

Charging Ahead

MODELLING THE GRID IMPACTS OF ELECTRIC SCHOOL BUS ELECTRIFICATION IN CALGARY

November 2026

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Land Acknowledgement

With a focus on mobility in what is now known as Alberta – subject to Treaties 6, 7 and 8 – this project is inherently land-based. The project team recognizes the true history of these lands and the injustices that First Nations, Métis, and Inuit peoples continue to experience through colonial systems and structures. We acknowledge these lands as the traditional and ancestral territory of many peoples – the Blackfoot Confederacy– Kainai, Piikani, and Siksika – the Cree, Dene, Saulteaux, Nakota Sioux, Stoney Nakoda, the Tsuu T'ina Nation, and the Métis People of Alberta.

We encourage readers to learn about the Indigenous history of where they live and work and the Truth and Reconciliation Commission of Canada's Calls to Action. We invite you to reflect on your own relationship with the lands you occupy and what meaningful actions you can take toward reconciliation.

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About

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RFS Energy

RFS Energy brings people together to propel planning, research, and climate change policy into the marketplace.

With 50+ years of combined experience working with non-profits, think tanks, 25+ utilities and government agencies across Canada, the RFS Energy team draws from unique experience rooted in on-the-ground program implementation to support clients and bring innovation to life.

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List of Acronyms

AESO	Alberta Electric System Operator	**kW**	Kilowatt
AUC	Alberta Utilities Commission	**kWh**	Kilowatt-hour
CBE	Calgary Board of Education	**MW**	Megawatt
CCSD	Calgary Catholic School District	**MHDV**	Medium- and Heavy-Duty Vehicle
ESB	Electric School Bus	**MW**	Megawatt
EV	Electric Vehicle	**TCO**	Total Cost of Ownership
GWh	Gigawatt-hour	**ZETF**	Zero Emission Transit Fund

Executive Summary

School buses are among the most promising candidates for early fleet electrification in Canada. Their predictable routes, fixed duty cycles, and centralized overnight parking make them well suited to battery-electric technology. Electrification offers clear opportunities to reduce emissions and improve air quality, but it also introduces new and concentrated demands on the electricity distribution system.

This report, developed by Pollution Probe in partnership with Mobility Futures Lab and RFS Energy, quantifies the projected energy and power demand associated with electrifying Calgary's school bus fleet from 2025 to 2040. Using real-world operational data, the analysis evaluates charging demand under different adoption and charging scenarios and maps resulting loads across the city's distribution system.

The results show that while total electricity demand remains modest, electrification creates localized peaks that can strain distribution infrastructure. Meeting localized peak charging demand through grid infrastructure capacity, rather than overall energy supply, is therefore the primary challenge for scaling electric school bus deployment.

Fleet electrification is gradual but highly sensitive to adoption assumptions. Starting from a base fleet of approximately 1,120 buses, the electric fleet is projected to reach roughly 170 vehicles under a base scenario and nearly 500 under an aggressive scenario by 2040, representing approximately 11% and 33% of the total fleet, respectively. Even under accelerated adoption, this reflects a partial transition, driven by cost trends and market conditions.

At the system level, energy impacts are limited. Annual electricity demand reaches approximately 4.2 GWh under the base scenario and 12.3 GWh under the aggressive scenario by 2040, a relatively small addition to Calgary's overall electricity requirements. These findings confirm that electric school buses do not pose a material challenge to generation or transmission capacity.

In contrast, distribution-level impacts are more significant and concentrated. Under unmanaged charging, fleet-level peak charging demand reaches approximately 0.67 MW in the base scenario and 1.82 MW in the aggressive scenario in a representative winter day in 2035. Managed charging reduces these peaks by approximately 28–32%, demonstrating meaningful but partial mitigation. Because charging demand is concentrated at a limited number of depot locations, even moderate aggregate loads can translate into localized stress on transformers and feeders.

Spatial analysis shows that a small number of substations are associated with a disproportionate share of charging demand, with localized charging peaks ranging from 90 kW to 376 kW in 2035. Near-term impacts at these locations are manageable and are most likely to require transformer-level upgrades, with feeder or substation reinforcement becoming relevant as electrification expands across additional medium- and heavy-duty vehicle and other sectors. Infrastructure costs may range from tens of thousands to several million dollars depending on the scale and location of demand.

These findings highlight the importance of proactive coordination between fleet operators and local utility ENMAX. Distribution upgrades, particularly at the feeder and substation level, can take several years to plan and construct. As federal support programs phase out, early engagement based on realistic load profiles becomes critical to avoiding costly, reactive infrastructure investments.

Managed charging should also be treated as a core operational strategy to reduce peak demand and improve asset utilization. Additional strategies, including behind-the-meter battery storage or targeted infrastructure upgrades, may further reduce local peak impacts and should be evaluated based on site-specific economics.

Overall, this analysis provides a data-driven foundation for planning electric school bus deployment in Calgary. While electrification does not materially impact system-wide energy demand, it introduces localized distribution challenges that require early coordination, targeted investment, and operational optimization. Addressing these challenges proactively will enable cost-effective, reliable electrification that supports Calgary's transportation, environmental, and grid planning objectives over the coming decades.

1 Introduction

School transportation plays a vital role in Alberta's mobility system, with the City of Calgary serving as one of the province's largest hubs for daily student travel. School buses operate on predictable, stop-and-go routes that are well suited to electrification, making them a strong early candidate for reducing emissions and improving air quality. As Alberta evaluates long-term pathways for fleet decarbonization, Calgary provides a valuable case for understanding the operational, economic, and grid-related implications of electric school bus deployment at scale.

Despite their strong technical fit, the economics of electric school buses remain challenging. Purchase prices are currently two to three times higher than comparable diesel buses, and near-term adoption depends on whether higher capital costs can be offset by lower operating costs, including access to predictable, low- cost electricity. Charging infrastructure costs and electricity rate structures therefore play a central role in determining where electrification becomes viable.

Grid impacts add another layer of complexity. Depot-based charging introduces concentrated loads that may require distribution upgrades planned several years in advance. Because utilities have limited visibility into where and when these loads will emerge, electrification increases the risk of reactive and higher-cost infrastructure deployment.[1]

As school bus electrification expands, utilities require better insight into the magnitude and timing of charging demand, regulators need clarity on future investment requirements, and fleet operators need reliable, cost-effective charging solutions that support daily operations. Governments similarly require evidence on how electrification interacts with grid planning, air-quality goals, and funding frameworks.

In this context, this study—developed by Pollution Probe in partnership with Mobility Futures Lab and RFS Energy—quantifies the projected energy and power demand associated with electrifying Calgary's school bus fleet. The analysis provides a data-driven foundation to support proactive distribution planning, inform regulatory decisions, and give fleet operators actionable insight into future charging requirements. Together, these findings support a coordinated approach to enabling cost-effective, reliable, and scalable school bus electrification in Calgary.

1 Energy Systems Integration Group (January 2024). Charging Ahead: Grid Planning for Vehicle Electrification. Retrieved from: https://www.esig.energy/wp-content/uploads/2024/01/ESIG-Grid-Planning-Vehicle-Electrification-report-2024.pdf

2 Impact of School Bus Electrification on the Grid

This section examines the economic context and infrastructure implications of school bus electrification, with a focus on how these emerging loads interact with electricity distribution systems and utility planning.

