Financial Analysis of Transitioning to Battery Electric Fire Service Vehicles

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of City of Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of City of Vancouver or the University of British Columbia.

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It is essential to reflect critically on the spaces where we live, work, and play. These lands, rich in heritage and deep cultural significance, offer us invaluable resources and inspiration that directly influence and enhance our work.

Engaging in this project on these lands, I am reminded of my own positionality and the privileges I hold through the access and use of this land, which is not my ancestral home. It is a privilege to be able to learn, grow, and create in this space, and with this privilege comes the responsibility to support the ongoing efforts of reconciliation, decolonization, and antiracism.

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Cover photo by DALL·E.[1]

[1] This image was created with the assistance of DALL·E 2.

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Abbreviations

VFRS	Vancouver Fire Rescue Services
EV	Electric Vehicles
BEV	Battery Electric Vehicle
ICEV	Internal Combustion Engine Vehicles
CEAP	Climate Emergency Action Plan
LCA	Lifecycle Cost Analysis
CCAS	Climate Change Adaptation Strategy
GHG	Greenhouse Gas
FMS	Fleet and Manufacturing Services

I. Executive Summary

This report presents a comprehensive financial analysis of the transitioning the Vancouver Fire Rescue Services (VFRS) fleet to electric vehicles (EVs). The project objectives centered on comparing battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEVs) across several dimensions, including capital costs, operational savings, and environmental impact. By analyzing data from current fleet operations, constructing financial models, and reviewing global case studies, the study offers a robust assessment of the potential for this transition.

The findings indicate that while BEVs entail a higher initial capital cost, this is effectively balanced by longer vehicle lifespans, substantial operational savings, and available government incentives. Specifically, BEVs present lower monthly maintenance expenses and more stable energy costs, contributing to a more predictable financial outlook over time. Moreover, the shift to BEVs aligns with broader environmental goals, notably through significant reductions in CO_2 emissions, which in turn offer indirect benefits such as lower healthcare costs and enhanced public health outcomes.

Considering these findings, it is recommended that VFRS prioritize the replacement of high-cost, low-efficiency ICEVs, leveraging available incentives to mitigate the initial financial outlay. Additionally, strategic investments in infrastructure, particularly in the installation of charging stations at key fire halls, will be essential. Furthermore, providing specialized training for staff on the operation and maintenance of EVs will ensure a smooth transition. A phased implementation plan, initiated with high-impact vehicle replacements and infrastructure upgrades, is advised to facilitate a cost-effective and manageable transition.

In conclusion, the transition to an electric fleet offers VFRS clear financial and environmental advantages. While the upfront costs are higher, the long-term savings in maintenance and operational expenses, coupled with significant environmental benefits, make a compelling case for adopting EVs. With careful planning and a phased approach, VFRS can realize a sustainable, cost-effective, and environmentally responsible fleet, positioning itself in alignment with the city’s broader goals for sustainability and public health.

II. Introduction

2.1 Background

Climate mitigation involves ongoing efforts to limit climate change by reducing greenhouse gas emissions in the atmosphere. The City of Vancouver has been at the forefront of climate change mitigation since the 1990s, showcasing a long-standing commitment to environmental sustainability. This dedication is embodied in the Climate Change Adaptation Strategy (CCAS), which aims to cut Vancouver's carbon pollution by 50% by 2030 and achieve carbon neutrality by 2050 (City of Vancouver, Climate change adaptation strategy 2024-2025 update and action plan, 2024).

The Climate Emergency Action Plan (CEAP), as detailed in the Council's 2024 Climate Budget report, includes a series of strategic carbon reduction actions known as "Big Moves" (City of Vancouver, 2023). One key initiative, Big Move 3, focuses on Zero Emission Vehicles, with a target that 50% of the kilometers driven on Vancouver's roads will be by zero emissions vehicles by 2030. This initiative highlights the city's commitment to reducing its carbon footprint through transformative changes in transportation.

The CCAS and the CEAP prioritize investments in initiatives with substantial climate impacts. One significant focus area is the deployment of EV-charging infrastructure and the electrification of the City's fleet and equipment. The 2023-26 Capital Plan earmarks $14.4 million for Climate Priority investments specifically aimed at vehicle and equipment electrification within the City fleet (City of Vancouver, 2023).

The City Council has established a comprehensive program to minimize the environmental impact of the City's vehicles and heavy equipment. This program has already produced notable results; in 2020, Vancouver exceeded its Greenest City target by achieving a 43% reduction in emissions below 2007 levels, surpassing the initial goal of a 30% reduction. The City now aims to further reduce fleet emissions to 60% below 2007 levels by 2030 and transition to 100% renewable energy usage by 2050 (City of Vancouver, Green fleets, n.d.).

Efforts to green the City's fleet are structured around three main pillars: fueling the fleet, electrifying the fleet, and utilizing the fleet efficiently. These pillars guide the City's strategy for integrating sustainable practices into fleet management, ensuring that each vehicle and piece of equipment contributes to the overarching goal of significant emissions reduction (City of Vancouver, Green fleets, n.d.).

As part of this initiative, VFRS is integrating EVs into its fleet. In December 2023, VFRS introduced Canada's first electric fire engine, marking a significant step towards reducing greenhouse gas emissions and improving air quality (City of Vancouver, 2023). This initiative demonstrates Vancouver's commitment to sustainability and innovation in emergency services.

VFRS is recognized as a world-class leader in building safe and healthy communities. Committed to the health and safety of both its staff and the community, VFRS enhances awareness through education and involvement while delivering premier fire and rescue services. Beyond fire suppression, VFRS provides pre-hospital care, vehicle rescue, marine response, hazardous materials response, technical rescue, and various other emergency services. The organization also works to create safe communities through public education, fire prevention and inspection services, and collaboration with partner agencies and community groups (City of Vancouver, Vancouver Fire Rescue Services, n.d.).

2.2 Purpose of the Study

The primary aim of this research is to conduct a comprehensive financial analysis of transitioning from traditional combustion engine fire service vehicles to BEVs within the VFRS fleet. This study seeks to evaluate both the capital and operational costs associated with BEVs, compared to their traditional counterparts, to determine the overall lifecycle costs. By quantifying these costs, the research will provide insights into the financial viability and potential savings of adopting an electric fleet. Additionally, the study will explore the broader environmental and social benefits, including the reduction in greenhouse gas emissions and improvements in air quality.

This research is significant because it aligns with the City of Vancouver's climate mitigation strategies and goals, particularly under the CEAP. By analyzing the deployment and performance of electric fire service vehicles, the study will support the city's objectives of reducing carbon pollution and transitioning to renewable energy sources. Furthermore, it will provide data-driven recommendations for optimizing the phased implementation of electric vehicles in the VFRS fleet, potentially serving as a model for other municipalities looking to make similar transitions.

2.3 Project Objectives

- Evaluate Lifecycle Costs: To assess the capital and operational costs of electric fire service vehicles compared to traditional combustion engine vehicles.
- Quantify Benefits: To quantify the benefits of transitioning to an electric fleet, including operational savings and environmental impact.

- Global Research and Recommendations: To research the deployment of electric vehicles in other fire services globally and develop optimization recommendations for the phased implementation of electric vehicles into the VFRS fleet.

2.4 Project Scope

- Reviewing and summarizing capital and operational costs of in-service electric vehicles and the associated infrastructure (~10%).
- Reviewing and summarizing capital and operational costs and performance (call volumes, response times, and vehicle downtime) of current fossil fuel powered vehicles (~30%).
- Analyzing and summarizing the performance and operational costs of the electric fire engine during the first few months of service and comparing the data to conventional engines (~30%).
- Researching electric vehicles deployed in other fire services globally and providing recommendations on how to optimize the VFRS fleet for electric vehicles. If available, focus will be on the following metrics: capital, maintenance, and infrastructure costs, fuel / electricity use, vehicle downtime, and emergency response times. (~30%)

III. Methodology

Literature Review

The methodology commenced with an extensive literature review to acquire a solid understanding of the existing body of research on EVs, particularly in the context of lifecycle cost analysis, environmental impacts, market dynamics, and manufacturer developments. This foundational step helped to frame the study within the current research landscape and informed the subsequent stages of the analysis.

Data Collection and Analysis

Data collection was a critical phase, involving the gathering of detailed information on both electric and traditional internal combustion engine (ICE) vehicles used by the VFRS. Data sources included internal VFRS databases such as the M5 system, insights from Fleet and Manufacturing Services (FMS) staff, manufacturer specifications, as well as external sources like research papers, newspapers, and reputable websites.

The collected data focused on key performance indicators (KPIs) across various dimensions:

- Financial Metrics: These included initial acquisition costs, incentives, maintenance expenses, and insurance premiums.
- Operational Performance Metrics: Metrics such as call volumes, response times, and vehicle downtime were analyzed to assess the operational efficiency of the fleet.
- Sustainability Metrics: Environmental benefits, including reductions in greenhouse gas emissions, were evaluated to quantify the sustainability advantages of transitioning to EVs.

The data was then systematically analyzed to draw comparisons between electric and traditional vehicles, identifying trends, anomalies, and patterns that informed the subsequent financial modeling and case study analysis.

The equipment capital data provides a detailed financial overview of the fleet's assets, including key metrics such as acquisition costs, depreciation terms, and residual values.

Within this dataset, each unit is uniquely identified by an equipment number (EquipNum), allowing for precise tracking of individual assets. Furthermore, the type of vehicle (e.g., fire trucks, ladder trucks) included in the dataset allows for a detailed comparison across different categories of equipment.

The fuel data encompasses detailed records of fuel consumption for each vehicle unit, categorized by type of fuel, and tracked on a monthly basis. The amount of fuel dispensed and its associated cost are essential for evaluating the operational efficiency of the fleet.

The maintenance and repairs data provide a comprehensive overview of the costs incurred in maintaining the fleet. Important fields such as labor and parts costs, sublet repair expenses, and miscellaneous costs are tracked for each equipment unit.

Insurance premiums represent a significant operational cost for the fleet, and **the insurance data** tracks these costs on an annual basis for each vehicle unit.

Financial Modeling

Financial models were developed to project the long-term costs and potential savings associated with transitioning the VFRS fleet to electric vehicles. The Total Cost of Ownership model was the primary tool used to evaluate the cost-effectiveness of electric vehicles over their expected lifecycle. This model incorporated all relevant cost components, including capital costs (adjusted for incentives), maintenance, energy, and insurance expenses. The financial analysis provided a detailed comparison of the long-term economic impacts of maintaining an ICEV fleet versus transitioning to EVs.

Case Study

Global case studies were researched and analyzed to gain insights into the experiences of other fire services that have adopted electric vehicles. These case studies offered valuable lessons on best practices, challenges faced, and the outcomes of implementing electric vehicles in fire service operations. The findings from these case studies helped to contextualize the financial and operational analysis conducted for the VFRS.

Recommendations and Reporting

Based on the comprehensive analysis, a set of actionable recommendations was developed to guide VFRS in transitioning to an electric fleet. These recommendations considered the financial viability, operational feasibility, and sustainability benefits of EVs. A phased implementation plan was proposed to ensure a smooth and cost-effective transition. The findings and recommendations were compiled into detailed reports and presentations to effectively communicate the proposed transition strategy to stakeholders.

Limitations

The research methodology acknowledges certain limitations. The analysis was based on available data, which may not encompass all variables influencing vehicle performance and costs. Additionally, projections made in the financial modeling are subject to uncertainties, such as future energy prices and technological advancements. The data set was also limited to a subset of vehicles with available matching data, which may not represent the entire fleet’s performance. Despite these constraints, the methodology aimed to provide a robust and comprehensive evaluation of the potential transition to an electric fleet for VFRS.

IV. Literature Review

4.1 Lifecycle Cost Analysis

The lifecycle cost analysis (LCA) of EVs versus traditional ICEVs has been extensively studied. This section summarizes key research findings on the cost components and overall financial implications of transitioning to electric fire service vehicles.

Ayodele and Mustapa (2020) provide a comprehensive review of the LCA of EVs, highlighting the various cost components involved. They categorize the lifecycle costs into tangible and intangible costs. Tangible costs include purchase cost, retail cost, and operating cost, while intangible costs encompass purchase restrictions and driving restrictions. Their framework emphasizes the comprehensive nature of LCA, accounting for initial purchase costs, energy consumption, maintenance, taxes, and insurance. They also compare other frameworks, such as those developed by Diao et al. (2019) and Kara and Sadjiva (2020), noting similarities and differences in the inclusion of intangible costs and subsidy considerations (Ayodele & Mustapa, 2020).

Yang et al. (2022) conducted a case study in China to assess the cost competitiveness of EVs compared to ICEVs. They found that while EVs generally have higher initial costs, the lifecycle costs can be competitive depending on factors such as battery lifespan, annual driving distances, and advancements in battery technology. Their study also highlighted the impact of external factors like power grid composition on the cost-effectiveness of EVs. The analysis showed that with improvements in the electricity mix and battery technology, the cost of EVs could become lower than that of ICEVs in the long run (Yang, Yu, Malima, et al., 2022).

