGY

This chapter defines the analytical framework used to evaluate the feasibility and sustainability of the Calgary-Edmonton passenger rail project. To ensure the final recommendation is not simply theoretical but practically executable, the study employs a methodology that integrates different frameworks, that encompasses the technical compliance, environmental life-cycle assessment [LCA] and strategic feasibility. By establishing clear system boundaries this chapter transitions the report from a broad strategic context to specific, evidence based and problem solving assessment.

2.1 THE HYPOTHESIS TREE

In order to address the core strategic question Which propulsion technology offers the optimal balance of environmental impact and financial feasibility? this analysis utilizes a Hypothesis Tree framework. This diagnostic tool enables the decomposition of the complex, multi-variable problem of decarbonization versus costs into testable components.

Moreover, it is central to this analysis the guiding hypothesis of a passenger rail service that can achieve sustainable triple-bottom-line success by selecting a propulsion strategy that balances financial reality (Profit), decarbonization mandates (Planet), and community wellbeing (People). By validating specific sub-hypotheses across these three streams, it will be possible to isolate a single technology path that fulfills all critical project constraints. The following structure outlines the thinking flow used to elaborate the final recommendation.

Root Hypothesis:

A passenger rail service can achieve sustainable triple-bottom-line success by selecting a propulsion strategy that balances financial reality (Profit), decarbonization mandates (Planet), and community wellbeing (People).

Hypothesis 1: PLANET Environmental Stewardship

Core Statement: The project can deliver a net-positive environmental impact immediately upon launch, despite Alberta’s high-carbon grid.

Sub-Hypothesis 1A:

A technology exists that lowers Life-Cycle (WTW) Emissions compared to the personal vehicle baseline (~132.5 g CO_2e /p-km) without requiring a 20-year wait for grid decarbonization.

Sub-Hypothesis 1B:

The solution eliminates tailpipe emissions (NOx, PM) in dense urban areas and directly addresses local pollution targets.

Hypothesis 2: PROFIT Economic Viability

Core Statement: The project can overcome the prohibitive capital costs of electrification through a phased, risk-managed investment strategy.

Sub-Hypothesis 2A:

A phased infrastructure development approach, by electrifying the segments that are inside urban areas initially, reduces the upfront barrier to entry by >90% compared to full corridor electrification.

Sub-Hypothesis 2B:

The chosen technology will help to avoid paying $170/tonne carbon taxes in the future and ensure long-term asset viability in a Net-Zero 2050 economy.

Hypothesis 3: PEOPLE Social License & Service

Core Statement: The technology secures the social license to operate by meeting the specific quality of life demands of corridor communities.

Sub-Hypothesis 2A:

The propulsion system enables quiet zones with zero noise related to engine roar for diesel and not exhaust fumes in sensitive neighbourhoods, securing necessary municipal approvals.

Sub-Hypothesis 2B:

The technology will ensure service continuity during Alberta 's extreme -40°C winters, ensuring passenger safety and trust when the grid or battery range is compromised.

Having established the core hypotheses that define success, the analysis moves from strategic theory to rigorous validation. To ensure a final recommendation to be practically executable, the study will continue with methodology & analytical frameworks.

2.2 METHODOLOGY & ANALYTICAL FRAMEWORKS

This independent assessment uses a multidisciplinary methodology that incorporates both quantitative and qualitative frameworks to transform strategic hypotheses into validated recommendations.
The quantitative analysis establishes success metrics, with a Life-Cycle Assessment [LCA] measuring true environmental impact and a Comparative Capital Expenditure (CAPEX) model determining financial feasibility. In addition, the qualitative analysis examines the strategic landscape using a PESTEL framework, identifying non-financial risks such as political alignment and social license, which are equally important to the project's success.

Quantitative Assessment

A. Life-Cycle Assessment [LCA]

To measure the true environmental impact of each propulsion technology, the study employs a comprehensive LCA aligned with ISO 14040 principles and Alberta's Greenhouse Gas Quantification Methodologies [AQM]. Crucially, this analysis defines the system boundary as Well-to-Wheel [WTW], quantifying emissions from the upstream production of energy or Well-to-Tank [WTT] through to the final tailpipe combustion or Tank-to-Wheel [TTW]. This rigorous scope is essential for exposing the hidden carbon costs of upstream energy, such as the high carbon intensity of Alberta's electricity grid or the methane slip of natural gas, which simpler tailpipe-only models fail to capture.

B. Comparative Capital Expenditure [CAPEX]

Modelling Financial feasibility is assessed through a comparative CAPEX model that distinguishes between vehicle acquisition costs (unit price) and system infrastructure costs (electrification/fueling). This framework extends beyond the unit price of the train, considering infrastructure costs that can later become barriers due to the massive upfront investment required. By separating these cost categories, the model identifies which technologies enable a logical investment strategy versus those that require a prohibitive initial expenditure.

Qualitative Assessment

C. PESTEL Strategic Analysis

To expand the previous assessments focused on emissions and costs, it is needed to evaluate the context in which this project will be developed. In this case, the macro-environmental reality of Western Canada is analyzed using a PESTEL Analysis (Political, Economic, Social, Technological, Environmental, Legal). This qualitative scan will identify critical non-financial risks that could derail the project, ensuring the recommended solution secures the necessary approvals to operate.

By triangulating these three dimensions, the study will determine the single technology path that satisfies all project constraints.

CHAPTER 3
QUANTITATIVE ANALYSIS

This chapter establishes the data-driven foundation for the technology recommendation. By conducting a parallel analysis of Environmental Impact (via LCA) and Financial Feasibility (via Comparative CAPEX Modelling), the study aims to measure the concrete trade-offs of each propulsion option.

3.1 THE ENVIRONMENTAL BASELINE: THE CURRENT ROAD CORRIDOR HIGHWAYS 2 & 2A LIFE CYCLE ASSESSMENT

To justify the investment in a new rail service, first determine what it's going to replace. This section quantifies the current environmental burden of the road-based transportation network (Highways 2 and 2A) through a Life Cycle Assessment of 4 stages - Manufacturing (Cradle to Gate), Infrastructure Constructions & Maintenance, Operational (Well-to-Wheel) and End-of-Life (Grave to Cradle) - for emissions.

