Guidehouse

Transportation Electrification Proactive Planning: Modeling Inputs & Assumptions Report

DRAFT FOR PUBLIC COMMENT

Prepared for:

California Public Utilities Commission

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Reference No.: 225223
August 25, 2025

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- AADT: Average Annual Daily Traffic
- AATE: Additional Achievable Transportation Electrification, used by the IEPR forecast as multiple transportation electrification scenarios with different levels of battery electric vehicle adoption
- AFDC: Alternative Fuels Data Center, information and data on alternative and renewable fuels, advanced vehicles, fuel-saving strategies, and emerging transportation technologies, provided by the Department of Energy
- BEV: Battery Electric Vehicle
- CAFE: Corporate Average Fuel Economy, standards set and enforced by the National Highway Traffic Safety Administration regulating how far vehicles must travel on a gallon of fuel
- CAISO: California Independent System Operator
- CARB: California Air Resources Board
- CDM: Corridor Designation Methodology, the methodology by which public DC charging load for LD and MDHD EVs is allocated to specific corridor segments throughout major corridors in California
- CEC: California Energy Commission
- CVC: Commercial vehicle cluster, one of IEPR's light duty vehicle classes
- DAC: Disadvantaged Community, as designated by CalEnviroScreen. Disadvantaged Communities refer to areas throughout California which experience a high burden from a combination of economic, health and environmental indicators.
- DCFC: Direct current fast charging infrastructure for electric vehicles
- DOE: United States Department of Energy
- Depot: Refers to private charging for fleets
- Drayage trucks: Heavy-duty trucks that transport containers and bulk freight between a port and intermodal rail facilities, distribution centers, and other near-port locations.
- EDF: Environmental Defense Fund
- ESJ: Environmental and Social Justice, referencing the U.S. Environmental Protection Agency's ESJ Screening and Mapping Tool
- EPA: U.S. Environmental Protection Agency
- EV: Electric Vehicle
- FHWA: Federal Highway Administration
- GIS: Geographic information system
- GVWR: Gross Vehicle Weight Rating

- HVIP: California’s Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, a CARB voucher intended to help transition California truck fleets to cleaner technologies and reduce trucking-related emissions in and around priority communities
- I&A: CPUC’s Transportation Electrification Modeling Inputs and Assumptions
- ICCT: International Council on Clean Transportation
- ICEV: Internal combustion engine vehicle
- IEPR: California Energy Commission’s Integrated Energy Policy Report
- IOU: Investor-Owned Utility
- IRP: The California Public Utility Commission’s Integrated Resource Planning process
- LD: Light-Duty [vehicle]
- L2: Level 2 charging infrastructure for electric vehicles, operating at anywhere from 3 kW to 19 kW of AC power
- MDHD: Medium and Heavy Duty [vehicle]
- MW: Megawatt
- NAA: [Ozone] Nonattainment areas, EPA terminology for areas that do not meet the national primary or secondary ambient air quality for a national ambient air quality standard (NAAQS)
- NAAQ: National Ambient Air Quality, referring to the standards set by the U.S. Environmental Protection Agency
- NHTS: National Household Travel Survey, conducted by the Federal Highway Administration to obtain American public travel behavior insights
- NHTSA: National Highway Traffic Safety Administration
- NREL: National Renewable Energy Laboratory
- OEHAA: California Office of Environmental Health Hazard Assessment, a specialized department within California’s EPA with responsibility for evaluating health risks from environmental chemical contaminants
- OEM: Original equipment manufacturer, more specifically automotive OEMs as referenced in this report (i.e., automakers)
- ORNL: Oak Ridge National Laboratory
- PM2.5: Particulate Matter, generally 2.5 micrometers and smaller
- POU: Publicly- owned utilities
- PVC: Personal vehicle cluster, one of IEPR’s light- duty vehicle classes
- SOC: State of Charge, representing an electric vehicle battery’s energy levels as a percentage; analogous to the fuel gauge of a gasoline-powered vehicle
- TCO: Total cost of ownership
- TE: Transportation Electrification
- TEPP: [CPUC] Transportation Electrification Proactive Planning

- TOU: Time-of-Use, used in reference to electric rates that have different costs of electricity based on the time of day the energy is pulled from the grid
- VMT: Vehicle Miles Traveled
- ZCTA: ZIP Code Tabulation Area, a geographic product of the U.S. Census Bureau created to allow mapping, display, and geographic analyses of the U.S. ZIP Codes
- ZEV: Zero-Emission Vehicle

1. Introduction

This document describes the key data definitions, categories, values, and sources of the transportation electrification (TE) modeling inputs and assumptions (I&A) for the California Public Utilities Commission's (CPUC) Transportation Electrification Proactive Planning (TEPP) framework.

