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Powering Seattle fleets

A CHARGING INFRASTRUCTURE STRATEGY FOR BATTERY-ELECTRIC MEDIUM- AND HEAVY-DUTY VEHICLES

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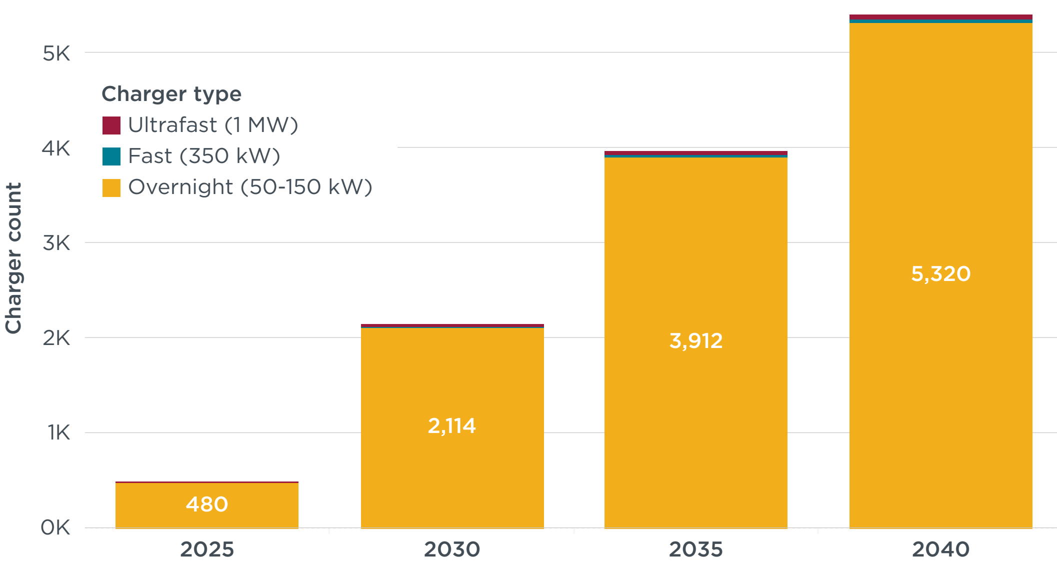
EXECUTIVE SUMMARY

The electrification of Class 4–8 medium- and heavy-duty vehicles (MHDVs) is projected to accelerate through 2040 due to reduced costs, improved technology performance, and a favorable policy landscape. Within the Puget Sound region, King County Metro, Seattle's main bus transit provider, and the robust local freight and distribution network serving the Ports of Seattle and Tacoma, are positioned to lead a surge in electric MHDVs. The municipal electric utility of Seattle, Seattle City Light (SCL), is responsible for ensuring sufficient infrastructure and grid capacity to meet the future energy requirements of transportation electrification.

This report serves to inform the development of SCL's charging infrastructure strategy as it plans for upcoming MHDV electrification. Downscaling methods from the International Council on Clean Transportation's recent analysis of near-term nationwide charging infrastructure deployment, we incorporate local vehicle activity data and other information specific to the Seattle area to determine the associated future charging needs within the SCL service territory from 2025 through 2040. We divide charging station types into public charging and depot chargers located at a fleet's home base. As seen in Figure ES1, our modeling predicts a marked increase in MHDV charging stations around 2030 based on fleet electrification goals and supporting regulation. We expect fleets will mostly rely on lower-powered overnight chargers for their energy needs due to fleet operations and lower cost.

Figure ES1

Projected count of chargers in SCL service territory by charger capacity, 2025–2040



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Between 2025 and 2040, we project total charger nameplate capacity and peak loads in the service territory will increase by an order of magnitude, or a factor of 10, as shown in Table ES1. An expected increase in charging demand in the southern part of SCL's service territory, where most warehouse and distribution centers in the service territory are located, will increase demand for local distribution grid capacity. This industrial area, which we label a "no regrets" zone, will likely require assessment in the near-term to determine needed substation upgrades and investment in existing infrastructure.

Table ES1
Projected peak load and charger nameplate capacity in SCL service territory, 2025–2040

Year	Peak load (MW)	Charger nameplate capacity (MW)
2025	13.2	47.8
2030	59.2	218.8
2035	111.8	439.8
2040	157.1	619.5

Our results and discussions with SCL suggest actions the utility could assess to guide charging infrastructure planning efforts and ensure its success in supporting the transition to electric MHDVs. Specifically, our analysis leads to seven broad recommendations SCL could consider.

1. **Gather information from fleets, particularly those with known transition plans.** As SCL prepares to deploy future charging infrastructure, the utility could consider strategies to connect with fleet operators throughout its service territory to collect information on their vehicles and electrification plans. Potential outreach methods include establishing a fleet database and developing relationships through fleet advisory services.
2. **Prioritize infrastructure development in "no regrets" zones.** Information gathered from fleets could be used to identify areas within SCL service territory where there will likely be high battery electric truck adoption and associated charging station deployment. This analysis suggests distribution upgrades will likely be required in South Seattle areas zoned for industrial activity.
3. **Address potential grid capacity constraints.** If grid infrastructure is insufficient to meet future energy requirements, particularly within southern Seattle, there could be delays that inhibit the transition to battery electric trucks. Possible ways to address this capacity challenge include deploying flexible front-of-meter infrastructure solutions, like mobile substations, and promoting customer-owned microgrids and other behind-the-meter technologies to reduce demand on the grid. If SCL cannot expand existing infrastructure, it could begin site procurement efforts to ensure new construction is ready for future electric fleets' energy demands.
4. **Prepare for opportunity and en-route charging needs.** Although depot charging is expected to be the main charging strategy for MHDVs, there will likely be public and en-route charging needed within the SCL service territory. Future public charging hubs could be sited at current commercial refueling sites, and additional locations could be identified using freight trip data. Coordination with other regional utilities could also be useful in determining optimal public charging sites.
5. **Account for the needs of fleets when ratemaking.** Fleet customers have unique operational constraints that may influence how they respond to pricing signals from the electric utility. SCL could consider collaborating with these customers to develop alternative commercial charging rates.
6. **Adjust internal operations.** Conversations with SCL staff suggest there may be challenges with internal processes and information sharing that could impede its preparations for MHDV electrification. A MHDV Electrification Task Force could help facilitate coordination across departments, and strengthening the

utility's internal expertise with staff familiar with fleet operations could support communications between the utility and its fleet customers. Improving the interconnection process with best practices from other utilities is one way to expedite MHDV electrification projects.

7. **Advance equity goals.** Accelerating truck electrification presents an opportunity to address environmental justice issues and advance SCL's equity goals. Involving impacted communities in the decision-making process could help the utility evaluate its long-term infrastructure projects. SCL could also demonstrate the benefits of transportation electrification to communities by establishing and monitoring project outcomes.

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LIST OF ACRONYMS

ACT	Advanced Clean Trucks
BEV	Battery electric vehicle
CCS	Combined charging system
CFN	Commercial fueling network
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
HEVI-LOAD	Medium- and Heavy-Duty Electric Infrastructure – Load Operations and Deployment
HPMS	Highway Performance Monitoring System
KCM	King County Metro
MHDV	Medium- and heavy-duty vehicle
MOVES	MOtor Vehicle Emission Simulator
NARUC	National Association of Regulatory Utility Commissioners
NEI	National Emission Inventory
NREL	National Renewable Energy Laboratory
NWSA	Northwest Seaport Alliance
SCL	Seattle City Light
SOC	State of charge
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
ZEV	Zero-emission vehicle

INTRODUCTION

The transition to electric medium- and heavy-duty vehicles (MHDVs) is underway in Seattle, Washington. A favorable policy landscape and intense freight activity within the local economic market makes the city and surrounding Puget Sound region a likely hot spot for future MHDV electrification. As the total cost of ownership of electric MHDVs becomes lower than their diesel counterparts, demand for these vehicles will increase, creating new challenges and opportunities for the city's municipal electric utility, Seattle City Light (SCL).

Policy activity at the city, state, and federal levels has established a strong foundation for the growing battery electric vehicle (BEV) market. The Inflation Reduction Act of 2022 includes federal funding for the acquisition of electric trucks and charging infrastructure deployment (U.S. Environmental Protection Agency, 2022; Slowik et al., 2023). Ambitious state policies like Washington's adoption of California's Advanced Clean Trucks (ACT) rule, which requires manufacturers to sell increasing percentages of zero-emission trucks over time, will accelerate the production of BEVs and drive down costs (Buysse & Sharpe, 2020; Union of Concerned Scientists, 2021). Seattle has also set its own electrification goals in the city's Transportation Electrification Blueprint, which establishes a target of 30% of goods delivery being zero-emission by 2030 (City of Seattle, 2021). The city is also setting up its own pilot incentive program to support the local adoption of electric Class 8 drayage trucks (City of Seattle, 2023b).

In response to these incentives and regulations, larger carriers and smaller fleet operators are planning for a future with electrified vehicles. Many local MHDVs move goods and cargo between distribution centers spanning from Seattle's Industrial District to Kent, Washington (Fehr & Peers, 2021). Most of these fleets service the Northwest Seaport Alliance (NWSA), the marine cargo operating partnership between the Port of Seattle and Port of Tacoma, which has its own decarbonization plans (Port of Seattle, 2020; The Northwest Seaport Alliance, 2023a). King County Metro (KCM), the largest bus transit provider for Seattle which operates more than 1,000 transit buses throughout the city and surrounding area, is also planning to electrify its bus fleet, making it one of the largest single operators of electric MHDVs in the region (King County Metro, 2022).

The anticipated electrification of MHDVs operating within SCL's service territory will require building capacity for future transmission and distribution needs. The International Council on Clean Transportation's (ICCT's) recent national charging infrastructure needs study projects that Seattle's King County will be ranked 16th in the nation in terms of energy demand from MHDV charging by 2030 (Ragon et al., 2023). With SCL only having 14 major substations in their service territory and operating within a space-limited urban environment, obstacles to building new infrastructure may result in a near-term imbalance in energy supply and demand (Seattle City Light, 2021). Achieving city and state electrification goals will require the utility to meet near-term needs while it prepares for long-term load-growth.

This report provides the foundation for a charging infrastructure strategy for SCL as it prepares for the oncoming electrification of Class 4–8 MHDVs and the installation of required charging infrastructure within its service territory. While there are other types of zero-emission vehicles (ZEVs), like hydrogen fuel-cell trucks, this report focuses solely on battery electric MHDVs. The ICCT's most recent total cost of ownership analysis for long-haul trucks—the segment most often identified as suitable for hydrogen—finds that battery-powered trucking presents a more cost competitive business case than hydrogen across a wide range of use cases (Basma et al., 2023). Therefore, electrification will likely be the preferred technology pathway (Basma et al., 2023).

Downscaling findings from the ICCT's recent study of near-term nationwide infrastructure deployment and incorporating known fleet transition plans and local traffic data, we estimate the number of MHDV chargers required from 2025 through 2040 and identify their potential location at the census tract level. Our results also include projections of future charging loads throughout the utility's service territory, which will help the utility identify important "no regrets" zones, or areas where the utility can feel the most confident about future charging needs.

With these results and knowledge of the geographic, technical, and policy challenges before Seattle City Light, we offer an informed charging infrastructure strategy to guide internal planning discussions within the utility.

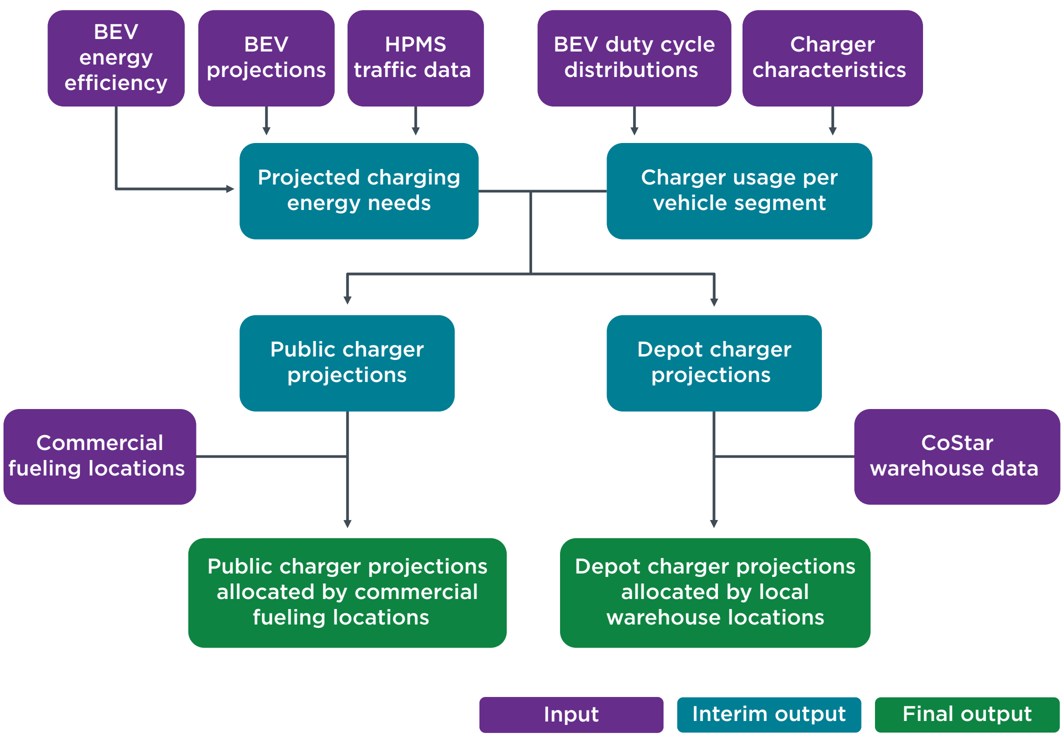
MODELING METHODS AND ASSUMPTIONS

In May 2023, the ICCT published a national charging infrastructure needs study for Class 4-8 MHDVs (Ragon et al. 2023). This analysis incorporates methods developed by Minjares et al. (2021) and outputs from the ICCT's Roadmap model, a global transportation emissions model, to assess the charging and refueling needs of different vehicle classes and types at the national, state, and county level (International Council on Clean Transportation, 2023). Ragon et al. (2023) also maps energy demand from zero-emission MHDVs, identifies likely locations for public infrastructure deployment, and produces projections of future ZEV deployment and the anticipated nameplate capacity of installed charging infrastructure.

This analysis adapts the methodology of the national infrastructure needs study to the Seattle context. A simplified schematic diagram of the modeling approach is shown in Figure 1, and each step of the modeling process and the various inputs is further explained in the subsequent sections.

Figure 1

Schematic diagram of the modeling approach



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This analysis is a first effort at downscaling the methods described within Ragon et al. (2023) to the census tract level. We incorporate known fleet data and characteristics specific to the Seattle area where possible to ensure our modeling projections reflect likely outcomes SCL should expect regarding the future deployment of MHDVs and their required charging infrastructure. However, as we are unable to gather information on operations and BEV transition plans from every MHDV fleet in SCL's service territory, we employ national data and assumptions from the Roadmap model in our modeling process where necessary. These assumptions reflect the generally limited data availability of battery electric trucks, which is still a nascent market. A detailed discussion of the data and modeling limitations of our methodology can be found in Appendix B.