A. Manufacturing (Cradle to Gate) Emissions

This stage quantifies the Cradle-to-Gate footprint, which represents the total carbon invested in a vehicle before it is ever driven. It represents the full environmental cost of production, accounting for all CO_2e emissions released from the extraction and processing of raw materials, such as steel, aluminum, and plastics, and the vehicle's final assembly. This is represented by the manufacturing footprint, being for a conventional gasoline vehicle 8.5 tonnes CO_2e per lifespan (15 years) and a Intercity bus 32.5 tonnes CO_2e per lifespan (15 years) (International Council on Clean Transportation, 2021).
This analysis shows that the total amortized manufacturing footprint of the current road fleet in the corridor is approximately 243.87 tonnes of CO_2e per year. (Appendix 1 - 2)

B. Infrastructure Construction & Maintenance Emissions

This stage represents the annual share of emissions from road maintenance (asphalt, concrete, and machinery) and is estimated at ~2.5 g CO2e per p-km (International Council on Clean Transportation, 2021). The total footprint for the corridor is 9.11 tonnes of CO_2e per year. (Appendix 3)

C. Operational (Well-to-Wheel) Emissions

This is the most significant phase, accounting for the vast majority of the corridor's environmental impact (79.59%)

- **Well-to-Tank [WTT] Emissions:** Greenhouse gases released to create the fuel before it even gets to the vehicle. Life-cycle studies show that these upstream processes add ~20-25% to the final tailpipe emissions (International Council on Clean Transportation, 2021) or 325.86 tonnes of CO_2e annually.
- **Tank-to-Wheel [TTW] Emissions:** These are the direct tailpipe emissions from fuel combustion. This is the largest source of emissions in the corridor, totalling 977.57 tonnes of CO_2e annually (Appendix 3).

D. End-of-Life (Grave-to-Cradle) Emissions

This stage assesses the environmental costs associated with vehicle disposal. Emissions are generated from the energy used to transport, shred, and process end-of-life vehicles. While metals are recycled, non-recyclable materials (plastics, foams, textiles) are sent to landfills, which can result in waste-related emissions. The footprint of this stage is 81.30 tonnes of CO_2e annually. (Appendix 3)

Summary of the Corridor LCA

To summarize the LCA, the following table separates the percentage of true Actual Environmental Cost per year of the highway 2 and 2A for stage (Table 1)

Table 1. Corridor Emissions per LCA stage

Life-Cycle Stage	Annual Emissions (KT CO_2e)	Percentage of Total
1. Manufacturing (Cradle-to-Gate)	243.87	14.89%
2. Infrastructure & Maintenance	9.11	0.56%
3. Operational (Well-to-Wheel)	1,303.43	79.59%
4. End-of-Life (Grave-to-Cradle)	82.30	4.96%
TOTAL (Environmental Cost)	**1637.71 KT CO_2e/ year**	**100%**

Note. Table 1. Corridor Emissions per LCA Stage. Primary source based on calculations of the LCA Annual Emissions with data retrieved from International Council on Clean Transportation (2021).

Based on the total life-cycle analysis complied, the Operational WTW emissions account for 79.59% of the total environmental cost of the current road transportation in the corridor. This high percentage indicates that the annual, recurring emissions from fuel production WTT and fuel combustion TTW are the most significant contributors to the environmental footprint. In addition, Personal vehicles account for 99.7% of the emissions from these two passenger modes, making them the primary target for a mode shift. In addition, infrastructure and mainteance annual emissions will be excluded from the total environmental costs to beat, due the highways exist previously and the lowering on the emissions will be negligible, giving the total environmental cost of 1,628.52 KT CO_2e per year.

With the baseline determined, the assessment will next be directed to the technology profiles to initiate the comparison stage.

3.2 TECHNOLOGY PROFILES

This section evaluates the primary characteristics of modern locomotive propulsion systems established in Objective 1, providing the technical data necessary for a critical procurement decision. This assessment is limited to technologies capable of meeting EPA Tier 4 emissions regulations and CFR 49 Part 238 passenger rail safety standards. The following profiles detail the seven technologies under consideration: Modern Diesel, Diesel/Battery Electric Hybrid, Natural Gas, Natural Gas/Electric Hybrid, Dual Power (ALP-45DP), Hydrogen, and Sole Battery Electric. Each profile establishes a baseline for the technology's specific emissions, estimated capital cost, and operational rationale.

For systems like Natural Gas that are not commercially available or in testing stages, this analysis uses Proxy Data (National Centers for Environmental Information, 2018) from the closest equivalent: freight technologies, rather than passenger. Consequently, Natural Gas technologies are included in this study strictly as a comparative baseline for emissions analysis; they are not being advanced as viable candidates for the final proposal due to commercial unavailability.

Modern Diesel (Tier 4)

This locomotive complies with the EPA Tier 4 emissions standards and features a high-efficiency diesel-electric propulsion system. A large diesel engine, known as the prime mover, operates an alternator to generate electrical power (Progress Rail, n.d.). This electricity is subsequently managed and delivered to electric traction motors mounted on the axles, which generate the tractive force necessary to propel the locomotive.

Available Models (CFR/EPA)	Siemens SC-44 Charger (Siemens, n.d.), Progress Rail (EMD) F125 (Progress Rail, n.d.).
Locomotive Cost (CAPEX)	~$7.0 - $8.0 M USD per locomotive (Siemens, n.d.).
Infrastructure Cost (For the Corridor)	Low. This technology uses all existing diesel fueling and maintenance infrastructure.
Emissions Profile	• NOx(Tailpipe): ~1.3 g/bhp-hr • PM (Tailpipe): ~0.03 g/bhp-hr • CO_2e (WTW): ~42.5 g/p-km.

Diesel/ Battery Electric Hybrid

This system utilizes a high-efficiency hybrid-electric propulsion system. It features a smaller EPA Tier 4-compliant diesel engine, a high-capacity battery, and a regenerative braking system. The diesel engine drives a generator to produce electrical power, which can be supplemented by or stored in the battery. This electricity is then managed and delivered to axle-mounted electric traction motors, with braking energy recaptured to recharge the battery (Stadler, 2025).

Available Models (CFR/EPA)	Stadler FLIRT. There is no direct North American passenger locomotive model; this is a common solution for Multiple Units [MUs] (Stadler, 2025).
Locomotive Cost (CAPEX)	~$10 - $15 Million (USD) per trainset (Stadler, 2025).
Infrastructure Cost (For the Corridor)	Low. This technology uses existing diesel fueling infrastructure. (Stadler, 2025).
Emissions Profile	• NOx / PM (Tailpipe): Meets EPA Tier 4 standards. Total output is lower than that of a standard diesel engine because it operates at a lower frequency. • CO_2e (WTW): ~34.0 g/p-km. This is 15-30% lower than standard diesel due to fuel savings. (Stadler, 2025).

Natural Gas (LNG)

This system utilizes a modified internal combustion engine operating on a dual-fuel mix of Liquefied Natural Gas [LNG] and diesel. It represents the standard approach currently piloted in the North American freight sector. This profile assumes the use of Fossil Natural Gas. Modelling this technology with fossil fuel reflects the most likely real-world operational scenario if it were adopted today. Due to methane slip - unburnt gas escaping the engine - and the carbon intensity of fossil gas, the total life-cycle emissions are significantly higher than a standard diesel train (Federal Railroad Administration, 2020a)

Available Models (CFR/EPA)	None. No CFR Part 238-compliant passenger model exists. Commercial implementations are currently limited to freight tenders, such as Florida East Coast Railway operating under special permits (Federal Railroad Administration, 2020).
Locomotive Cost (CAPEX)	~$8.6 million USD (Freight Proxy).
Infrastructure Cost (For the Corridor)	High. Requires new cryogenic fueling depots.
Emissions Profile	• NOx / PM (Tailpipe): Comparable to Tier 4 Diesel. • CO_2e(WTW): ~92.5 g/p-km (due Methane Slip calculated in Appendix 4)

Natural Gas/Electric Hybrid

This advanced concept integrates a natural gas engine with a large battery system. The battery enables the engine to operate at a constant, optimal speed (steady state), which stabilizes combustion and significantly reduces methane slip compared to a standard variable-speed engine (OptiFuel Systems, n.d.). This profile assumes the use of Renewable Natural Gas [RNG]. Modelling this technology with RNG to demonstrate the best-case scenario for gas technology, but at the same time acknowledging that this supply chain does not currently exist at scale for rail.