The **purpose** of establishing the TEPP Modeling I&A is identify a common set of values and assumptions that can be used to model TE charging's electric system impacts along highway corridors. The **objective** of this document is to identify and vet the best available data relevant to modeling transportation patterns, charging and fueling patterns, and expected zero emission vehicle (ZEV) charging technology adoption timelines and locations.

The TEPP Modeling I&A will inform a Transportation Electrification Corridor Disaggregation Methodology (CDM) that can be used to disaggregate the CEC's Integrated Energy Policy Report (IEPR) California Energy Demand Forecast. This methodology will provide localized insights to identify the timing, location, and size of expected TE load growth along highway corridors in California for use in existing planning and cost recovery processes. The TEPP Modeling I&A will also allow for consistent forecasting and scenario building across existing planning and cost recovery processes, including but not limited to the Distribution Planning Process (DPP) and Transmission Planning Process (TPP). This document focuses primarily on I&A for public charging of electric light-duty vehicles (LD) and a combined medium and heavy-duty vehicle category (MDHD). TEPP I&A are in alignment with IEPR I&A wherever feasible.

TEPP Modeling I&A Categories

This document includes detailed explanations of the data inputs listed by category in Table 1-1. Subsequent sections provide the definitions, values, sources, and assumptions for each input.

Table 1-1. TEPP Modeling Inputs & Assumptions Categories

Vehicles	Charging Infrastructure	Grid Impacts	Geospatial Layers
• Vehicle Forecast • IEPR LD Mapping • Fleet Vehicle Domicile Location (Telematics) • Personal Vehicle Domicile Location (Registration) • Vehicle Use Cases	• Level 2-DCFC Power Split[1] • Vehicles per Charger • Charger Power	• "Fuel" Efficiency • Vehicle Miles Traveled • Driving Range • Trip Data • Public vs. Private Charging Allocation • Load shapes • State of Charge (SOC) • Tract Drayage Operations	• California Counties • Freight Analysis Framework 5 Model • LD Average Annual Daily Traffic (AADT) • Investor-Owned Utilities (IOU) / Publicly Owned Utilities (POU) Service Areas • Disadvantaged Communities • PM2.5 and Ozone Non-Attainment Areas (NAA) • Planned & Existing Public Infrastructure • Truck Stops • Rest Stops • Fleet Depots

This draft I&A is intended to serve as a starting point in establishing common I&A for TE planning and solicit feedback from stakeholders on data values and sources.

This draft TEPP Modeling I&A report is accompanied by a spreadsheet workbook known as the "TEPP Modeling I&A Library" (Library). The Library contains more detailed data inputs for TEPP. Both documents are intended to be reviewed together. The TEPP Modeling I&A Report contains more information on the data sources and summarizes key inputs, whereas the Library shows more detailed input values, including values by year.

1.1 Overview of Transportation Electrification Proactive Planning (TEPP)

TEPP aims to inform size, timing, and location of corridor-based TE charging in California through a collaborative effort with the California Energy Commission (CEC). The initial TEPP focus will be to develop I&A that will inform a disaggregation methodology that assigns load to highway corridor segments. This document identifies I&A for LD and MDHD battery electric vehicles (BEVs)[2] because these vehicle segments are expected to have significant localized load impacts on electric transmission and distribution infrastructure along key highway

[1] Preferences for vehicles to charge with either L2 or DCFC

[2] This report focuses on fully battery electric vehicles, and does not include inputs and assumptions for plug-in hybrid vehicles

corridors.[3] I&A related to off-road vehicles, fuel cell vehicles,[4] and hydrogen production or usage are currently out of scope for this analysis, but may be added in the future.