Several studies have focused on the specific cost components within the LCA framework. For instance, Yang et al. (2022) also outlined the initial, ownership, and disposal costs associated with EVs. They emphasized that initial costs include the manufacturer's suggested retail price, taxes, and subsidies, while ownership costs cover energy, maintenance, and insurance expenses. Disposal costs consider the residual value of vehicles and recycling costs, particularly for batteries. This comprehensive approach ensures that all significant financial aspects are considered, providing a clear comparison between EVs and ICEVs (Yang, Yu, Malima, et al., 2022).

The social and environmental costs of vehicle emissions are also crucial in lifecycle cost assessments. Studies by Zhang and Han (2017) and Hao et al. (2017) indicated that the electricity mix significantly influences the cost competitiveness of EVs. For example, in regions with a high proportion of renewable energy, the lifecycle emissions and associated costs of EVs are lower, making them more competitive compared to ICEVs. These studies highlight the importance of considering external environmental costs, such as emissions from battery production and fuel consumption, in the overall LCA (Zhang & Han, 2017; Hao et al., 2017).

Furthermore, the residual value of vehicles at the end of their lifecycle plays a significant role in the total cost analysis. Nealer et al. (2015) noted that EVs often have residual value due to their components being reusable in other applications, such as energy storage. However, the residual value of EVs is currently challenging to evaluate accurately because many EVs have not yet reached the end of their service life. Despite this, the study suggests that the potential for reuse and recycling of EV components can contribute to lowering the overall lifecycle costs (Nealer et al., 2015).

In conclusion, the existing literature indicates that while EVs typically have higher upfront costs, their lifecycle costs can be competitive with ICEVs, particularly when considering environmental and social benefits. The transition to electric fire service vehicles within the VFRS fleet could lead to significant long-term savings and environmental benefits, aligning with the City of Vancouver's climate action goals.

4.2 Environmental Impact

The transition from ICEVs to EVs has garnered significant attention due to its potential to reduce greenhouse gas (GHG) emissions and improve air quality. Several studies have investigated the environmental impacts of EVs, providing valuable insights into their benefits and challenges.

Hawkins et al. (2012) conducted a comprehensive life cycle assessment comparing the environmental impacts of conventional and electric vehicles. The study highlights that EVs have the potential to significantly reduce GHG emissions, particularly when powered by low-carbon electricity sources. However, the benefits are less pronounced when the electricity is generated from coal, as EVs then tend to have higher SOx emissions compared to ICEVs. The research emphasizes the importance of the electricity grid mix in determining the overall environmental impact of EVs (Hawkins et al., 2012).

Similarly, a study by Buekers et al. (2014) evaluated the societal impact of EV introduction in the EU-27 under different electricity production scenarios. The analysis revealed that countries relying on low air pollutant emitting fuel mixes could gain substantial economic benefits from avoided external costs. In contrast, countries dependent on more polluting fuels might not experience the same level of benefit. This study underscores the regional variability in the environmental advantages of EVs and the significance of clean energy integration (Buekers et al., 2014).

Wu et al. (2019) assessed the life cycle greenhouse gas emission reduction potential of battery electric vehicles in China. The study found that EVs could reduce emissions of CO2, VOCs, and NOx compared to ICEVs. However, the research also pointed out that EVs could lead to higher emissions of PM2.5 and SO2, primarily due to the energy-intensive battery manufacturing process. The findings suggest that while EVs offer considerable climate benefits, attention must be paid to reducing the environmental impacts associated with battery production (Wu et al., 2019).

A case study by Yu et al. (2018) compared the life cycle environmental impacts of electric and gasoline vehicles in China. The study concluded that EVs are more efficient in reducing carbon emissions and improving air quality. However, the research also indicated that the environmental benefits are contingent upon the electricity mix used for charging the vehicles. Regions with higher renewable energy penetration could achieve more substantial reductions in GHG emissions through EV adoption (Yu et al., 2018).

In summary, the transition to electric vehicles presents significant opportunities for reducing greenhouse gas emissions and improving air quality. However, the extent of these benefits is heavily influenced by the electricity grid mix and the environmental impacts associated with battery production and disposal.

4.3 Electric Fire Vehicles

The operational performance of fire vehicles, particularly in terms of response times and vehicle downtime, is critical for ensuring effective emergency response and public safety.

A study by Bowditch, Leonard, and O'Brien (2003) examined the performance measurements of fire trucks during bushfire scenarios in Australia. This research, commissioned by the Country Fire Authority of Victoria and the Rural Fire Service of New South Wales, aimed to enhance fire truck designs to better protect firefighters during bushfire burnovers. Usanov et al. (2019) studied how to dispatch fire trucks in order to strike the right balance between responding quickly to the present fire, while maintaining good coverage for possible simultaneous incidents.

Leading Manufacturers in the Electric Fire Vehicle Market

Rosenbauer and Pierce Manufacturing are among the leading manufacturers in the electric fire vehicle market. As a key player in the fire vehicle industry, Rosenbauer has delivered numerous electric fire trucks worldwide, including to cities like Vienna, Berlin, and Basel. Their vehicles are known for integrating advanced electric drivetrains and backup systems to ensure operational efficiency.

Rosenbauer's RTX electric fire truck represents a significant innovation in firefighting vehicles. Designed from scratch as a pure firefighting vehicle, the RTX features a fully electric drive system and numerous advanced features to enhance operational efficiency and safety. The RTX's electric motors, with a total peak output of 360 kW, provide rapid acceleration, especially in urban environments. Additionally, the vehicle's low center of gravity and balanced axle load distribution ensure high driving stability and reduced accident risks (Rosenbauer, 2023).

Pierce Manufacturing is another significant manufacturer. Pierce has developed the Volterra electric fire truck, which is already in service in Gilbert, Arizona, and Madison, Wisconsin. Pierce focuses on creating flexible and efficient electric vehicles that meet the rigorous demands of fire services.

Volterra electric fire truck utilizes Oshkosh's patented parallel-electric drive train. The Volterra platform is designed to look and operate like traditional fire trucks while integrating electric power for most operations. This approach allows for zero-emissions operation when powered by onboard batteries and ensures continuous and uninterrupted power to the pumping or drive system through an internal combustion engine backup (Pierce Manufacturing Inc., 2023).

Advantages of Electric Fire Vehicles

Electric fire vehicles offer several advantages over traditional internal combustion engine fire trucks. One of the primary benefits is the reduction in greenhouse gas emissions. This reduction is crucial for urban areas with high traffic volumes and dense populations, where air quality improvements are most needed.

Furthermore, electric fire vehicles like the Rosenbauer RTX and Pierce Volterra produce minimal noise and emissions during operation. This feature is particularly beneficial in urban settings, where reduced noise pollution can alleviate stress for both emergency personnel and residents. The emission-free driving capability of these vehicles also contributes to better air quality at emergency scenes, enhancing the overall working environment for firefighters (Rosenbauer, 2023; Pierce Manufacturing Inc., 2023).

The maintenance of electric fire vehicles is another area where they hold an advantage. Electric drivetrains typically have fewer moving parts compared to ICEs, leading to lower maintenance requirements and costs. This reduction in maintenance downtime can result in higher vehicle availability and reliability, which is critical for emergency response services (Ayodele & Mustapa, 2020).

Moreover, the integration of advanced digital solutions in electric fire vehicles, such as Rosenbauer's autonomous Wi-Fi network and RDS Connected Command system, enhances operational coordination and efficiency. Similarly, Pierce's Volterra platform maintains the same drivability and operability as traditional fire trucks, ensuring consistency in training and vehicle operation (Rosenbauer, 2023; Pierce Manufacturing Inc., 2023).

V. Data Analysis

The financial analysis of transitioning to battery electric fire service vehicles involves a comprehensive evaluation of both capital and operational costs. By examining the purchase costs, depreciation terms, and residual values, we gain insights into the initial and ongoing financial commitments required for maintaining a fleet of fire service vehicles. Electric vehicles, while potentially having higher initial costs, may benefit from different depreciation patterns and higher residual values, contributing to a more favorable long-term financial outlook.

Operational costs, including fuel, maintenance, and insurance expenses, are critical in assessing the total cost of ownership. Electric vehicles typically incur lower fuel and maintenance costs due to their more efficient energy use and simpler mechanical structures. Insurance costs, while varying based on several factors, can also impact the financial viability of transitioning to electric vehicles. Detailed analysis of these costs, supported by vehicle performance metrics such as response time and travel time, provides a clear understanding of the financial benefits and challenges associated with adopting electric vehicles in the fire service fleet.

By integrating these financial and performance metrics, we can make informed decisions about the transition to battery electric fire service vehicles, ensuring that the VFRS fleet is optimized for both cost-efficiency and operational effectiveness. This comprehensive financial analysis will support strategic planning and investment decisions, helping to achieve long-term sustainability and cost savings.

5.1 Capital Costs

The capital costs associated with fire service vehicles encompass the initial purchase cost, depreciation, and residual values. These costs are fundamental in evaluating the long-term financial sustainability of the fleet.

5.1.1 Initial Purchase Cost

Each vehicle's initial purchase cost represents a significant capital investment. The acquisition date and purchase cost fields provide insight into the initial capital outlay required for each vehicle type, which is essential for understanding the upfront investment needed for electric vehicles compared to traditional combustion engine vehicles.

From the dataset provided, the capital cost for the electric fire truck (HVY TRK) is $1,753,958, compared to $939,937 for ICE pumpers, indicating that BEVs have a higher initial capital cost.

However, it's important to distinguish between historical cost, which reflects the acquisition price at the time of purchase, and fair value, which represents the current market price. Based on recent market trends, the current cost for a heavy truck is approximately CAD $2.6M ($1.9M USD) for EVs, CAD $1.77M for ICE pumpers, and CAD $3.1M ($2.25M USD) for ICE aerials.

Table 1: Historical Cost and Fair Values of VFRS Vehicles

Category Class	Average Historical Cost	Fair Value
BEV	1.75 million CAD	2.60 million CAD
ICEV		
- AERIAL	1.60 million CAD	3.10 million CAD
- PUMPER	0.94 million CAD	1.77 million CAD

Depreciation is a critical factor in lifecycle cost analysis. The depreciation term, reflecting the expected useful life of each vehicle in months, and the residual value, representing the estimated salvage value at the end of its useful life, is crucial for calculating the annual depreciation expense.

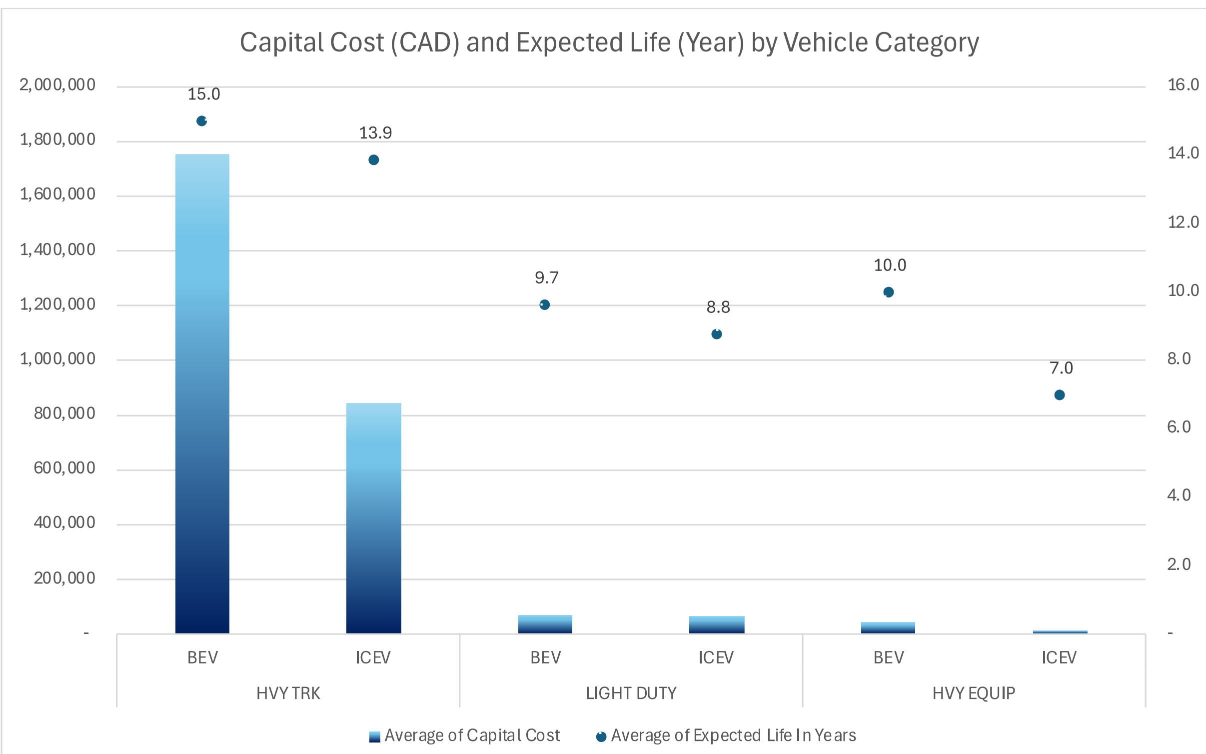
Electric vehicles tend to have different depreciation patterns compared to traditional vehicles, affecting their long-term financial viability. Understanding the depreciation policy and comparing it between electric and traditional vehicles helps in determining which option provides better long-term value. For example, heavy equipment (HVY EQUIP) BEVs have a longer expected life of 10 years compared to 7 years for ICEVs, potentially resulting in lower annual depreciation costs. Generally, responding vehicles have an expected life of 15 years.