Available Models (CFR/EPA)	None. This is a niche technology currently in development for freight switching, e.g., OptiFuel. No passenger-compliant model exists.
Locomotive Cost (CAPEX)	~$5.5 Million USD (Freight Proxy) (Bioenergy Insight, 2024).
Infrastructure Cost (For the Corridor)	Very High. Requires both specialized fueling infrastructure and a dedicated, premium-priced RNG supply chain.
Emissions Profile	• NOx / PM (Tailpipe): Near-Zero. • CO_2e(WTW): ~10.0 g/p-km (Conditional on RNG).

Dual Power (ALP-45DP)

This locomotive utilizes a redundant dual-power propulsion system. It can operate as a diesel-electric locomotive, using two EPA Tier 4-compliant diesel engines to drive generators, or as a pure electric locomotive, drawing high-voltage AC power from an overhead catenary via a pantograph. In either mode, the electricity is conditioned and delivered to axle-mounted electric traction motors, providing tractive effort (Pacific Western Rail Systems, 2025).

Available Models (CFR/EPA)	Alstom ALP-45A (the Tier 4-compliant version of the ALP-45DP).
Locomotive Cost (CAPEX)	~$8.8M Usd (NJ Transit, 2020) to $17M USD (NJ Transit, 2025).
Infrastructure Cost (For the Corridor)	Medium-Scalable. This locomotive's primary benefit is flexibility on routes that are already partially electrified. It enables a phased electrification strategy. The estimated capital cost to electrify the initial urban segments in Calgary and Edmonton is approximately $44.4 million.
Emissions Profile	• NOx / PM (Tailpipe): Zero in electric mode (urban zones). In diesel mode (rural segments), it is identical to a Modern Diesel (Tier 4 compliant). • CO_2e (WTW): Variable. The life-cycle footprint improves over time as more track segments are electrified, thereby preventing the lock-in risk associated with a standard diesel fleet.

Hydrogen (Hydrogen-Electric)

This system utilizes a zero-tailpipe-emission electric propulsion system powered by a hydrogen fuel cell. Hydrogen gas from high-pressure storage tanks is combined with oxygen from the air in a fuel cell stack to produce electrical power (Stadler, 2025). This electricity is then managed, often via a battery buffer, and delivered to axle-mounted electric traction motors, which provide the tractive effort.

Available Models (CFR/EPA)	Stadler FLIRT H2 Hydrogen-Electric Multiple Unit [HEMU] (Stadler, 2025).
Locomotive Cost (CAPEX)	~$21 Million (USD) per 2-car trainset (Stadler, 2025).
Infrastructure Cost (For the Corridor)	Very High. Requires the construction of new, complex hydrogen production and high-pressure refuelling stations.
Emissions Profile	• NOx / PM (Tailpipe): Zero. The only tailpipe emission is water vapour. • CO_2e(WTW): If used Green Hydrogen (from renewables): ~10.0 g/p -km. If used Grey Hydrogen (from natural gas): ~90.0 g/p-km.

Sole Electric Battery

This system utilizes a zero-tailpipe-emission electric propulsion system powered entirely by onboard batteries. Stored electrical energy is drawn from a large, high-capacity battery system, which is then managed and delivered to axle-mounted electric traction motors (Stadler, 2025). The system utilizes a regenerative braking circuit to recapture kinetic energy; however, it must be recharged from an external grid-based power source.

Available Models (CFR/EPA)	Stadler FLIRT Akku - Battery-Electric Multiple Unit, [BEMU] (Stadler, 2025).
Locomotive Cost (CAPEX)	~$19 - $20 Million (USD) per 2-car trainset.
Infrastructure Cost (For the Corridor)	Very High. It requires either full electrification of the line ($3.5M - $8.5M per kilometre) or the construction of static, high-megawatt charging stations at terminals and along the route (Stadler, 2025).
Emissions Profile	• NOx / PM (Tailpipe): Zero. • CO_2e(WTW): ~41.5 g/p-km. This is 100% dependent on the electricity grid. In the corridor, it must utilize Alberta's high-carbon grid, resulting in its current life-cycle emissions being slightly higher than those of a Diesel/Electric Hybrid.

3.3 ENVIRONMENTAL IMPACT RAIL SYSTEM LIFE-CYCLE ASSESSMENT

To validate the scope of the LCA comparison, this analysis first deconstructs the rail system into its four distinct life-cycle stages: Manufacturing, Infrastructure, Operational, and End-of-Life. By first assessing the embodied emissions of the rolling stock and track infrastructure, it can be determined whether these non-operational phases represent a significant portion of the total carbon footprint.

This diagnostic assessment confirms that, consistent with the road baseline, the Operational Phase drives the overwhelming majority (>90%) of the system's life-cycle impact. Consequently, to mantain logic the comparison against vehicle traffic, the final technology benchmarking focuses on the Well-to-Wheel [WTW] boundary, isolating the energy efficiency and fuel source differences that ultimately define the project's environmental success.

A. Vehicle Manufacturing (Cradle-to-Gate)

This phase evaluates the carbon generated during the extraction of raw materials, such as steel, copper, and aluminum, and the manufacturing and assembly of locomotives and passenger cars. It was noticed that production of rolling stock represents a tangible carbon debt that must be amortized over the vehicle's life. However, due to the high passenger capacity and extremely long lifespan (30–40 years) of railway vehicles, this impact is highly diluted. Benchmarks for conventional commuter rail indicate that manufacturing contributes approximately 6–8 g CO_2e/p-km to the life-cycle footprint (Chester & Horvath, 2009). This is significantly lower than the manufacturing burden of private automobiles, which is estimated at ~35 to ~40 g CO_2e/p-km, yet it is included here to fully account for the fleet acquisition impact of the new Dual Power trains (Chester & Horvath, 2009).

B. Infrastructure Construction & Maintenance

Infrastructure typically represents the largest source of embodied carbon in rail projects, driven by the energy-intensive production of concrete and steel for track beds, tunnels, and stations. It was acknowledged that building new rail infrastructure creates a massive upfront burden, adding approximately 60 g CO2e/p-km to the life-cycle footprint, a figure that effectively doubles the operational emissions (Chester & Horvath, 2009). However, the proposed project leverages the existing CPKC corridor. By reusing the existing rail bed, the project avoids the massive ~60 CO2e g/p-km civil works penalty associated with new earthworks and concrete production. The analysis, therefore, focuses only on the incremental infrastructure: the installation of overhead catenary systems [OCS] for the electrified urban zones. Industry data quantifies this specific electrical infrastructure cost at approximately 2.0–4.0 g CO2e/p-km (Baron et al., 2011). This confirms that the decision to upgrade existing lines rather than build new ones is the single most effective strategy for minimizing the project's embodied carbon.