1.2 Document Contents

The sections of this document are organized as follows:

- **Section 2: Vehicles** outlines the vehicle-related inputs required to determine the total charging infrastructure need, including total vehicle stock and BEV adoption forecasts. The accompanying Library includes data supporting TEPP Input Category "Vehicles" for identifying the number of vehicles expected to electrify over a given time period.
- **Section 3: Charging infrastructure** outlines the charger-related inputs needed to determine the total charging infrastructure need, including charger type allocation, properties, and specifications. The accompanying Library includes data supporting TEPP Input Category "Charging Infrastructure" for identifying the amount of charging infrastructure necessary to support the vehicles expected to electrify over a given time period.
- **Section 4: Grid impacts** documents the inputs and their respective sources for forecasts of BEV electric load, peak demand, and hourly charging load profiles. These forecasts are categorized by vehicle and charging use case. The accompanying Library includes data supporting TEPP Input Category "Grid Impacts" for forecasting the energy demand impacts on California's electric system from vehicle electrification.
- **Section 5: Geospatial layers** identifies inputs associated with characteristics for California's major arterial roads and interstate highway corridors .

Each section represents an input category with subsections providing individual inputs (e.g., Section 2.1 Input: Vehicle Forecast). Each input includes a definition, complete or sample value(s)[5], source(s), as well as assumptions regarding data availability, justification for inclusion in the TEPP Modeling I&A, and key questions or limitations.

[3] Transport Refrigerated Units (TRUs), which are on-road vehicles, are out of scope for the current TEPP Modeling I&A

[4] The IEPR forecast includes fuel-cell vehicle adoption projections. While this analysis focuses on impacts from BEVs, it also assumes some customers are driving fuel cell vehicles.

[5] Sample values are used for larger data sets. In such instances, complete values are available in the Library.

2. Vehicles

This section provides I&A for vehicle forecasting:

- **BEV forecast** from IEPR, provides IOU-level vehicle count forecast
- **Vehicle registration data** can be used to develop more granular geographic forecasts; to supplement domicile data where gaps exist
- **Vehicle domicile location** can be used to develop more granular geographic forecasts at a higher precision than registration data, where available
- **Vehicle use cases** can inform behavior such as when and where vehicles will charge

BEV forecasts provide the foundation for TE planning. The forecasts identify the number of expected battery electric vehicles on the road over an analysis period. The BEV forecast is the most important factor in determining charging infrastructure, installed capacity, and power demand impacts. The primary source for electric BEV adoption in TEPP is the CEC's IEPR. The IEPR forecast includes multiple TE scenarios with different levels of BEV adoption, referred to as the Additional Achievable Transportation Electrification (AATE) scenarios.[6]

The IEPR provides BEV adoption figures by vehicle class and IOU service areas as well as the rest of California. However, an accurate analysis of precise locational impacts for the CDM along one-mile-wide highway corridor segments requires more geographically granular vehicle counts.

2.1 Input: Vehicle Forecast

The TEPP will use the most recent IEPR vintage available. This version of the TEPP includes 2023 IEPR report values adopted on February 14, 2024[7], for illustrative purposes only. In the 2022 IEPR, scenarios were run with both AATE Scenario 2 and AATE Scenario 3. However, in the 2023 IEPR, only AATE Scenario 3 was developed due to a higher-than-expected ZEV[8] adoption rate in the first half of 2023. Since IEPR includes expected BEV adoption from these California policies, incorporating the forecast into TEPP will help plan for necessary infrastructure to meet anticipated energy (kWh) and demand (kW) from these vehicles. Due to their generally unfamiliar class name and description, Table 2-1 lists IEPR non-bus BEV classes with definitions and examples.

[6] California Energy Commission, 2022. Additional Achievable Transportation Electrification (AATE). Available at https://efiling.energy.ca.gov/GetDocument.aspx?tn=247954

[7] California Energy Commission. 2023. 2023 Integrated Energy Policy Report. Docket Number 23-IEPR-01. Available at https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report.