The residual value, or the salvage value at the end of the vehicle's useful life, also contributes to the overall capital cost evaluation. For fleet management decisions, analyzing the current value after accounting for depreciation offers insight into the present worth of each asset. This is particularly relevant for decisions regarding whether to retain, replace, or upgrade vehicles. For example, the current value data can help assess the overall health and financial standing of the fleet, ensuring optimal resource allocation and investment strategies.

Table 2: Capital Cost by Category

Category Class	Number of Vehicles	Average Capital Cost (CAD)	Average Expected Life (Year)
HVY EQUIP	**16**	**18,113**	**7.4**
BEV	2	43,812	10.0
ICEV	14	14,442	7.0
HVY TRK	**64**	**859,701**	**13.9**
BEV	1	1,753,958	15.0
ICEV	63	845,506	13.9
- AERIAL	12	1,601,665	15.0
- PUMPER	27	939,937	15.0
- Other Heavy Truck	24	361,192	12.0
LIGHT DUTY	**57**	**67,400**	**9.1**
BEV	20	71,407	9.7
ICEV	37	65,235	8.8
Grand Total	**137**	**431,770**	**11.1**

Figure 1: Capital Cost and Expected Life by Category



5.1.2 Investments in Charging Infrastructure

Investments in charging infrastructure are also essential to support the efficient operation of these vehicles. The capital cost for installing two charging stations at Fire Hall #1 was approximately $150,000 per station, totaling $300,000. These costs were elevated due to the need for an electrical service upgrade to increase capacity. Investing in charging infrastructure ensures that the vehicles can be reliably charged and ready for deployment, thus maintaining the operational efficiency of the fire service. These investments are a fundamental component of the overall strategy to integrate electric vehicles into the fleet, supporting long-term sustainability goals.

5.1.3 Incentives and Rebates

Although the transition to electric fire service vehicles involves significant initial capital costs, incentives and rebates play a crucial role in mitigating these upfront costs, making EVs a more attractive option for municipal fleets.

The Go Electric BC initiative under CleanBC is instrumental in helping British Columbia achieve its emissions goals by reducing transportation emissions by about a third by 2030. This program supports the shift to cleaner transportation by making EVs more affordable and accessible, including providing rebates for fleet vehicles. Businesses, non-profit organizations, or local governments in B.C. can get rebates of $3,000 for battery electric, fuel-cell, and long-range plug-in hybrid vehicles and $1,500 for plug-in hybrid vehicles with an electric range of less than 85 km. These incentives significantly lower the financial barrier to adopting EVs, making them a more viable option for municipal fleets (Government of BC, 2024).

For vehicle C9109, the electric fire truck, the City of Vancouver received several incentives:

- $500,000 from the Federation of Canadian Municipalities (FCM)
- $150,000 from CleanBC (Provincial)
- $100,000 from the iMHZEV program (Transport Canada)

C9109 is the first electric fire truck in Canada, which allowed the city to receive substantial incentives. Based on information from FMS, we can anticipate that future BEVs will be eligible for approximately $250,000 in grants and rebates per vehicle.

5.2 Operational Costs

Operational costs are a critical component of the total cost of ownership for fire service vehicles. These include energy consumption, maintenance and repair expenses, insurance premiums, and other costs associated with vehicle operations.

5.2.1 Energy Costs

Fuel consumption is a major operational expense for traditional combustion engine vehicles. The cost of fuel varies based on type, consumption rate, and price fluctuations. EVs, on the other hand, incur electricity costs, which can be more stable and potentially lower than fuel costs.

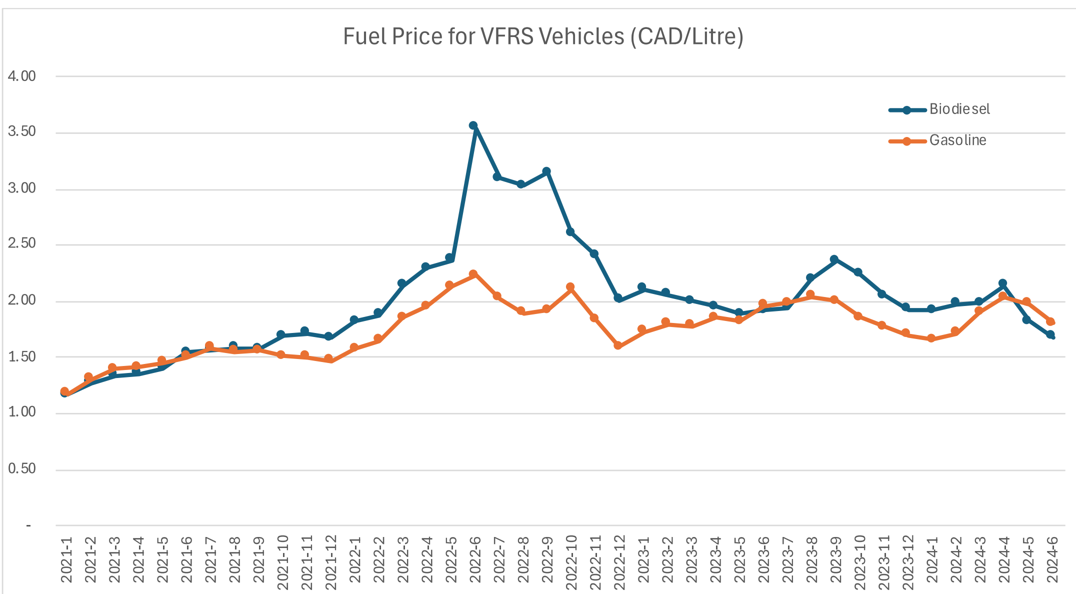
Fuel Use and Costs for ICEVs

By examining the average fuel cost per year and the total liters dispensed, we can identify trends in fuel consumption and cost fluctuations. It helps us pinpoint periods of high fuel usage, which can be correlated with specific operational demands or inefficiencies. Comparing the fuel costs of traditional combustion engine vehicles with the electricity costs of electric vehicles highlights potential cost savings and environmental benefits of transitioning to electric power.

Table 3: VFRS Vehicle Fuel (Biodiesel and Gasoline) Cost: 2021- Jun 2024

Fuel Cost (CAD)	2021	2022	2023	2024H1	2024 Estimate
Biodiesel	433,932	782,461	649,201	308,120	616,241
Gasoline	66,177	126,170	145,085	75,719	151,438
Combined	**500,109**	**908,631**	**794,286**	**383,839**	**767,678**

Figure 2: Fuel Price for VFRS Vehicles (CAD/Litre) (Biodiesel and Gasoline)



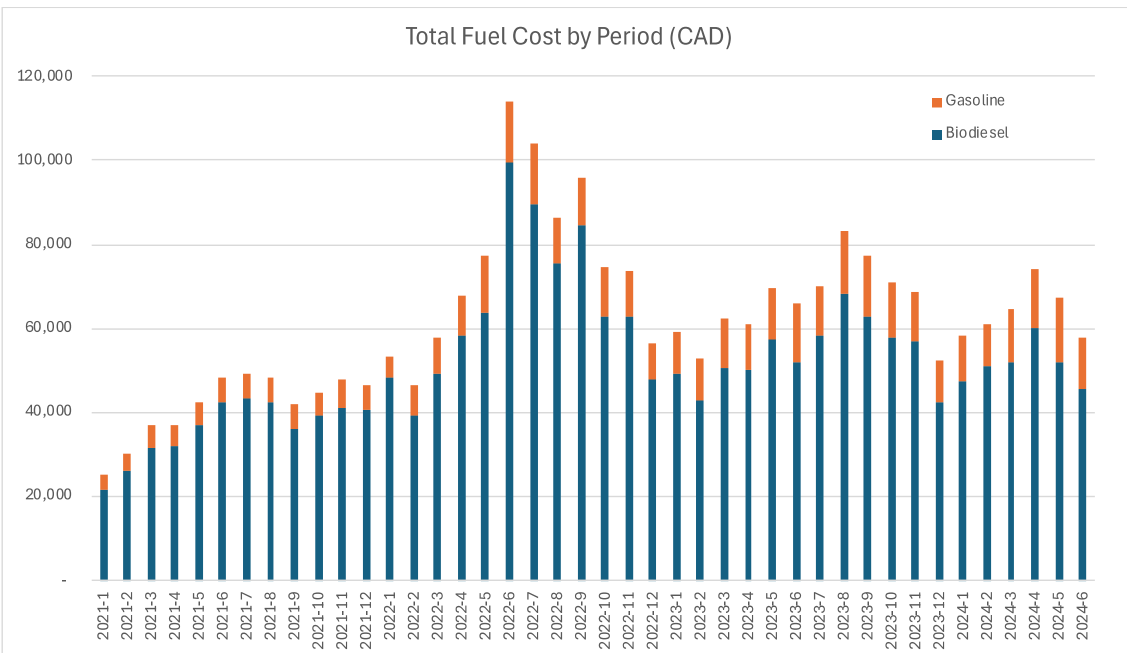
- Biodiesel: The average unit price over the period is CAD 2.011 per liter, with a total cost of CAD 2,173,714 for 1,081,125 liters.
- Gasoline: The average unit price is CAD 1.782 per liter, with a total cost of CAD 413,150 for 231,806 liters.

- Biodiesel vs. Gasoline: Biodiesel is generally more expensive than gasoline. The substantial peak in mid-2022 highlights the price volatility of biodiesel, which can significantly impact operational budgets.

The fuel price plot (Figure 2) shows biodiesel prices peaking sharply around mid-2022, coinciding with global fuel price spikes due to geopolitical tensions and supply chain disruptions. Gasoline prices show a similar but less pronounced peak, indicating the volatile nature of fuel costs.

The total fuel cost plot (Figure 3) indicates a general upward trend in costs, with significant spikes during periods of higher biodiesel usage. This suggests that biodiesel, despite its environmental benefits, incurs higher costs, which fluctuate more significantly than gasoline. Periods of high total fuel costs often correlate with increased operational demands, highlighting the impact of operational intensity on fuel expenses.

Figure 3: Fuel Cost by Period (Biodiesel and Gasoline)



We selected all ICE pumpers and calculated their average monthly cost of fuel from the year of 2022 to 2024, no matter what type of fuel they use:

Table 4: Fuel Cost of ICE Pumpers

Period / Fuel Cost	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	1,151.81	948.51	1,203.44	1,316.90	1,541.05	2,223.98	2,378.97	1,864.01	2,022.17	1,588.85	1,584.69	1,278.81
2023	1,195.24	1,004.70	1,175.58	1,260.68	1,233.02	1,232.58	1,384.65	1,550.73	1,352.01	1,429.59	1,409.06	397.16
2024	1,209.18	1,171.68	1,202.51	1,279.10	1,212.70	1,001.59						

Thus, we can estimate the monthly energy cost for an ICEV truck:

$$\text{Monthly Energy Cost} = 1360.16 \text{ CAD}$$

Electricity Use and Costs for EVs

Transitioning to electricity costs, it is essential to recognize the differences in operational cost structures between fuel and electricity. EVs offer a stable and potentially lower-cost alternative to traditional fuel, with reduced price volatility and environmental benefits.