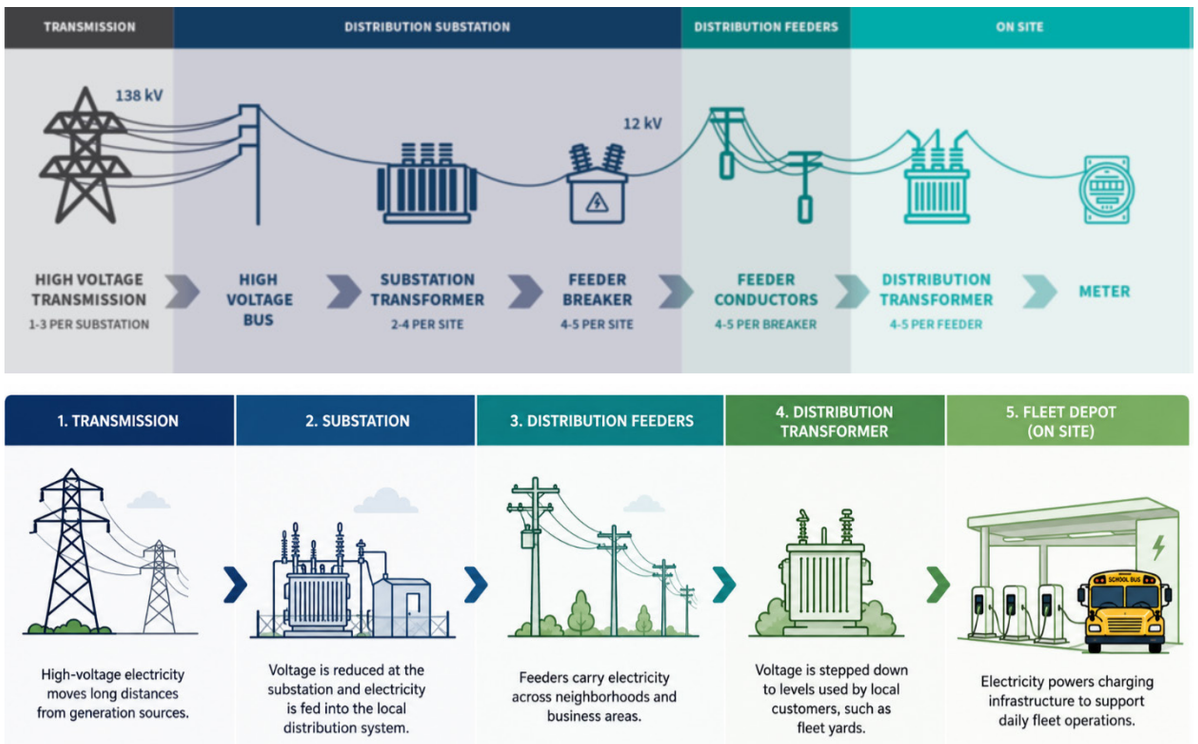
2.1 How Electricity Distribution Works and Why It Matters for Fleets

Electricity moves from generation facilities through high-voltage transmission lines to the lower-voltage distribution system that serves homes, businesses, and fleet depots. The distribution network is composed of three main components:

- **Substations**, which receive electricity from the transmission system and distribute it into the local network.
- **Feeders**, which carry power across defined geographic areas within the distribution system.
- **Transformers**, which step voltage down to levels required by individual customers such as fleet yards.

Each of these components has a maximum amount of power it can safely deliver, and exceeding those limits triggers upgrades at that level of the system. The hierarchy is illustrated in **Figure 1** below.

Figure 1: Electricity grid topography.[2]



2 RMI (2023). Preventing Electric Truck Gridlock. Meeting the Urgent need for an Updated Electricity System. Retrieved from: https://rmi.org/resources/preventing-electric-truck-gridlock/

In Calgary, the distribution system is owned and operated by ENMAX, with transmission supplied by the Alberta Electric System Operator (AESO). For fleet operators planning to install charging infrastructure, the process begins by estimating total charging load at a depot and working with ENMAX to determine whether upgrades are required at the transformer, feeder, or substation level.

The scale of required upgrades depends on the magnitude and timing of the new load. Smaller increases in demand can often be accommodated through transformer upgrades, which are relatively quick and lower cost. Larger deployments, particularly where multiple vehicles charge simultaneously, may require feeder or substation upgrades, which are more complex, costly, and time-intensive. In general, larger loads drive impacts further upstream in the distribution system, increasing both cost and project timelines.

Table 1 summarizes typical upgrade types, costs, and timelines associated with increasing levels of charging demand, from transformer replacements to new substation construction.[3]

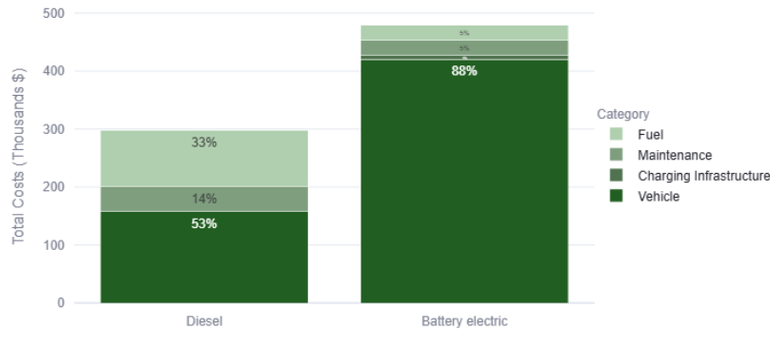
Table 1: Typical upgrades, costs and average timeline [4]

Infrastructure	Typical Load Upgrade	Average Cost	Average Timeline
New Transformer	200+ kW load	$15k-$200k	3-8 months
Install/upgrade feeder circuit and breaker	5+ MW load	$2M-$12M	3-12 months
Substation upgrade	3-10+ MW load	$3M-$5M	12-18 months
New substation installation	3-10+ MW load	$4M-$35M	24-48 months

2.2 Electric School Bus Economics and Infrastructure Costs

Building on the distribution-system considerations outlined in Section 2.1, the economics of electric school buses remain a central factor in determining the pace of fleet electrification. Electric school buses have higher upfront costs but lower operating costs over time. The capital premium is expected to narrow as battery prices decline and manufacturers achieve economies of scale, and savings in maintenance and electricity compared to diesel fuel will help offset lifecycle costs. As of 2024 in the Calgary context, total cost of ownership remains approximately 64 percent higher than diesel when no financial incentives are applied.[5]

Figure 2: Total cost of ownership over 13 years of a diesel versus electric type C school bus



3 These represent estimates, with substations varying in size and complexity resulting in higher costs than listed.

4 Borlaug, B., Muratori, M., Gilleran, M. et al. (2021). Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems. Nat Energy 6, 673–682. Retrieved from: https://doi.org/10.1038/s41560-021-00855-0

5 Mobility Futures Lab (2026). AltFleet Insight Tool. Retrieved from: https://altfleetinsight.mobilityfutureslab.ca/

In addition to the higher upfront cost of electric school buses, electrification at scale can introduce significant grid infrastructure costs, depending on how many of the distribution components described in Section 2.1 require upgrades. In practice, upgrade needs can range from relatively modest transformer replacements to feeder or substation reinforcement, meaning infrastructure costs for a single depot can span from hundreds of thousands to several million dollars depending on its location. Under the current regulatory framework, the fleet operator requesting the upgrade generally bears most of the associated costs, although some utilities offer limited cost-recovery mechanisms based on usage.

Until early 2026, federal incentives through the Zero Emission Transit Fund (ZETF) helped fleets cover both vehicle purchases and distribution-system upgrade costs, allowing projects to move forward even when the required grid infrastructure ultimately benefited utilities through long-term load growth.[6] Utilities, including ENMAX, also provide capacity-mapping tools that give prospective customers an initial sense of where distribution capacity is available and help rule out sites that would require major upgrades.[7] With these incentives no longer available, early coordination between fleets and ENMAX becomes even more important to avoid reactive, last-minute upgrades that are more expensive, take longer to complete, and can become cost-prohibitive for fleet operators.