[8] Note that IEPR forecast also included PHEV and hydrogen; note that TEPP Modeling I&A only focuses on BEV

Table 2-1. IEPR Vehicle Class[9] and Definitions

IEPR Class	GVWR[10] (lbs.)	Example Make & Models	Notes
CVC[11] PC (Commercial Passenger Car)	0-10,000	VW ID4	LD commercial passenger cars
CVC LT (Commercial Light Truck)	0-10,000	Rivian R1	LD commercial light trucks
PVC[12] PC (Personal Passenger Car)	0-10,000	Tesla Model 3	LD personally owned passenger cars
PVC LT (Personal Light Truck)	0-10,000	Ford F-150 Lightning	LD personally owned light trucks
Other PC (Passenger Car)	0-10,000	Nissan Ariya	LD government & rental passenger cars
Other LT (Light Truck)	0-10,000	Chevy Silverado EV	LD government & rental light trucks
GVWR3	10,001 – 14,000	Bollinger B2	Class 3 Truck
GVWR4and5	GWVR 4: 14,001 – 16,000 GVWR 5: 16,001 – 19,500	Ford F-550	Class 4 and 5 Trucks
GVWR4and5 Delivery	GWVR 4: 14,001 – 16,000 GVWR 5: 16,001 – 19,500	Ford E-Transit	Same as GVWR4and5, but for delivery applications
GVWR6	19,501 – 26,000	BYD 6D Step Van	Class 6 Trucks
GVWR6 Delivery	19,501 – 26,000	GM BrightDrop ZEVO 600	Same as GVWR6, but for delivery applications
GVWR7	26,001 – 33,000	Freightliner eM2 108/106	Class 7 Trucks (Straight truck, all axles connected to single frame)
GVWR8_SU	>33,001	Volvo VNR2	Single-unit Class 8 Trucks
GVWR8 REFUSE AND RECYCLING	>33,001	Peterbilt 520EV	Used for refuse and recycling applications

9 Note that IEPR and Federal Highway Administration (FHWA) classify MDHD vehicle classes beginning at Class 3 (GVWR > 10,000 lbs.), whereas the EPA, CARB, and CPUC classify MDHD vehicle classes beginning at Class 2b (GVWR > 8,500 lbs.)

10 GVWR stands for Gross Vehicle Weight Rating; values based on Federal Highway Administration classification

11 Commercial vehicle cluster, one of IEPR's light duty vehicle classes

12 Personal vehicle cluster, one of IEPR's light duty vehicle classes

IEPR Class	GVWR[13] (lbs.)	Example Make & Models	Notes
GVWR8 COMBO	>33,001	Volvo VNR2	Combination trucks (Semi trucks, can detach from cargo)
GVWR8 IRP	>33,001	Freightliner eCascadia	Combination trucks registered for interstate travel through the International Registration Plan (e.g. sleeper cab tractors)
GVWR8 PORT	>33,001	Kenworth T680	Combination trucks operating at ports in California (e.g. day cab tractors, drayage trucks)
GVWR8_SU DUMP	>33,001	Peterbilt 520EV	Single-unit dump trucks
GVWR8 CAIRP	>33,001	Freightliner eCascadia	Same as GVWR8 IRP, but with fleet's base jurisdiction in CA
GVWR8 PUBLIC AND UTILITY	>33,001	Peterbilt 520EV	Public and utility applications trucks

IEPR forecasts BEV adoption by the vehicle classes in Table 2-1. Table 2-2 provides an example IEPR BEV forecast for California in 2024 and 2025 by vehicle class. The complete IEPR forecast through 2045 is available in the Library[14].

[13] GVWR stands for Gross Vehicle Weight Rating; values based on Federal Highway Administration classification

[14] The 2041-2045 data is an extension of the IEPR forecast modeling results, but not a part of the adopted IEPR forecast.

Table 2-2. 2024 and 2025 CA BEV Adoption Values

BEV[15] class	2024	2025
CVC PC (Commercial Passenger Car)	104,803	126,866
CVC LT (Commercial Light Truck)	22,940	34,092
PVC PC (Personal Passenger Car)	1,464,560	1,991,554
PVC LT (Personal Light Truck)	22,509	52,364
Other PC (Passenger Car)	43,384	63,385
Other LT (Light Truck)	4,622	10,205
GVWR 3	2,075	7,240
GGVWR 4 and 5	4,393	9,231
GGVWR 4 and 5 – Delivery	495	1,038
GGVWR 6	1,151	2,998
GGVWR 6 – Delivery	804	2,363
GVWR 7	579	1,142
GVWR 7 – Combo	110	266
GVWR 7 – Delivery	40	107
GVWR 8 – Combo	1,975	4,213
GVWR 8 – CAIRP	-	-
GVWR 8 – IRP	-	-
GVWR 8 – Port	1,956	3,607
GVWR 8 – Refuse and Recycling	55	257
GVWR 8 – Public and Utility	20	302
GVWR 8 – SU (single unit)	222	492
GVWR 8 – SU Dump	164	249
Intercity Bus	-	-
Other Bus	595	671
School Bus	788	925
Urban Bus	2,258	2,424
Total	**1,680,498**	**2,315,991**