C. Operational Phase (Well-to-Wheel)

The operational phase was found the dominant driver of the system's environmental performance, encompassing the active energy use from Well-to-Tank [WTT] upstream production to Tank-to-Wheel [TTW] tailpipe combustion. For this analysis, the Modern Diesel (Tier 4) unit establishes the corridor's operational baseline at 42.5 g CO2e g/p-km. This will be the primary lever for emissions reduction; next, the analysis evaluates how alternative technologies, such as Hydrogen, Battery, and Dual Power, perform relative to this 42.5 g benchmark. It can be anticipated that technologies that can significantly lower this figure below the diesel baseline, without incurring excessive infrastructure penalties, will demonstrate the highest net environmental benefit.

D. End-of-Life (Disposal & Recycling)

The final phase covers the decommissioning, dismantling, and material recovery of the rolling stock and infrastructure. Passenger rail vehicles maintain a recoverability rate of approximately 95% due to their high concentration of valuable steel and copper (Delogu et al., 2017). Is for that reason this analysis models the End-of-Life phase as a Net Neutral factor. The energy savings and avoided emissions achieved by recycling these high-value metals typically offset the energy required for the disposal process, ensuring no additional penalty is added to the life-cycle total (Delogu et al., 2017).

Although the embodied emissions from rail manufacturing and electrical infrastructure are proportionally higher than those of the road sector, contributing an estimated 10–12 g CO2e/p-km combined, the Life-Cycle Assessment confirms that they do not displace the Operational Phase as the primary driver of the system's total carbon footprint. Consequently, to ensure a accurate comparison against the established road baseline, the following technology benchmarking focuses exclusively on the Well-to-Wheel (WTW) boundary. This approach isolates the specific efficiencies of the propulsion systems, identifying the technology capable of delivering the highest net environmental benefit.

3.4 ENVIRONMENTAL COMPARATIVE BENCHMARK

With the boundary to compare previously defined, the analysis proceeds to benchmark the seven propulsion candidates against the existing road baseline. The following comparison isolates the Well-to-Wheel (WTW) performance of each technology. Then it will be compared the Annual Impact Assessment, where these individual savings are scaled against the gravity model's (Arduin & Fryer, 2025) projected ridership of 5.2 million passengers. By determining the precise delta between the environmental cost of the road and the rail alternative, the analysis calculates the total avoided emissions the quantifiable net carbon benefit the project delivers to the province annually.

In the Table 2 the summary of the Comparative emissions between technologies results are presented below to drive the strategic recommendation, the full breakdown of emission factors, energy consumption rates, and detailed calculation methodologies is available in Appendix 5. This comparison reveals that zero-tailpipe emissions do not always equate to low-carbon when the upstream energy source is taken into account.

Table 2 Comparative emissions between technologies

Transport mode	*Technology*	*Est. WTW emissions (g CO_2e/p-km)*
Current (Baseline)	Personal Vehicle	~128.5 g
Current (Baseline)	Intercity Bus	~40.0 g
Proposed Rail	Modern Diesel (Tier 4)	~42.5 g
Proposed Rail	Diesel/Electric Hy-brid	~34.0 g
Proposed Rail	Natural Gas/Electric	~92.5 g
Proposed Rail	Natural Gas Hybrid	~10.0 g (Requires RNG)
Proposed Rail	Dual Power (ALP-45A)	Start in 42.47 g and Final Goal is Zero
Proposed Rail	Hydrogen-Electric	~10.0 g (Green H_2) ~90.0 g (Grey H_2)
Proposed Rail	Sole Battery	~41.5 g (Alberta Grid)

Note: . Comparative emissions between technologies, primary source with data retrieved from analysis of the technologies.

3.5 ANNUAL IMPACT ASSESSMENT AND AVOIDED EMISSIONS

Using the complete LCA framework, we can now project the total annual environmental impact for every proposed rail technology. Based on (Arduin & Fryer, 2025) Gravity Model's projection of 5.2 million annual passengers, and applying the Realistic Commuter Scenario occupancy rate of 1.1 persons per vehicle (Statistics Canada, 2024), the rail service will displace approximately 321.9 million vehicle-kilometers annually. When measured against the total corridor traffic of 3.64 billion vehicle-kilometers calculated in Appendix 1, this translates to a 8.85% reduction in total vehicle traffic on Highways 2 and 2A. Consequently, applying this capture rate to the total environmental liability of 1,628.52 KT CO_2e. the gross avoided emissions from personal vehicles are 144.12 KT CO_2e.

This figure, 144.12 KT establishes the realistic baseline to beat. Table 3 summarizes the Net Annual Savings, calculated by subtracting the rail system's own operational emissions (Appendix 3) from this avoided baseline.

Table 3 Net Annual Emissions Savings per technology

Propulsion Technology	***Avoided Personal Vehicle Emissions (kT CO_2e)***	***Generated Rail Emissions (kT CO_2e)***	***Net Annual Savings (kT CO_2e)***
Hydrogen (Green H_2)	144.12	3.54	140.58
Diesel/Electric Hybrid	144.12	12.04	132.08
Sole Battery (Alberta Grid)	144.12	14.70	129.42
Modern Diesel (Tier 4)	144.12	15.05	129.07
Dual Power (Diesel Mode)	144.12	15.05	129.07
Hydrogen (Grey H_2)	144.12	31.87	112.25
Natural Gas/Electric	144.12	32.75	111.37

Note: Table 3 Net Annual Emissions Savings per Technology Summary. The Dual Power (ALP-45A) values represent the conservative "Phase 1" scenario. While the net savings (~129 KT) are lower than the theoretical maximums previously modeled, they represent a statistically valid, verifiable reduction in the province's carbon footprint equal to removing nearly 8.8% of all highway traffic

While the Annual Impact Assessment identifies the most effective decarbonization strategies, environmental performance is only one half of the equation. The project's ultimate viability hinges on financial feasibility. The following Comparative CAPEX Analysis shifts the lens from carbon to capital, quantifying the upfront investment required for each technology to determine which solutions are not just environmentally superior, but economically deliverable today

3.5 ECONOMIC IMPACT: COMPARATIVE CAPEX ANALYSIS

To determine financial viability, this analysis evaluates two distinct categories of capital expenditure (CAPEX): the recurring cost of Vehicle Acquisition and the one-time, upfront cost of Infrastructure Construction.

Capital Expenditure (CAPEX) Analysis

A. Vehicle Acquisition Costs (Unit Price)

The cost of rolling stock varies significantly by technology complexity. Standard diesel locomotives represent the financial baseline, while advanced zero-emission trainsets (Hydrogen/Battery) command a premium of nearly 200%.