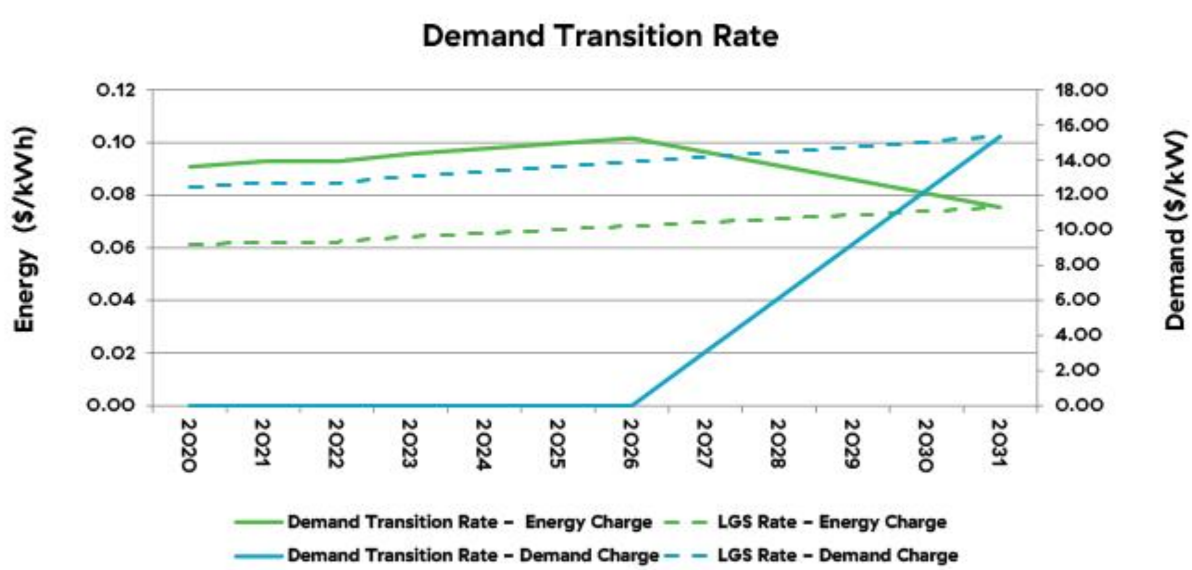
Electricity consumption for EVs is measured in kilowatt-hours (kWh), and costs are relatively stable compared to fuel prices. This stability makes budgeting and financial planning more predictable. The analysis of electricity usage and costs includes examining monthly consumption trends and identifying potential savings through fleet electrification.

BC Hydro's Demand Transition Rate supports fleet electrification by offering reduced rates to mitigate high demand charges during the transition period. The rates are as follows:

- Energy Charge: CAD 0.099/kWh
- Demand Charge: CAD 0.00/kW until March 31, 2026, increasing gradually to match the Large General Service Rate by 2032.

The Overnight Rate provides an economical alternative for fleets with primarily overnight charging needs, with an energy charge of CAD 0.0805/kWh and a demand charge of CAD 13.30/kW during peak hours.

Figure 4: Electricity Demand Transition Rate by BC Hydro



These tailored rates by BC Hydro are designed to encourage the transition to electric fleets, reducing operational costs and supporting environmental goals.

Actual Electricity Bills Analysis

The electricity usage for two vehicles shows dynamic daily consumption, with vehicle V17140 (electric fire truck) exhibiting higher usage compared to V17141 (assistant chief's vehicle). The fluctuation in electricity consumption aligns with operational demands and vehicle charging schedules.

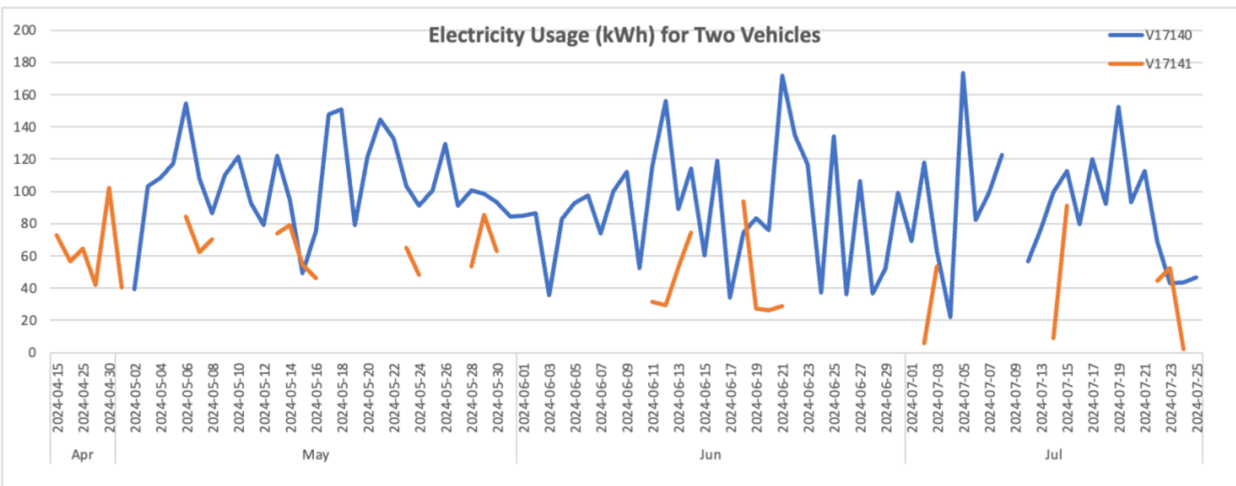
For a sample electric fire truck V17140 (Unit #C9109), the monthly energy consumption over different months is recorded as follows: 3,128.72 kWh in May, 2,665.429 kWh in June, and 1,947.36 kWh in July (22 days). The average monthly consumption is

$$\text{Average Monthly Consumption} = (3128.72 + 2665.43 + 2656.2)/3 = 2816.78 \text{ kWh}$$

Note that July's data has been normalized to a 30-day month for a consistent comparison:

$$\text{Normalized July Consumption} = 1947.36*30/22 = 2656.2 \text{ kWh}$$

Figure 5: Electricity Usage for Two Vehicles



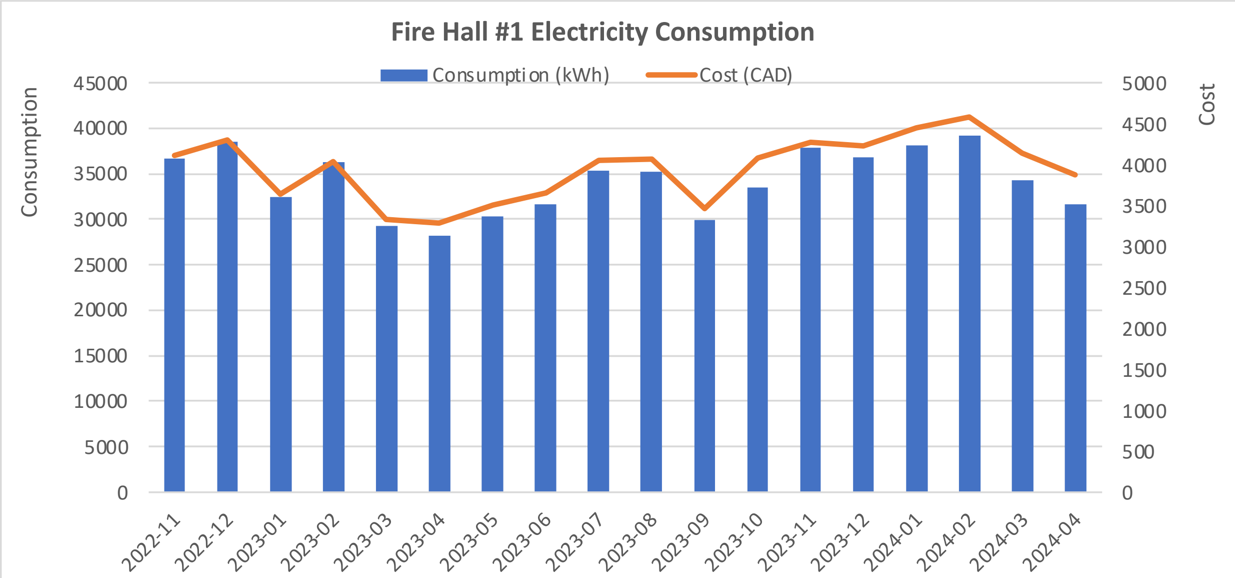
To estimate the monthly energy cost for V17140, calculate the average unit cost of electricity from the provided "Fire Hall #1 Electricity Bills" data:

- Average Monthly Consumption: 35,015 kWh
- Average Monthly Cost: CAD 4,083.29

Thus, the average unit cost of electricity is

$$4083.29/35015 = 0.1166 \text{ CAD/kWh}$$

Figure 6: Fire Hall #1 Electricity Consumption



Now, using the average unit cost of electricity (0.1166 CAD/kWh), we can estimate the monthly energy cost for an electric fire truck:

$$\text{Monthly Energy Cost} = 2816.78 * 0.1166 = 328.38 \text{ CAD}$$

Comparison of Fuel and Electricity Costs

- Fuel Price Volatility: Fuel prices have shown significant volatility, particularly biodiesel, which peaked at around CAD 3.50 per liter. This volatility poses a challenge for budget forecasting and cost management. This variability makes it difficult to predict and control operational costs effectively. In general, the average monthly fuel cost for a sample of heavy trucks in the year 2022, 2023 and 2024 is approximately CAD 1155.43.
- Electricity Costs: Electricity costs are relatively stable, providing a predictable expense for fleet operations. The estimated monthly energy cost for an electric fire truck is around CAD 328.38, showing a significantly lower and more stable cost compared to ICEVs.
- Demand Transition Rate: BC Hydro offers two optional fleet electrification rates to support customers transitioning to electric vehicles: the Demand Transition Rate and the Overnight Rate. The Demand Transition Rate, available from April 1, 2020, to March 31, 2032, helps mitigate high demand charges during the initial EV fleet ramp-up period by eliminating the Demand Charge for the first six years. This rate structure provides financial incentives for the adoption of electric vehicles, further stabilizing operational costs.

By understanding the costs associated with both fuel and electricity, it becomes clear that EVs provide a more stable and predictable expense structure, further supported by targeted incentives and rates from providers like BC Hydro. This analysis underscores the potential cost savings and operational efficiencies achievable through the adoption of electric fire service vehicles.

5.2.2 Maintenance and Repair Costs

Maintenance and repair expenses are another significant component of operational costs. These expenses typically encompass routine servicing, unexpected repairs, and parts replacements.

Routine Maintenance: Regular checks, fluid replacements, tire rotations, and brake servicing are necessary to keep the vehicles operational. EVs, in particular, benefit from reduced routine maintenance costs due to their simpler mechanics, such as the absence of engine oil changes and less frequent brake replacements due to regenerative braking.

Repairs: Repairs address wear and tear or damage from usage. ICEVs typically require more frequent repairs due to the complexity of their engines and associated systems, which is reflected in the higher repair costs seen across different periods in the table.

Parts Replacement: Parts replacement costs also vary between EVs and ICEVs. For ICEVs, engine parts and exhaust system components are common replacements, which contribute to their higher overall maintenance costs.

Table 5 offers insight into the average maintenance costs across different vehicle categories and periods in 2023 and 2024. BEVs consistently show lower maintenance costs across the board, particularly in the heavy truck category, where the difference is most pronounced. This can be attributed to the reduced complexity of electric drivetrains and fewer moving parts, leading to lower routine maintenance needs and fewer repairs.

- Heavy Trucks (HVY TRK): Since the BEV heavy truck was in service in December 2023, the average monthly maintenance cost is CAD 410.17, indicating relatively low maintenance expenses compared to ICEVs. ICEV heavy trucks incurred significantly higher maintenance costs, CAD 6,953.56 for aerial and CAD 6610.52 for pumper on average per month. This disparity highlights the potential long-term cost savings associated with BEVs.
- Light Duty Vehicles (LIGHT DUTY): Light duty BEVs had an average maintenance cost of CAD 472.41, which is similar compared to their ICEV counterparts, amounting to CAD 455.83.

Table 5: Total Maintenance Cost by Period (Jul 2023 – Jun 2024)

Period	HVY TRK				LIGHT DUTY	
	BEV	ICEV			BEV	ICEV
		AERIAL	PUMPER	Other Heavy Truck		
2023-7	-	8,358.13	9,131.97	1,713.38	765.03	213.73
2023-8	-	5,754.00	3,085.06	1,006.55	989.27	613.46
2023-9	-	4,564.09	4,764.96	452.30	294.06	469.21
2023-10	-	3,323.78	4,504.26	1,448.47	241.34	292.34
2023-11	-	2,867.96	4,591.02	736.69	408.72	386.79
2023-12	-	7,913.68	6,390.76	1,384.88	1,019.77	392.13
2024-1	1,161.34	13,530.04	10,876.75	1,115.44	548.57	553.72
2024-2	-	9,294.10	7,366.65	1,359.31	199.97	381.22
2024-3	10.43	9,189.28	6,718.84	1,630.55	308.83	420.84
2024-4	-	8,362.49	8,369.10	1,275.30	659.89	289.28
2024-5	860.23	5,458.61	6,979.99	1,806.29	230.41	1,091.40
2024-6	839.16	3,866.50	5,443.28	2,800.55	-	146.58
Grand Total	**410.17**	**6,953.56**	**6,610.52**	**1,405.66**	**472.41**	**455.83**

By calculating the average annual maintenance cost and breaking down the total labor and parts costs, we gain insights into the financial burden of keeping the fleet operational. Detailed analysis of normal maintenance costs versus sublet and miscellaneous expenses helps in identifying areas where cost-efficiency can be improved.

Table 6 provides a detailed breakdown of maintenance costs from the year 2022 to June 2024, categorized into labor, parts, and sublet expenses. For ICEVs, heavy trucks incur the highest total maintenance cost, reaching CAD 6.01 million, with significant contributions from labor (CAD 2.65 million). Light duty ICEVs also exhibit substantial costs, particularly in sublet services. BEVs demonstrate markedly lower maintenance costs across all categories.