VEHICLE CLASSES

Our analysis is focused on categories of Class 4–8 MHDVs from the Environmental Protection Agency's (EPA) MOtor Vehicle Emissions Simulator (MOVES), a modeling system used to estimate air pollutants, greenhouse gases, and air toxics from the transportation sector (U.S. Environmental Protection Agency, 2023a). This includes the following vehicle segments from MOVES: other buses, transit buses, school buses, refuse trucks, single unit short-haul trucks, single unit long-haul trucks, combination short-haul trucks, and combination long-haul trucks (U.S. Environmental Protection Agency, 2021). Due to challenges in determining motor home locations and their future charging preference, we omit this vehicle segment from our analysis.

Vehicles are classified into these segments based on body type and other characteristics, such as who owns them, their travel routines, and whether they travel short- or long-haul routes. Table A2 in Appendix A provides a detailed description of the vehicle segments.

INCORPORATION OF TRAFFIC DATA

We map the location of observed MHDV fleet activity within the SCL service territory using annual average daily traffic data acquired from the Federal Highway Administration's (FHWA) Highway-Performance Monitoring System (HPMS). Originally representing state-level traffic, the annual average daily traffic on each road segment is multiplied by segment length to calculate vehicle kilometers traveled (VKT) for combination and single-unit vehicles. The calculated VKT is then adjusted based on total annual vehicle miles traveled (VMT) data for Washington state (FHWA, 2019a; 2019b). Road segments and corresponding VKT are isolated within the SCL service territory at the census tract level for our analysis.

We next determine the share of observed VKT performed by each vehicle segment, applying methods described in Appendix A of International Council on Clean Transportation (2022). This process relies on MOVES population and activity data as well as the estimated vehicle population and annual VMT for each vehicle segment in Seattle, sourced from a recent electrification report authored by the Electric Power Research Institute (EPRI) (U.S. Environmental Protection Agency, 2021; Alexander et al., 2022). Information from EPRI can be seen in Tables A2 and A3 in Appendix A. The EPRI report does not provide a population count that distinguishes between single-unit and combination trucks, so we apply a ratio from the National Emission Inventory's (NEI) 2020 population estimates for King County (U.S. Environmental Protection Agency, 2023b). The resulting distribution of observed VKT per vehicle segment can be found in Table A4 in Appendix A.

The makeup of vehicle activity varies between road segments, such as a higher share of long-haul trucks driving on interstates and highways compared to school buses. Thus, the VKT percentage allocated to each vehicle segment also differs by road type, which are defined in MOVES. The percentages are multiplied by the observed single-unit and combination VKT within the SCL service territory, attributing the VKT to each vehicle segment.

Figure A1 of Appendix A offers a simplified diagram of how this analysis incorporates traffic data.

BEV DEPLOYMENT PROJECTIONS

Our BEV deployment projections come from the Roadmap model, which is programmed with scenarios developed by the ICCT to inform policy options for EPA's Phase 3 greenhouse gas emission standards for heavy-duty vehicles. Table A5 in Appendix A depicts BEV adoption assumptions, expressed as the percentage of total VKT for each vehicle segment. These projections reflect BEV deployment from 2020–2040 under Washington state's adoption of California's ACT rule (Portillo & Mui, 2021). Under the ACT rule, truck manufacturers must produce an increasing number of ZEVs through 2035. At that time, 55% of new Class 2b-3 trucks, 75% of new Class 4-8 trucks, and 40% of new Class 7-8 tractor trucks must be zero-emission (WAC 173-423-075).

We integrate Roadmap's ACT BEV adoption projections into our analysis, while also incorporating announced transition plans of certain MHDV fleets in the Seattle area. We adapt electrification projections for Seattle's transit bus and school bus vehicle segments, which have easily identifiable fleet operators and detailed electrification plans. Details regarding how we incorporate known fleet transition plans can be found in Appendix B.

We multiply the future BEV deployment projections and projections of how vehicle activity will change over time with the observed VKT for each MHDV segment to calculate the share performed by battery electric trucks each year. Multiplying the battery electric truck share by energy efficiency assumptions for BEVs (in kWh/km), which can be seen in Table A6 in Appendix A, we determine the energy consumption of observed and projected vehicle activity at the census tract level.

DAILY VEHICLE ACTIVITY PROFILES

As part of the process to determine charging needs for electric MHDVs, daily vehicle activity profiles were developed for each vehicle segment based on multiple sources. The daily VKT for rigid long-haul trucks was set to 322 kilometers based on the MOVES cut-off between short- and long-haul vehicles, and daily activity values for combination trucks were based on Borlaug et al. (2022). Other bus and truck segments were characterized based on data from the National Renewable Energy Laboratory's (NREL) Fleet DNA Project (Walkowicz et al., 2014).

Where available, activity data were cross-checked with Seattle-specific figures. For example, our daily mileage estimate for school buses is 96 km (60 miles), which matches an estimate by Seattle Public Schools of 60–80 miles per day (Seattle Public Schools, 2021). Our estimate for transit buses of 160 km (100 miles) aligns with King County Metro estimates, which state that 70% of their routes are covered by buses that drive under 140-miles (King County Metro, 2022).

With daily VKT estimates and the vehicle energy intensity values obtained from Basma et. al (2023), we can calculate expected energy consumption for each vehicle segment as they go about their daily operations. We assume log-normal distributions for vehicle activity, shown in Figure A2 in Appendix A. Energy demand distributions and the charger assumptions explained in the following section inform the share of each charger type necessary to satisfy the energy requirements for each MHDV segment.

CHARGER TYPES AND CHARGING CHARACTERISTICS

There are several charging system options for battery electric trucks on the market, the most common being wired stationary charging. Some vehicle markets are also exploring emerging solutions like battery swapping and wireless in-road charging (Rajon Bernard et al., 2022). In this analysis, we focus on wired stationary charging, which we consider the most likely charging option to be employed by fleets in the Seattle area.

Wired stationary charging infrastructure needs may vary depending on the individual characteristics of members of the MHDV fleet, including fleet size, daily mileage, and time of operation (Rajon Bernard et al., 2022). Table 1 classifies chargers into three different types depending on their charging power: overnight, opportunity fast, and opportunity ultra-fast.

Table 1
Summary of wired stationary charging types

Charger type	Nominal power	Available for large-scale commercialization	Estimated charging times
Overnight	50–150 kW	Before 2023	Up to 8 hours
Opportunity fast	350 kW	Before 2023	Up to 0.5 hours
Opportunity ultra-fast	1 MW	2027	Up to 0.5 hours

Compared to opportunity charging, overnight charging occurs at lower power levels of up to 150 kW. These chargers are commercially available and can be deployed at depots or public charging stations. Based on assumptions regarding vehicle battery capacity and charger power and efficiency, we assess that most MHDV batteries will be able to be fully charged in less than 8 hours. Fleets utilizing trucks with smaller batteries may deploy 50 kW overnight chargers or high-power Level 2 chargers to reduce their charging costs.

Fleets relying on trucks with larger batteries or those with specific operating constraints may rely on opportunity fast or ultra-fast chargers to satisfy their remaining energy needs. Opportunity charging can occur at depots, warehouses, public stations in industrial areas, or along freight corridors. Due to these chargers' high power and the operating constraints of fleets, opportunity charging sessions are assumed to last up to 30 minutes. The megawatt charging standard is still under development, but we assume commercial deployment of opportunity ultra-fast chargers beginning in 2027 (Basma et al., 2023; CharIN, 2023).

We model the assumed charging behavior of the average fleet for each MHDV segment within SCL's territory, although each segment's truck use case can vary, which necessitates different charging requirements. Figure A3 in Appendix A displays the share of charging needs met by the three charging types for each vehicle segment, showing that overnight charging can satisfy the charging needs for most battery electric trucks.

Additional assumptions regarding charging activity can be found in Appendix B.

REDISTRIBUTING DEPOT CHARGING

Influenced by our HPMS vehicle traffic data, our modeling allocates depot chargers based on the traffic patterns of vehicles, placing them where vehicle activity occurs. However, depot chargers are located at the vehicles' home base, and subsequently need to be assigned to these locations for our analysis. Without identifying every fleet and determining their fleet depot location, we use warehouse locations to allocate depot charging infrastructure for trucks geographically.

Warehouse data were sourced from the CoStar real estate database, which includes detailed information on commercial properties such as address, building type, and building and land area. We focus on properties designated as distribution, manufacturing, refrigeration/cold storage, or warehouse facilities with a rentable building area greater than 10,000 ft^2 (CoStar, 2023). Properties with less than 50,000 ft^2 in rentable building area are considered warehouses, provided the presence of at least 5 loading docks. Regardless of warehouse size, all properties designated as truck terminals are included in the analysis. The warehouse area is calculated as the rentable building area minus office and vacant space.

We allocate depot chargers by calculating the percentage of total warehouse space located in each census tract within the SCL service territory. Therefore, census tracts containing more warehouse space than others are allocated more depot chargers for each vehicle segment. Figure A5 in Appendix A shows the location of major warehouses and other commercial properties in the Seattle area.

The number of operators of transit buses, school buses, other buses, and refuse trucks is small, allowing for more precise redistribution of depot chargers to identified depot locations. Several of these fleets also have announced electrification plans, so we can ensure the allocation of depot chargers align with anticipated fleet conversions. Based on these electrification plans and known vehicle populations, we adjust our modeled results for each depot location to ensure depot charger and energy needs for these segments align with expected vehicle populations. The allocation of depot chargers for these fleets reflects the weight of anticipated electric MHDVs at each respective depot at our dates of interest. For fleets without announced plans, we assume they follow ACT adoption rate projections, and we estimate their depot capacity with satellite images from Google Maps.

A more detailed discussion of how we allocate depot chargers for the different bus and refuse truck segments can be found in Appendix B.

REDISTRIBUTING PUBLIC CHARGING

Presently, there are only a few public MHDV charging locations in the United States, but widespread publicly accessible charging will become necessary as the electric truck market matures, especially for long-haul trucks (Rajon Bernard et al., 2022). For SCL, there is similar uncertainty, as it remains to be seen where public charging infrastructure for MHDVs will be requested and installed. Through conversations with fleet operators, SCL can evaluate what a future public charging network for MHDVs may look like in its service territory.

Our modeling process estimates public charging needs based on expected vehicle activity and the resulting energy demand within SCL's service territory, originally locating public chargers where vehicle activity occurs. Without information about fleet operations and future public charging preferences, our modeled public charging network is hypothetical, allocating public chargers to existing commercial fueling sites within the SCL service territory. However, MHDVs presently access these locations for their fueling needs, so it is reasonable to assume that these fueling locations might be preferred charging sites, as it would require minimal alterations of current truck operations.

We evenly allocate fast and ultra-fast public chargers between eight priority locations suited for larger commercial vehicles, which can be seen in Figure A4 of Appendix A. These sites were identified through Commercial Fueling Network and Pacific Pride, two major commercial fueling providers, and include their respective and cardlock locations (Commercial Fueling Network, 2023; Pacific Pride, 2023). Cardlock locations are commercial fueling locations designed specifically for commercial vehicles that require a fuel card to access and refuel (Odlozil, 2022). We also include Shree's Truck Stop, which is the only large truck stop in Seattle.

We elect to evenly allocate fast and ultrafast public chargers between these locations because of the uncertainty regarding a future public charging network in Seattle. Except for Shree's Truck Stop, these refueling sites are small; a site evaluation would be required to determine whether the sites are suitable for public chargers and how many can be installed at each one. SCL may determine that additional locations are necessary, but we do not have the required information to identify prospective public charging sites.

Like depot overnight charging, public overnight charging is assumed to take up to 8 hours and require a location where trucks can charge for extended periods while away from their home bases. These may take the form of semi-private charging hubs, such as those offered by Forum Mobility or WattEV (Forum Mobility, 2023; WattEV, 2023a). For example, WattEV recenlty opened a battery electric truck charging hub at the Port of Long Beach, where electric drayage trucks can securely charge (WattEV, 2023b). We present public overnight charging needs associated with future truck activity in Seattle, but we do not estimate where these chargers may be located, as the location of charging sites depends on land availability, infrastructure capacity, and fleets' charging preferences.

CALCULATING PEAK CHARGING LOAD AND INSTALLED NAMEPLATE CAPACITY

We calculate estimates of the peak power demand and installed nameplate capacity for required MHDV chargers at the census tract level. With these projections, SCL can assess the status of its distribution network and identify where future charging needs may be easier or more challenging to satisfy.

Vehicles' charging needs will vary throughout the day and will differ between each fleet and vehicle segment. We use typical fleet load profiles from the Medium- and Heavy-Duty Electric Infrastructure – Load Operations and Deployment (HEVI-LOAD) project by Lawrence Berkeley National Laboratory to determine the hourly distribution of vehicle charging needs (Wang et al., 2021). HEVI-LOAD calculates charging patterns for MHDV segments based on energy market conditions, grid constraints, and fleet preferences. Due to limited electric MHDV fleet data availability, the load profiles currently only reflect the California electric truck market.

Our peak load estimates represent the highest likely energy demand that SCL will face from MHDV charging, but the utility must be prepared for higher energy demand for occasions when there is concurrent vehicle charging. More information about how we determine peak charging loads for each vehicle segment can be found in Appendix B.

In addition to calculating the estimated peak load requirements for each census tract, we also determine the installed nameplate capacity of chargers, which represents the nominal power drawn on the grid from these chargers if operating 100% simultaneously. With chargers likely to be used at different times, nameplate capacity is typically higher than the expected peak load at any given time. The nominal power for overnight charging differs per vehicle segment, and is 350 kW for fast chargers, and is 1 MW for ultra-fast chargers. The total installed nameplate capacity for each census tract is found by multiplying the count of each charger type by its respective nominal power level.

CHARGING AND INFRASTRUCTURE NEEDS

Using downscaled methods from Ragon et al. (2023), our modeling approach produces results that rely on known vehicle activity data to present the associated number of public and depot chargers, the expected energy consumption from charging, and the correlated VKT for each vehicle segment at the census tract level. With any modeling approach, there remains uncertainty, but our results provide SCL with new information to estimate future charging loads, anticipate the distribution of charging needs, and identify potential pain points and "no regrets" zones.

SCL SERVICE TERRITORY CHARGER NEEDS

Table 4 shows the number of charging stations required in 2030 and 2040 for each vehicle segment, identifying them by charger type and location. As shown in Figure A2, overnight charging sessions are capable of meeting most of the charging needs for battery electric trucks, so most charging stations are projected to be overnight chargers. The required chargers are mainly located at large fleet depots.