2.3 Utility Planning Challenges and the Need for Proactive Coordination

Utilities plan and invest in distribution infrastructure based on projected demand growth, typically driven by population, economic activity, and industrial development.[8] In Calgary, ENMAX Power develops multi-year distribution and capital plans to anticipate system needs. While these plans increasingly recognize electrification trends, school bus charging demand is not yet systematically incorporated into long-term planning.

At the same time, electric school bus adoption remains uncertain and cost-sensitive (Section 2.2), limiting the justification for proactive grid investment in the absence of confirmed demand. From a utility perspective, building capacity too far in advance risks creating underutilized infrastructure, while delaying investment until service requests are submitted can result in longer timelines, higher costs, and reactive upgrades. Regulators must also approve utility capital investment plans, and may be unwilling to approve proactive investments.

This creates a planning gap: utilities lack visibility into where and when charging demand will emerge, while major infrastructure upgrades, particularly at the feeder and substation level, can take several years to complete. Without early coordination, electrification increases the likelihood of delayed and higher-cost infrastructure deployment.

School bus operators represent a new and evolving class of electricity customer. Understanding the spatial distribution and timing of their charging demand is critical for maintaining reliability and planning upgrades efficiently. More broadly, increased medium- and heavy-duty electrification can contribute to higher electricity sales and improved asset utilization, particularly where new loads can be integrated without triggering major upgrades.[9]

6 Housing, Infrastructure and Communities Canada (2026). Zero Emission Transit Fund. Retrieved from: https://housing-infrastructure.canada.ca/zero-emissions-trans-zero-emissions/index-eng.html

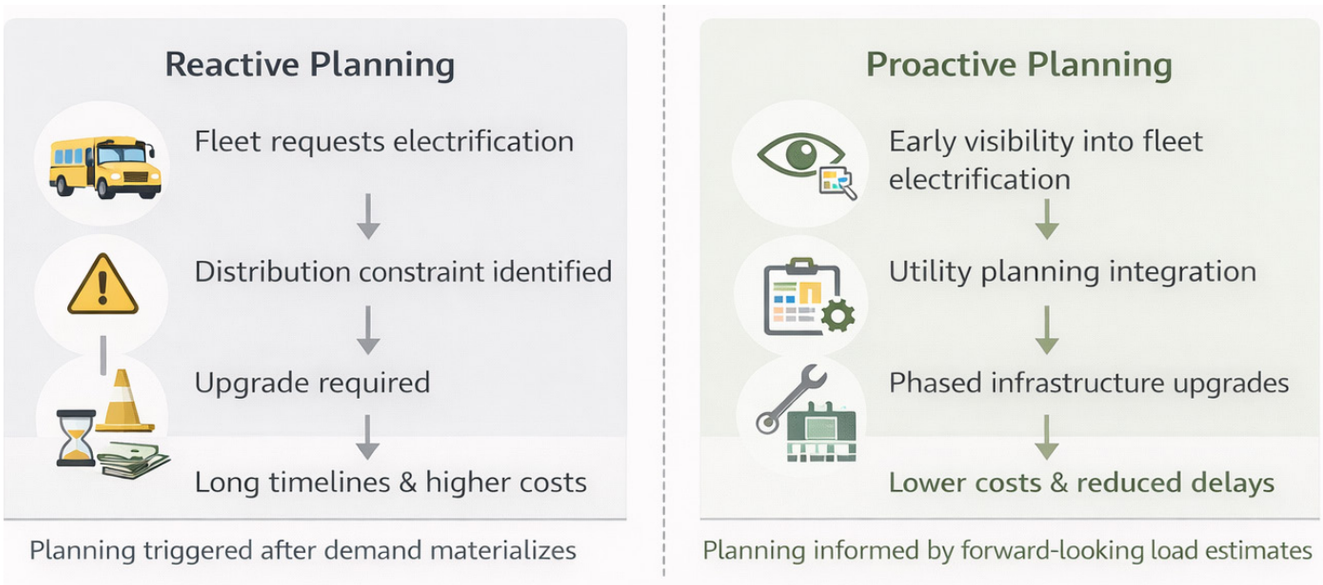
7 Atlas Public Policy (2024). Hosting capacity maps for EV charging. Lessons Learned in Implementing Utility Hosting Capacity Maps to Support Electric Vehicle Charging. Retrieved from: https://www.atlasevhub.com/wp-content/uploads/2024/12/Final-Report-Hosting-Capacity-Maps-for-EV-Charging.pdf

8 RMI (2024). Transportation electrification building blocks. Practical guidance for regulators and utilities to strategically plan for rapid electric vehicle load growth. Retrieved from: https://rmi.org/app/uploads/dlm_uploads/2024/07/transportation_electrification_building_blocks_rmi_july_2024.pdf

9 Synapse Energy Economics (2024). On the Road to Fleet Electrification A Framework for Estimating Distribution System Impacts of Medium- and Heavy-Duty Vehicle Electrification. Retrieved from: https://advancedenergyunited.org/reports/on-the-road-to-fleet-electrification/

Figure 3 illustrates the contrast between reactive and proactive planning approaches. By quantifying both the magnitude and timing of charging demand, this study provides a foundation for more coordinated planning between fleet operators and utilities.

Figure 3: Reactive versus proactive utility planning for school bus electrification.



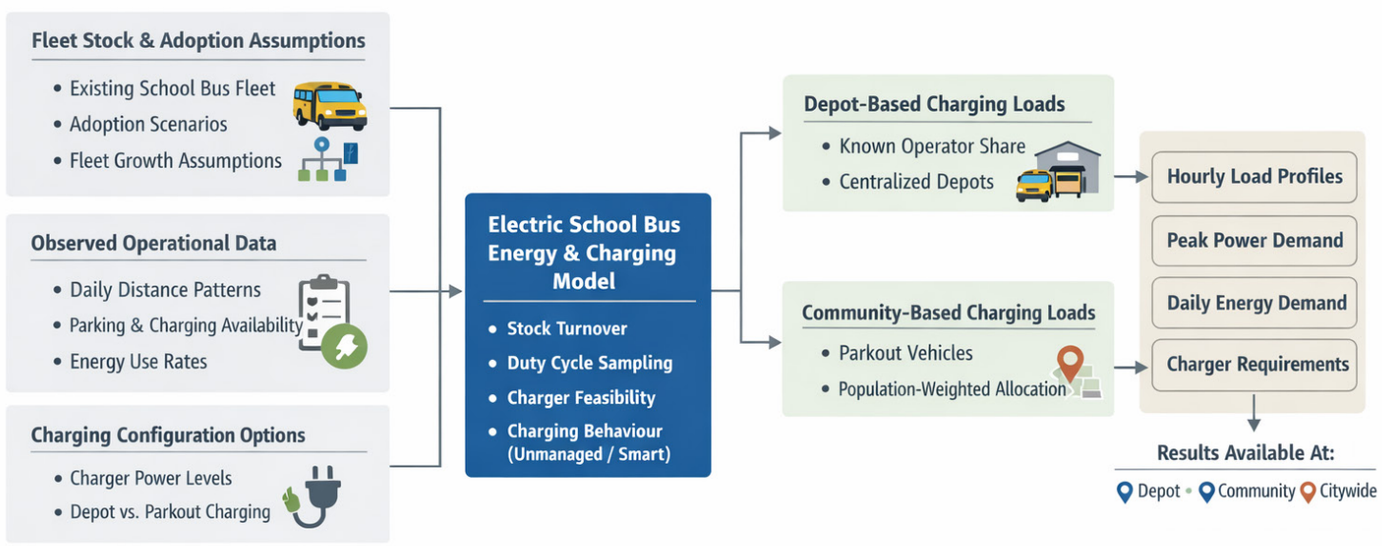
3 Modelling Approach

This section describes the modelling approach used to estimate energy consumption and charging power demand associated with electrifying Calgary's school bus fleet. **Figure 4** provides an overview of the modelling framework and its main components.