Table 2-3. BEV Forecast Sources & Assumptions

Source	Availability	Justification
CEC, IEPR, AATE 3 vehicle forecast scenario*	Publicly available through public agency	AATE Scenario 3 recommended for TEPP because it is included in the "single forecast set" used by CPUC, CEC, and California Independent System Operator (CAISO).

* 2023 Integrated Energy Policy Report

[15] BEV values in this table represent fully electric vehicles, and do not include hydrogen or plug-in electric vehicles

2.1.1 Limitations

While the TEPP Modeling I&A was designed to identify and vet the best available data relevant to support future transportation analyses, some known limitations of the forecast are mentioned here to guide researchers and analysts to the best usage of the data.

2.1.1.1 Forecast Period

The TEPP Modeling I&A values will run to 2045, while the adopted IEPR forecast values run to 2040. To incorporate BEV adoption figures for the complete TEPP analysis period, the TEPP Modeling I&A will use CEC's 2041-2045 IEPR data, which is an extension of the IEPR forecast modeling results, but not a part of the adopted IEPR forecast.

2.1.1.2 Geographic Granularity

The IEPR forecast provides vehicle stock projections at the IOU level (e.g., Pacific Gas and Electric Company service area). However, the purpose of the CDM is to determine power demand impacts along granular highway corridor segments – for example, down a one-mile stretch of Interstate 5. To meet this need, the TEPP Modeling I&A will need to provide more geographically granular estimates for vehicle domicile locations (e.g., at ZIP Code Tabulation Areas (ZCTA), or at census tract level). The I&A will address this limitation from IEPR data through domicile location data for MDHD BEV (see Section 2.3 below) and registration data for LD BEV (see Section 2.4 below). Thus, MDHD vehicle telematics and LD vehicle registration data will be used to disaggregate IEPR IOU BEV forecasts to a more granular geography.

2.2 Input: IEPR LD Mapping

The CEC forecasts light-duty vehicle adoption across many classes including compact cars, mid-size SUVs, and minivans. For purposes of the TEPP, these classes can be combined into either light-trucks or passenger cars, since those vehicle types have significantly different fuel efficiency. The mapping from CEC's broad set of light-duty vehicle classes to those used in TEPP is available in Table 2-6.

Table 2-4. IEPR Light Duty Mapping

IEPR Light Duty Class	TEPP Light Duty Mapping
S Car-Midsize	Passenger Car
P SUV-Compact	Passenger Car
S SUV-Compact	Passenger Car
S Car-Compact	Passenger Car
P Car-Large	Passenger Car
S SUV-Subcompact	Passenger Car
S Car-Subcompact	Passenger Car
P Car-Compact	Passenger Car
P Car-Midsize	Passenger Car
S Car-Sport	Passenger Car
P Car-Subcompact	Passenger Car
S Car-Large	Passenger Car
P Car-Sport	Passenger Car
P SUV-Subcompact	Passenger Car
S SUV-Midsize	Light Truck
S Pickup-Std	Light Truck
S Pickup-Compact	Light Truck
S SUV-Large	Light Truck
P SUV-Midsize	Light Truck
S Van-Minivan	Light Truck
S Pickup-Heavy	Light Truck
S Van-Heavy	Light Truck
S Van-Std	Light Truck
P SUV-Large	Light Truck
P Van-Minivan	Light Truck
P Pickup-Std	Light Truck
S SUV-Heavy	Light Truck
P Van-Std	Light Truck
P Pickup-Heavy	Light Truck

Table 2-5. IEPR LD Mapping Sources & Assumptions

Source	Availability	Justification
CEC, IEPR, AATE 3 vehicle forecast scenario*	Publicly available through public agency	For IEPR, the CEC rolls up vehicles by owner (commercial, personal, or other). However, there are significant differences in fuel efficiency between passenger cars and light trucks, which would influence charging needs. This LD mapping allows TEPP to distinguish between light trucks and passenger cars.