Table 6*:* Maintenance Cost Breakdown (Jan 2022 – Jun 2024)

Category Class	Labor	Parts	Sublet	Total Cost
HVY EQUIP	**-**	**-**	**7,851**	**7,851**
BEV	-	-	-	-
ICEV	-	-	7,851	7,851
HVY TRK	**2,647,893**	**1,419,035**	**1,948,951**	**6,015,879**
BEV	2,842	29	-	2,871
ICEV	2,645,050	1,419,006	1,948,951	**6,013,007**
- AERIAL	783,732	373,533	802,353	1,959,617
- PUMPER	1,685,622	990,949	1,049,895	3,726,467
- Other Heavy Tru	175,696	54,523	96,703	326,923
LIGHT DUTY	**37,052**	**10,702**	**72,685**	**120,439**
BEV	3,565	261	27,189	31,016
ICEV	33,487	10,441	45,496	89,424
Grand Total	**2,684,945**	**1,429,737**	**2,029,487**	**6,144,168**

5.2.3 Insurance Costs

Insurance premiums for fire service vehicles depend on various factors, including the vehicle type (EV vs. ICEV), usage patterns, and the inherent risk profile. Typically, EVs might attract lower insurance premiums due to better safety ratings and fewer accident-related claims.

By analyzing the average annual insurance cost and identifying trends over the years, we can assess the financial impact of insuring different types of vehicles.

Table 7 shows the average net premiums (in CAD) for different classes of vehicles over the years 2020 to 2024.

Table 7*:* Average Insurance Premium by Category (2020 – 2024)

Category Class	2020	2021	2022	2023	2024	Grand Total
HVY EQUIP	**283.29**	**287.29**	**261.00**	**204.63**	**162.18**	**231.78**
BEV	577.00	597.00	597.00	464.00	463.00	539.60
ICEV	234.33	235.67	213.00	167.57	132.10	189.03
HVY TRK	**3,592.18**	**3,804.60**	**3,804.60**	**2,865.90**	**3,098.35**	**3,417.81**
BEV					3,755.00	3,755.00
ICEV	3,592.18	3,804.60	3,804.60	2,865.90	3,087.76	3,416.63
- AERIAL	3,907.67	4,114.33	4,114.33	3,241.00	3,664.83	3,808.43
- PUMPER	3,852.59	4,061.07	4,061.07	3,176.48	3,575.96	3,745.44
- Other Heavy Truck	2,916.13	3,139.50	3,139.50	2,187.63	2,213.57	2,662.21
LIGHT DUTY	**2,009.03**	**2,215.05**	**2,170.09**	**1,416.08**	**1,414.65**	**1,798.11**
BEV	1,713.55	2,110.36	1,981.92	1,324.37	1,343.00	1,614.64
ICEV	2,125.11	2,252.19	2,240.66	1,467.32	1,453.38	1,880.78
Grand Total	**2,751.53**	**2,925.92**	**2,867.52**	**2,041.27**	**2,119.20**	**2,508.10**

For heavy trucks, BEV was introduced in December 2023 with a premium of CAD 3,755, and the premium for an ICE pumper is CAD 3,745 on average, which is slightly lower. BEV heavy equipment shows higher premiums than ICEV heavy equipment, which aligns with initial deployment costs and potential risk assessments.

Overall, insurance costs for both BEVs and ICEVs tend to decrease over time, reflecting potentially better risk management and lower claims.

5.3 Performance Metrics

The performance metrics of fire service vehicles are critical indicators of their operational efficiency and effectiveness. Analyzing these metrics provides valuable insights into the capabilities of both traditional and electric vehicles, helping to inform strategic decisions regarding fleet management and optimization.

Vehicle performance, including response times, incident handling, and travel time, directly impacts operational efficiency and costs. Electric vehicles may offer different performance characteristics that can influence overall operational costs.

5.3.1 Call Volumes

The analysis of call volumes for VFRS vehicles provides essential insights into the operational demand placed on different types of vehicles within the fleet, including both BEVs and ICEVs.

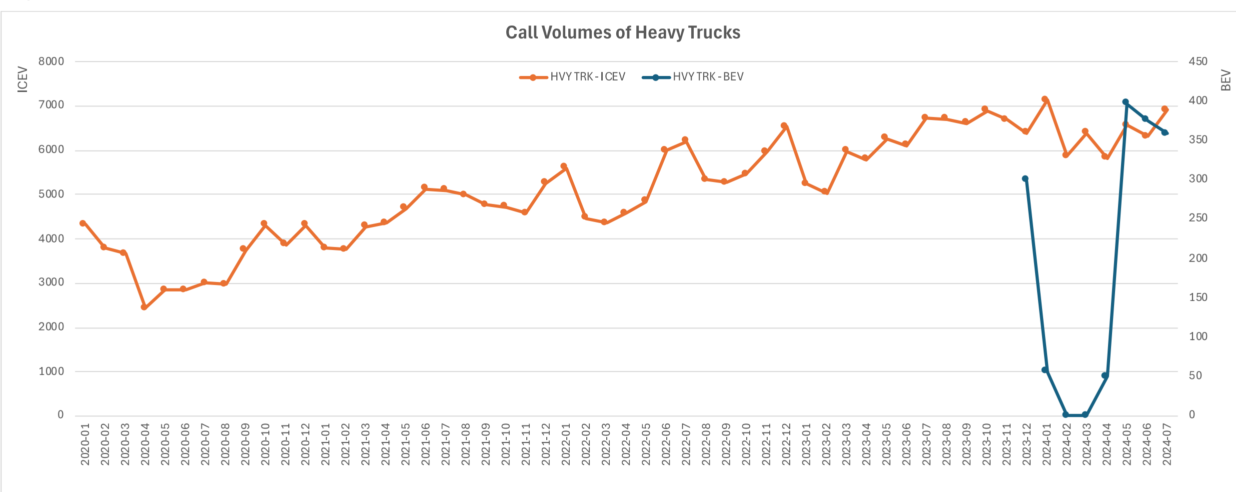
Call volume data from January 2020 to July 2024 has been considered to understand the trend and distribution of calls across these vehicle categories. This data allows for an evaluation of the workload distribution and the effectiveness of different vehicle types in responding to emergencies.

The time series charts further illustrate the disparity in call volumes between ICEVs and BEVs. The ICEV HVY TRK consistently maintained higher call volumes throughout the analyzed period. Notably, the BEV HVY TRK (C9109) entered service on December 6, 2023, but was taken out of service on January 4, 2024. The truck was then reactivated on April 26, 2024. Based on the incident data for Apparatus VAE01, which includes C9109, the estimated call volume from December 2023 to July 2024 is approximately 1,537 calls.

Table 8*:* Call Volumes of C9109 by Period

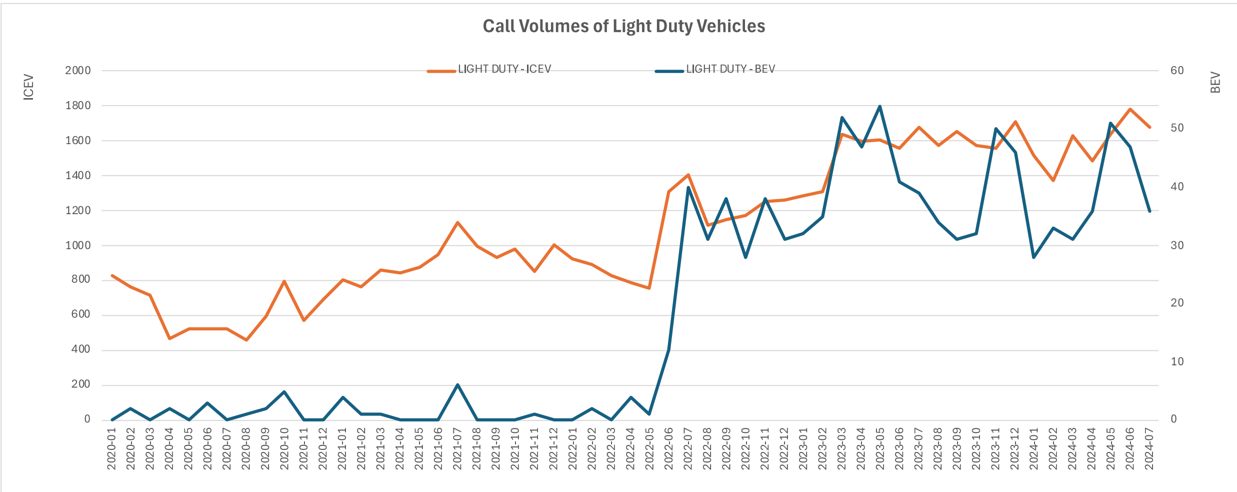
Period	2023-12	2024-01	2024-02	2024-03	2024-04	2024-05	2024-06	2024-07	Total
Call Volumes	299	56	-	-	50	397	376	359	**1,537**

Figure 7*:* Call Volumes Trend of Heavy Trucks



For LIGHT DUTY vehicles, the introduction of BEVs is more recent, as seen in the sharp rise in call volumes from mid-2021 onwards. However, the monthly call volumes for BEV LIGHT DUTY vehicles remain below their ICEV counterparts, indicating that BEVs are not yet fully integrated or utilized to the same extent as ICEVs.

Figure 8*:* Call Volumes Trend of Light Duty Vehicles



Limitations of the Data

It's important to acknowledge the limitations of the dataset, particularly the fact that the analysis is based on call volume data from only 79 vehicles in scope, which have been roughly matched with the apparatus. This limited sample may not fully represent the entire fleet's performance, and the trends observed should be interpreted with caution, as they might not capture the complete operational dynamics of VFRS vehicles.

The call volume data highlights the ongoing reliance on ICEVs within the VFRS fleet, with BEVs gradually being integrated into service. The lower call volumes for BEVs reflect their relatively recent introduction. As BEVs continue to be integrated, further analysis will be required to assess their performance and potential to match or surpass the call volumes of ICEVs, particularly in critical emergency response scenarios.

5.3.1 Response Time

The response time data, spanning from January 2020 to July 2024, sheds light on the fleet's capability to reach incident sites promptly, which is vital for the effectiveness of emergency services. Understanding response times also aids in evaluating the performance of different vehicle types within the fleet, including both BEVs and ICEVs.

From the provided dataset, heavy trucks show the highest total call volumes, with 283,240 calls, and an average response time of 3.54 minutes per call. Within this category, the BEV handled

1,537 calls with a slightly faster average response time of 3.25 minutes compared to ICE pumpers, which managed 181,992 calls at 3.49 minutes per call. Among light-duty vehicles, BEVs responded to 1,008 calls with an average response time of 4.75 minutes, while ICEVs responded to 61,162 calls with a quicker average response time of 3.59 minutes. Overall, BEVs are showing competitive response times, indicating their efficiency in operational performance.

Table 9: Call Volumes and Response Time by Category

Category	Total Call Volumes	Total Response Time (min)	Response Time per Call (min)
HVY TRK	**283,240**	**1,002,256**	**3.54**
BEV	1,537	5,001	3.25
ICEV	281,703	997,256	3.54
- AERIAL	65,587	226,420	3.45
- PUMPER	181,992	635,432	3.49
- Other Heavy Truck	34,124	135,404	3.97
LIGHT DUTY	**62,170**	**224,137**	**3.61**
BEV	1,008	4,790	4.75
ICEV	61,162	219,347	3.59
Grand Total	**345,410**	**1,226,394**	**3.55**

Considerations and Limitations

It is important to note several limitations in this analysis. The response time per call is derived from monthly accumulative travel time divided by the number of incidents, which may not fully capture the nuances of each emergency situation. Additionally, other factors that could influence response times, such as the distance to the incident site and traffic conditions, are not considered in this dataset.

Furthermore, the analysis is based on a limited dataset, focusing on 79 vehicles that were roughly matched with an Apparatus. This restricted sample may not fully represent the entire fleet's performance, potentially skewing the results and limiting the generalizability of the findings.

The response time analysis reveals that both BEVs and ICEVs in the VFRS fleet are performing similarly in terms of response efficiency, with BEVs showing slightly better average response times overall. However, the higher response times for BEV light-duty vehicles suggest that there may be areas for improvement in the deployment or operation of these vehicles.

5.3.3 Uptime and Downtime

The uptime and downtime of fire service vehicles are critical metrics for evaluating fleet performance and operational readiness. Uptime refers to the period when vehicles are operational and available for service, while downtime covers the time vehicles are unavailable due to maintenance, repairs, or other factors. The analysis of these metrics provides insights into the reliability and efficiency of the fleet, which are crucial for ensuring prompt emergency response.

Table 10 covers uptime and downtime statistics for various vehicle categories in the VFRS fleet from May 2019 to June 2024. The dataset includes information on total uptime minutes, total operational and maintenance downtime, and average uptime percentages for both BEVs and ICEVs.