Table 4
Number of charger stations required in 2030 and 2040 by vehicle segment

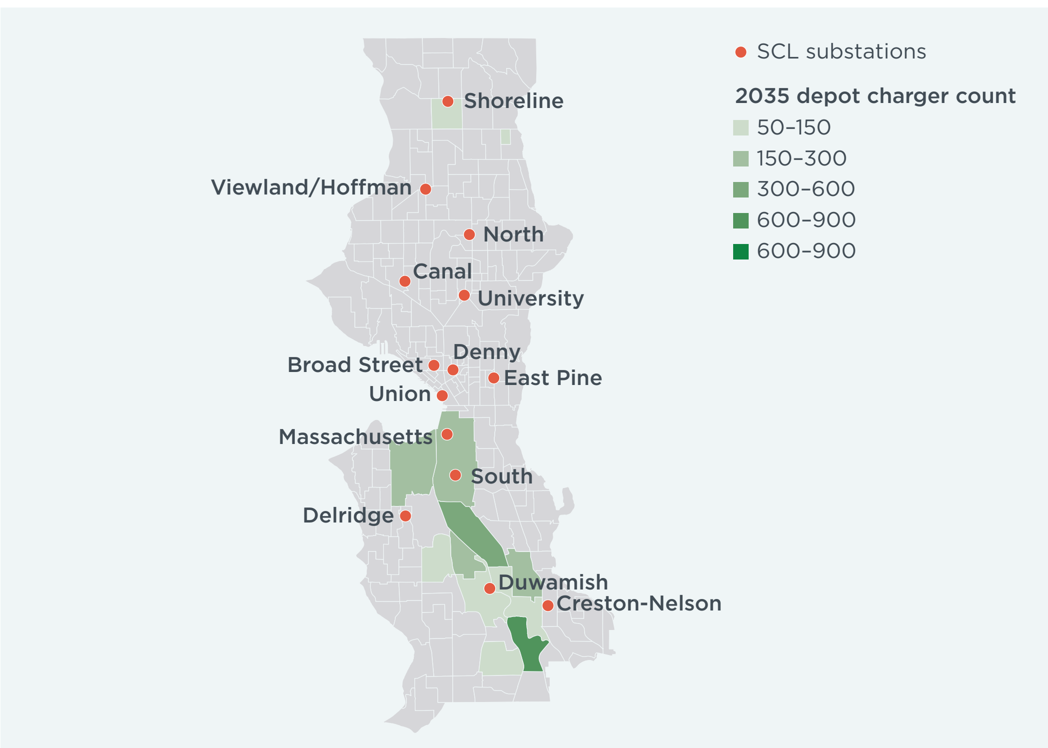
Vehicle group	Segment	Charger location	2030			2040		
			Overnight 50–150 kW	Fast 350 kW	Ultrafast 1 MW	Overnight 50–150 kW	Fast 350 kW	Ultrafast 1 MW
Rigid trucks	Short-haul (Class 4–5)	Depot	370	1	0	1,083	2	0
		Public	0	1	0	0	2	0
	Short-haul (Class 6–8)	Depot	299	0	0	1,076	1	0
		Public	0	0	0	0	1	0
	Long-haul (Class 4–5)	Public	3	0	0	8	1	1
	Long-haul (Class 6–8)	Public	4	0	0	16	1	1
	Refuse	Depot	50	0	0	157	0	0
Tractor trucks	Short-haul	Depot	154	0	0	615	0	0
		Public	103	9	10	410	27	29
	Long-haul	Public	16	0	1	220	5	8
Buses	Transit	Depot	697	0	0	1,265	0	0
	School	Depot	400	1	0	400	0	0
	Coach/other	Depot	17	0	0	70	0	0
Total public			**126**	**10**	**11**	**654**	**37**	**39**
Total depot			**1,987**	**2**	**0**	**4,666**	**4**	**0**

Our modeling results indicate that the increase in the number of battery electric trucks and associated charging stations will vary between vehicle segments, but as electrifying MHDV fleets becomes more economical, this increase will be notable for most vehicle segments. For combination short-haul tractor trucks, the number of chargers needed will increase from 276 in 2030 to 1,081 by 2040, with most of these being overnight depot chargers. However, we expect a different electrification timeline for school buses, which will be almost totally electrified by 2030 in the Seattle area due to goals set by the local transportation providers. SCL will need to be prepared for the rapid increase in vehicles and required chargers in its service territory that will occur from 2030 onwards, but it should also consider each vehicle segment's different rates of uptake. This example suggests SCL should plan for future demands from electric combination short-haul trucks while preparing to meet the near-term electrification demand from school buses.

CHARGER NEEDS AT THE CENSUS TRACT LEVEL: DEPOT CHARGERS

In addition to producing territory-wide charger summaries, our census tract level results present the locations of different chargers throughout the SCL territory. We estimate the location of depot chargers based on the location of warehouses within the SCL service area, which largely concentrates these chargers in the Duwamish Valley area, as seen in Figure 2. Most of the municipal utility's substations are not located near the census tracts that will contain most depot chargers, with only the Massachusetts, South, Delridge, Duwamish, and Creston-Nelson substations in proximity. SCL will need to evaluate the readiness of these substations for MHDV fleet electrification, as our results suggest most depot charging stations will be in nearby census tracts.

Figure 2
Location of depot chargers and SCL substations, 2035



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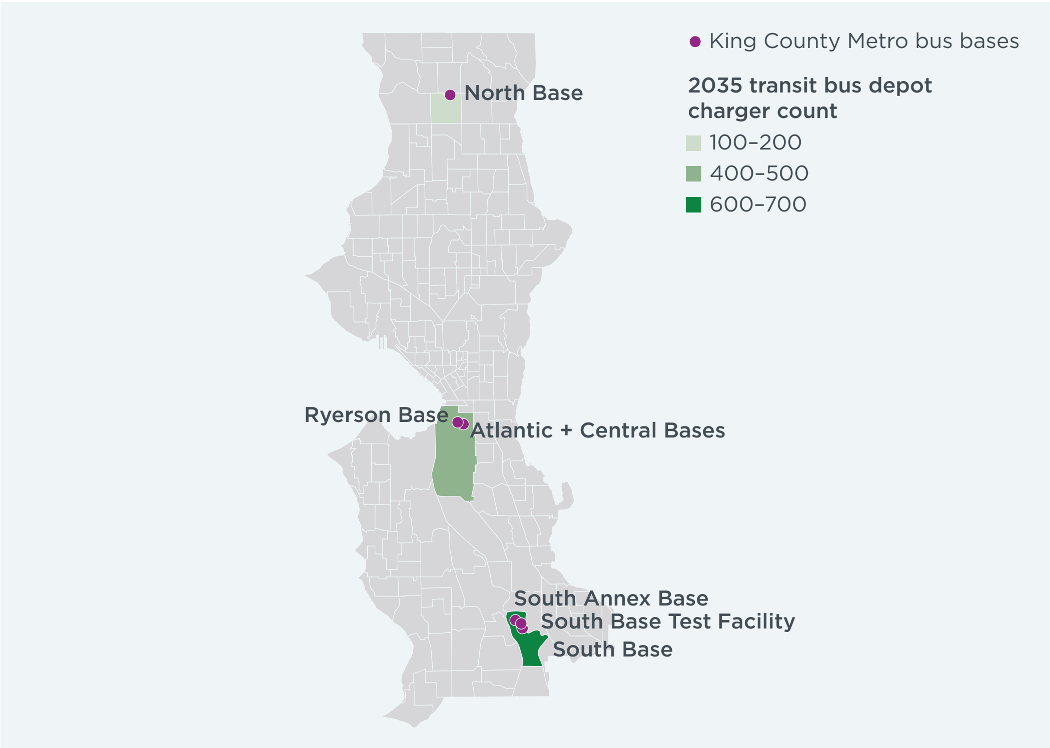
Our modeling results also provide charger counts for individual vehicle segments. Figure 3 shows the number and location of overnight depot chargers for future electric transit buses that belong to King County Metro in 2035. These chargers will be concentrated in just a few census tracts due to the location of the agency's bus bases.

Figure 3
Count of depot transit bus chargers, 2035



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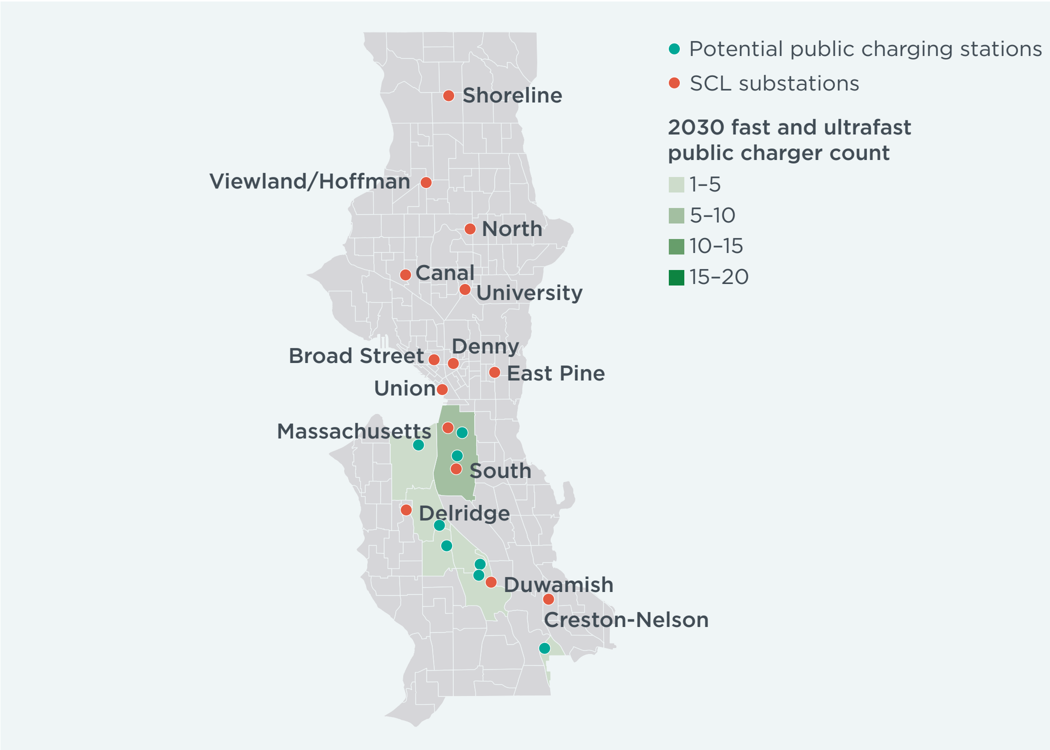
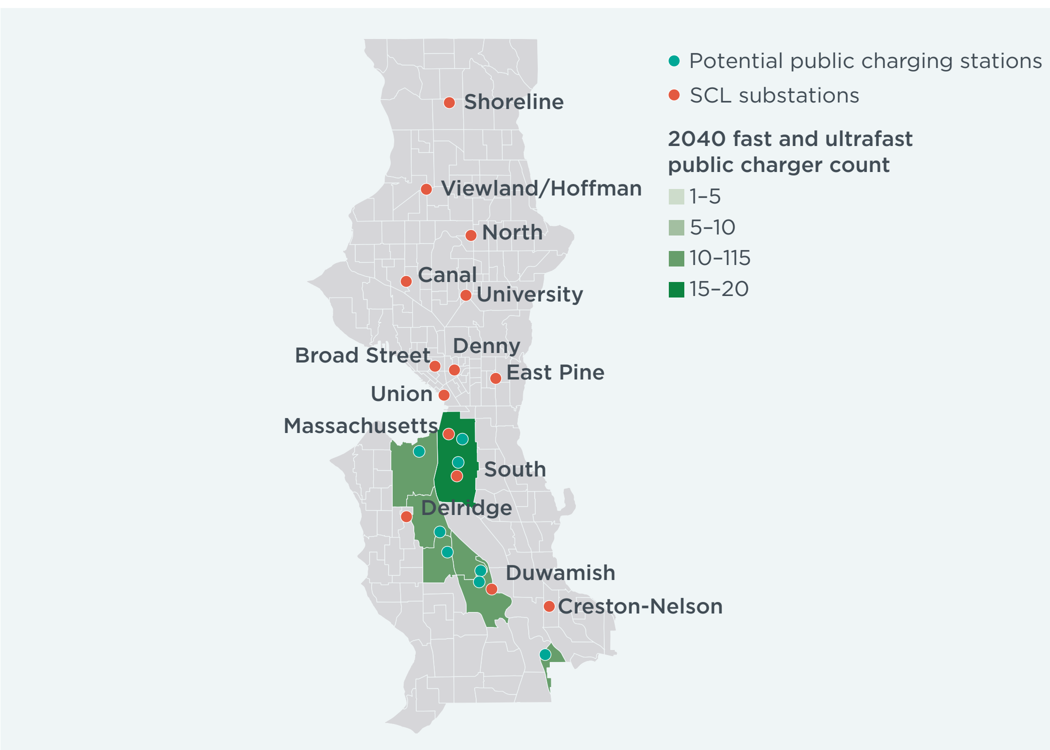
As more vehicle segments plan to electrify, where these fleets are located will be important for infrastructure planning. Electrification will be easier in some areas than others due to infrastructure readiness, community support, and other logistical factors.

CHARGER NEEDS AT THE CENSUS TRACT LEVEL: PUBLIC CHARGERS

Determining future public charging locations will require information from fleet operators about their charging preferences. Available sites will also need to be identified and assessed for their suitability for public charging. We offer a hypothetical public charging network that assumes existing commercial fueling locations are preferred sites for public charging to avoid unwanted changes to vehicle operations. As mentioned, we identify eight potential public charging locations within SCL's service territory, with chargers evenly distributed among them. Figure 4 shows these locations as well as the expected increase in fast and ultra-fast public chargers between 2030 and 2040.

Figure 4
Public charger counts, 2030 and 2040





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Depot chargers will need to be quickly deployed after 2025 to keep pace with BEV adoption, but public charging demand is not projected to increase until after 2030.

In 2030, we estimate that, based on charging preferences and expected energy consumption, fleets will require 147 total public and nearly 2,000 depot chargers. However, public charging demand is expected to increase about 400% after 2030, requiring 730 public chargers by 2040. These results suggest that, in the near term, SCL has more time to plan for public charging than depot charging.

Although we identify eight locations as potential sites for future public MHDV charging, public charging could occur at other commercial fueling sites in SCL's service territory, as seen in Figure A4 in Appendix A. Depot chargers need to be sited at specific locations for fleets, but there is more flexibility in siting public chargers, as fleets can adjust their routes to access public charging. SCL may determine that it can influence the development of the public charging network within its service territory to ensure that the future network aligns with its long-term goals. For example, SCL may decide to concentrate public chargers away from already industrialized areas, siting public chargers at locations where land is more available, or where grid infrastructure is already prepared to handle increased energy demand.

We do not estimate where overnight public charging is to be sited within the SCL service territory due to lack of information regarding, for example, available land. This charger type will be important, however, as it is expected to make up the largest public charger category. In 2030, 86% of needed public chargers will be overnight chargers. Similarly, in 2040, 90% of public chargers will be overnight chargers. The electric utility is better positioned to identify secure sites where battery electric trucks can charge for several hours. As mentioned, examples exist of secure public charging facilities being developed in California, with initial facilities near ports and distribution hubs. Conversations with fleets and the Port of Seattle may help SCL decide whether similar facilities are necessary and where they should be located.