* 2023 Integrated Energy Policy Report

2.2.1 Limitations

Multiple light-duty classes are combined into passenger cars or light trucks. Though this may result in the loss of some granularity around charging impacts, the loss is negligible due to the relatively small difference in corridor charging along corridors for these vehicle types.

2.3 Input: Fleet Vehicle Location: Telematics

There is a well-known mismatch between vehicle registration locations and domicile location, especially for fleet vehicles. Therefore, the TEPP Modeling I&A recommends using telematics to determine where fleet vehicles are domiciled. This will give a more accurate estimate of trip origination, highway corridors used for vehicle travel, and where infrastructure should be located to meet those vehicles' charging needs. This data will be used to disaggregate fleet vehicles from the IEPR forecast to more geographically granular locations based on their actual activity.

Table 2-6. Vehicle Domicile Location

Source	Availability	Justification
Geotab[16]	Due to CPUC contractual obligations with Geotab, raw aggregate data inputs from those data sets cannot be made publicly available. These sources and data sets are the best available at the time of this research, and are subject to change.	Including fleet vehicle domicile location will accurately determine where vehicle depots are and where they are likely to charge.

2.3.1 Limitations

Currently available telematics data account for less than 5% of California fleet vehicles. This relatively small sample will result in vehicles being concentrated geographically after inflating the domicile figures to match the IEPR forecast.

2.4 Input: Personal Vehicle Location: Vehicle Registration

Precise and accurate estimates of charging infrastructure and energy impacts require geographically granular vehicle domicile locations. Registration data provides reliable locations at the ZCTA or census-tract level for personally owned LD BEV (IEPR class 'PVC').

[16] Geotab maintains data privacy for telematics data by excluding Origin/Destination details from vehicle trips at more granular levels if there are a limited number of organizations with Geotab devices to ensure that owners of vehicles cannot be discerned from the data sets.

Table 2-7. Vehicle Domicile Location

Source	Availability	Justification
S&P Global Mobility	Due to contractual obligations with commercial providers raw aggregate data inputs from those data sets cannot be made publicly available. These sources and data sets are the best available at the time of this research, and are subject to change.	Vehicle registration data obtained from the 'Vehicles in Operation National Vehicle Population Profile (NVPP) data dated January 1, 2024, for California, vehicles through class 8, includes geographically granular counts of all personally owned LD vehicles (IEPR class 'PVC') in California by zip code.

2.4.1 Limitations

Fleet vehicles may not be domiciled where they are registered, which would cause incorrect load growth estimates; however, vehicle registration data is a more reliable indicator of domicile location for individually owned LD vehicles.

2.5 Input: Vehicle Use Cases

The TEPP Modeling I&A will create vehicle use cases to model vehicle travel behavior and forecast anticipated BEV load and power demand growth at a localized geographic granularity. IEPR classes GVWR8 IRP and GVWR8 CAIRP are mapped to the long-haul truck vehicle use case, which are expected to mostly charge along highway corridors and have higher VMT than other Class 8 semi-trucks. Like long-haul trucks, bus and delivery truck use cases offer insight into when vehicles are being used and how much power they need to complete their trips.

Vehicle use cases are mapped to specific IEPR vehicle classes as shown in Table 2-8.

Table 2-8. Vehicle Use Cases

Duty	IEPR class	Vehicle Use Case	Example make	Example model
LDV	CVC (commercial vehicle)	Commercial Light Truck	Rivian	R1
	Other (government and rental)	Commercial Passenger Car	Nissan	Ariya
	PVC (personal vehicle)	Personal Light Truck	Ford	F-150 Lightning
		Personal Passenger Car	Ford	Mustang Mach-E
MDV	GVWR3	GVWR3 Pickup	Bollinger	B2
	GVWR4and5	GVWR4-6 Delivery	Ford	E-Transit
	GVWR6			
	GVWR4and5 Delivery			
	GVWR6 Delivery			
HDV	GVWR7	GVWR7-8 Delivery	Peterbilt	220 EV
	GVWR7 Delivery			
	GVWR7 COMBO			
	GVWR8 COMBO	Short-Haul Truck	Volvo	VNR2
	GVWR8_SU			
	GVWR8 CAIRP	CA Long-Haul	Freightliner	eCascadia
	GVWR8 IRP	OOS* Long-Haul		
	GVWR8 PORT	Drayage Truck	Kenworth	T680
	GVWR8 REFUSE AND RECYCLING	Vocational Trucks	Peterbilt	520EV
	GVWR8 PUBLIC AND UTILITY			
	GVWR8_SU DUMP			
	Other Bus	Transit Bus	BYD	30 ft
	Urban Bus			
	School Bus	School Bus	Blue Bird	Vision Electric