- Modern Diesel (Tier 4): $7.0 – $8.0 Million USD (Locomotive only). Lowest entry cost (Amtrak, 2021).
- Dual Power (ALP-45A): $8.8 – $17.0 Million USD (Locomotive only). The wide range reflects recent inflationary pressures and the premium for dual-mode propulsion systems (NJ Transit, 2020; NJ Transit, 2025).
- Battery-Electric: ~$19.3 Million USD (Trainset). High cost due to onboard battery storage capacity (Metra, 2024).
- Hydrogen-Electric: ~$21.2 Million USD (Trainset). Highest vehicle CAPEX due to fuel cell cost and novelty (Caltrans, 2024).

B. Infrastructure Investment (The Barrier to Entry)

Infrastructure costs are the primary driver of project viability. The analysis identifies a massive disparity between technologies that utilize existing tracks versus those requiring full electrification.

Low Barrier (Diesel / Hybrid): $0. Utilizes the existing CPKC rail infrastructure and diesel supply chain.
Scalable Barrier (Dual Power): ~$45 Million USD (Phase 1). Requires electrification only in urban zones (~$9.0M/km) while deferring rural infrastructure costs (Levy, 2018).
Prohibitive Barrier (Battery / Full Electric): ~$1.1 Billion+ USD. Requires continuous overhead catenary systems [OCS] for the entire 300 km corridor, estimated at $3.5M – $8.5M per km depending on complexity (Caltrain, 2018).

Table 4 Comparative Cost Table

Propulsion Technology	*Vehicle Unit Cost (Estimated USD)*	*Infrastructure Barrier (System Cost)*	*Financial Verdict*
1. Modern Diesel (Tier 4)	$7.0 – $8.0 Million (Locomotive)	None. Uses existing fueling depots.	Baseline. Lowest entry price but highest long-term carbon tax exposure.
2. Diesel/Electric Hybrid	$10.0 – $15.0 Million (Trainset)	None. Uses existing fueling depots.	Best Value Moderate vehicle premium yields immediate fuel savings with zero infrastructure spend.

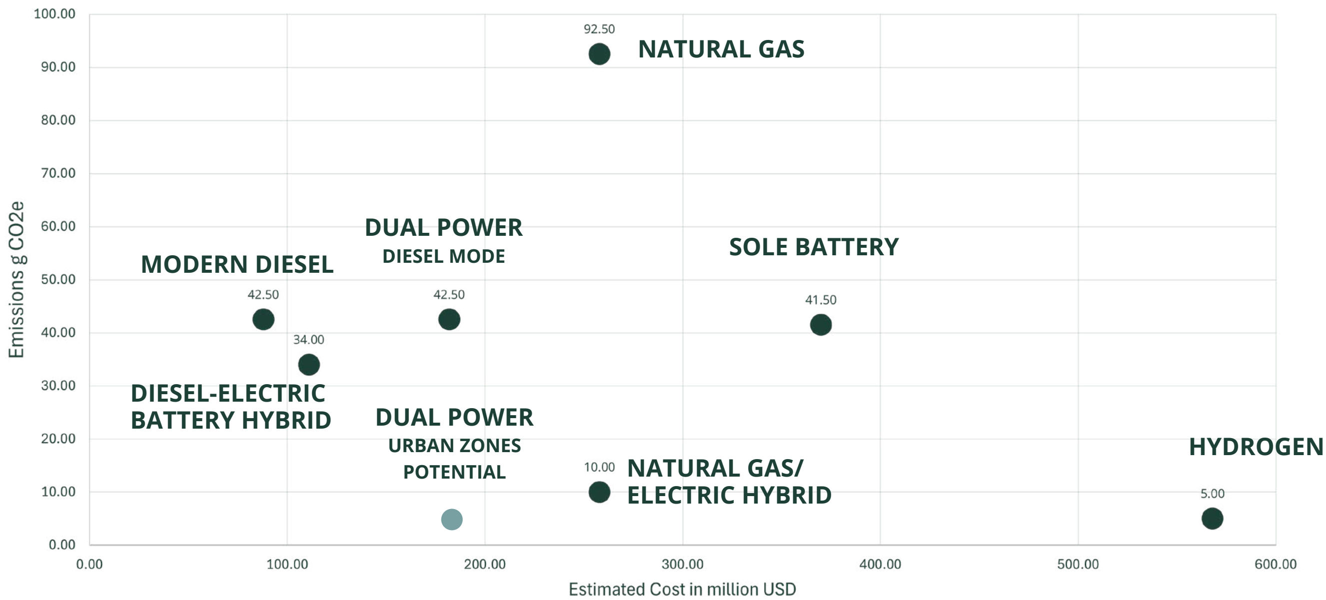
Propulsion Technology	*Vehicle Unit Cost (Estimated USD)*	*Infrastructure Barrier (System Cost)*	*Financial Verdict*
3. Natural Gas (LNG)	~$8.6 Million (Freight Proxy)	High. Requires new cryogenic fueling depots.	N/A Cheaper fuel is offset by the expense of new infrastructure and poor emissions.
4. Gas/Electric Hybrid	~$5.5 Million (Freight Proxy)	Very High. Requires cryogenic depots + dedicated Renewable Natural Gas (RNG) supply chain.	N/A Relies on a non-existent, premium-priced fuel network to be viable.
5. Dual Power (ALP-45A)	$8.8 – $17.0 Mil-lion (Locomotive)	Scalable. Requires ~$45M (Urban) to launch; defers $1B+ (Rural) until future phases	Strategic. High unit cost is justified by the massive savings on avoided infrastructure.
6. Hydrogen-Electric	~$21.2 Million (Trainset)	Very High. Requires new high-pressure production, storage, and fueling network (~$50M+).	High Risk. The highest vehicle cost. Infrastructure has high costs.
7. Battery-Electric	~$19.3 Million (Trainset)	Prohibitive. Requires full corridor electrification (~$1.1 Billion+).	Cost Prohibitive.

Note. Unit costs for locomotives are estimated based on 2024 North American market averages for CFR 49-compliant rolling stock (Railway Age, 2024; Stadler, n.d.). Infrastructure estimates for Full Electric (Catenary) are derived from regional rail modernization benchmarks of ~$2.5 million USD per track-kilometer (Levy, 2018; Stats Market Research, 2025). Hydrogen and LNG infrastructure costs include onsite production, storage, and liquefaction facilities required for heavy-rail applications (California Air Resources Board, 2014; IEA, 2024; Sandia National Laboratories, 2021). Battery infrastructure costs account for rapid-charging substations and grid upgrades (Natural Resources Canada, 2025). The fleet requirement of 12 units is calculated to meet the peak frequency demands projected by the Gravity Model Analysis (Arduin & Fryer, 2025).

The CAPEX modelling highlights that the primary barrier to decarbonization is not the cost of the trains, but the cost of the infrastructure. While fully electric solutions offer the highest long-term efficiency, prohibitive upfront requirement for full corridor electrification (~$1.1 billion) of some technologies categorizing them as unviable for a Day 1 launch. For the contrary, while standard Diesel minimizes initial risk, it creates a dead end asset with no future value as it seen in Figure 1

This analysis confirms that the optimal financial strategy is not merely to minimize vehicle unit price, but to focus on the infrastructure dependency. This insight sets the stage for the final quantitative step: merging the environmental benefits of the LCA with these financial constraints to visualize the ultimate strategic trade-off in the Cost vs. Emissions (Table 5)

Figure 1 Scatter Chart between Emissions and Costs in Million USD



Note: Primary Source. Scatter Chart between Emissions and Costs in Million USD. Dual Power in Diesel mode and urban zones electric mode potential.