PEAK LOAD PROJECTIONS

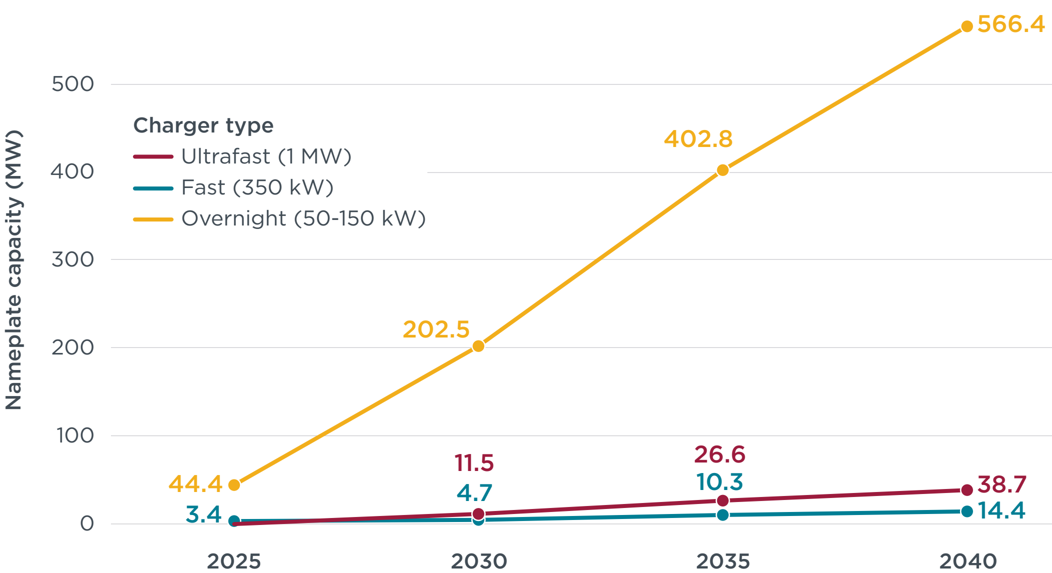
As seen in Table 5, our modeling results indicate that the vehicle charging associated with our vehicle activity data could produce peak loads of up to 157 MW by 2040. This represents the highest power requirement from MHDV charging that SCL may experience. We also identify the cumulative charger nameplate capacity for our target years, which represents the power demand if all chargers were used simultaneously and were operating at 100% of their charging capacity. By 2040, this will be almost 620 MW. Although peak loads represent the likely highest energy demand that SCL may face from MHDV charging, the utility should ideally be prepared to meet higher loads up to the nameplate capacity. There may be instances where energy demand could spike above average demand, such as if a local grid outage causes operators to charge their vehicles at a higher power level to avoid a disruption in operations.

Table 5
Projected peak load and charger nameplate capacity

Year	Peak load (MW)	Charger nameplate capacity (MW)
2025	13.2	47.8
2030	59.2	218.8
2035	111.8	439.8
2040	157.1	619.5

Figure 4 shows the rate of increase of the system-wide charging station nameplate capacity for the three charger types. Most electric MHDVs can satisfy their energy needs using overnight charging stations, so these chargers represent the largest proportion of overall charger nameplate capacity. The total charger nameplate capacity will increase in tandem with the increase in BEV and charger uptake. Between 2025 and 2040, total charger nameplate capacity is expected to increase by a factor of 13, fueled by the proliferation of overnight chargers, which will see similar growth in nameplate capacity during that period. Fast and ultra-fast charging deployment is also projected to increase, but we expect the scale of these chargers to be much smaller than overnight charging stations.

Figure 5
Charging station nameplate capacity by year



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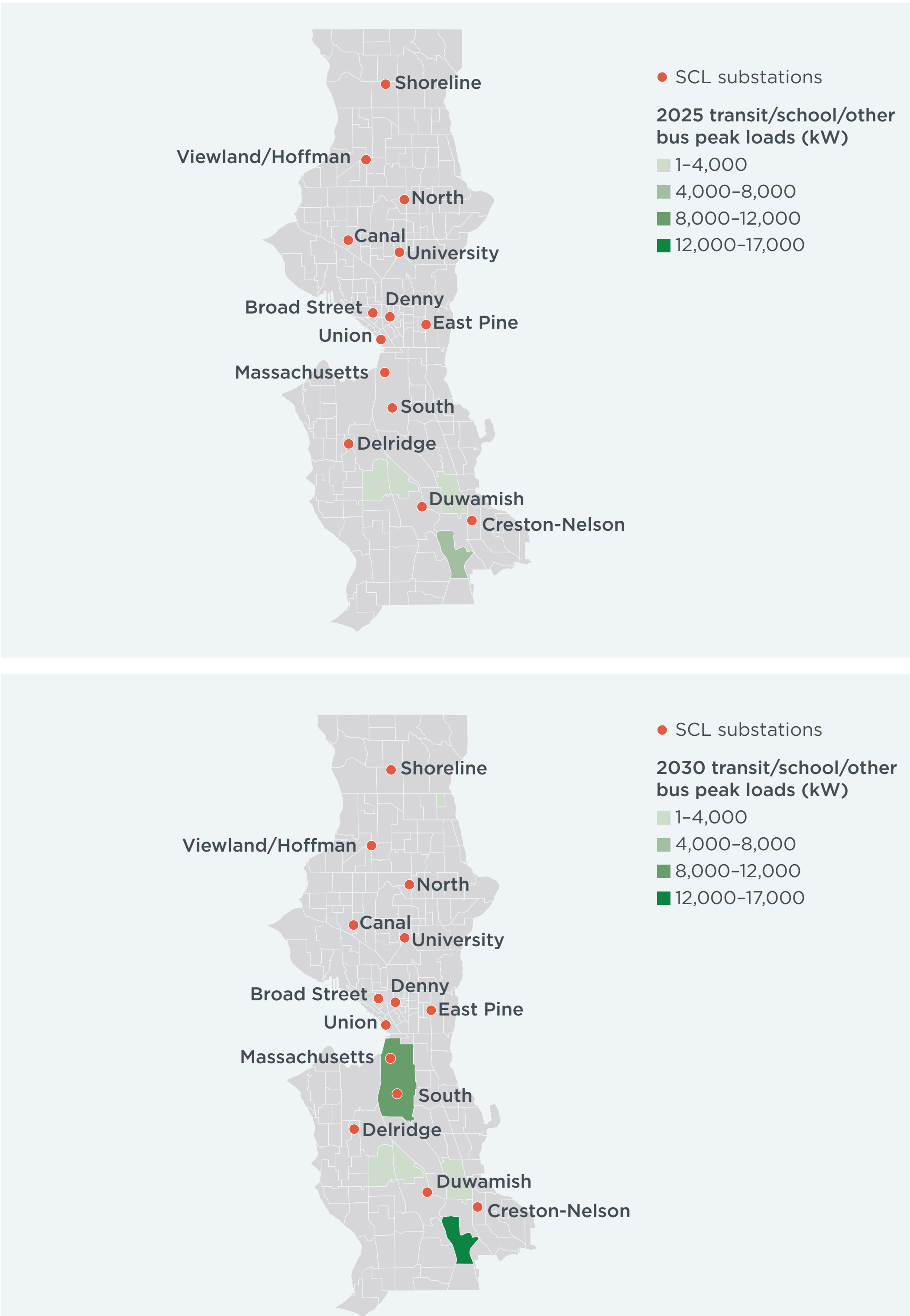
With our modeling outputs, we can determine the likely location and scale of peak loads throughout the SCL service territory. Figure 5 shows the peak loads for transit, school, and other buses in 2025 and 2030, as well as SCL's substations. Peak loads will grow over time as additional vehicles electrify, increasing the demand on nearby substations. This information is useful to determine whether existing substations are capable of satisfying future energy demand or if new infrastructure construction is necessary. Like the distribution of charging stations, peak loads are mostly expected in census tracts located within the Duwamish Valley region, indicating the greatest pressure will be on substations sited in this area.

Figure 6

Peak loads for transit, school, and other buses, 2025 and 2030



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RECOMMENDATIONS FOR SCL

Washington state's adoption of California's ACT rule in 2021 has committed the state to the decarbonization of the transportation sector. The compliance requirement timeline set forth by the ACT rule—and potentially the Advanced Clean Fleet rule, if adopted by Washington—will accelerate the turnover of on-road fossil fuel trucks to ZEVs, particularly battery electric trucks (Mills, 2023). As evident in known Seattle fleet transition plans and in our modeling results, the shift to electric MHDVs will accelerate from 2030– 2040, but preparations for needed grid capacity additions will need to begin sooner to meet customers' electrification timelines.

Like other electric utilities, SCL has historically experienced flat load growth and was able to defer new distribution grid capacity as much as possible, energizing any new infrastructure on a just-in-time basis. However, as fleets begin to electrify, they will want reassurance that their BEVs can charge and be consistently available, which will require new bulk distribution capacity and installed infrastructure made available in advance. The municipal utility would ideally ensure the planning, design, construction, and activation timelines required are incorporated into its near- and long-term grid planning.

We consulted with senior SCL staff engaged in grid modernization, load forecasting, and distribution planning to discuss their work, challenges, and thoughts on transportation electrification. Based on our conversations with SCL staff, our modeling results, and our understanding of the evolving policy and market landscapes, we offer the following recommendations for SCL to consider as it formulates its charging infrastructure strategy.

1. Gather information from fleets, especially those with known transition plans

Our modeling results estimate charging needs and energy demand associated with recorded on-road MHDV activity in Seattle. While we have worked to incorporate known fleet information to improve our results, this information is changing quickly. Therefore, regularly updating its understanding of MHDV energy needs within its service territory could allow SCL to better predict overall demand. Fleets with known transition plans, like King County Metro and Zūm, could work with SCL to ensure their adoption goals won't strain the grid. However, information from smaller truck operators that may or may not yet have plans to electrify their vehicles would also help SCL to better predict future demand.

SCL could consider strategies to connect with nearby fleets and facilitate information sharing, where SCL educates truck operators on electrification best practices and available incentives and operators provide information about their operations and vehicle procurement plans. Specifically, SCL could consider:

Establishing a fleet database

A fleet database containing data such as fleet size, depot locations, and transition timelines, could inform grid planning and infrastructure deployment, helping to streamline the MHDV electrification process. The database could be updated by SCL staff or the operators themselves could submit their information to the utility through an annual survey. The Washington State Department of Ecology implemented a one-time fleet reporting requirement in 2023 that contains relevant fleet information in the SCL service territory (WAC 173-423-083). The fleet reporting platform developed by the agency could serve as a model for SCL for collecting fleet information (Washington State Department of Ecology, 2023).

Developing relationships through fleet advisory services

SCL could consider having staff dedicated to fleet engagement and business development, who could connect with fleets through the utility's Fleet Electrification Program (Seattle City Light, 2024). Fleet working groups, trade associations, and other forums like the NWSA's Puget Sound Zero Emission Truck Collaborative, could also help to provide SCL with access to MHDV operators (The Northwest Seaport Alliance, 2023b).

2. Prioritize infrastructure development in "no regrets" zones

Historically, municipal electric utilities have been reluctant to build new grid infrastructure and commit ratepayer funds to projects ahead of customer demand. However, a lack of planning for load growth may put at risk the goals set by state and local fleet electrification policies. By collecting information on MHDV operators and their vehicle activity, SCL could identify future "no regrets" zones where the municipal utility can be confident battery electric truck adoption will occur and charging infrastructure will be needed. Infrastructure investments in these zones could help to balance the utility's priorities of avoiding stranded infrastructure while supporting battery electric truck adoption. As SCL works to identify "no regrets" zones in its service territory, it could consider:

Focusing distribution grid upgrades in South Seattle areas zoned for industrial activity

Our modeling results project that depot chargers will be deployed at warehouses concentrated in the Industrial District and areas directly south that serve nearby port terminals. Freight activity is heavily concentrated in this region, which contains two airports, three freeways, two rail lines, and a host of warehouse and distribution centers near the port (University of Washington, 2022). Through information sharing with fleets, SCL could learn about fleet charging behavior and utilize this data to inform future infrastructure development throughout the SCL service territory.

Incorporating transportation electrification load growth factors into distribution grid planning

Over the past decade, SCL has experienced declining energy demand, but future electrification will reverse this trend. Conversations with SCL revealed that it has yet to adopt new load forecasting techniques better suited for transportation electrification. Incorporating spatial and temporal information, such as vehicle telematics data, routes and dwell times, and warehouse and distribution center data, could improve SCL's identification of "no regrets" zones and planning efforts for future loads from BEV fleets.

3. Address potential grid capacity constraints

If SCL does not adequately prepare its grid, the utility may experience challenges keeping up with the pace and scale of the necessary charging infrastructure build out for BEVs. In near-port industrial zones where MHDV charging will be concentrated, for example, local grid constraints will need to be addressed to enable trucks to electrify. The Massachusetts, South, Delridge, Duwamish, and Creston-Nelson substations will likely be responsible for handling the increased load from charging battery electric trucks in this region, but discussions with SCL staff suggest grid capacity in this area is inadequate to meet future MHDV electrification needs. Some of these substations, such as the South substation, are already nearing maximum capacity and may face additional challenges expanding because they are sited within a space-limited urban environment.

Determining whether grid infrastructure within these areas can be made ready to meet future energy demands, and possible solutions where needed, could help avoid impeding transportation electrification. Specifically, SCL could consider:

Beginning site procurement efforts for needed grid infrastructure

If SCL is unable to upgrade existing infrastructure, SCL should consider starting site procurement work where additional substation transformer and distribution feeder capacity can be added quickly. New construction can be slow and costly, as illustrated by the installation of the Denny Substation, which took almost a decade to be built and brought online in 2019 (Kroman, 2019). With battery electric trucks more widely adopted by 2030, new construction would ideally begin promptly.

Utilizing flexible and transitional front-of-the-meter infrastructure solutions

Fleets might be able to leverage existing infrastructure without overloading the local grid. This could involve switching loads to nearby circuits with headroom and taking advantage of non-firm load carrying capacity on existing distribution feeders. Mobile substations that are usually reserved for emergencies or planned outages are another option to serve new truck charging loads on an interim basis.

Supporting deployment of customer-owned microgrids and other behind-the-meter solutions

With solar panels and battery storage, customer-owned microgrids can provide necessary power to charge trucks with or without a grid connection. While this solution may not be financially attainable for all fleets, it may be a worthwhile investment for the largest fleet operators like King County Metro, where a loss in power will impact their ability to provide essential services.

4. Prepare for opportunity and en-route charging needs

Although our results indicate that depot charging will be the predominant strategy taken by MHDV fleets, there likely will be demand for public opportunity and en-route charging within the service territory. Battery electric truck drivers may select these charging options if they want to charge between trips or if they are operating at the edge of their vehicle range. Considering the smaller scale of public charger deployment and their likely concentration at fewer charging sites, public charging may not create the same adverse impacts as depot charging within the SCL service territory.