* Out of State

Table 2-9. Vehicle Use Case Input Source, Availability, and Justification

Source	Availability	Justification
CEC	Publicly available through public agency	Reduced complexity by consolidating similar vehicles (e.g., GVWR4-6 delivery trucks). Combined IEPR classes have similar VMT and fuel efficiency and are expected to have similar charging needs (charging mostly at night at private charging stations).

2.5.1 Limitations

The justification for combining the IEPR vehicle classes into the use cases shown in Table 2-8 is that it will help reduce complexity and make the results easier to understand. The limitation associated with this justification is that it may reduce important differentiation across classes. An additional limitation is the combining of government and rental light-duty vehicles into the "Other" category. There are some key differences between these vehicle types, for example, government vehicles are subject to the Advanced Clean Fleets ZEV sales mandates, and rental vehicles have higher VMT than individually owned vehicles.

There are some situations where developing more granularity for vehicle classes in future iterations of the CDM could provide additional insights. For example, LD taxis and rentals have significantly different driving patterns compared to typical commercial vehicles.

Use cases and routes for BEV are at different stages of development, with MDHD being the least developed. The I&A could be updated as the market evolves, and as driving behaviors and public and private charging assumptions change.

3. Charging Infrastructure

This section provides inputs and assumptions to determine the infrastructure necessary to support different vehicle types and their use cases. These assumptions cross both charger power level by vehicle use case and charging accessibility (public or private). BEVs are assumed to charge at either private (depot, home, work) or public ports. Additional details about the allocation of vehicle charging to public or private ports are available in Section 3.2. Charger attribute inputs were compiled from multiple sources, considering data availability and the methodologies utilized to generate the inputs.

3.1 Input: Power Preference and Suitability

The TEPP Modeling I&A will use insights from Guidehouse-conducted commercial fleet manager interviews to inform the portion of BEV charging sessions use either Level 2 (L2, currently around 12 kW)[17] or DCFC (≥ 50 kW)[18] ports. Guidehouse-led interviews with large fleet managers in California and across the US have indicated a preference for L2 depot charging when possible due to operational effectiveness, cost, permitting, and expediency. Using the VMT and fuel efficiency values in Sections 4.1 and 4.2, the I&A will calculate[19] whether vehicles would have enough time to recharge using L2 ports. This calculation will incorporate changes in fuel efficiency over time. Even if vehicles are expected to mostly rely on L2 charging, light-duty and medium-duty fleet managers are assumed to have DCFC ports available for emergencies. Consequently, vehicles associated with L2 depot charging are also assumed to occasionally use DCFC and public charging.

Table 3-1. Power Preference and Suitability Input Source, Availability, and Justification

Source	Availability	Justification
Guidehouse, commercial fleet manager interviews	Publicly available through public agency	Associating charging levels with vehicle use cases increases both precision and accuracy.
NREL EVI Pro-Lite	Publicly available through research agency	EVI Pro-Lite provides charging use case estimates (e.g., L2 Home and DCFC Public) for personally owned vehicles (IEPR class 'PVC').

3.1.1 Limitations

This input assumes charging power preferences derived from fleet manager interviews represent the actual average and does not change over time. As the EVSE network expands, NREL's EVI Pro-Lite indicates personally owned LD BEV (IEPR class 'PVC') will use more intercity DC charging for uses like vacation travel. These assumptions are features of the underlying data.

[17] The long-run L2 charging power is assumed to be 22 kW

[18] While some DC chargers can provide 30 or 40 kW, the TEPP Modeling I&A is using 50 kW for modeling purposes.