The framework resolves charging demand spatially by attributing loads to both centralized depots and distributed community locations. This allows results to be assessed at the level of individual depots, communities, and the citywide system, consistent with how distribution planning decisions are made.

The analysis projects electric school bus adoption over a 15-year horizon, starting from the existing school bus fleet serving the City of Calgary. Projected electric vehicle stock is combined with observed operational duty cycles and feasible charging configurations to estimate hourly and daily charging loads under different adoption and charging-behaviour scenarios.

Figure 4: Overview of the electric school bus energy and charging demand modelling framework. [10]



10 The model integrates fleet adoption scenarios with observed operational data and feasible charging configurations to estimate energy use and power demand. Charging loads are spatially resolved by distinguishing between depot-based and community-based charging, allowing results to be assessed at multiple geographic scales.

3.1 Calgary School Bus Fleet Overview

School transportation in Calgary is organized around multiple school boards, with the Calgary Board of Education (CBE) and Calgary Catholic School District (CCSD) accounting for most routes. These boards design service routes and contract operations to private school bus operators through competitive procurement processes.

Vehicles are typically assigned to specific routes and operate similar duty cycles each day. Depending on operator practices, buses may be parked overnight at centralized depots or at off-site locations ("parkouts"), which directly influences where charging demand is concentrated.

In the modelling framework, parkout charging is represented in aggregate at the community level rather than at individual residential sites. This approach reflects the distributed nature of parkouts while remaining appropriate for distribution-level planning.

Two primary categories of school buses operate in Calgary (**Figure 5**):

- **Type A buses**, smaller vehicles typically used for specialized transportation needs.
- **Type C buses**, the full-size conventional yellow school buses used for the majority of student transportation.

Based on discussions with school boards and major operators, the total number of buses serving the City of Calgary and the relative proportions of Type A and Type C vehicles were estimated to inform model inputs (**Appendix A.1**).

Figure 5: Type A versus Type C school bus.



3.2 Battery-Electric Vehicle Penetration Projections

Electric school bus adoption remains highly cost-sensitive and is driven primarily by the relative cost of electric and diesel vehicles. With federal incentives having expired in March 2026 and a substantial upfront price premium persisting, near-term adoption is expected to remain limited. Longer-term adoption may accelerate if battery costs decline, manufacturing scale improves, or import tariffs on electric school buses are reduced.

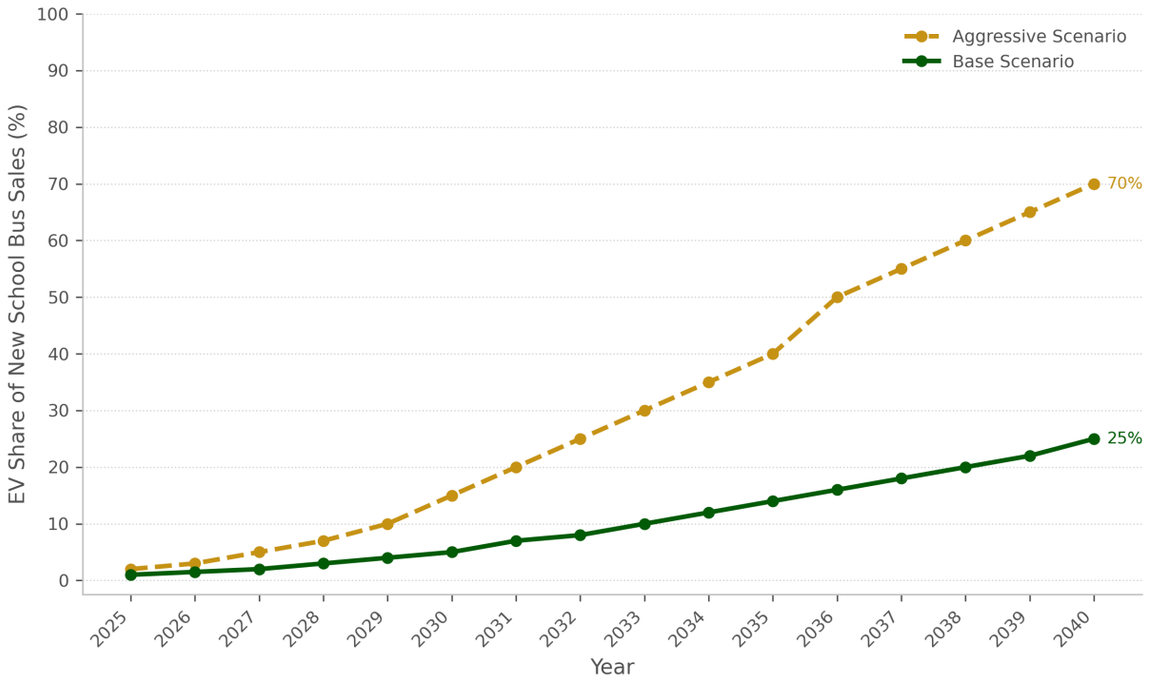
Two adoption scenarios were modelled:

1. **Base scenario**, reflecting gradual cost declines and approximate cost parity in the early 2030s
2. **Aggressive scenario**, reflecting faster cost declines and the potential removal of import tariffs

While Type A buses electrify earlier than larger buses in some jurisdictions, this analysis assumes similar adoption trajectories for Type A and Type C vehicles. In Calgary, Type A buses often serve longer, more geographically dispersed routes with higher daily variability, reducing their relative suitability for early electrification.

A stock-turnover model replaces retiring vehicles based on age distributions and survival probabilities, combined with assumptions about annual fleet growth (**Appendix A.2**). **Figure 6** shows the assumed share of new vehicle purchases that are electric under each scenario.

Figure 6: Yearly Battery Electric School Bus Sales under each Scenario



3.3 Energy and Power Demand Modelling Framework

The charging model uses empirical operational data from Calgary's school bus fleet, including distributions of daily distance travelled and typical parking and charging availability windows. Daily energy requirements are calculated using sampled distances and vehicle-type-specific energy consumption rates (**Appendix A.4**).

To maintain computational efficiency at higher adoption levels, the model simulates representative samples of vehicles within each segment and scales results to projected fleet totals.

Charging demand is divided into depot-based and community-based charging to reflect where electricity demand occurs. Depot-based charging represents vehicles parked at centralized fleet yards, while community-based charging represents vehicles parked at off-site locations such as residential parkouts.

For each modelling year, the electric fleet is divided into:

- A known operator share, assigned to specific depots
- A residual share, distributed across communities using population-based weights

Depot-level charging profiles are generated at the individual depot level and spatially attributed to their corresponding communities. These are combined with community-based charging demand to produce community-level and system-wide load estimates.

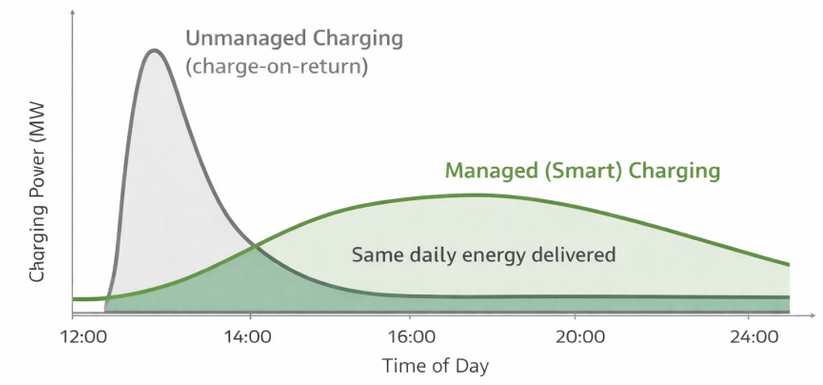
Each simulated electric school bus is assigned the lowest-power charger capable of meeting its daily energy requirement within the available charging window. Duty cycles that cannot be served using the largest charger option are flagged as infeasible. Throughout this report, "peak charging demand" refers to aggregate fleet charging load and does not imply coincidence with Calgary or Alberta system peak demand periods.