In addition to evaluating existing commercial fueling sites, SCL could examine alternative locations that might be suitable for public charging. For example, some form of public charging will most likely be needed for drayage truck traffic at or near the Port of Seattle. SCL could consult with charging-as-a-service providers to determine if near-port public charging hubs like those installed in California could be in Seattle. King County Metro has also indicated interest in en-route charging at its Burien Transit Center (King County Metro, 2022). To prepare for MHDV public charging needs, SCL could consider:

Analyzing freight trip data to identify predictable truck parking locations

As SCL broadens its MHDV operator network, it could consider collecting vehicle activity data that defines truck origins, terminations, and routes. Partners such as EPRI and truck manufacturers could also provide this information to identify optimal public charging locations and develop infrastructure deployment timelines. Data and tools in EPRI's recently launched EVs2Scale2030 initiative could be used inform SCL's public charging investments (Electric Power Research Institute, 2023). SCL may find that some of the public charging demand will likely be met by charging stations located elsewhere, such as at refueling stations in Snoqualmie Pass, Snohomish County, and south of Seattle.

Focusing on current truck refueling sites

Commercial fueling sites, such as cardlock fueling stations operated by Seattle-based Commercial Fueling Network, are designed for the fueling needs of MHDVs (Commercial Fueling Network, n.d.). Considering that many fleet operators already refuel at these locations, they might be optimal sites for concentrated public opportunity and en-route charging. Like for fleet depots, SCL could create a database for truck stops and fueling sites to inform the creation of a robust public charging network for electric MHDVs.

Exploring a regional plan for electric truck charging infrastructure

Truck and bus movements do not stop at utility service territory boundaries. SCL could consider working with Puget Sound Energy, Tacoma Power, and other utilities in the region to understand and forecast transportation electrification loads, and ultimately, collaborate on capacity investment decisions. SCL may find that there is no need for a robust public charging network for MHDVs within its service territory if most trucks currently refuel in surrounding areas before entering Seattle. Partner utilities may have also more flexibility to meet the opportunity and en-route charging needs of trucks before they enter SCL's service territory.

5. Account for the needs of fleet customers in ratemaking

Electric utilities are accustomed to considering the needs the average customer when designing rates and grid planning, but this may be inappropriate for MHDVs due to the variation in vehicle operation, type, and charging behavior between fleets and how those factors will impact the grid.

During our conversations with SCL staff, they expressed the utility's priority of mitigating spikes in power demand that put pressure on the grid and indicated that the utility could implement price signals to guide charging behavior and maintain grid stability. For most EV charging, rates differ across the day, with off-peak rates being more favorable for BEV owners (City of Seattle, 2023a). However, commercial fleets with strict schedules may be unable to respond to these price signals, incurring high costs while not avoiding negative impacts on the grid. Therefore, to account for the specific requirements of MHDVs when ratemaking, SCL could consider:

Collaborating with customers to develop alternative commercial charging rates

SCL could work with affected stakeholders and its regulator, the city council, to develop charging rates that recognize the priorities of all parties. Guidance on rate design is also offered from organizations like the National Association of Regulatory Utility Commissioners (NARUC) and the Alliance for Transportation Electrification

(Ryan et al., 2022; The Rate Design Task Force, 2022). For example, the Alliance for Transportation Electrification suggests utilities can promote charger deployment through short-term mitigation of demand charges while charger utilization is low, subscription rates that incorporate fixed rates, service fees, and power levels, and discounted demand charges based on charger utilization rates.

6. Adjust internal operations

Conversations with SCL staff members suggest there may be challenges with internal processes and information sharing that could inhibit the utility's ability to prepare itself for widespread MHDV electrification. For example, while it is reasonable for teams to specialize in specific utility concerns, a more integrated approach could ensure there is maximal cross-team awareness of what each is doing and how their efforts all interconnect, mitigating the negative effects of information siloes. As the utility takes on the responsibility of supplying energy for the transportation sector, SCL could considering the following to meet the future needs of an electric truck fleet.

Establishing an MHDV electrification task force

An MHDV electrification task force could be used to establish clear responsibility for implementing the MHDV electrification strategy across the organization. A structure that cuts across departments could provide clear ownership within individual departments and facilitate coordination between them. The departments could include the distribution planning, grid modernization, and other teams working on issues relevant to transportation electrification.

Improving the interconnection process

Like other electric utilities, SCL has experienced a growing backlog of interconnection requests, with complex new service connection projects taking 30 weeks or longer to complete (Moore, 2020; Seattle City Light, 2023). To ensure the utility can manage the rapid increase in MHDV charging requests expected by 2030, SCL could look for best practices from other utilities that have already installed high levels of MHDV charging. Additional considerations include providing early education to fleet operators about the interconnection application process, creating an expedited interconnection process for fleet customers, and syncing interconnection timelines for joint charging, solar, and storage projects.

Strengthening and expanding internal capacity and expertise

As SCL evaluates the preparedness of its workforce to manage the challenges from transportation electrification, it could consider bolstering the utility's internal expertise from outside the utility sector. For example, individuals with experience leading BEV infrastructure projects, managing fleet operations, and analyzing vehicle activity could complement the strengths of current staff and support communications between the utility and its fleet customers.

7. Advance equity goals

The transportation sector, and particularly MHDVs, has long been recognized as a contributor to air pollution and greenhouse gas emissions (U.S. Environmental Protection Agency, 2023c, 2023d). Some parts of the Duwamish Valley, which is also one of the most diverse regions in the state and is majority non-White (University of Washington, 2020), historically suffered under intense pollution levels from concentrated MHDV and industrial activity. A 2013 study between the Just Health

Action and Duwamish River Community Coalition concluded that the pollution burden was significantly impacting the health and well-being of Georgetown and South Park residents, resulting in a life expectancy 8 years shorter than the Seattle and King County average (Duwamish River Community Coalition & Just Health Action, 2013).

Besides producing environmental benefits, advancing truck electrification could also mitigate inequities within the existing transportation system. SCL has officially incorporated equity within its Transportation Electrification Strategic Investment Plan, describing broadly its goals for centering equity in its electrification work (Seattle City Light, 2020). SCL could consider the following activities to advance its equity goals:

Involving impacted communities in the decision-making process

Community organizations could be part of the decision-making process and share their preferences with SCL and MHDV fleets regarding proposed projects. The Duwamish River Community Coalition shared with the ICCT that residents support the environmental and health benefits from battery electric trucks, but they are wary of further industrialization in their community as well as the impact of heavy battery electric trucks on their already deteriorating roads and bridges. This feedback could be helpful for SCL as it evaluates long-term infrastructure projects.

Setting project-specific goals and monitoring progress before and after MHDV electrification

With input from residents, SCL could determine desired project outcomes and conduct pre- and post-project monitoring. Partnering with MHDV fleets, SCL could also collect data on existing vehicles' air pollution, greenhouse gas, and noise pollution levels and evaluate how these improve in impacted communities after trucks electrify. This effort would help communicate the environmental and social benefits from fleet electrification to communities and city policymakers.

CONCLUSION

The transition to battery electric trucks in the Seattle area is expected to be driven by ambitious regulations, fleet adoption goals, and favorable economics. SCL is tasked with meeting the demands of electrifying fleets, many of which will begin to arrive by 2030. Based on vehicle activity in the SCL service territory, we estimate SCL will experience peak charging loads of near 13 MW with associated nameplate capacity of about 48 MW in 2025, increasing to about 59 MW and 219 MW respectively, by 2030.

Through our analysis of the MHDV fleet and the associated traffic patterns, we have identified near-port industrial zones, such as the Industrial District, and warehousing concentrated in southern Seattle as areas where MHDV fleets will likely be concentrated due to the large network of distribution centers, warehouses, and other facilities involved in freight activity. SCL could consider focusing on the energy demands of fleets and potential grid constraints in this region. Nearby substations near these areas will face growing energy demands that are likely to require the largest investments in capacity upgrades. Transit buses and school buses, which are expected to electrify ahead of other MHDV segments, represent the first opportunity for the utility to prepare for fleet electrification.

We offer SCL a set of seven recommendations to consider as it develops its charging infrastructure strategy. The first steps include assessing the readiness of its grid infrastructure by connecting with fleets that have known electrification goals and evaluating public and depot charging constraints. Obtaining input from affected stakeholders and reexamining internal operations could maximize SCL’s ability to meet the new challenges of the electrified future.

REFERENCES

Alexander, M., Bowermaster, D., Clarin, B., Deboever, J., Dunckley, J., Duvall, A., Johnson, B., Krishnamoorthy, S., Kwong, J., Laaguidi, I., Narayanamurthy, R., O'Connell, A., Porter, E., Sankaran, S., Schurhoff, R., Smith, J., Trinko, D., & Vairamohan, B. (2022). *Seattle City Light Electrification Assessment* [Technical Report]. Electric Power Research Institute. https://powerlines.seattle.gov/wp-content/uploads/sites/17/2022/01/Seattle-City-Light-Electrification-Assessment.pdf

Angueira-Grist, G. A. (2023, June 15). This Oakland depot will be able to fast-charge 96 electric big rigs simultaneously. *Fast Company*. https://www.fastcompany.com/90909543/oakland-depot-fast-charge-96-electric-big-rigs-simultaneously

Basma, H., Buysse, C., Zhou, Y., & Rodríguez, F. (2023). *Total cost of ownership of alternative powertrain technologies for Class 8 long-haul trucks in the United States*. International Council on Clean Transportation. https://theicct.org/publication/tco-alt-powertrain-long-haul-trucks-us-apr23/

Basma, H., Rodríguez, F., Hildermeier, J., & Jahn, A. (2022). *Electrifying last-mile delivery: A total cost of ownership comparison of battery-electric and diesel trucks in Europe*. International Council on Clean Transportation. https://theicct.org/publication/tco-battery-diesel-delivery-trucks-jun2022/

Bazzaz, D. (2022, February 17). Seattle Public Schools will decide on new bus contract after years of chaotic service. *The Seattle Times*. https://www.seattletimes.com/education-lab/seattle-public-schools-will-decide-on-new-bus-contract-after-years-of-chaotic-service/

Buysse, C., & Sharpe, B. (2020). *California's Advanced Clean Trucks regulation: Sales requirements for zero-emission heavy-duty trucks*. International Council on Clean Transportation. https://theicct.org/publication/californias-advanced-clean-trucks-regulation-sales-requirements-for-zero-emission-heavy-duty-trucks/

CharIN. (2023). *Megawatt Charging System (MCS)*. CharIN. https://www.charin.global/technology/mcs/

City of Seattle. (2021). *Seattle's Clean Transportation Electrification Blueprint*. https://www.seattle.gov/documents/Departments/OSE/ClimateDocs/TE/TE%20Blueprint%20-%20March%202021.pdf

City of Seattle. (2023a). *Business Rates*. Seattle City Light. https://www.seattle.gov/city-light/business-solutions/business-billing-and-account-information/business-rates#seattlebusinesses

City of Seattle. (2023b). *City of Seattle's Electric Trucks Incentive Pilot*. Seattle. https://www.seattle.gov/environment/climate-change/transportation-/transportation-electrification/heavy-duty-truck-electrification

City of Seattle. (2023c). *Collection & Disposal*. Seattle Public Utilities. https://www.seattle.gov/utilities/your-services/collection-and-disposal

Commercial Fueling Network. (2023). *Why CFN – Commercial Fueling Network*. CFN. Retrieved September 18, 2023, from https://cfnfleetwide.com/become-a-member/why-cfn/

CoStar. (2023). *The Power of CoStar*. CoStar. https://www.costar.com/overview#

Duwamish River Community Coalition, & Just Health Action. (2013). *Cumulative Health Impacts Analysis (CHIA)*. Duwamish River Community Coalition. https://www.drcc.org/chia

Electric Power Research Institute. (2023). *EVs2Scale2030*. EVs2Scale2030. https://msites.epri.com/evs2scale2030

Improvements to Generator Interconnection Procedures and Agreements, RM22-14-000 (Federal Energy Regulatory Commission July 28, 2023). https://www.ferc.gov/media/e-1-order-2023-rm22-14-000

Federal Highway Administration. (2019a). *Table VM-2 - Highway Statistics 2018*. https://www.fhwa.dot.gov/policyinformation/statistics/2018/vm2.cfm

Federal Highway Administration. (2019b). *Table VM-4 - Highway Statistics 2018*. https://www.fhwa.dot.gov/policyinformation/statistics/2018/vm4.cfm

Fehr & Peers. (2021). *City of Seattle—Zero Emission Area Data Collection*. City of Seattle. https://www.seattle.gov/documents/Departments/SDOT/FreightProgram/Seattle_Freight_Zero_Emission_Data_Collection_Report_Clean-07-16-2021.pdf

Fleet Reporting Requirement, Washington Administrative Code § 173-423-083 (2021). https://casetext.com/regulation/washington-administrative-code/title-173-ecology-department-of-see-also-titles-197-317-372-and-508/chapter-173-423-clean-vehicles-program/section-173-423-083-fleet-reporting-requirement

Forum Mobility. (2023, March 7). *Charging depot and heavy-duty electric trucks for zero-emission drayage*. https://forummobility.com/

Godfrey, J., & Eyth, A. (2022). *Development of 2020 Default Onroad Activity Data for the National Emissions Inventory*. U.S. Environmental Protection Agency. https://gaftp.epa.gov/air/nei/2020/doc/supporting_data/onroad/DefaultOnroadActivity.pdf

International Council on Clean Transportation. (2022, May 14). *ICCT Comments on EPA Proposed HDV Rule*. https://theicct.org/comments-epa-proposed-hdv-rule-may22/

International Council on Clean Transportation. (2023). *Roadmap v2.2 Documentation*. Roadmap Model Documentation. https://theicct.github.io/roadmap-doc/versions/v2.2/

King County Metro. (2022). *Moving to a Zero-Emission Bus Fleet: Transition Plan*. King County Metro. https://kingcounty.gov/~/media/depts/metro/accountability/reports/2022/zero-emission-bus-fleet-transition-plan-may-2022#:~:text=Metro%20will%20transition%20its%20fleet,onward%20will%20be%20zero%2D%20emission

King County Metro. (2023). *Bus base expansion program*. Bus Base Expansion. https://kingcounty.gov/en/legacy/depts/transportation/metro/programs-projects/transit-corridors-parking-and-facilities/bus-base-expansion

Kroman, D. (2019, April 19). *Seattle went big on its new $210M power station—But did it need to?* Crosscut. https://crosscut.com/2019/04/seattle-went-big-its-new-210m-power-station-did-it-need

Mills, R. (2023, July 3). *Understanding California's Advanced Clean Fleet Regulation*. RMI. https://rmi.org/understanding-californias-advanced-clean-fleet-regulation/