Table 5 Comparative Cost Table

Propulsion Technology	*Benefit*	*Rationale*
Modern Diesel (Tier 4)	Low Cost / Low Bene-fit	Pre Selected Cheap to buy and run today, but fails all future 2050 climate mandates.
Diesel/Electric Hybrid	Low Cost / Med Bene-fit	Pre Selected The most capital-efficient way to reduce emis-sions (~20%) today, without building new infrastructure.
Dual Power	Scalable Cost / Scala-ble from Med to High Benefit	Pre Selected Starts with moderate benefits (Urban Zones) but automatically improves to High Benefit as the grid cleans and infrastructure expands.
Natural Gas (using LNG) **Gas Hybrid (using RNG)**	High Cost / Negative Benefit	High infrastructure spending for a solution that is either dirtier than diesel (LNG) or relies on phantom fuel supplies (RNG).
Hydrogen **Battery-Electric**	Very High Cost / High Benefit	The idealistic and perfect environmental solutions are blocked by the impossible financial barrier of day 1 infrastructure costs ($1.1B+).

Note: The Dual Power (ALP-45A) values represent the conservative "Phase 1" scenario (operating primarily in diesel mode with urban electric zones). As more of the corridor is electrified in future phases, the "Generated Rail Emissions" will decrease, and the "Net Annual Savings" will increase.

Based on the quantitative trade-offs established previously, the analysis retrieves the following candidates: Diesel-Electric Hybrid, due the lowest capital cost, Battery Electric due the highest environmental potential, and Dual Power, due its strategic feasibility. The following Qualitative Analysis will assess the candidates to the PESTEL Framework against Alberta's unique context to ensure the feasibility of this project.

CHAPTER 4
QUALITATIVE ANALYSIS

This section assesses the external macro-environmental influences on the Calgary-Edmonton passenger rail project by applying the PESTEL framework, which examines Political, Economic, Social, Technological, Environmental, and Legal factors. Although the quantitative analysis sets Diesel-Hybrid trains as the most cost-effective option for immediate implementation, a broader qualitative review uncovers significant strategic risks that ultimately support the adoption of Dual Power technology instead.

1. POLITICAL

Focus on Regulatory & Policy Environment.

Federal vs. Provincial Friction

The project faces a complex regulatory landscape characterized by conflicting government targets. While the Federal Clean Electricity Regulations require the power grid to reach net-zero emissions by 2035, the Alberta government opposes this timeline, instead aiming for 2050 to maintain reliable and affordable electricity (Government of Alberta, 2024). This disagreement introduces significant risk for fully battery-electric trains, as their eligibility for environmental funding depends on the power grid becoming green much faster than the province currently plans to allow.

Sovereignty Act Risk

The implementation of the Alberta Sovereignty Act introduces potential legal uncertainty for infrastructure projects that rely on federal funding, particularly if those projects appear to conflict with provincial energy objectives (Government of Alberta, 2023a). To mitigate this, adopting a technology with independent operational capabilities, such as the diesel mode available in Dual Power locomotives, offers a strategic safeguard against the risks associated with these disputes between levels of government.

Funding Alignment

Access to the Canada Infrastructure Bank [CIB] requires projects to demonstrate significant GHG reductions and “green” credentials (CIB, 2020). A standard diesel fleet would likely disqualify the project from billions in low-interest federal loans, necessitating a zero-emission capable solution.

2. ECONOMIC

Focus on Market & Financial.

Carbon Pricing Exposure

As the federal government mandates the carbon price to reach $170 per tonne by 2030 (Government of Canada, 2021), organizations must anticipate a fundamental shift in the economics of fleet management. While standard diesel locomotives currently require a lower investment (CAPEX) compared to green alternatives, due the escalating cost of carbon emissions that will inflate operational expenses over service life of a fleet.

Infrastructure Inflation

The construction sector in Western Canada is currently facing inflationary pressure, with non-residential building costs rising approximately 4.0% year-over-year due to labour shortages and material price volatility (Statistics Canada, 2025). In order to manage this uncertainty, the phased electrification strategy, made possible by Dual Power technology, serves as a critical risk mitigation tool. By adopting this approach, the project can strategically delay heavy investment required for rural electrification infrastructure, postponing these costs until funding is solidified.

Green Bond Eligibility

Global investment markets are increasingly mandating adherence to green bond standards as a condition for funding. Frameworks such as the Climate Bonds Standard and the Green Bond Principles explicitly exclude fossil fuel-dependent transport from green certification (International Capital Market Association [ICMA], 2025). Also, projects relying on fossil fuel combustion risk significantly higher borrowing costs and exclusion from Environmental, Social, and Governance [ESG] portfolios (RBC Global Asset Management, n.d.). This will limite their ability to secure capital.

3. SOCIAL

Focus on Public Acceptance & Health.

Social Approval in Urban Areas

Residents in dense, high-value urban corridors like Old Strathcona in Edmonton and Bridgeland in Calgary have a low tolerance for noise and diesel pollution (Railway Association of Canada, n.d.). Municipal approval for new rail rights-of-way often hinges on minimizing these local impacts.

Zero-Emission Zones [ZEZs]:

Cities in Canada, for example, Montreal, are increasingly exploring ZEZs to combat local air pollution. A Dual-Power train running in electric mode can operate as a good neighbour in these zones, securing the political support that a noisy diesel train would otherwise alienate (C40 Cities, 2024).

4. TECHNOLOGICAL

Focus on Innovation & Readiness.

Cold Weather Reliability

Winters in Alberta, with temperatures dropping to -40°C, is an unique challenge. Hydrogen fuel cell systems face risks of water management freezing, and battery-electric trains suffer from significant range loss due to heating demands (Power Progress, 2024). Diesel engines, and the diesel component of Dual Power, offer proven reliability in these extreme conditions.

Grid Dependency

A pure battery-electric fleet is 100% dependent on the grid. In the event of a grid failure, Dual Power provides operational redundancy, ensuring service continuity by utilizing diesel during power disruptions.

5. ENVIRONMENTAL

Focus on Climate & Ecosystems

The Commit Risk

Buying a standard diesel fleet today commits to the emissions for 30 years. In contrast, a Dual Power fleet is a dynamic asset; its life-cycle emissions automatically decrease as the Alberta grid decarbonizes (from 470 g/kWh today to net-zero by 2050), ensuring that the project remains aligned with long-term climate goals without requiring a mid-life fleet replacement for this purpose.

Local Air Quality

Beyond global GHGs, the project must address local air quality. Reducing Nitrogen Oxides [NOx], a precursor to smog, and Particulate Matter [PM2.5] is a key health priority for Alberta Health Services (Poirier et al., 2017). Electric operations in cities directly address this by eliminating tailpipe emissions where population density is highest.