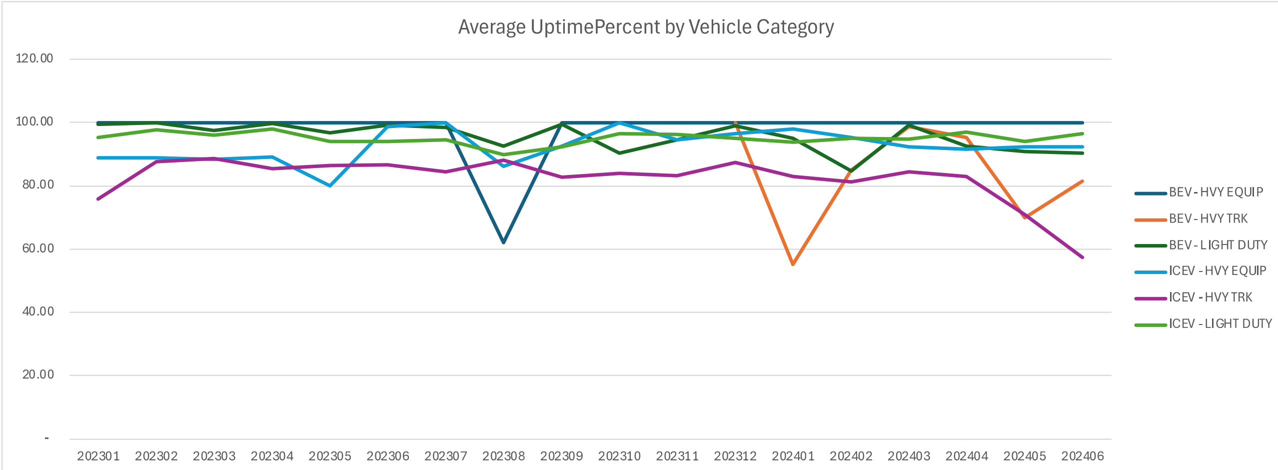
Table 10: Vehicle Uptime and Downtime (Minutes) by Category

Category Class	Total Uptime	Operational Downtime	Maintenance Downtime	Average Uptime%
HVY EQUIP	**28,464,060**	**1,437,691**	**1,443,781**	**95.05**
BEV	2,718,720	18,905	18,905	99.32
ICEV	25,745,340	1,418,786	1,424,876	94.61
HVY TRK	**144,466,020**	**19,913,156**	**21,709,766**	**86.00**
BEV	306,720	50,264	50,264	83.67
ICEV	144,159,300	19,862,892	21,659,502	86.01
- AERIAL	26,754,480	5,145,950	6,464,495	80.32
- PUMPER	71,532,900	11,838,909	12,192,648	83.50
- Other Heavy Truck	45,871,920	2,878,033	3,002,359	93.74
LIGHT DUTY	**105,464,970**	**4,084,412**	**4,499,910**	**96.27**
BEV	25,786,320	965,073	1,200,128	96.48
ICEV	79,678,650	3,119,339	3,299,782	96.19
Grand Total	**278,395,050**	**25,435,259**	**27,653,457**	**90.91**

The data shows that BEVs in the HVY EQUIP category demonstrate the highest average uptime percentage at 99.32%, indicating exceptional reliability. In comparison, ICEVs within the same category show a slightly lower uptime at 94.61%. Within the HVY TRK category, BEVs have an uptime of 83.67%, which is similar to the ICE pumpers' uptime of 83.50%. However, BEVs in the LIGHT DUTY category exhibit strong performance with a 96.48% uptime, closely matching ICEVs' 96.19%.

The line chart (Figure 9) from January 2023 to June 2024 indicates fluctuations in uptime percentages across different vehicle categories. Notably, there is a sharp dip in uptime for ICEV heavy trucks around August 2023, which could be attributed to significant maintenance or operational issues. Such outliers need to be investigated to understand the root cause and address potential systemic issues.

Figure 9*:* Average Uptime Percentage by Category



Overall, the data suggests that BEVs in the VFRS fleet are more reliable with higher uptime and lower downtime compared to their ICEV counterparts. The noticeable outlier in ICEV heavy trucks indicates potential challenges that require further investigation.

5.4 Sustainable Impact

The transition to battery electric fire service vehicles offers significant environmental benefits, contributing to improved public health and aligning with broader climate action goals. These benefits can be quantified using methods like Social Return on Investment or Shadow Pricing to capture the indirect financial implications through improved community health and compliance with governmental environmental targets.

Sustainable Benefits of BEVs

Reduction in Greenhouse Gas Emissions: BEVs significantly reduce GHG emissions compared to ICEVs. Life cycle assessments have shown that the GHG impact of a BEV is roughly 60% that of an equivalent ICEV. This reduction is due to the higher energy efficiency of electric drivetrains and the use of renewable energy sources for electricity generation. The exact environmental benefit varies depending on the energy mix used to generate the electricity for charging the BEVs. Regions with a higher penetration of renewable energy see more significant reductions in CO2 emissions from BEVs (Tang et al., 2022).

Improvement in Air Quality: BEVs contribute to lower levels of air pollutants such as nitrogen oxides (NOx) and particulate matter (PM). These pollutants are major contributors to urban air pollution and have adverse effects on public health. The elimination of tailpipe emissions from BEVs can lead to substantial improvements in air quality, reducing the incidence of respiratory and cardiovascular diseases (Caltabellotta et al., 2021).

Noise Pollution Reduction: BEVs are quieter than traditional ICEVs, leading to a reduction in noise pollution. This is particularly beneficial in urban areas where noise from traffic is a significant concern. Reduced noise levels can improve the quality of life for residents and contribute to better mental health outcomes.

Quantifying Environmental Impact

Shadow pricing involves assigning a monetary value to non-market goods, such as environmental benefits. By estimating the shadow prices for reduced emissions and improved air quality, we can quantify the indirect financial benefits of transitioning to BEVs.

Let's consider a scenario where this transition results in a reduction of 10 tons of CO_2 emissions annually per vehicle. We will estimate the monetary value of the associated sustainability benefits by considering three key areas: reduction in healthcare costs, productivity gains, and compliance with environmental regulations.

- Reduction in Healthcare Costs: Assume that the reduction of 1 ton of CO_2 emissions is estimated to prevent healthcare costs related to air pollution by CAD 100. This value is based on studies that link CO_2 reductions with decreased rates of respiratory and cardiovascular diseases.
- Productivity Gains: Improved air quality and public health from the reduction of CO_2 can lead to fewer sick days and higher productivity. We assume a productivity gain valued at CAD 150 per ton of CO_2 reduced.
- Compliance and Avoidance of Penalties: By reducing CO_2 emissions, the City may avoid potential fines or penalties associated with non-compliance with environmental regulations. We assume the avoided penalty costs are CAD 200 per ton of CO_2 reduced.

Thus, Healthcare Cost Savings = 10 tons of CO_2 * 100 CAD/ton = 1,000 CAD

Productivity Gains = 10 tons of CO_2 * 150 CAD/ton = 1,500 CAD

Avoided Penalties = 10 tons of CO_2 * 200 CAD/ton = 2,000 CAD

Based on these reasonable assumptions, the transition to BEVs in the VFRS fleet could generate an estimated total sustainability benefit of CAD 4,500 annually per vehicle.

The environmental benefits of transitioning to battery electric fire service vehicles extend beyond direct financial savings. By reducing GHG emissions, improving air quality, and lowering noise pollution, BEVs contribute to better public health and align with climate action goals. Quantifying these benefits using shadow pricing provides a comprehensive view of the long-term financial advantages, supporting the case for adopting electric vehicles in the fire service fleet.

VI. Financial Modeling

This section compares BEV fire trucks and ICE pumpers within the VFRS fleet, focusing on capital costs, operational expenses, and potential financial benefits.

Table 11: Summary of Key Variables

Variable	BEV (Assumption)	ICEV (Assumption)
Charging Station (one-time)	$ 150,000	N/A
Expected Life (Years)	15	15
Annual Depreciation Rate	6.67%	6.67%
Salvage Value	immaterial	immaterial
Monthly Energy Cost	$ 328.38	$ 1,360.16
Monthly Maintenance Cost	$ 410.17	$ 6,610.52
Annual Insurance Premium	$ 3,755.00	$ 3,745.44

Table 12: Total Cost Forecast Over Vehicle Lifetime

Cost Component	BEV	ICE Pumper	Assumptions
Initial Cost	$ 2,600,000.00	$ 1,770,000.00	Use fair value. Depreciated fully over the expected lifespan of 15 years.
Incentives	$ (250,000.00)	N/A	Eligible for provincial & federal rebates.
Charging Infrastructure Cost	$ 300,000.00	N/A	One-time cost of two charging stations for BEV.
Energy Costs	$ 59,108.40	$ 244,828.80	BEV energy at CAD 328.38/month; ICEV fuel at CAD 1,360.16/month.
Maintenance Costs	$ 73,829.92	$ 1,189,894.28	BEV maintenance at CAD 410.17/month; ICEV at CAD 6,610.52/month.
Insurance Premium	$ 56,325.00	$ 56,181.60	Insurance over the full vehicle lifespan.
Total Lifetime Cost	**$ 2,839,263.32**	**$ 3,260,904.68**	BEV shows lower total lifecycle cost over the full expected life.

Accounting for reasonable incentives, when fully depreciated over 15 years, BEVs incur significantly lower operational costs, including energy and maintenance. The total lifetime cost for a BEV, including infrastructure investments, is approximately CAD$2.84M, compared to CAD $3.26M for an ICE pumper over its 15-year lifespan.

This analysis underscores the long-term financial benefits of transitioning to electric vehicles in the VFRS fleet. Despite higher initial purchase costs, the substantial savings in energy, maintenance, and insurance, combined with the benefit of incentives, make BEVs a more cost-effective option over their expected lifespan.

VII. Case Study

7.1 Overview of Electric Vehicles in Fire Services

The transition to EVs in fire services is part of a broader effort to reduce carbon emissions and promote sustainability. This shift is driven by technological advancements in battery storage and increasing environmental regulations. Several fire departments globally are pioneering the use of electric fire trucks, reflecting a commitment to environmentally friendly practices.

The shift towards electric fire vehicles presents significant environmental and operational benefits. Reduced emissions, lower maintenance costs, and advanced technological features make electric fire trucks a compelling option for modern firefighting services. The adoption of electric vehicles in municipal fleets aligns with broader sustainability goals and can significantly contribute to reducing the overall carbon footprint of emergency services.

However, the successful integration of electric fire vehicles requires careful planning and infrastructure support. Both Rosenbauer and Pierce Manufacturing emphasize the importance of installing appropriate charging solutions and coordinating with local utilities to support the transition. As more municipalities recognize the benefits of electric fire trucks, these vehicles are likely to become an essential part of sustainable urban infrastructure (Rosenbauer, 2023; Pierce Manufacturing Inc., 2023).

The public's attitude towards electric fire trucks has been generally positive, driven by growing environmental awareness and support for sustainable initiatives. However, concerns about the safety and efficacy of EVs, particularly regarding their performance in emergencies and fire risks, persist.

Fire departments have noted that while EV fires are rare, they can be challenging to manage due to the nature of lithium-ion batteries, which can reignite even after being extinguished. This has prompted ongoing research and the development of new firefighting techniques, such as those tested by the International Association of Fire Services, which found that certain methods can extinguish EV fires more effectively and with less water.

In summary, the transition to electric fire vehicles offers considerable advantages in terms of environmental impact and operational efficiency. Continued research and development in this area will further optimize these vehicles for enhanced performance and sustainability in emergency response operations.

7.2 EVs in Fire Services in Major Canadian Cities

The integration of electric vehicles into fire services across Canadian cities represents a significant step towards achieving sustainability and reducing greenhouse gas emissions. Cities like Vancouver, Calgary, Brampton, Victoria, Toronto, and Varennes are leading the way in adopting electric fire trucks and investing in the necessary infrastructure to support these initiatives. These efforts not only align with broader environmental goals but also offer operational benefits such as reduced maintenance costs and improved air quality.

Brampton

Earlier in the year of 2024, Brampton unveiled the latest addition to the Brampton Fire and Emergency Services fleet—the Rosenbauer RTX, marking Brampton as the first municipality in Ontario to deploy an electric-powered front-line emergency response vehicle (City of Brampton, 2024). This initiative follows the footsteps of cities like Berlin, Amsterdam, Dubai, Los Angeles, and Vancouver, positioning Brampton at the forefront of eco-friendly firefighting.

The journey to purchase the Rosenbauer RTX electric fire truck began in 2021, with the city earmarking approximately $1.6 million for its procurement from the Austria-based manufacturer, Rosenbauer Group. This investment demonstrates Brampton's commitment to integrating advanced, zero-emission technology into its emergency response fleet.

Following the successful deployment of the initial electric fire truck, Brampton has budgeted over $5 million to add two more electric fire trucks to its fleet in 2024. This expansion aligns with the city's broader goal of transitioning to a greener and more sustainable fleet, with plans to integrate a total of 14 electric and hybrid fire trucks over the next three years (Electric Autonomy, 2024).