Two charging-behaviour scenarios are assessed (**Figure 7**):

- Unmanaged charging, where vehicles begin charging immediately upon return
- Managed (smart) charging, where charging is distributed across available parking windows to reduce peak charging demand

The managed charging scenario reflects operationally achievable coordination (e.g., staggered charging or delayed start times) rather than real-time optimization or vehicle-to-grid operation.

Figure 7: Illustrative comparison of unmanaged and managed school bus charging profiles. [11]



11 Under unmanaged charging, vehicles begin charging immediately upon return, producing a pronounced coincident peak. Managed charging redistributes charging within available parking windows, reducing peak demand while delivering the same total daily energy.

3.3.1 Baseline Charging Simulation (Unmanaged Charging)

Under the unmanaged assumption, buses begin charging immediately upon returning to a location where charging is available. Charging continues until daily energy requirements are met. When aggregated across the fleet, this produces a conservative, peak-oriented load profile.

3.3.2 Smart Charging Scenario (Managed Charging)

Under the managed charging scenario, charging is distributed across each vehicle's available parking window rather than beginning immediately upon return. Charging schedules remain constrained by charger power and daily energy requirements but reduce simultaneous charging start times.

This scenario reflects operationally achievable coordination through practices such as delayed start times, staggered charging, or basic software-controlled sequencing. It does not assume real-time optimization, vehicle-to-grid operation, or dynamic price-based dispatch.

Prior studies indicate that coordinated depot charging can reduce peak demand by approximately 20–40 percent, depending on fleet size and duty cycles.[12] Results from this analysis should therefore be interpreted as a plausible, moderate coordination case rather than a theoretical maximum.

12 Pollution Probe (2026). Optimizing Depot Charging for Electric School Buses. A Calgary Case Study on Costs and Peak Demand. Retrieved from: https://www.pollutionprobe.org/wp-content/uploads/2026/08/Pollution-Probe_ESB-Calgary-Report_Aug7-1.pdf

4 Results and Analysis

This section presents results from the electric school bus electrification modelling in four steps. First, projected fleet growth and charging infrastructure requirements are presented to illustrate the scale and pace of adoption. Second, system-level energy impacts are assessed to contextualize electrification within Calgary's broader electricity demand. Third, distribution-level power impacts are evaluated under unmanaged and managed charging assumptions. Finally, charging loads are spatially mapped to identify substations most exposed to mid-term electrification impacts.

Together, these results move from fleet scale to grid impact, linking adoption trajectories to the distribution-system assets most likely to require early attention.

4.1 EV Stock Projections and Charging Infrastructure Needs

Question answered: ***How big does this get, and how fast?***

Under the base scenario, the electric school bus fleet grows steadily from 2025 onward, reaching approximately 170 vehicles by 2040. Under the aggressive scenario, the fleet expands more rapidly to nearly 500 vehicles by 2040.

With the total Calgary school bus fleet projected to grow from approximately 1,120 vehicles in 2025 to around 1,500 by 2040 (assuming 2% annual growth), this corresponds to approximately 11% electrification under the base scenario and 33% under the aggressive scenario. Even under accelerated adoption, this represents a partial transition rather than full fleet replacement within the modelling horizon.

The divergence between scenarios becomes more pronounced after the early 2030s, highlighting the cumulative effect of higher electric school bus shares in annual replacements rather than abrupt changes in fleet turnover. These results indicate that long-term electric school bus stock levels are highly sensitive to assumptions about the share of electric vehicles in new sales, with implications for the scale and timing of charging infrastructure investments required to support large-scale deployment.

Figure 8: Projected battery-electric school bus stock in Calgary under base and aggressive adoption scenarios, 2025–2040. Growth reflects cumulative replacement of retiring vehicles rather than abrupt fleet turnover.

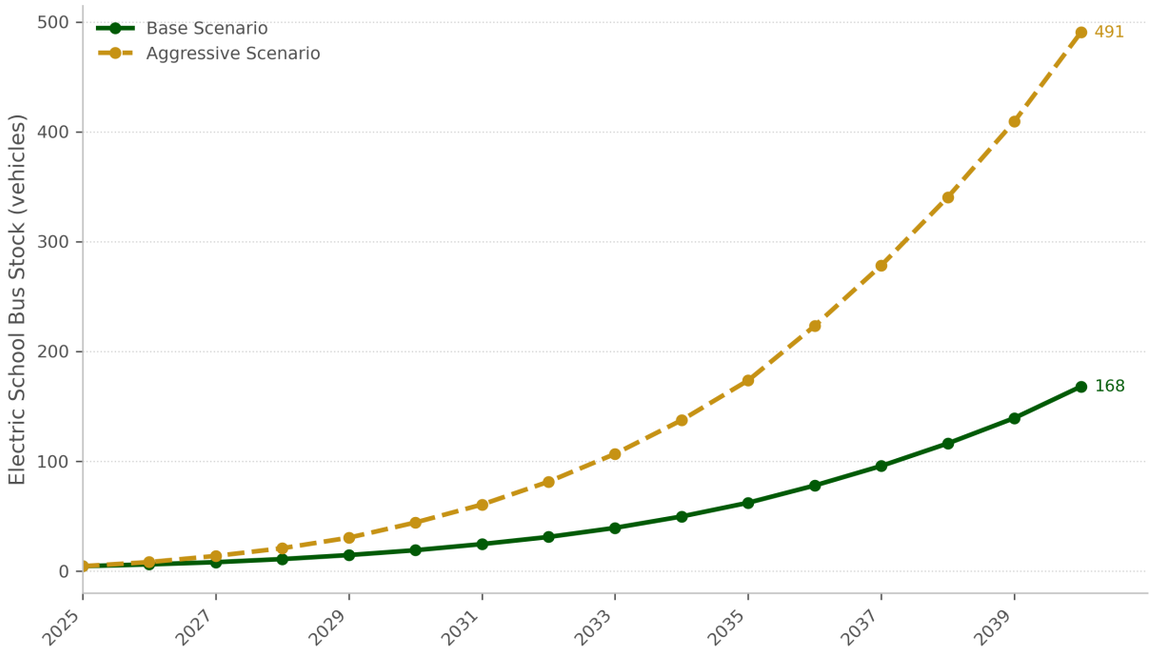


Table 2 summarizes the number of charging ports required in 2040 under both scenarios, disaggregated by charger power level. In both cases, the majority of buses are served by lower-power chargers, reflecting the early electrification of routes with shorter daily distances.

As electrification expands under the aggressive scenario, the share of higher-power chargers increases, indicating growing infrastructure and power requirements over time.