6. LEGAL

Focus on Compliance & Standards.

Railway Safety Act

Any new technology, such as hydrogen or battery-electric, triggers rigorous and lengthy safety reviews under the Railway Safety Act (Transport Canada, 2025). Dual Power locomotives (like the ALP-45A) are already fully certified and compliant with CFR 49 Part 238 safety standards, offering a faster and lower-risk path to regulatory approval.

Impact Assessment Act

Major infrastructure projects trigger federal impact assessments. A project that can demonstrate a credible path to net-zero (like Dual Power) will face fewer regulatory hurdles and delays than one that relies on fossil fuels or unproven false economies like Natural Gas (Canadian Climate Institute, 2024).

The PESTEL analysis shows the next layer needed to assess qualitative results with strategic feasibility. On the one hand, traditional propulsion options offer financial stability. On the other hand, fail to meet the essential political and social mandates for decarbonization and noise reduction. The finding of this analysis: fully zero-emission technologies satisfy these environmental demands but currently face prohibitive costs that present infrastructure barriers and regulatory risks in Alberta.

The disconnection between financial reality and strategic viability indicates that no single-mode technology assessed can secure the project’s long-term success. Moreover, the optimal solution must be a hybrid strategy capable of navigating these competing constraints. On the following section of this report it will be presented the specific technology recommendation and implementation roadmap.

CHAPTER 5
Recommendations & Implementation Strategy

Note: Image of a 3D Model of the Locomotive Dual Power ALP-45A (Turbosquid, 2025)

5.1. TECHNOLOGY RECOMMENDED: DUAL POWER

After evaluating the financial costs, environmental impact, and long-term strategy, this report advises selecting Dual Power locomotives for the Calgary-Edmonton passenger line. While standard Diesel-Electric Hybrids have less CAPEX upfront and currently produce fewer emissions, given the nature of Alberta's electricity grid, Dual Power technology uniquely bridges the gap between immediate affordability and the mandatory goal of decarbonization by 2050. This choice will ensure the rail service remains viable regardless of how the energy market or government policies evolve, while offering three specific benefits:

- **Political Viability:** It enables immediate Zero-Emission Zones in sensitive urban cores, securing the social approval in urban areas from municipalities.
- **Capital Efficiency:** It allows for a phased electrification strategy, deferring over $1 billion USD in rural infrastructure costs while still launching a modern, electric-capable service (Levy, 2018).
- **Futureproofing:** Unlike a standard diesel fleet, which is committed to a fossil-fuel profile, a Dual Power fleet is a dynamic asset. Its life-cycle emissions will automatically decrease annually as the Alberta grid adds renewable capacity, ensuring compliance with the federal Net-Zero 2050 mandate without requiring a mid-cycle fleet replacement (Government of Canada, 2024).

5.2 PHASED ROLLOUT ROADMAP

To maximize the benefits of Dual Power while minimizing initial financial risk, it is recommended that a three-phase rollout of the infrastructure be implemented. This strategy aligns capital expenditure with ridership growth and grid decarbonization.

Phase 1: Project Launch at Urban Quiet Zones (Years 1-5)

Objective: To establish zero-emission, quiet operations in high-density city centers to secure municipal support and improve local air quality.
Infrastructure Scope: Electrification of approximately 3-5 km at each terminus.

Edmonton: Government Centre ⟷ Strathcona

Calgary: Downtown Terminal ⟷ Inner City Periphery

Operational Profile: Trains switch to Electric Mode upon entering the urban boundary and switch to Diesel Mode (Tier 4) for the high-speed rural segments.
Estimated CAPEX: ~$44.4 million USD. Infrastructure only.
Rationale: This targeted investment delivers sound political value, aiming for quiet cities, for less than 5% of the total electrification cost (Caltrain, 2018).

Phase 2: Commuter Expansion (Years 5-10)

Objective: Extend electric service to high-frequency commuter hubs as ridership revenue stabilizes.
Infrastructure Scope: Extension of the Overhead Catenary System in the North Segment (Edmonton): Extending the overhead catenary from the urban core (Phase 1) to Leduc requires covering the 30.7 km commuter corridor. South Segment (Calgary): Extending the overhead catenary from the downtown terminal (Phase 1) out to Airdrie requires covering the 36.4 km commuter corridor (Arduin & Fryer, 2025).
Operational Profile: 90% of daily commuter trips are operated with the highest frequency service, which operates with zero tailpipe emissions - conditional to the Alberta grid status. The stationary switch occurs at Leduc and Airdrie stations during scheduled stops.

Phase 3: The Net-Zero Corridor (Year 20+)

Objective: Full decarbonization in alignment with federal 2050 mandates.
Infrastructure Scope: Electrification of the remaining rural areas, such as the Red Deer region. However, in scenarios where expanding the electrical grid proves economically unfeasible due to high costs, the initiative can still maintain its commitment to zero-emission standards by pivoting to alternative energy solutions, such as biofuels.
Operational Profile: 100% Zero-Emission operation.

5.3 RISK MANAGEMENT

Although the Dual Power recommended strategy lowers the high upfront costs of full electrification, no infrastructure project of this size is immune to external threats. This mitigation section discusses the primary risks that the Alberta Regional Rail service faces, including regulatory, operational, environmental, and financial risks. It also explains how the chosen technology's built-in flexibility protects against each of these risks.

A. Regulatory Risk

Risk: The ongoing friction between the Federal Net-Zero 2035 mandate and the Provincial 2050 target creates a volatile regulatory environment. A pure battery passenger rail project could become a stranded asset if provincial grid decarbonization slows, while a pure Diesel fleet faces penalties under federal Clean Electricity Regulations

Mitigation: Dual Power technology ensures compliance with federal mandates in urban centers (Zero-Emission Zones) while maintaining the ability to operate under provincial energy policies in rural corridors, securing the project's viability regardless of future government decisions

B. Operational Risk

Risk: Alberta's electricity market is subject to price spikes and capacity alerts, particularly during extreme weather events (AESO, 2025). A 100% electric fleet would be vulnerable to grid instability or prohibitive peak-hour pricing.

Mitigation: The locomotive's diesel engines provide embedded redundancy. In the event of a grid failure or extreme price surge, the operator can switch to diesel power to maintain schedule integrity. This capability converts service cancellation events into mode switch events, protecting passenger trust (Stadler, n.d.).

C. Environmental Risk: Extreme Weather Performance

Risk: Temperatures of -40°C can cause icing on overhead catenary wires, rendering them unusable for electric traction, a known failure point for light rail systems in similar climates (Network Rail, 2024).

Mitigation: During severe winter storms when icing compromises the catenary connection, Dual Power trains can drop their pantographs and operate seamlessly on diesel power. (RailTEC, n.d.).

D. Financial Risk: Construction Inflation

Risk: Western Canada's construction sector is facing inflation rates of ~4% annually, threatening the budget of large-scale linear infrastructure projects.