Minjares, R., Rodríguez, F., Sen, A., & Braun, C. (2021, September 14). *Infrastructure to support a 100% zero- emission tractor-trailer fleet in the United States by 2040.* International Council on Clean Transportation. https://theicct.org/publication/infrastructure-to-support-a-100-zero-emission- tractor-trailer-fleet-in-the-united-states-by-2040/

Moore, J. (2020, December 1). Temporary Revised Timelines for New Service Connections. *Powerlines*. https://powerlines.seattle.gov/2020/12/01/temporary-revised-timelines-for-new-service-connections/

Mulholland, E. (2022). *Cost of electric commercial vans and pickup trucks in the United States through 2040*. International Council on Clean Transportation. https://theicct.org/publication/cost-ev-vans-pickups-us-2040-jan22/

Narayan, R. (2022, August 5). Electric School Buses & the Benefits of an EV-Powered Fleet. *Zūm*. https://www.ridezum.com/blog/electric-school-buses-the-benefits-of-an-ev-powered-fleet/

Odlozil, K. (2022, August 1). *What Is Cardlock Fuel and How Does It Work?* PFleet. https://www.pfleet.com/blog/what-is-cardlock-fuel-and-how-does-it-work

Pacific Pride. (2023). The Nation's Largest Cardlock Fueling Network. https://www.pacificprideusa.com/

Patel, A. (2022, September 1). *First Student to Assume Seattle School Bus Routes*. First Student, Inc. https://firststudentinc.com/resources/newsroom/first-student-to-assume-seattle-school-bus-routes/

Port of Seattle. (2020). *Northwest Ports Clean Air Strategy*. https://www.portseattle.org/page/northwest-ports-clean-air-strategy

Ragon, P.-L., Mulholland, E., Basma, H., & Rodríguez, F. (2022). A Review of the AFIR

Proposal: Public Infrastructure Needs to Support the Transition to a Zero-Emission Truck Fleet in the European Union. The International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2022/03/review-afir-public-infrastructure-to-support-transition-to-zero-emission-truck-fleet-eu-mar22.pdf

Ragon, P.-L., Kelly, S., Egerstrom, N., Brito, J., Sharpe, B., Allcock, C., Minjares, R., & Rodríguez, F. (2023). *Near-term infrastructure deployment to support zero-emission medium- and heavy-duty vehicles in the United States*. International Council on Clean Transportation. https://theicct.org/publication/infrastructure-deployment-mhdv-may23/

Rajon Bernard, M., & Hall, D. (2022). *Assessing charging infrastructure needs in Québec*. International Council on Clean Transportation. https://theicct.org/publication/lvs-ci-quebec-can-en-feb22/

Rajon Bernard, M., Tankou, A., Cui, H., & Ragon, P.-L. (2022). *Charging solutions for battery electric trucks*. International Council on Clean Transportation. https://theicct.org/publication/charging-infrastructure-trucks-zeva-dec22/

Rendahl, L. (2024, April 7). Washington school districts are poised to start swapping out their diesel buses for electric under new law. *The Spokesman Review*. https://www.spokesman.com/stories/2024/apr/07/washington-school-districts-are-poised-to-start-sw/

Ryan, N., Burger, A., Bosco, J., & Muller, M. (2022). *Best Practices for Sustainable Commercial EV Rates and PURPA 111(d) Implementation*. National Association of Regulatory Utility Commissioners. https://pubs.naruc.org/pub/55C47758-1866-DAAC-99FB-FFA9E6574C2B

Seattle City Light. (2020). *Transportation Electrification Strategic Investment Plan*. Seattle City Light. https://www.seattle.gov/documents/Departments/CityLight/TESIP.pdf

Seattle City Light. (2021). Fingertip Facts. https://www.seattle.gov/documents/Departments/CityLight/FingertipFacts.pdf

Seattle City Light. (2023). *Requirements for Electric Service Connection 2023 Edition*. Seattle City Light. https://web8.seattle.gov/city-light-engineering-standards/Home/GetPDF?libId=RESC&searchForfileName=RESC%202023%20EDITION%20FINAL%20Online.pdf

Seattle City Light. (2024). *Fleet Electrification Program*. https://www.seattle.gov/city-light/business-solutions/renewable-energy-services/fleet-electrification-program

Seattle Public Schools. (2021). *Request for Proposal No. RFP102112. Student Transportation Services for 2022-2025 and Succeeding Years.* https://s3.documentcloud.org/documents/21151562/sps127_student_transportation_72243_21750_rfp102112.pdf

Slowik, P., Searle, S., Basma, H., Miller, J., Zhou, Y., Rodríguez, F., Buysse, C., Minjares, R., Kelly, S., Pierce, L., Orvis, R., & Baldwin, S. (2023). *Analyzing the impact of the Inflation Reduction Act on electric vehicle uptake in the United States*. International Council on Clean Transportation. https://theicct.org/publication/ira-impact-evs-us-jan23/

The Northwest Seaport Alliance. (2023a). *Cargo Statistics*. Northwest Seaport - Port of Tacoma. https://www.nwseaportalliance.com/about-us/cargo-statistics

The Northwest Seaport Alliance. (2023b, June 30). *The Northwest Seaport Alliance Applauds Launch of Zero-Emission Truck Collaborative; Major Milestone on Path to Sustainable Trucking in the Puget Sound*. Newsroom. https://www.nwseaportalliance.com/newsroom/northwest-seaport-alliance-applauds-launch-zero-emission-truck-collaborative-major

The Rate Design Task Force. (2022). *Rate Design for EV Fast Charging: Demand Charges*. Alliance for Transportation Electrification. https://evtransportationalliance.org/wp-content/uploads/2022/06/Rate.Design.TF_.Demand-Charge-Paper-Final-5.25.22.pdf

Union of Concerned Scientists. (2021). *What the Advanced Clean Truck Rule Will Do for Washington*. Union of Concerned Scientists. https://www.ucsusa.org/sites/default/files/2021-12/wa-clean-trucks-fact-sheet.pdf

University of Washington. (2020). *Mapping Race and Segregation in Seattle and King County 1940-2020*. Civil Rights and Labor History Consortium. https://public.tableau.com/views/Seattle-segregation1940-2020largescreen/Story1940-2020?:embed=y&:showVizHome=no&:host_url=https%3A%2F%2Fpublic.tableau.com%2F&:embed_code_version=3&:tabs=no&:toolbar=yes&:animate_transition=yes&:display_static_image=no&:display_spinner=no&:display_overlay=yes&:display_count=yes&:language=en-US&publish=yes&:loadOrderID=0

University of Washington. (2022). *Duwamish Valley*. Interdisciplinary Center for Exposures, Diseases, Genomics and Environment. https://deohs.washington.edu/edge/duwamish-valley

U.S. Environmental Protection Agency. (2020). *MOVES3 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity*. Office of Transportation and Air Quality. https://www.epa.gov/sites/default/files/2020-11/documents/420b20052.pdf

U.S. Environmental Protection Agency. (2021). *Population and Activity of Onroad Vehicles in MOVES3*. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1011TF8.pdf

U.S. Environmental Protection Agency. (2022, December 6). *Clean Heavy-Duty Vehicle Program* [Overviews and Factsheets]. https://www.epa.gov/inflation-reduction-act/clean-heavy-duty-vehicle-program

U.S. Environmental Protection Agency. (2023a). *2020 National Emissions Inventory (NEI) Data*. Air Emissions Inventories. https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-data

U.S. Environmental Protection Agency. (2023b, August). *Latest Version of MOtor Vehicle Emission Simulator (MOVES)* [Data and Tools]. MOVES and Related Models. https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

U.S. Environmental Protection Agency. (2023c, May 11). *Smog, Soot, and Other Air Pollution from Transportation* [Overviews and Factsheets]. Transportation, Air Pollution, and Climate Change. https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-other-air-pollution-transportation

U.S. Environmental Protection Agency. (2023d, August 23). *Fast Facts on Transportation Greenhouse Gas Emissions* [Overviews and Factsheets]. Green Vehicle Guide. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

Walkowicz, K., Duran, A., & Burton, E. (2014). *Fleet DNA Project Data Summary Report*. National Renewable Energy Laboratory. https://www.nrel.gov/transportation/assets/pdfs/fleet_dna_delivery_vans_report.pdf

Wang, B., Black, D., Cong, Z., & Tong, F. (2021). *Medium and Heavy-Duty Electric Vehicle Infrastructure—Load Operations and Deployment (HEVI-LOAD) v1.0* [Computer software]. Lawrence Berkeley National Laboratory. https://www.osti.gov/biblio/1836645

Washington State Department of Ecology. (2023). *Fleet Reporting Platform Guidebook for Fleet Managers* (23-02–068; p. 29). Washington State Department of Ecology. https://apps.ecology.wa.gov/publications/summarypages/2302068.html

Washington State Department of Transportation. (2021). *Washington State Freight and Goods Transportation System (FGTS) 2021 Update*. Washington State Department of Transportation. https://wsdot.wa.gov/sites/default/files/2021-12/2021-FGTS-update.pdf

WattEV. (2023a). *Electrifying Heavy Duty Transport*. WattEV. Retrieved February 22, 2023, from https://www.wattev.com

WattEV. (2023b, July 25). *WattEV opens electric commercial truck charging depot at Port of Long Beach—Largest of its kind in the nation*. Cision. https://www.prnewswire.com/news-releases/wattev-opens-electric-commercial-truck-charging-depot-at-port-of-long-beach--largest-of-its-kind-in-the-nation-301885708.html

Zero-emission vehicle standards, 173 Washington Administrative Code § 173-423-075. (2023). https://app.leg.wa.gov/wac/default.aspx?cite=173-423-075#:~:text=Zero%2Demission%20vehicle%20standards.&text=Beginning%20with%20model%20year%202025,c)%20ZEV%20credits%20and%20values

Zūm. (2023a). *Sustainability is Now Within Reach*. Zum. https://www.ridezum.com/sustainability/environmental-commitment/

Zūm. (2023b, July 20). *Zum ushers in new era of student transportation for Seattle Public Schools*. Cision. https://www.prnewswire.com/news-releases/zum-ushers-in-new-era-of-student-transportation-for-seattle-public-schools-301590374.html

APPENDIX A

This appendix contains tables that serve as inputs to the modeling process. The figures are visuals of other inputs to the charging infrastructure model.

Table A1
Vehicle segments

Vehicle segment	Description
Other buses	Buses that do not fit within the transit or school bus categories, such as intercity buses owned by commercial operators
Transit buses	Buses owned and operated by public transit organizations
School buses	Buses used for carrying students between their home and school
Refuse trucks	Trucks used for garbage and recycling services
Single unit short-haul trucks	Single-unit trucks with a maximum daily driving range of 322 km (200 miles)
Single unit long-haul trucks	Single-unit trucks with a maximum daily driving range greater than 322 km (200 miles)
Motor home	Recreational vehicles that have mobile living accommodations
Combination short-haul trucks	Combination trucks with a maximum daily driving range of 322 km (200 miles)
Combination long-haul trucks	Combination trucks with a maximum daily driving range greater than 322 km (200 miles)

Source: U.S. Environmental Protection Agency (2021)

Table A2
Vehicle population in SCL service territory, 2020

Vehicle segment	Vehicle population
Transit bus	1,252
School bus	405
Refuse truck	204
Other buses	45
Motor home	3,795
Short-haul truck	24,136
Long-haul truck	2,400

Source: Alexander et al. (2022)

Note: Vehicle counts for motor homes, short-haul trucks, and long-haul trucks were calculated from 2017 NEI vehicle population counts for King County that were scaled based on vehicle activity estimated to take place in SCL territory. EPRI estimated SCL territory contains 40% of King County vehicle activity.

Table A3
Estimated annual vehicle miles traveled by vehicle segment

Vehicle segment	Annual VMT/vehicle
Transit bus	44,874
School bus	12,405
Refuse truck	14,511
Other buses	77,117
Motor home	1,360
Single-unit short-haul truck	9,760
Single-unit long-haul truck	13,607
Combination short-haul truck	75,160
Combination long-haul truck	127,501

Source: Alexander et al. (2022)

Table A4
Fraction of vehicle activity assigned to each vehicle segment by road classification

Vehicle group	Vehicle segment	Rural restricted	Rural unrestricted	Urban restricted	Urban unrestricted
Buses and rigid trucks	Transit bus	18.1%	16.2%	21.2%	21.3%
	School bus	1.8%	1.8%	1.5%	1.8%
	Refuse truck	1.0%	1.0%	1.1%	1.0%
	Other buses	1.2%	1.0%	1.1%	1.4%
	Motor home	2.0%	1.9%	1.6%	1.7%
	Single unit short-haul truck (Class 6–8)	44.0%	45.1%	42.5%	42.0%
	Single unit short-haul truck (Class 4–5)	30.0%	30.7%	29.0%	28.6%
	Single unit long-haul truck (Class 6–8)	1.4%	1.5%	1.4%	1.5%
	Single unit long-haul truck (Class 4–5)	0.6%	0.6%	0.6%	0.6%
	Total	**100%**	**100%**	**100%**	**100%**
Tractor trucks	Combination short-haul truck	27.0%	49.7%	40.9%	53.0%
	Combination long-haul truck	73.0%	50.3%	59.1%	47%
	Total	**100%**	**100%**	**100%**	**100%**

Table A5

Percentage of vehicle kilometers traveled performed by BEVs in SCL service territory

Year	Combination long-haul truck	Combination short-haul truck	Other buses	Refuse truck	School bus	Single unit long-haul truck (Class 6–8)	Single unit long-haul truck (Class 4–5)	Single unit short-haul truck (Class 6–8)	Single unit Short-haul truck (Class 4–5)	Transit bus
2020	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
2021	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
2022	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
2023	0%	0%	1%	2%	0%	1%	2%	1%	2%	4%
2024	0%	1%	2%	3%	0%	2%	5%	2%	5%	4%
2025	0%	3%	3%	5%	50%	4%	8%	4%	8%	10%
2026	0%	5%	5%	7%	50%	6%	11%	6%	11%	10%
2027	1%	7%	7%	11%	100%	8%	14%	8%	14%	22%
2028	1%	11%	8%	15%	100%	11%	17%	11%	17%	28%
2029	2%	15%	10%	19%	100%	14%	21%	14%	21%	29%
2030	3%	19%	12%	25%	100%	17%	26%	17%	26%	43%
2031	5%	23%	14%	30%	100%	21%	30%	21%	30%	47%
2032	6%	29%	17%	35%	100%	25%	36%	25%	36%	60%
2033	9%	35%	21%	41%	100%	29%	41%	29%	41%	69%
2034	12%	41%	25%	47%	100%	34%	46%	34%	46%	72%
2035	16%	48%	30%	53%	100%	38%	52%	38%	52%	94%
2036	20%	54%	35%	59%	100%	42%	57%	42%	57%	95%
2037	25%	60%	41%	64%	100%	47%	62%	47%	62%	97%
2038	31%	66%	46%	68%	100%	52%	67%	52%	67%	98%
2039	38%	70%	52%	73%	100%	58%	71%	58%	71%	99%
2040	45%	75%	56%	77%	100%	63%	76%	63%	76%	100%

Source: This BEV timeline comes from the ICCT's Roadmap model (2023), targeted for states implementing the ACT rule. BEV projections for school and transit buses have been altered to match expectations for Seattle.