Table 2: Minimum Required Charger Ports by Power Level Under 1:1 Port-to-Bus Assumption (Winter, 2040)

Scenario	EV Buses (count)	Charger Power Level	Number of Chargers	Share of Chargers (%)
Base	168	11 kW	155	92%
		22 kW	13	8%
Base – Total		—	**168**	**100%**
Aggressive	491	11 kW	451	92%
		22 kW	40	8%
Aggressive – Total		—	**491**	**100%**

4.2 System-Level Energy Impacts

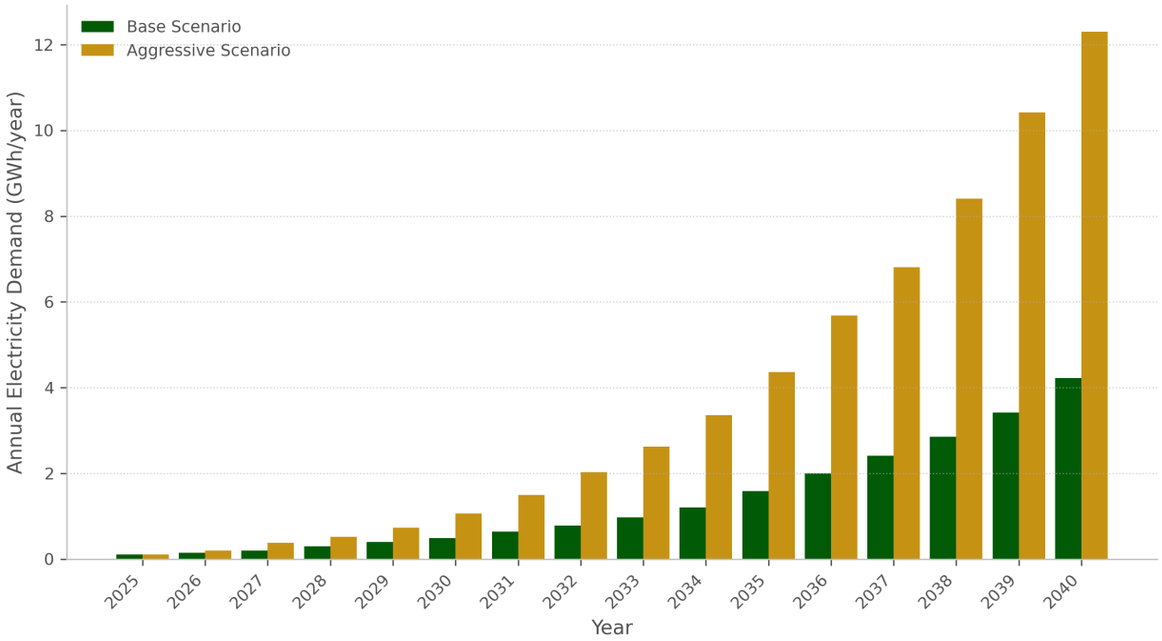
Question answered: *Does this materially change electricity demand?*

Figure 9 shows the projected annual electricity demand associated with charging Calgary's electric school bus fleet from 2025 to 2040 under the base and aggressive adoption scenarios. By 2040, total annual demand reaches approximately 4.2 GWh under the base scenario and 12.3 GWh under the aggressive scenario.

Even under accelerated adoption, this represents a relatively small addition to Calgary's overall electricity demand, indicating that school bus electrification does not materially affect generation or transmission capacity.

However, charging demand is highly time- and location-dependent. As a result, distribution-level power impacts, rather than total energy demand, represent the primary infrastructure planning challenge associated with electric school bus deployment.

Figure 9. Projected annual electricity demand associated with charging Calgary's electric school bus fleet under base and aggressive adoption scenarios, 2025–2040.



4.3 Distribution-Level Power Impacts

While electric school bus adoption and total energy demand are presented over the full 2025–2040 horizon, the power-demand and spatial analyses in this section focus on 2035. 2035 is used as a representative mid-horizon year, where electrification levels are high enough to create distribution impacts while remaining within typical utility planning timelines.

All distribution-impact results are presented for a winter typical day, reflecting a conservative stress case for electric school bus energy consumption and alignment with Alberta's historically winter-peaking conditions. Results are presented as aggregate fleet-level charging demand profiles and do not represent asset-specific loading without further site-level analysis.

4.3.1 Unmanaged vs Managed Charging

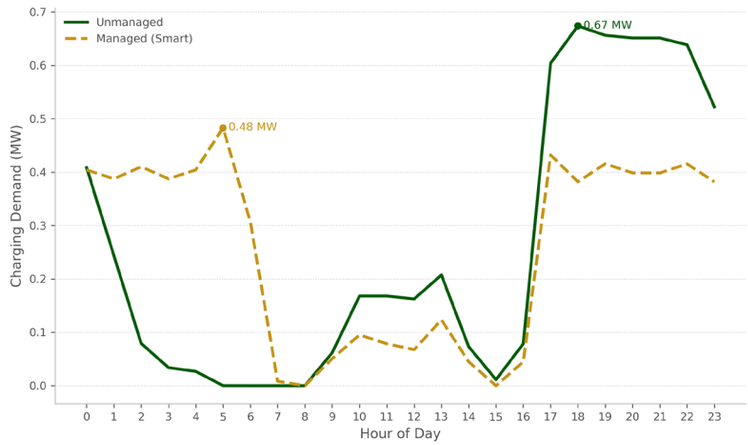
Question answered: *How bad can peaks get, and how much can coordination help?*

Figures 10a and 10b show hourly charging demand profiles for the electric school bus fleet under unmanaged and managed charging assumptions for the base and aggressive adoption scenarios, respectively, using 2035 as a representative winter planning year. Presenting the scenarios side by side highlights how coincident charging demand scales with fleet size, while illustrating the consistent peak-reduction benefits of managed charging across adoption trajectories.

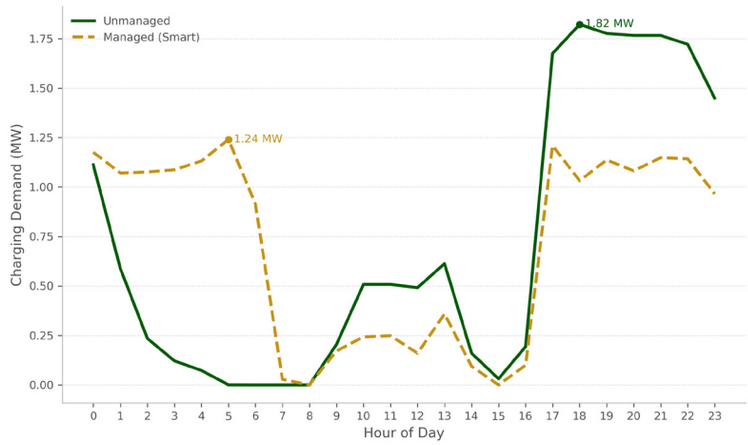
Under the base scenario, unmanaged charging produces a fleet-level charging peak of approximately 0.67 MW, which is reduced to 0.48 MW (approximately a 28% reduction) under managed charging. In the aggressive scenario, unmanaged peak charging demand increases to approximately 1.82 MW, while managed charging reduces the peak to 1.24 MW, corresponding to a reduction of roughly one-third (32%).

These results demonstrate that managed charging can materially reduce charging peaks but does not eliminate distribution capacity constraints as fleet size increases.

Figure 10. Hourly charging demand for Calgary's electric school bus fleet under unmanaged and managed charging assumptions on a representative winter day in 2035: (a) base adoption scenario and (b) aggressive adoption scenario. Profiles represent aggregate fleet-level demand.



a) base adoption scenario



b) aggressive adoption scenario

4.3.2 Why This Matters for Planning

While **Section 4.3.1** presents aggregate fleet-level peak demand, distribution-system impacts are driven by how and where that demand materializes on the network. Because charging loads are concentrated at a limited number of depot locations, even moderate aggregate demand can create localized stress on transformers and feeders.

Under unmanaged charging, charging peaks may exceed local capacity at individual depots, particularly where multiple routes are co-located. Managed charging reduces peak demand and improves utilization of existing infrastructure, but it does not eliminate the need for upgrades at sites with limited underlying capacity. Additional mitigation strategies may also be considered at high-demand sites, including behind-the-meter battery storage, staged infrastructure deployment, or targeted transformer upgrades. Fleet operators will ultimately need to assess whether investments in load-management technologies are more cost-effective than distribution upgrades, depending on site conditions and utility requirements.

As electrification expands, impacts may extend beyond transformers and feeders to upstream assets such as substations, particularly in areas with high depot concentration. The extent to which upgrades can be deferred depends on both fleet growth and the spatial distribution of charging demand, as well as other areas of load growth, such as conversion to electric heating.