Mitigation: By deferring rural electrification, the project avoids locking in over $1 billion of infrastructure costs at peak inflationary pricing. This allows the project to wait for market stabilization and revenue generation before committing to the most expensive segment of the build.

The project turns potential failure points into manageable operational decisions by building redundancy directly into the propulsion technology and phasing capital investment. This multi-layered plan for reducing risk makes sure that political deadlock, grid instability, and extreme weather will not hurt the service's long-term viability. This gives stakeholders the confidence they need to move forward.

CONCLUSIONS

The feasibility analysis of the Calgary-Edmonton Passenger Rail Service reveals that a successful launch depends on navigating a critical tension between environmental ambition and financial reality. While the corridor's current situation is translated to a massive environmental liability of 1,628 kT of CO2e annually, the traditional solution of full electrification presents a prohibitive capital barrier ($1.1 billion USD) that threatens the project's economic viability from the outset.

The study determines that Dual Power (ALP-45A) propulsion is the optimal technology to resolve the decarbonization mandates in the particular Alberta context. Unlike standard diesel options, which offer low costs but fail to meet future climate mandates, and full electrification, which is currently unaffordable and misaligned with Alberta's high-carbon grid, Dual Power offers a strategic middle path. This technology secures the necessary social license to operate by enabling Zero-Emission Quiet-Zones in sensitive urban centers immediately, while simultaneously deferring over $1 billion in rural infrastructure costs until ridership revenue stabilizes.

Critically, this approach futureproofs the fleet against regulatory risk. As a dynamic asset, the environmental performance of the Dual Power locomotive improves in tandem with the development of the Alberta electricity grid. This ensures that the service remains compliant with federal Net-Zero 2050 mandates without requiring a mid-life fleet replacement, avoiding the risk of creating stranded assets.

To operationalize this strategy, the report recommends a Phased Rollout Roadmap. By restricting initial electrification to just 3–5 km at urban terminuses in Phase 1, the project can deliver high-value environmental benefits where they matter most in densely populated areas, while maintaining fiscal responsibility. This strategy transforms the rail service from a theoretical ideal into an executable, financially sustainable reality, balancing the immediate needs of the province with its long-term environmental obligations

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Appendix

Appendix 1

LCA Corridor for Vehicles Internal Combustion

Life Cycle Stage	*Personal Vehicle Internal Combustion Engine*	*Total emissions in (KT CO_2e)*
Manufacturing	15%	243.67
Well-to-Wheel (WTW)	80%	1,299.56
End-of-Life (EOL)	5%	81.22

Note: : Elaborated with emissions from Transportation Arrangement: An AADT Analysis, Emissions Study and the impact of COVID-19 on the Calgory-Edmonton corridor (Sun, 2024)

Appendix 2

LCA Corridor for Buses Diesel

Life Cycle Stage	*Personal Vehicle Internal Combustion Engine*	*Total emissions in (KT CO_2e)*
Manufacturing	5%	0.20
Well-to-Wheel (WTW)	95%	3.87
End-of-Life (EOL)	2%	0.08

Note: : Elaborated with emissions from Transportation Arrangement: An AADT Analysis, Emissions Study and the impact of COVID-19 on the Calgory-Edmonton corridor (Sun, 2024)

Appendix 3

LCA Corridor total

Life Cycle Stage	*Personal Vehicle Internal Combustion Engine*	*Total emissions in (KT CO_2e)*
Manufacturing	243.87	14.89
Well-to-Wheel (WTW)	1,303.43	79.59
End-of-Life (EOL)	81.30	4.96
Highways	9.11	0.56

Note:: Elaborated with emissions from Transportation Arrangement: An AADT Analysis, Emissions Study and the impact of COVID-19 on the Calgory-Edmonton corridor (Sun, 2024)

Appendix 4

Calculating Methane Slip in Natural Gas (LNG)

Natural Gas (LGN) produces ~70 g CO_2 /p-km. In addition, in the current profile analysis, it was identified that Methane Slip is a major contributor of GHG, and the assumption of CO_2e ~92.5 g/p-km (being worse than diesel) is due to a penalty given for the small amounts released during burning. (FRA/Argonne report - Federal Railroad Administration, 2020)

Methane is ~23x more potent (as a GHG) than CO_2e (FRA/Argonne report - Federal Railroad Administration, 2020). The penalty of the Methane Slip for this report was calculated in the worst case scenario band, in locomotives with high end of methane slip:

Combustion CO_2 base (~70g/p-km) + Methane Slip ~23x (high end methane slip for a locomotive is ~3.5 - 4%) = ~ 92.5 g /p-km

The FRA/Argonne report (Federal Railroad Administration, 2020) states that while natural gas offers significant CO_2 benefits, methane slip is a major performance and emissions risk that can negate the greenhouse gas reductions unless specific technologies in locomotives are applied to mitigate it.

Appendix 5

Calculating the annual share of manufacturing emissions

Based on the 2023 data, the total annual distance travelled on Highways 2 and 2A by personal vehicles and buses in kilometres is:

Type of Vehicle	*Highway 2:*	*Highway 2A:*	*Total Annual*
Personal Vehicle	3,238,285,201 km	397,310,450 km	3,635,595,651 km
Buses	7,093,201 km	908,342 km	8,001,542 km

External data inputs (Total annual VKT/lifespan) x Average manufacturing emissions = total annual emissions

Total emission corridor for Year 2023

Corridor segment	*2023 Total emissions (KT CO_2e)*	*Personal Vehicles (KT CO_2e)*	*Buses (KT CO_2e)*
Highway 2	1,439.14	1,435.54	3.60
Highway 2A	189.38	188.91	0.47
Full corridor	1,628.52	1,624.45	4.07

Note: Elaborated with emissions from Transportation Arrangement: An AADT Analysis, Emissions Study and the impact of COVID-19 on the Calgory-Edmonton corridor (Sun, 2024)

Calculations of Annual Impact Emissions

Green Hydrogen (10 g/p-km): 354.1M p-km × 10 g = 3,541 tonnes CO_2e / year
Diesel/Battery Electric Hybrid (avg. 34 g/p-km): 354.1M p-km × 34 g = 12,040 tonnes CO_2e / year
Sole Electric Battery - Alberta Grid (41.5 g/p-km): 354.1M p-km × 41.5 g = 14,696 tonnes CO_2e / year
Modern Diesel (avg. 42.5 g/p-km): 354.1M p-km × 42.5 g = 15,050 tonnes CO_2e / year
Dual Power (Diesel Mode) (avg. 42.5 g/p-km): 354.1M p-km × 42.5 g = 15,050 tonnes CO_2e / year
Hydrogen (Grey H_2) (90 g/p-km): 354.1M p-km × 90 g = 31,869 tonnes CO_2e / year
Natural Gas/Electric (avg. 92.5 g/p-km): 354.1M p-km × 92.5 g = 32,754 tonnes CO_2e / year

The total transport work of 354.1 million p-km is derived from the Gravity Model Arduin & Fryer (2025), with a ridership forecast of 5.2 million annual passengers, assuming a weighted average trip length of approximately ~68 km - ~70 km.