Table A6

Average BEV energy efficiency (kWh/km)

Year	Combination long-haul truck	Combination short-haul truck	Other buses	Refuse truck	School bus	Single unit Long-haul truck (Class 6–8)	Single unit long-haul truck (Class 4–5)	Single unit short-haul truck (Class 6–8)	Single unit short-haul truck (Class 4–5)	Transit bus
2020	1.48	1.43	1.13	1.27	0.82	1.12	0.65	0.93	0.54	0.76
2025	1.43	1.40	1.12	1.25	0.81	1.11	0.65	0.92	0.54	0.76
2030	1.35	1.35	1.08	1.20	0.79	1.08	0.63	0.90	0.53	0.74
2035	1.28	1.31	1.05	1.17	0.77	1.04	0.61	0.88	0.51	0.72
2040	1.24	1.28	1.03	1.14	0.75	1.02	0.59	0.86	0.50	0.71

Source: Basma et al. (2023)

Figure A1

Process for incorporating vehicle traffic data

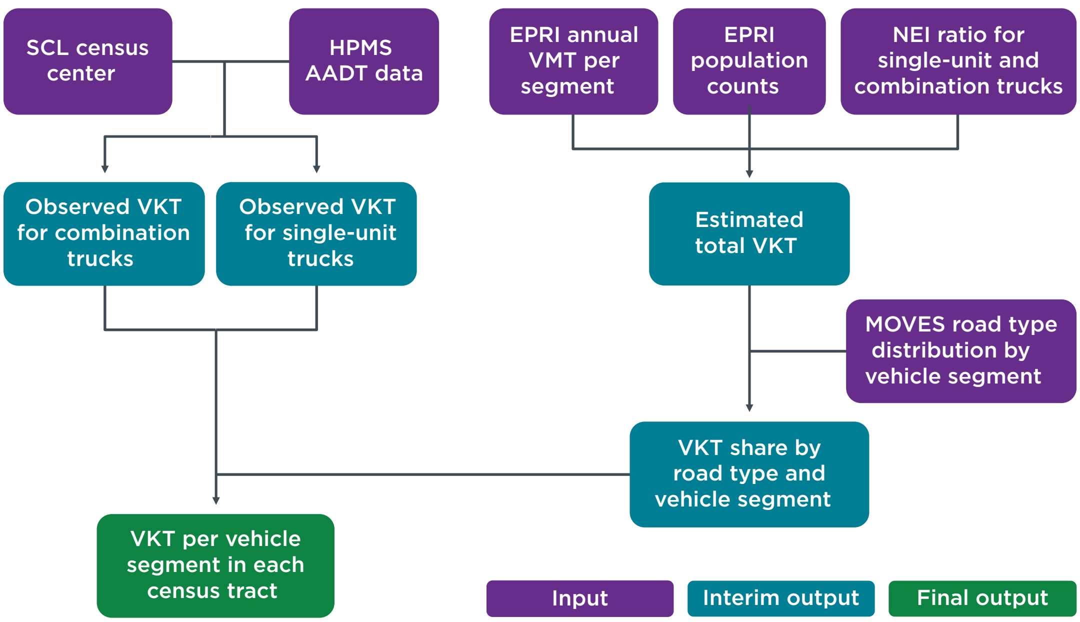

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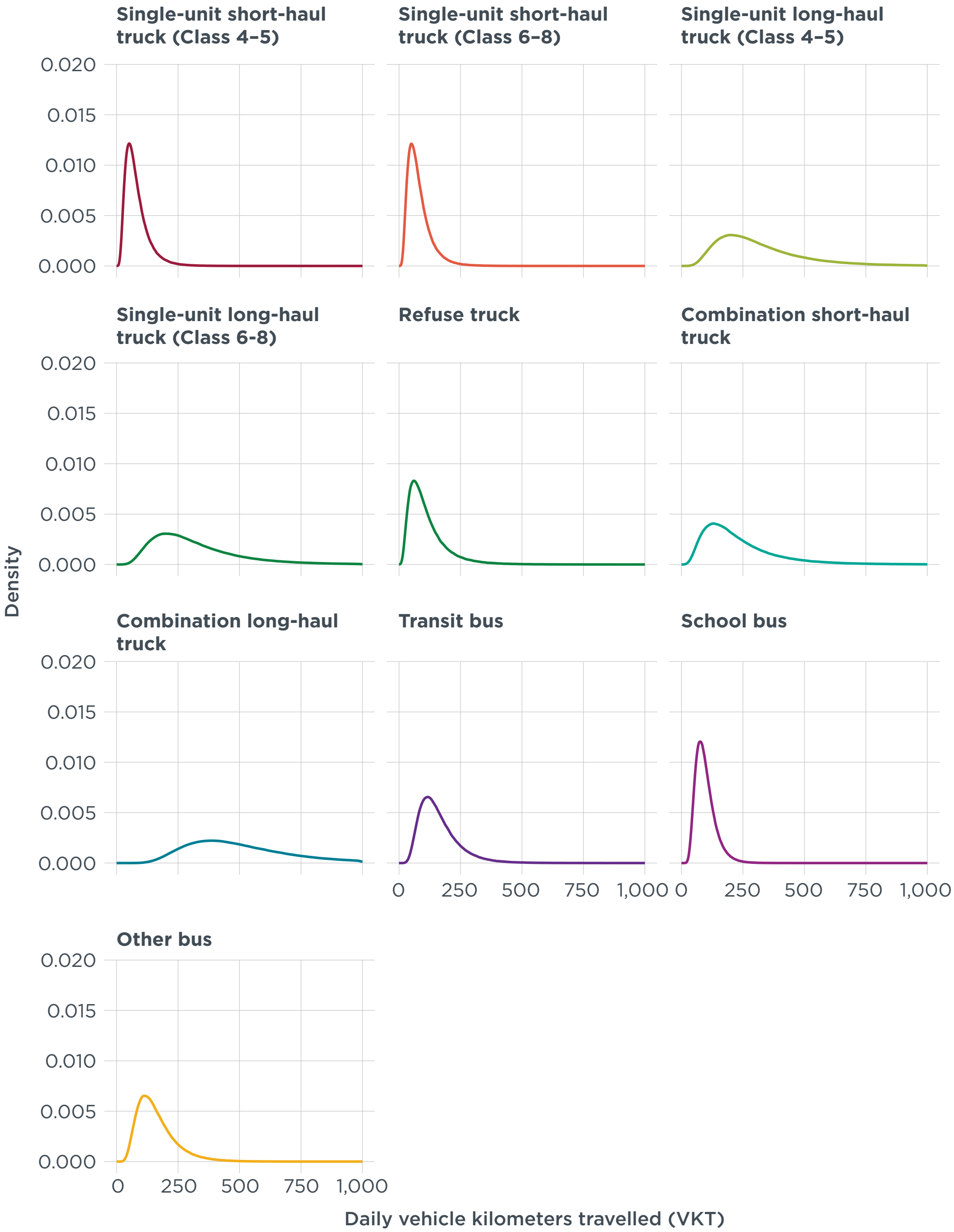
Figure A2

Probability density functions of daily vehicle activity by vehicle segment



Note: The x-axis is the same for all graphs.

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Figure A3

Share of charging needs met by charger types by vehicle segment, 2030

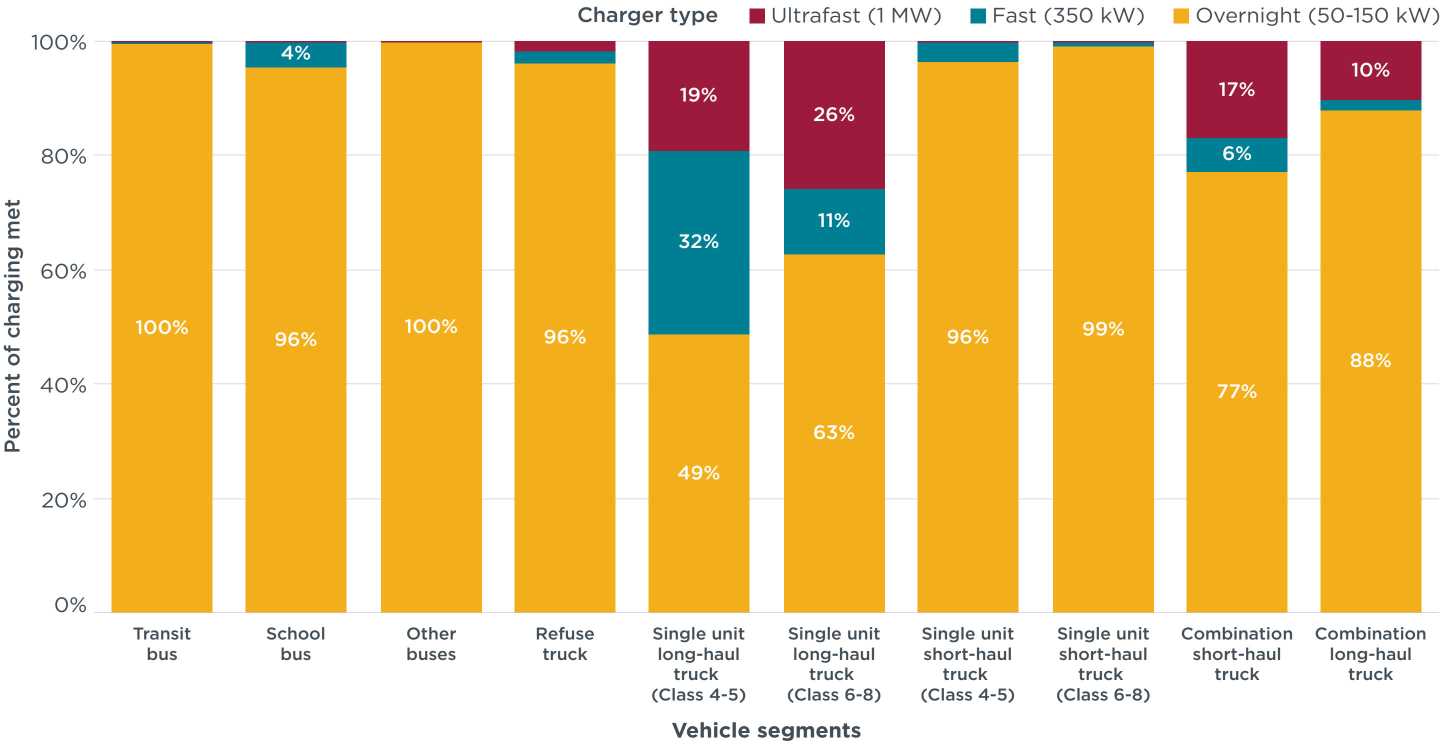

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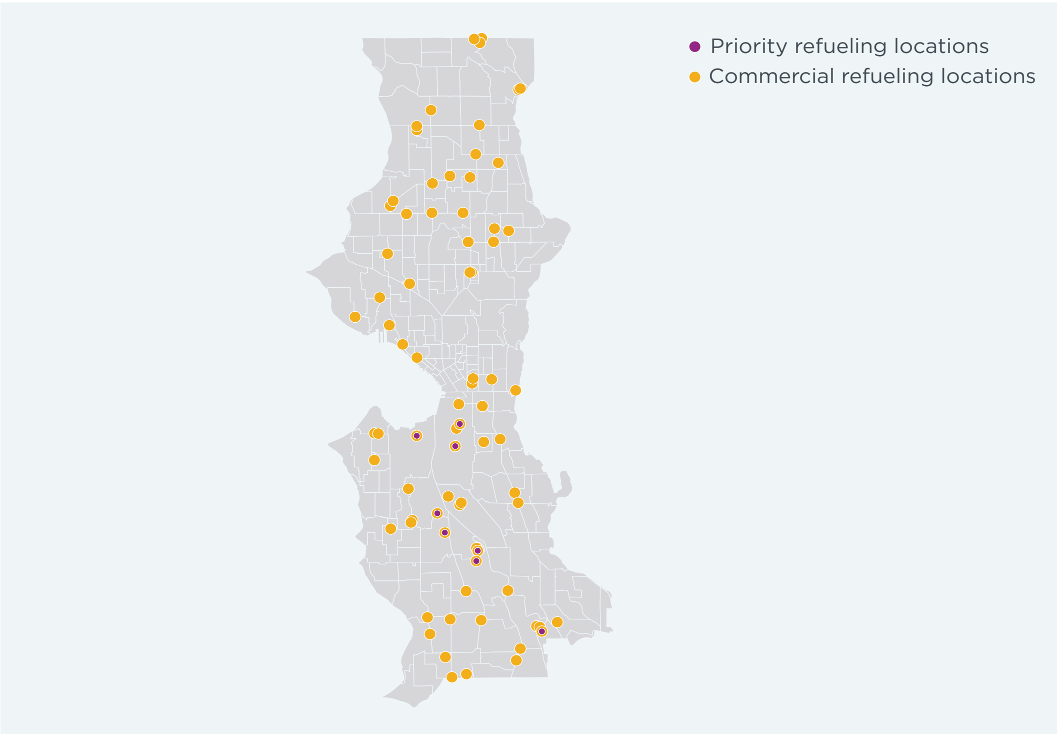
Figure A4

Commercial fueling locations



Sources: Commercial Fueling Network (2023) and Pacific Pride (2023)

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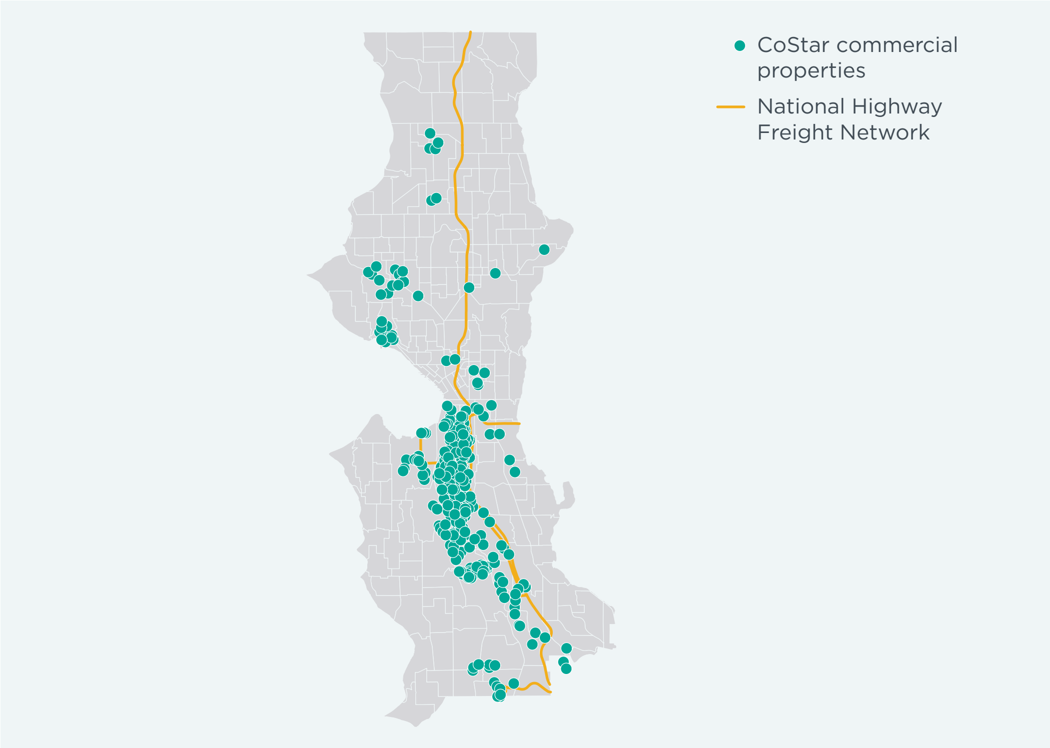
Figure A5

Warehouses in Seattle City Light service territory



Source: CoStar (2023)

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APPENDIX B

This appendix contains supplementary information about specific steps to the modeling process, describing in further detail some of our modeling assumptions.