For these reasons, evaluating system-wide demand alone is insufficient for infrastructure planning. Spatially resolved analysis is required to identify where electrification is most likely to trigger upgrades and to support targeted, proactive coordination with utilities.

4.4 Substation-Level Exposure

Question answered: *Where does this actually hit the grid?*

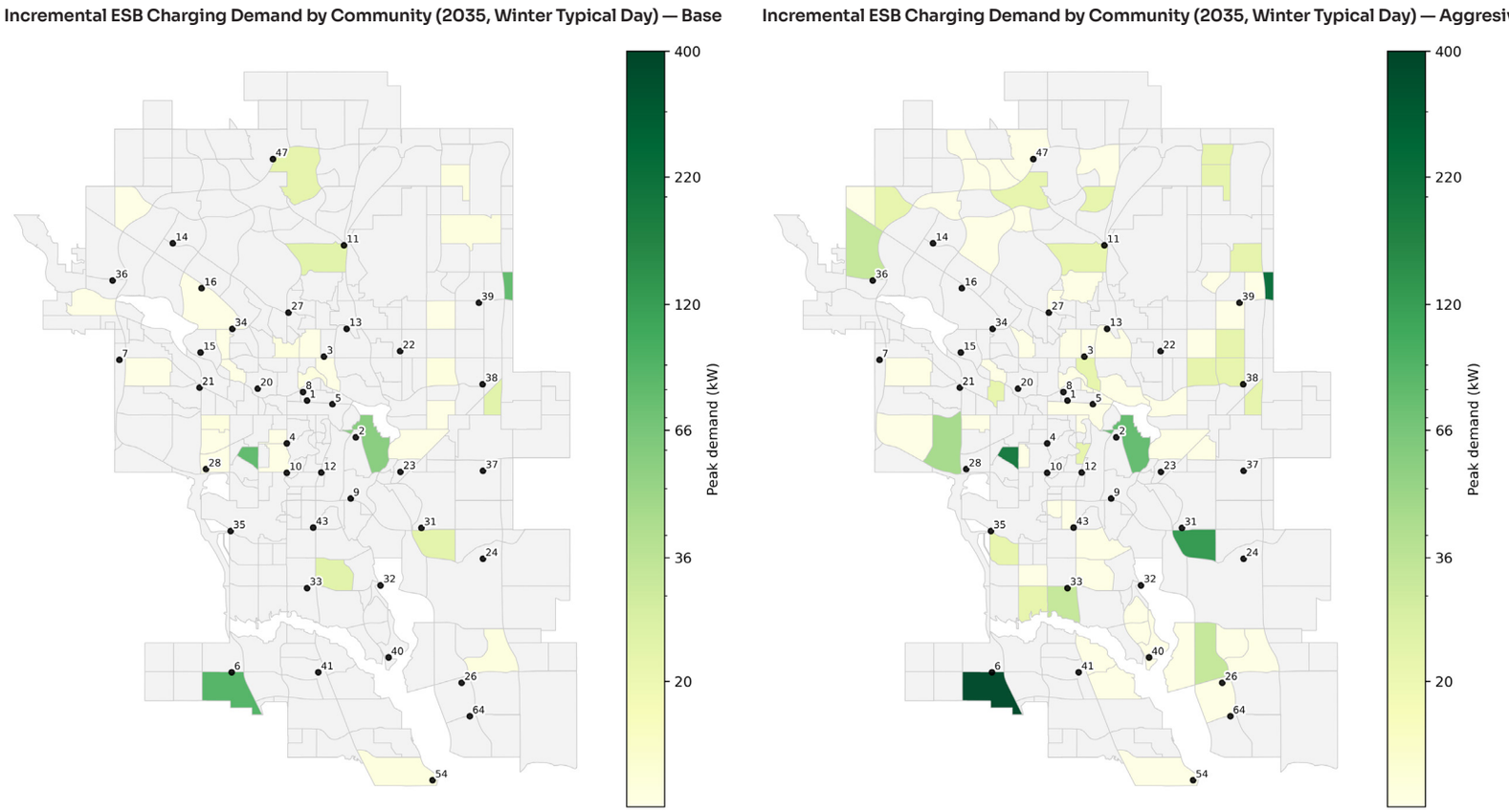
Figures 11a and 11b map incremental electric school bus charging demand in 2035 to Calgary communities under the base and aggressive adoption scenarios, respectively. Depot-level charging loads are spatially attributed to the communities in which depots are located, while vehicles without precise depot information are distributed across communities using population-weighted assumptions. This approach preserves total system demand while providing a geographically intuitive representation of where charging loads are most likely to materialize across the city

The figure highlights elevated charging demand in communities that host major school bus depots, with remaining loads more diffusely distributed across the city. The highest community-level charging demand peak reaches approximately 89 kW under the base scenario and 376 kW under the aggressive scenario.

While results are presented at the community level, distribution-system impacts ultimately manifest at upstream assets such as feeders and substations. To support screening-level planning, community-level charging demand was associated with substations by mapping each community's centroid to the nearest distribution substation and aggregating charging demand profiles. This approach provides an indicative view of where school bus electrification is most likely to create localized grid impacts, without implying direct electrical connectivity.

Table 3 summarizes the five substations associated with the highest incremental electric school bus charging demand in 2035 under the base and aggressive adoption scenarios. These associations are intended to support early-stage prioritization and coordination rather than detailed engineering design. Because not all depot locations could be precisely geolocated, and because community-to-substation mapping is approximate, results should be interpreted as indicative rather than definitive.

Figure 11. Incremental electric school bus charging demand by Calgary community in 2035 under unmanaged charging, (a) base and (b) aggressive adoption scenarios.



a) Base adoption scenario

b) Aggressive adoption scenario

Table 3: Substations with Highest Peak ESB Charging Demand (2035, Winter Typical Day)

Substation ID	Base Scenario – Peak Demand (kW)	Aggressive Scenario – Peak Demand (kW)
39	115	311
6	90	376
4	81	205
2	58	78
38 / 31*	40	127

*** Substation 38 appears in the Base top five, while Substation 31 replaces it under the Aggressive scenario.**

Results indicate that a small number of substations are associated with disproportionately high incremental charging demand, reflecting the concentration of large school bus depots within nearby communities. In particular, Substations 39 and 6 are linked to the highest incremental loads in 2035 under both scenarios. These locations are therefore priority candidates for early engagement with ENMAX to assess potential transformer-, feeder-, or substation-level reinforcement needs as electrification progresses.

Based on the infrastructure cost ranges outlined in **Table 1**, localized charging peaks in the range of 90–376 kW would likely trigger transformer-level upgrades in the near term, with feeder- or substation-level investments becoming relevant only as additional electrification loads, such as medium- and heavy-duty vehicle charging and other sectoral loads, are added. As a result, upgrade costs could range from tens of thousands of dollars for early transformer replacements to several million dollars if feeder reinforcement is ultimately required.

5 Key Findings

This section summarizes the key findings from the analysis and frames their implications for fleet operators, utilities, utility regulators, and governments.

Table 4. Summary of stakeholder implications

Stakeholder	What the results imply
Fleet operators	Early depot screening is essential; managed charging can meaningfully reduce peak demand and may defer upgrades.
Utilities	System-wide energy impacts are limited, but localized depot peaks can be material; spatially resolved forecasts improve planning.
Regulators	Infrastructure lead times and cost allocation can slow early adoption; planning and rate design need to evolve.
Government	Incentives can de-risk early upgrades; policy certainty improves planning for utilities and fleets.