Capital and Maintenance Costs: The initial investment for the Rosenbauer RTX electric fire truck was approximately $1.6 million. The city has allocated an additional $5.4 million for the purchase of two more electric fire trucks. Over their 12-year lifespan, these trucks are expected to generate potential annual savings of at least $384,000, primarily from reduced fuel and maintenance costs.

Fuel and Electricity Use: The Rosenbauer RTX operates with zero emissions, significantly reducing the carbon footprint of Brampton's emergency response fleet. By going electric, Brampton estimates a reduction of 256 tons of CO2 emissions per truck over its lifespan. This transition is part of Brampton's strategy to minimize fuel use and promote the adoption of cleaner energy sources (Electric Autonomy, 2024).

Emergency Response Times: The Rosenbauer RTX's advanced technology allows for efficient movement through urban spaces and enhanced ergonomics for firefighters, which can potentially improve response times during emergencies. The quiet operation of electric engines also contributes to better communication during responses, further enhancing operational efficiency (City of Brampton, 2024).

Figure 10: Electric Fire Vehicle - City of Brampton[2]

Calgary

In July 2024, the Calgary Fire Department welcomed its first electric fire engine. The investment in the Pierce Volterra™ electric fire engine aligns with Calgary's Green Fleet Strategy, part of the city's 2023-2026 Climate Implementation Plan. The introduction of the electric fire engine is anticipated to significantly reduce emissions and improve air quality in Calgary.

The Pierce Volterra™ EV engine was custom-made to meet CFD specifications and is the first of its kind in Canada. The engine will be tested and evaluated against performance measures,

[2] Source: https://www.brampton.ca/EN/residents/Fire-Emergency-Services/Pages/Announcement.aspx?ItemID=5

including its battery's ability to operate in Calgary's varied climate. The engine is expected to enter service by the end of summer 2024, following training and commissioning of the CFD personnel (City of Calgary, 2024).

Capital and Maintenance Costs: The pilot program allows the CFD to test the functionality and performance of an electric engine without making a long-term financial commitment. The electric engine is anticipated to reduce maintenance costs due to fewer moving parts compared to traditional internal combustion engines. Additionally, the dual-power setup with a backup diesel system ensures continuous power and operational readiness under all circumstances.

Fuel and Electricity Use: The electric engine is expected to substantially minimize fuel use, with the primary operations powered by a 244-kWh battery solution. The backup diesel system will only be utilized when necessary, ensuring that the vehicle predominantly operates on electric power, thus reducing overall fuel consumption.

Vehicle Downtime and Infrastructure Costs: The Mount Pleasant Fire Station has been outfitted with the necessary charging infrastructure to support the new electric fire engine. The integration of this infrastructure is expected to streamline the charging process and reduce vehicle downtime associated with refueling. Moreover, the use of electric engines, which typically require less maintenance, will contribute to increased vehicle availability and reliability.

Emergency Response Times: The electric fire engine's quieter operation will reduce noise pollution, allowing for better communication during emergency responses. The Pierce Volterra™ EV engine, with features like the Pierce Enforcer custom chassis and TAK-4® Independent Front Suspension, ensures high maneuverability and stability, potentially improving response times in urban settings.

Calgary's investment in the Pierce Volterra™ electric fire engine represents a significant advancement in the city's efforts to promote sustainability and operational efficiency within its fire services.

Figure 11: Electric Fire Vehicle - City of Calgary[3]

Victoria

The City of Victoria has taken a pioneering step by adding an electric fire engine to its fleet, aligning with its Climate Leadership Plan. In August 2023, Victoria announced the purchase of the Rosenbauer Revolutionary Technology (RT) pumper fire engine, and it arrived in May 2024. (City of Victoria, 2023). This truck will help reduce emissions by about 20 tons per year and lead to a cleaner, quieter and healthier city.

Capital and Maintenance Costs: The total cost of the Rosenbauer RTX electric fire truck is approximately $1.7 million. This investment is supported by a grant from the Province of British Columbia's CleanBC Commercial Vehicle Pilots Program, which covers 33% of the total cost, including the charging infrastructure. This grant brings the city's expenditure to approximately $1.2 million, in line with that of a traditional fire engine, making the transition financially feasible (City of Victoria, 2023).

Fuel and Electricity Use: The electric fire engine has a battery range of 100 kilometres and is equipped with an onboard diesel range extender. The Rosenbauer RTX is designed to operate 95% of the time in full-electric mode, with a backup diesel engine that engages when the battery charge falls below 20%. This feature ensures continuous operation without interruptions during extended emergency responses. The truck's electric operation is expected to significantly reduce

[3] Source: https://www.fireengineering.com/industry-news/calgary-fire-department-first-in-canada-to-receive-pierce-volterra-electric-pumper/

fuel consumption and associated costs, contributing to the city's sustainability goals (City of Victoria, 2023; Bell, 2024).

Vehicle Downtime and Infrastructure Costs: The electric fire engine will be stationed at the new Victoria Fire Department Headquarters on Johnson Street, which has been equipped with a 25-kilowatt direct current fast charger. This infrastructure allows the engine to be rapidly charged between runs, minimizing downtime and ensuring the vehicle is always ready for service. The city's existing infrastructure, enhanced for electric vehicle support, facilitates this seamless integration (City of Victoria, 2023).

Emergency Response Times: The Rosenbauer RTX features an agile and climate-friendly design that is three feet shorter and four inches narrower than typical diesel counterparts, enhancing its maneuverability in urban spaces. This compact design, combined with air suspension that allows height adjustments, makes navigating city streets and accessing equipment easier for firefighters, potentially improving response times (Brendan, 2024).

The Victoria Fire Department already has another electric fire truck on order, which is scheduled to arrive in 16 to 19 months (Brendan, 2024).

Figure 12: Electric Fire Vehicle - City of Victoria[4]

[4] Source: https://bc.ctvnews.ca/victoria-welcomes-first-of-2-electric-fire-trucks-1.6909107

Mississauga

Mississauga's first electric fire truck, a Pierce Volterra, is set to begin service in 2024, marking a significant step in the city's efforts to enhance sustainability within its fire services (insauga.com, 2023).

The total cost of the electric fire truck is approximately $2 million, which is about twice the price of a conventional diesel-powered apparatus. Life cycle for the EV is expected to be equivalent to any other apparatus in the fleet, 12-15 years. The electric fire truck will be stationed at Fire Station 125, located in Ward 9, which is scheduled to open in late summer 2024. This station will also be the city's first net zero energy fire station, equipped with the necessary infrastructure to support a DC fast charger capable of recharging the truck in 90 minutes (Modern Mississauga, 2023).

Capital and Maintenance Costs: The electric fire truck costs approximately $2 million, compared to $1.2 million for a conventional diesel truck. The truck's electric components, such as the battery and motors, add approximately 2,000 pounds to the gross vehicle weight, but do not significantly affect its operational capabilities (Modern Mississauga, 2023).

Fuel and Electricity Use: The Pierce Volterra has a battery range of about 60 miles (100 km) and is equipped with a backup diesel engine that automatically engages if the battery charge falls below 20%. The electric range accounts for a fully loaded truck, and regenerative braking capabilities help to extend the range. The expected reduction in fuel consumption is significant, contributing to the city's sustainability goals (insauga.com, 2023).

Vehicle Downtime and Infrastructure Costs: The new Fire Station 125 will include a DC fast charger capable of restoring the truck's battery to full capacity within 90 minutes. The station's infrastructure investments ensure that the electric fire truck can be rapidly charged between runs, minimizing downtime. The charger installation and associated infrastructure costs are part of the overall investment in the new fire station, designed to support the city's growing fleet of electric vehicles (Modern Mississauga, 2023).

Emergency Response Times: The electric fire truck is designed to perform effectively in all operating conditions, with capabilities such as all-wheel steering and adjustable ride height, which enhance maneuverability on narrow roads and during floods (Modern Mississauga, 2023).

Figure 13: Electric Fire Vehicle - City of Mississauga[5]

Toronto

In July 2022, the City of Toronto announced the purchase of two Vector™ electric fire trucks from Spartan Emergency Response, a subsidiary of the REV Group Inc., at a cost of $2 million each. These purchases support Toronto's TransformTO Net Zero Strategy, which aims to achieve net zero emissions community-wide by 2040 (City of Toronto, 2022).

Capital and Maintenance Costs: The total capital investment for the two electric fire trucks is $4 million. While this is approximately twice the cost of traditional diesel-powered trucks, the long-term savings in fuel and maintenance costs are expected to offset the higher initial expenditure. The electric trucks are equipped with 327 kWh of automotive-grade batteries, ensuring substantial operational savings over their lifecycle (REV Group, 2022).

Fuel and Electricity Use: The Vector™ trucks are designed to operate almost exclusively on electric power, with an industry-leading electric pumping duration. The trucks feature low to zero carbon emissions, significantly reducing the environmental impact of Toronto Fire Services. The estimated range of these trucks is sufficient to handle typical urban emergency responses, minimizing the reliance on the backup diesel engine (REV Group, 2022).

Emergency Response Times: The Vector™ trucks maintain the same functionality and capabilities as traditional pumper trucks, eliminating the need for extensive retraining of personnel. Their design allows for improved maneuverability and safety, contributing to efficient emergency response times. Since Toronto Fire Services responds to 300 to 400 calls per day, these trucks are

[5] Source: https://www.insauga.com/first-electric-fire-truck-in-mississauga-will-start-fighting-blazes-in-2024/

expected to maintain operational effectiveness in Toronto's busy urban environment (City of Toronto, 2022).

Figure 14: Electric Fire Vehicle on the Road[6]

Varennes

The City of Varennes, Quebec, has taken a significant step towards sustainable emergency services by ordering a fully electric Vector™ Rescue Decon truck from E-ONE, a subsidiary of the REV Group Inc. Announced in June 2022, this investment is part of Varennes' broader strategy to electrify its municipal fleet and enhance environmental sustainability (E-ONE, 2022).

Capital and Maintenance Costs: The total cost of the Vector™ Rescue Decon truck is $2.3 million, with $500,000 funded by the Green Municipal Fund. The electric truck is expected to save more than $12,000 annually in fuel and maintenance, while reducing greenhouse gas emissions by over 13 tons per year (Roulons Électrique, 2024).

Fuel and Electricity Use: The Vector™ Rescue Decon truck features a battery range of 225 km and includes a range extender for emergency backup power. This ensures the truck remains operational during extended interventions without relying on traditional fuel. The electric operation significantly reduces fuel consumption and emissions, contributing to Varennes' environmental goals (E-ONE, 2022).

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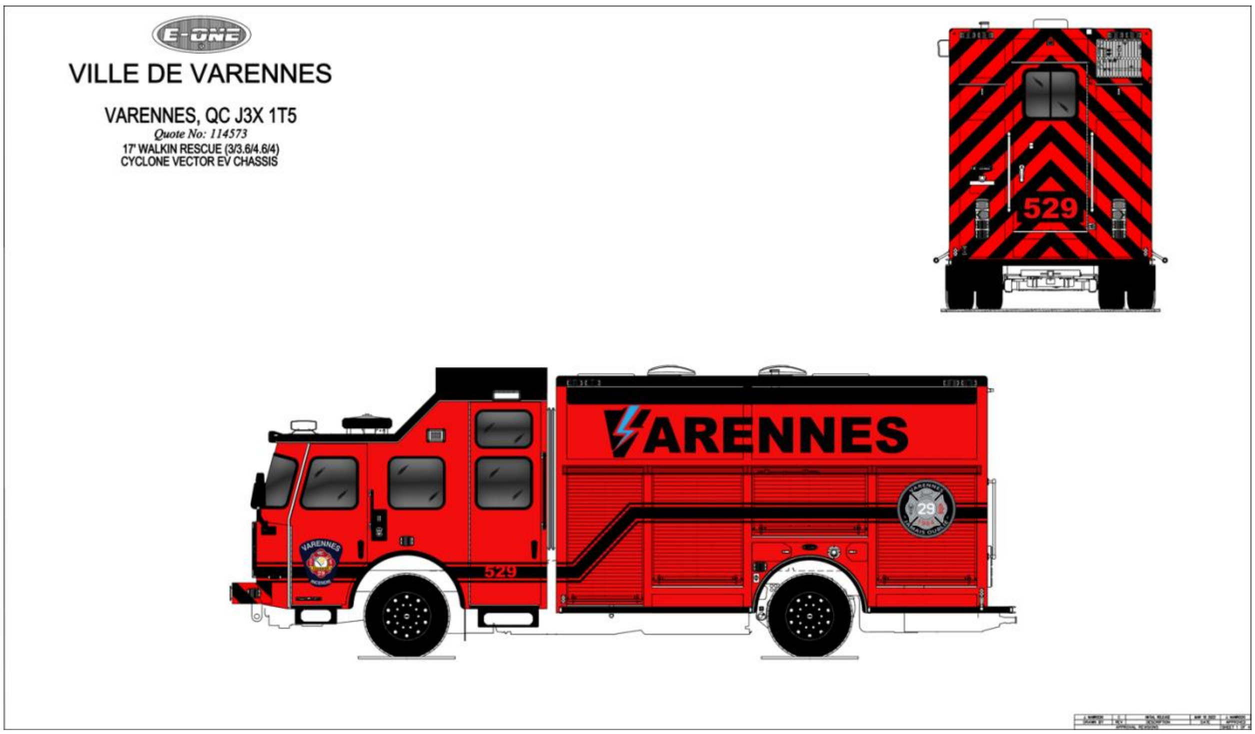
[6] Source: https://revgroup.com/toronto-fire-services-orders-two-fully-electric-vector-pumpers

Vehicle Downtime and Infrastructure Costs: The truck's advanced design, including low battery cell placement for enhanced stability, minimizes downtime associated with maintenance. The city has also invested in the necessary charging infrastructure to support the truck's operation, ensuring it can be quickly recharged and ready for service (Roulons Électrique, 2024).