ACCOUNTING FOR TRANSIT AND SCHOOL BUS TRANSITION PLANS

Several bus agencies operate within Seattle; King County Metro (KCM) is the largest bus transit operator. Other operators, such as Sound Transit and Community Transit, provide intercity bus options for commuters and have bus bases located outside of SCL's service territory, so we focus solely on KCM for this analysis. Although KCM has announced that all its buses will be electric by 2035, recent conversations with the agency suggest this goal may not be achieved until 2040 (King County Metro, 2022; Metro Community Engagement Team, personal communication, September 21, 2023). KCM's electrification process is expected to be performed in stages, with one bus base being electrified before moving on to another. Based on information shared with the ICCT, Table B1 shows the current anticipated timeline of BEV bus uptake at KCM bases within SCL's service territory.

Table B1
King County Metro electrification timeline

Year of acquisition	Count of BEV buses
Fall 2022	36
Spring 2023	51
Fall 2023	51
Spring 2024	51
Fall 2024	51
Fall 2025	131
Fall 2026	131
Fall 2027	282
Fall 2028	353
Fall 2029	363
Fall 2030	545
Fall 2031	600
Fall 2032	755
Fall 2033	870
Fall 2034	905
Fall 2035	1,193
Fall 2036	1,207
Fall 2037	1,221
Fall 2038	1,235
Fall 2039	1,250
Fall 2040	1,264

Note: This timeline could change in the future.

Beginning in 2024, Seattle Public Schools will be serviced by two school bus providers, First Student and Zūm, each covering the same number of bus routes (Patel, 2022). First Student has 200 buses in its Seattle fleet, and the organization has committed to electrifying 30,000 of its approximately 43,000 buses by 2035 (J. Biddinger, personal communication, July 21, 2023). Zūm, which is expected to begin providing transportation services in 2024, is expected to have the same number of buses as First Student (Zūm, 2023b). Zūm has pledged to have an all-electric on-road fleet by 2027 (Zūm, 2023a).

For First Student, we assume the company's electric school bus adoption rate in Seattle will be more advanced than its national fleet to match its main competitor. For both bus providers, we assume their fleets will be 50% electric in 2025 and 100% electric by 2027 (Bazzaz, 2022).

ADDITIONAL INFORMATION ON CHARGING ACTIVITY ASSUMPTIONS

Our charging assumptions inform our calculation of the share of energy provided by each charger type for each MHDV segment (Ragon et al., 2022). We assume trucks will start their operational day with a full battery, and their batteries will operate between 15%–95% state of charge. We also assume fleets will maximize the use of overnight charging to minimize costs. By charging at lower power when there is less demand on the SCL grid, fleets can access more affordable rates and save on charging costs (City of Seattle, 2023a). For fleets that rely on opportunity charging, we assume they will use a combination of fast and ultra-fast charging, minimizing the number of ultra-fast chargers needed because of their higher charging costs.

We employ infrastructure utilization rates from (Ragon et al., 2023), which were determined based on discussions with a MHDV charging point operator. Beginning at low levels, utilization rates grow logarithmically as a function of the ZEV stock deployment. We assume one overnight charging session per day. The number of opportunity charging sessions per day for each vehicle increases from one to over nine by 2040.

ADDITIONAL INFORMATION ON THE DEPOT CHARGING REDISTRIBUTION PROCESS

With announced fleet electrification plans, we can estimate the locations of depot chargers for specific vehicle segments. Table 3 shows how the allocation of transit bus depot chargers will change overtime as KCM changes its bus fleet to electric. We assume a 1:1 ratio between overnight chargers and vehicles. The weight given to each bus base reflects previous KCM transition plans and is different from our electric transit bus projections because the latest information shared with the ICCT did not include the timeline and allocation to each bus depot. For example, in 2035, there are to be 1,193 transit buses, not 1,265, but we allocate transit depot chargers based on previous plans.

Table B2

Allocation of transit bus depot chargers based on King County Metro transition plans

Bus depot	2025		2030		2035		2040	
	Bus count	% of total	Bus count	% of total	Bus count	% of total	Bus count	% of total
Test facility	40	25.00	40	5.74	40	3.16	40	3.16
South Interim	120	75.00	120	17.22	120	9.49	120	9.49
South Annex			250	35.87	250	19.76	250	19.76
Atlantic + Central			287	41.18	287	22.69	287	22.69
South (main)					274	21.66	274	21.66
Ryerson					173	13.68	173	13.68
North					121	9.57	121	9.57

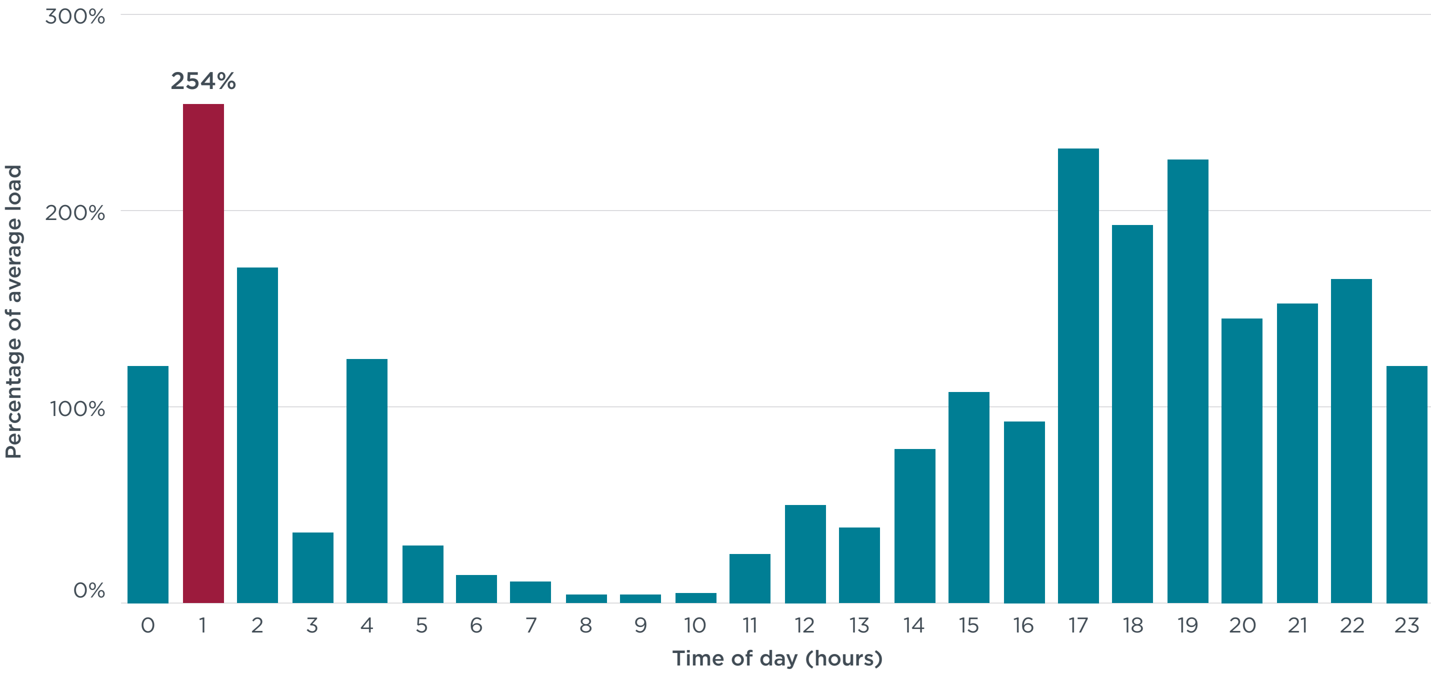
Note: This allocation could change with KCM transition plans, such as if it opens its now on-pause South King County Base (King County Metro, 2023).

Half of school bus depot chargers are allocated to Zūm's depot, and the other half are allocated between First Student's two depots, with two-thirds allocated to the larger school bus yard located in the South Park neighborhood. Other bus depot chargers are redistributed to identified commercial operators, such as MTR Western and Starline Luxury Coaches. For refuse trucks, Seattle is serviced by Waste Management and Recology CleanScapes, and we allocate 50% of refuse depot chargers to these two operators' depots, assuming each carrier has about 100 refuse trucks (City of Seattle, 2023c).

ADDITIONAL INFORMATION ON PEAK CHARGING LOADS CALCULATIONS

Our methodology for calculating peak loads recognizes that vehicle charging is distributed throughout the day, but the electric utility must be ready for the period with the highest energy demand. For each vehicle segment, we first calculate a peak load ratio, which is the daily peak load divided by the average load. This peak load ratio is then multiplied by the daily average energy consumption per census tract to determine the maximum peak load each census tract will experience from MHDV charging. The daily average energy consumption is found by dividing the total daily energy consumption by 24 hours. Figure B1 shows the aggregated daily load profile for drayage trucks in 2030, illustrating how the charging demand varies throughout the day. This image shows that drayage trucks have a peak load ratio of 2.54.

Figure B1
Charging load profile for drayage trucks



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HEVI-LOAD breaks down vehicle classes differently from MOVES's vehicle types, resulting in a misalignment with our analysis. For single-unit and combination trucks, we apply a peak load ratio averaged between HEVI-LOAD's drayage truck, tractor-trailer, and other freight truck categories, which is 1.96.

For transit buses, school buses, other buses, and refuse trucks, we take a different approach, assuming that their charging load profiles are fixed and less distributed across the day. We assume these vehicle segments rely almost solely on overnight depot charging, so we divide their energy consumption by eight hours, the maximum length of an overnight charging session, to estimate their average peak loads. This method is sensitive to assumptions about charging session length and power level. For example, if all 2030 electric transit buses could only charge for six hours instead of eight, the associated charging load would be 37.7 MW instead of 28.3 MW.

We then add together the peak load estimate for single-unit and combination trucks and the load calculations for transit buses, school buses, other buses, and refuse trucks to obtain the peak charging load.

DATA AND MODELING LIMITATIONS

Our modeling process is based on national and Seattle-specific assumptions, reflecting data from primary and secondary sources as well as the ICCT's own national-scale modeling regarding transportation electrification. The results from our modeling are dependent on these assumptions. Considering the electric MHDV market is still nascent, these assumptions may change over time, requiring future model updates.

Our HPMS traffic data does not include origin and stop locations. Therefore, our modeling results may include the infrastructure needs of vehicles based outside of SCL's service territory. Detailed telematics data would improve our modeling results.

With our HPMS data, we identify the VKT of combination and single unit vehicles at the census tract level. We estimate the VKT performed by each vehicle segment using the values in Table A5, and our results appear sensitive to the percentage of VKT we allocate to each vehicle segment. Table A5 could be further refined by updating source information from EPA to reflect local data. Additionally, the table was created using vehicle population counts from EPRI, which are based on vehicle activity and may not truly reflect vehicles based in Seattle.

Our assumptions about battery electric truck adoption from Roadmap reflect anticipated BEV uptake in Washington state under California's ACT rule. This uptake rate may look different for fleets within the SCL service territory due to city-specific policies in place or for specific adoption goals—or lack of—set by the fleet operators themselves. While we have attempted to incorporate known adoption plans for some vehicle segments, these plans could also change. For example, while Zūm states it will have an all-electric fleet by 2027, its previous target date was 2025, signaling this timeline may be flexible (Narayan, 2022).

Daily VKT activity profiles are based on analysis of NREL's Fleet DNA project and other published sources. These data represent the activity of observed fleets, but the fleets operating in the Seattle area may have their own unique vehicle activity profiles (mean VKT and standard deviation of VKT), which consequently impact each segment's energy consumption. Data that is drawn from fleets operating within Seattle's service territory would produce modeling inputs that more closely reflect the operations of local fleets.

The development of the charging market for electric MHDVs may differ from our assumptions, such as the megawatt charging standard becoming commercially available before or after 2027. Additionally, our assumptions about charger utilization rates reflect analysis of the light-duty vehicle market due to the lack of data for battery electric truck fleets (Rajon Bernard & Hall, 2022). These utilization rates are projections subject to uncertainty and will be refined as data from real-world applications become available. We also assume that fleet operators will optimize the use of lower powered overnight charging, but Seattle fleets may have different charging preferences.

Our results regarding public charging reflect a hypothetical public charging network if fast and ultrafast chargers are installed at certain commercial fueling locations in SCL. Different locations may be preferred by charging fleets. Communications with fleets will help SCL determine whether public charging in its service territory is necessary and what a public charging network should look like. We anticipate most charging for battery electric trucks to take place within fleet depots because of fleet preferences to control charging resources and the expected lower charging cost overnight, significant overnight dwell time, access to land, cost of charging equipment, and other techno-economic variables.

Like public chargers, the location and calculation of needed depot chargers reflects our vehicle traffic data, which may not capture the true number of vehicles based within SCL's service territory, as not all trucks driving in Seattle stay within the city. When redistributing depot chargers, we first allocate chargers based on warehouse square footage, but this is a representation of likely depot locations and may not align exactly with existing vehicle depots. While we try to incorporate known fleet plans and depot locations to improve this process, these plans may change, such as KCM's evolving bus electrification plan, or we may have failed to identify existing depots for vehicle segments, such as additional private other bus operators that have buses parked within SCL's service territory.

Regarding peak load calculations, we rely on projections produced from HEVI-LOAD, which reflect California's emerging electric MHDV market. As the MHDV market develops within Washington and the Seattle area, the typical fleet load profiles and consequently, the peak load ratios, could look different. If we were able to attribute anticipated loads to additional HEVI-LOAD categories, like drayage, tractor-trailer, or utility trucks, we could utilize different peak ratios that would impact our peak load calculations. Lasty, we shifted away from the HEVI-LOAD approach for buses and refuse trucks, assuming they will charge overnight at the same times at the lowest power level necessary. Seattle fleets may have different charging preferences, charging at different power levels.

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