5.1 Fleet Operators

- **Vehicle depot location is the critical planning variable**. Charging demand concentrates at a small number of locations, making accurate tracking of where vehicles park overnight, including depots and parkouts, essential for forecasting infrastructure needs.
- **Early utility engagement reduces cost and risk**. Fleets that share projected load profiles with ENMAX ahead of deployment are better positioned to avoid long lead times and last-minute upgrade costs.
- **Managed charging materially reduces peak demand**. By staggering charging within available parking windows, fleets can reduce peak demand and potentially defer or reduce the scale of grid upgrades. At high-demand sites, behind-the-meter battery storage may provide additional flexibility.
- **Some duty cycles will require operational adjustments as electrification expands**. Routes with longer distances or limited charging windows may need midday charging access or reassignment as the electric fleet grows.

5.2 Utilities

- **Localized distribution impacts matter more than system-wide demand.** Overall energy demand from school bus electrification remains modest, but charging loads concentrate at a small number of depot locations, creating localized pressure on transformers and feeders. Spatially resolved forecasting is essential for identifying priority areas ahead of deployment.
- **Managed charging improves asset utilization but does not eliminate upgrade needs**. Peak demand can be reduced by roughly one-third through managed charging, improving utilization of existing infrastructure. However, sites with limited underlying capacity will still require upgrades as the electric fleet grows.
- **Rate design is a meaningful lever for grid-aligned charging**. Fleet-oriented rate structures and managed charging programs can encourage off-peak charging, reduce coincident peak demand, and lower operating costs for fleet operators simultaneously.

5.3 Utility Regulators

- **Infrastructure planning timelines and fleet adoption timelines are not aligned.** Substation and feeder upgrades can take several years to plan and construct, while fleet electrification can accelerate quickly under favourable market conditions. Without early incorporation of fleet loads into utility planning cycles, the risk of reactive and higher-cost infrastructure investment grows.
- **Cost allocation shapes the pace of adoption.** Where early adopters bear a disproportionate share of upgrade costs, electrification may slow even when broader long-term system benefits exist through incremental electricity sales and improved asset utilization.
- **Data sharing and structured engagement between fleets and utilities reduce planning uncertainty.** Supporting early utility-fleet coordination, spatially resolved load forecasting, and pilot rate program designs can improve planning outcomes while maintaining fairness and cost-causality principles.

5.4 Governments and Policymakers

- **Infrastructure readiness is as important as vehicle affordability.** Even as electric school bus costs decline, adoption can be constrained if grid planning and construction timelines lag behind fleet growth. Deployment barriers are as likely to emerge from distribution capacity as from vehicle economics.
- **Targeted early-stage incentives reduce first-mover risk.** Early support for vehicle purchases and grid upgrade costs accelerates adoption, enables operational learning, and gives utilities the demand signals needed to incorporate school bus electrification into long-term planning.
- **Policy certainty enables better planning across the sector.** Stable and predictable policy signals allow utilities, regulators, and fleet operators to align investment timelines, reducing the likelihood of unplanned, higher-cost grid upgrades and improving the cost-effectiveness of electrification overall.

6 Appendices:

Appendix A.1: School Bus Fleet Composition in Calgary (Base Year)

This appendix summarizes the estimated number of school buses serving the City of Calgary in the base year. These values are used to initialize the fleet stock model described in **Appendix A.2**.

Fleet composition estimates were informed by discussions with school boards and major operators and reflect vehicles actively providing student transportation services within the City of Calgary.

School Bus Type	Number of Vehicles
Type A	673
Type C	446

Appendix A.2: Fleet Stock Turnover Model

Year-by-year projections for Calgary's school bus fleet are generated using a stock-turnover modelling approach. The model represents the fleet by vehicle type and tracks how vehicles age, retire, and are replaced over time as the fleet evolves. Fleet growth is incorporated through externally defined assumptions linked to population growth and service demand. Electrification is introduced through scenario-based assumptions about the share of new vehicle purchases that are electric over time.

For each modelling year, vehicles reaching the end of their service life are retired and replaced as needed to maintain the target fleet size. New vehicle purchases are assigned powertrain types based on the applicable adoption scenario, ensuring that projected electric vehicle stocks are internally consistent with assumed fleet growth, vehicle lifetimes, and adoption trajectories.

The stock-turnover model is used solely to estimate the number of electric school buses in operation in each year of the analysis. It does not influence vehicle routing, daily distance travelled, parking behaviour, or charging behaviour, which are handled separately within the energy and power demand modelling framework.

Appendix A.3: Vehicle Age Structure and Fleet Growth Assumptions

A.3a Vehicle Age Structure and Survival

The age structure of the school bus fleet is represented using vehicle age distributions and associated survival probabilities by vehicle type. These inputs determine the likelihood that a vehicle of a given age remains in service from one year to the next and govern the timing of vehicle retirements within the stock-turnover model.

Age distributions and survival assumptions are applied uniformly within each vehicle type and are intended to reflect typical replacement cycles observed in Canadian school bus operations.

A.3b Fleet Growth Assumptions

Fleet growth assumptions reflect e xpected changes in total school transportation demand over time, driven primarily by population growth and service needs within the City of Calgary.

Growth assumptions are applied at the vehicle-type level and influence the number of new vehicles required each year to meet projected service demand. These assumptions affect total fleet size but do not alter individual vehicle duty cycles or charging behaviour.

Appendix A.4 Energy and Power Demand Modelling Framework

This appendix documents the conceptual structure of the stochastic modelling framework used to estimate daily energy consumption and charging power demand associated with electric school bus deployment in Calgary.

A.4.1 Operational Data Inputs

The energy and power model draws on empirical real-world operational data, including:

- Distributions of daily distance travelled by school buses
- Typical daily parking and charging availability patterns
- Vehicle-type-specific energy consumption rates

Together, these inputs are used to generate realistic duty cycles for electric school buses projected to be in service in each modelling year.

A.4.2 Daily Energy Requirement Estimation

For each simulated electric bus, a daily distance is sampled from the empirical distribution corresponding to its vehicle type. Routes exceeding electrification feasibility thresholds are excluded to reflect evolving vehicle range capabilities.

Daily battery energy requirements are calculated based on sampled distance and vehicle-specific energy intensity. Optional seasonal adjustments may be applied to represent higher energy consumption under winter operating conditions.

A.4.3 Charging Availability Representation

Charging availability is represented over a 24-hour period, reflecting when buses are typically parked at locations where charging is feasible.

Charging for a given service day is assumed to begin after vehicles return from their first trip and may continue overnight until the next morning departure, subject to availability constraints.

A.4.4 Charger Selection and Feasibility

A predefined set of charger power levels is evaluated for each vehicle. The model assigns the smallest charger capable of delivering the required daily energy within the available charging window.

If a vehicle's daily energy requirement cannot be met within the available charging time using the largest charger considered, that duty cycle is flagged as infeasible and tracked separately. This provides insight into operational constraints without assuming infrastructure solutions that may not be practical.

A.4.5 Charging Behaviour Scenarios

Two charging behaviour scenarios are evaluated:

- Unmanaged charging, in which vehicles begin charging immediately upon returning to an available charging location and continue until energy requirements are met, producing a conservative, peak-oriented load profile.
- Managed (smart) charging, in which charging is redistributed within each vehicle's available window to reduce coincident charging start times while still meeting daily energy requirements.

The managed-charging scenario represents moderate, operationally achievable coordination rather than full real-time optimization, vehicle-to-grid operation, or dynamic price-based dispatch.

A.4.6 Spatial Allocation of Charging Demand

To reflect the physical location of electricity demand, electric school buses are divided into two groups:

- Vehicles associated with known operators and assigned to centralized depots
- Vehicles parked at off-site locations, represented in aggregate at the community level

Depot-level charging demand is spatially attributed to the communities in which depots are located, while community-based charging demand is distributed using population-based weights. This approach enables charging demand to be assessed at the depot, community, and citywide levels while preserving consistency in total system load.

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