Emergency Response Times: The Vector™ Rescue Decon truck is equipped with specialized features such as a decontamination shower and air refueling system, which enhance the safety and efficiency of firefighters during operations. Its design allows for seamless integration into existing emergency response protocols, ensuring no compromise in performance or response times (E-ONE, 2022).

Figure 15: Electric Fire Vehicle - City of Varennes[7]



7.3 Global Deployment of EVs in Fire Services

The transition to EVs within fire services globally represents a significant shift towards sustainability and operational efficiency. Cities worldwide are increasingly adopting electric fire engines to reduce their carbon footprint, enhance response capabilities, and leverage advanced technological features. From North America to Europe, fire departments are integrating electric

[7] Source: https://www.roulonselectrique.ca/en/flotte-de-vehicules/inspiration/municipalites/varennes-donner-lexemple/

and hybrid fire trucks into their fleets, driven by both environmental policies and the need for innovative solutions to urban firefighting challenges. These vehicles, developed by leading manufacturers such as Rosenbauer and REV Group, offer zero or low emissions, reduced noise pollution, and advanced performance metrics, supporting the broader goal of achieving climate neutrality and improving public health.

North America

Los Angeles, USA

Los Angeles Fire Department introduced its first electric fire truck, the Rosenbauer RT, in early 2022. This electric fire engine marks a significant step in the efforts to reduce emissions and modernize its fleet. The Rosenbauer RT is equipped with a 132-kWh battery pack and a diesel range extender to ensure continuous operation during extended emergencies.

Boulder, Colorado, USA

Boulder Fire-Rescue became the first city in Colorado to purchase an electric fire engine in April 2023 and a second electric fire engine in Jan 2024. The Rosenbauer RTX, with its all-electric drivetrain and diesel backup system, aims to enhance firefighter safety and operational efficiency. The cost of each engine is approximately $1.8 million. Both engines are expected to be delivered late this summer or early in the fall 2024. The engine offers features such as adjustable suspension, all-wheel drive, and ergonomic cab design. The vehicle's operational capabilities include a 95% completion rate of calls on battery power alone. The dual-power capacity reduces service interruptions, and the city anticipates lower costs for fuel and maintenance compared to traditional diesel engines.

Madison, Wisconsin, USA

Madison Fire Department has also adopted electric fire trucks to meet its operational needs. The city's electric fire engines are part of a broader strategy to incorporate green technology into emergency response services. Madison's pumper has about 155 kilowatt-hours of energy; the production model is closer to 245 kWh. The pumper was put in service in May 2021. It is placed at Station 8, taking on an average of 10 to 12 calls per day, and an upwards of 24 calls on busy days. The department reported that it saves about $15,000 per year on fuel.

Gilbert, Arizona, USA

Gilbert Fire and Rescue introduced Arizona's first electric fire truck, enhancing their fleet with the latest in electric vehicle technology. This zero-emissions electric pumper reduces exposure to harmful diesel exhaust and performs better in emergencies, when every second matters. The projected lifespan of the Volterra pumper is the same as Gilbert's diesel-powered vehicles – 10 years in service, 5 years in reserve.

Mesa, USA

Mesa Fire and Medical Department unveiled Arizona's first all-electric, North American-style fire truck by E-ONE in Jan 4, 2024. It can pump four hose lines at 750 gallons per minute for four hours on a single charge – allowing for continuous emergency response, when needed.

Middle East

Dubai, UAE

The Dubai Civil Defense introduced the first electric-powered fire engine in the Middle East and the second worldwide in April 2021. This advanced vehicle, developed with cutting-edge technology, boasts a 20% speed increase and 40% efficiency improvement over traditional fire engines. Key features include an intuitive 17-inch display for crew operation, CAN-bus-based Logic Control System, Wi-Fi hotspot, and remote communication capabilities. The vehicle is equipped with a Rosenbauer NH35 pump, 4,000-liter water tank, 400-liter foam tank, and Fix Mix 2.0A foam system. Additional enhancements include central locking, integrated power supply, and quick charging capabilities that allow for 80% charge in 40 minutes, supporting 6-8 hours of continuous operation. These innovations aim to enhance response times and operational efficiency, ensuring the safety of lives and properties across Dubai (Dubai Civil Defense, 2021).

Europe

Basel, Switzerland

The Basel-City fire brigade has placed an order for four all-electric fire fighting vehicles from Rosenbauer's RT model series, marking the first fleet order for this electric vehicle. These vehicles are equipped with two electric motors providing 350 kW of drive power, supported by a 100-kWh high-voltage battery and a BMW diesel-powered range extender. During the trial period, the vehicles demonstrated that over 90% of operations could be conducted using battery power alone, significantly reducing CO_2 emissions by up to 16 metric tons per vehicle per year compared to traditional diesel engines. The RT vehicles feature high-quality fire extinguishing equipment, including a N25 firefighting pump and CAFS technology, and are designed to meet the operational needs of urban fire services with a comprehensive onboard equipment set. The initiative supports Basel's commitment to sustainability and sets a precedent for the adoption of electric fire service vehicles in Europe (Randall, 2021).

Berlin, Germany

The Berlin Fire Department is advancing its commitment to reducing CO_2 emissions by ordering additional electric vehicles from Rosenbauer. This new order includes four “Revolutionary Technology” (RT) models, designed specifically as electric firefighting and rescue vehicles (eLHFs) through a collaborative multi-year innovation partnership. Following a successful 13-month trial involving three fire stations, where 90% of nearly 1,400 deployments were completed using electric power alone, the department decided to expand its electric fleet. The trial phase demonstrated significant environmental benefits, with around ten metric tons of CO_2 equivalents saved per vehicle compared to diesel-powered counterparts. The RT vehicles feature advanced firefighting equipment, including the N25 pump and CAFS technology, and are capable of carrying 1,200 liters of water and 100 liters of foam concentrate. Additionally, Rosenbauer is developing an electric equipment vehicle to enhance operational hygiene by providing on-site cleaning and changing facilities. This initiative aligns with Berlin’s climate protection goals, aiming for carbon neutrality in public fleets by 2030 and city-wide by 2045 (Hoey, 2022).

London, UK

The London Fire Brigade has collaborated with Emergency One to develop the Zero Emission Capable Pumping Appliance (ZEPA1), an electric-hybrid fire engine aimed at significantly reducing carbon emissions in support of the Mayor of London’s net zero carbon goal by 2030. Set to be trialled in late 2022, ZEPA1 represents a pioneering effort in the UK fire service to deploy electric-hybrid technology. This vehicle, designed to handle all standard fire service operations, boasts a range of over 200 miles and can pump water continuously for four hours. The Brigade’s fleet already includes extensive electric vehicle infrastructure with 242 charging sockets across 96% of its buildings. The project is part of a broader strategy to decarbonize the fleet, including the use of Hydrogenated Vegetable Oil to reduce emissions by 24% from existing diesel engines (London Fire Brigade, 2022).

Amsterdam, Netherlands

The Amsterdam fire brigade, in collaboration with Rosenbauer, is conducting practical tests with a pre-series hybrid fire truck based on the Concept Fire Truck (CFT). These tests, set to last two years, began with the vehicle’s delivery at the end of 2020. This initiative supports Amsterdam’s “Clean Air” action plan, which aims to ban combustion engine trucks, buses, and taxis in urban areas by 2025, and private cars by 2030. The hybrid fire truck will be assessed on its performance in Amsterdam’s narrow streets and urban conditions. The vehicle features range-extended electric capabilities, with a target to achieve an 80% electric quota for deployment scenarios. This project aligns with Amsterdam’s goal of an emission-free fire department by 2030, contributing to a better environment while integrating state-of-the-art technology and real-time information in fire operations (Randall, 2019).

Vienna, Austria

The Vienna Professional Fire Department has purchased two Rosenbauer electrically powered basic firefighting vehicles (BLF), each equipped with a 66-kWh high-voltage battery and capable of delivering 360 kW of peak electrical drive power. These vehicles also feature a 225-kW diesel range extender, known as the Energy Backup System (EBU), to ensure operational capability during prolonged missions. These vehicles combine the functionalities of rescue and tank firefighting vehicles, making them highly versatile. This initiative aligns with Vienna's goal to become climate-neutral, reflecting the city's commitment to environmental sustainability and advanced firefighting technology (Westerheide, 2023).

7.4 Best Practice for Deployment of EVs in Fire Services

The deployment of electric fire service vehicles has shown promising results in various regions, highlighting key best practices and insights for future implementations:

Environmental and Operational Benefits: Electric fire engines significantly reduce greenhouse gas emissions and improve air quality. For example, Berlin's electric vehicles saved around ten metric tons of CO_2 annually compared to diesel engines. These benefits are critical for cities aiming to meet stringent environmental goals.

Technological Advancements: The integration of advanced technologies, such as range extenders and sophisticated battery management systems, ensures that electric fire trucks can meet demanding operational requirements. Vienna's use of Rosenbauer's RT models with diesel range extenders exemplifies how hybrid solutions can provide reliability and extended operational capabilities.

Cost and Infrastructure Considerations: While the initial capital cost of electric fire trucks is higher than traditional vehicles, long-term savings in fuel and maintenance can offset these expenses. For instance, Varennes, Canada, received substantial grant funding to bridge the cost differential, emphasizing the importance of financial support and incentives for widespread adoption.

Performance Metrics: Effective deployment involves monitoring key performance indicators such as vehicle downtime, emergency response times, and operational efficiency. Amsterdam's extensive testing of hybrid fire trucks in narrow urban streets provides valuable insights into the practical challenges and performance benchmarks needed for successful integration.

Collaborative Development and Customization: Partnerships between fire departments and manufacturers are crucial for developing vehicles that meet specific operational needs. The collaboration between the Berlin fire department and Rosenbauer demonstrates the importance of customizing electric fire trucks to suit local requirements and enhance functionality.

By incorporating these best practices and leveraging the insights from current deployments, future implementations of electric fire service vehicles can achieve greater efficiency, environmental benefits, and operational effectiveness.

VIII. Next Steps

This report underscores the significant long-term financial and operational benefits of transitioning the VFRS fleet to EVs. While the initial capital costs for EVs are higher, these are offset by lower maintenance expenses, stable energy costs, and incentives that reduce overall investment. Additionally, the environmental benefits align with broader city goals for sustainability and reduced carbon emissions.

Recommendations for Optimizing the VFRS Fleet

To optimize the VFRS fleet for electric vehicles, a strategic approach should be taken that includes:

- Prioritizing Vehicle Replacement: Focus on replacing older, high-maintenance ICEVs first, particularly those with higher operational costs and lower efficiency.
- Leverage Incentives: Continue to explore and capitalize on available government incentives and rebates to lower upfront costs.
- Energy Cost Management: Monitor and manage energy consumption effectively by utilizing BC Hydro’s Fleet Electrification Rates, which offer cost-saving opportunities during non-peak hours.

Operational Changes to Accommodate Electric Vehicles

Transitioning to electric vehicles will require several operational adjustments, including:

- Training: Providing specialized training for staff on the operation and maintenance of electric vehicles to ensure efficient and safe use.
- Infrastructure Upgrades: Investment in charging infrastructure is crucial. The installation of additional charging stations at key fire halls, like Fire Hall #1, will support the growing number of EVs in the fleet.

- Maintenance Planning: Establishing a dedicated EV maintenance schedule that accounts for the different servicing needs of electric vehicles compared to ICEVs.

Phased Implementation Plan

A phased implementation plan is recommended to ensure a smooth and cost-effective transition:

1. Phase 1 (Year 1-2): Begin with the replacement of high-cost ICEVs with EVs, focusing on vehicles with the highest operational costs and lowest efficiency. Simultaneously, install necessary charging infrastructure and provide training for staff.
2. Phase 2 (Year 3-4): Expand the EV fleet by replacing additional ICEVs. Optimize maintenance schedules and further integrate EV-specific operational practices.
3. Phase 3 (Year 5+): Complete the transition by phasing out remaining ICEVs and ensuring full integration of EVs into the fleet, with a focus on monitoring performance and adjusting strategies as needed.

These next steps will guide VFRS in making informed decisions, ensuring that the transition to an electric fleet is both effective and aligned with the City’s long-term goals.

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