[19] This calculation is available in 5.8.1.

Additionally, because charging power preferences are derived from currently available data sources and interviews, they will not capture changes in technology-driven preferences such as alternative battery chemistries/designs, which are better suited for DCFC[20].

3.2 Input: Vehicles per Charger

For fleet vehicles, the TEPP Modeling I&A incorporates the assumptions of fleet managers' preference for L2 depot charging and that depots will optimize and have more vehicles per DCFC port in the future. Vehicles per charger is a ratio that identifies how charging infrastructure scales with vehicles on the road. In a simplified example, if a fleet has five vehicles that all share the same DCFC port the vehicle to charger ratio would be 5-to-1. The number of vehicles per charger and its active charging utilization[21] are important metrics for investment costs and cost recovery. With low utilization numbers, the port is less active in charging, and generally would take longer to recover the cost to install the stations. California Assembly Bill 2127 estimated 2023 utilization for 250 kW and 350 kW chargers to be 5% and 2.5%, respectively.[22] The same bill suggested utilization would increase over the next ten years to 8.5% and 7% respectively. Assuming average VMT per vehicle does not change, this increase in utilization indicates more vehicles per charger. This progression is aligned with organizational incentives to save on capital costs for charging stations with an increase in utilization.

Individual vehicle per charger values come from current BEV fleet operations across a variety of charging use cases (e.g., LD fleets, school bus depot, medium-duty depot, and drayage). The TEPP Modeling I&A will estimate current vehicle per charger values for public charging by dividing the number of registered MDHD or LD BEVs in California by the number of ports designated for the same duty vehicles from the Alternative Fuels Data Center (AFDC).[23] For example, there are projected to be 1,662,818 LD BEVs in California in 2024, and AFDC indicates there are 12,577 DCFC ports in the state. That results in a vehicle per charger value of 132.

For long-term (i.e., 2045) personally owned LD (IEPR class 'PVC') ratios, the I&A uses NREL's EVI Pro-Lite assumptions about EVSE availability, vehicle trips, and charger demand. These vehicles per charger values are not stating that a fast charger can support 90 LDV in 2024, but rather that for every 90 LDV, there would be one fast charger. The majority of LDV will not use a fast charger at all, as they are expected to mostly rely on home charging.

The complete set of vehicle per charger values along with sources are available in the "Vehicles per Charger" tab of the Library. For example, an article looking at Amazon electric delivery vans indicated there were 10,000 ports for 12,000 vehicles. Amazon's electric delivery trucks would need several hours to recharge with an L2 port or less than an hour with a fast charger. This indicates the electric delivery trucks are most likely using L2 ports and have a 1-to-1 vehicle-to-charger ratio.

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[20] Liu, Yayuan, Yangying Zhu, and Yi Cui. "Challenges and opportunities towards fast-charging battery materials." Nature Energy 4.7 (2019): 540-550.; Li, Matthew, et al. "Fast charging Li-ion batteries for a new era of electric vehicles." Cell Reports Physical Science 1.10 (2020).

[21] The period a charger was providing energy divided by the maximum time it could provide energy - https://www.nrel.gov/docs/fy24osti/85902.pdf

[22] https://efiling.energy.ca.gov/GetDocument.aspx?tn=251866&DocumentContentId=86859 (page C-2)

[23] https://afdc.energy.gov/stations#/analyze?region=US-CA&maximum_vehicle_class=MD

Table 3-2 provides examples of vehicle charging applications such as public transportation corridor charging and MD vehicle depots. The Library includes the full set of vehicle per charger values.

Of note in Table 3-2 below, no change is expected in long-term charging for private LD fleet depot DCFC charging (first row in the table) due to private LD fleet managers' preference for L2 over DCFC due to cost, convenience, and simplified permitting compared to DCFC, and preference to rely on DCFC just for emergency backup. L2 charging has been found to be suitable for LD fleet vehicles, which have lengthy dwell times due to duty cycle and relatively low charging needs. This has reduced the need for fleet managers to invest in expensive fast charging.

Conversely, public LD fleet (intercity) DCFC applications are expected to increase in the long-term, as more vehicles are expected to charge along interstate highways. The assumption here, validated by the AB 2127 report, is that public DCFC charging will have higher utilization in the future, resulting in a higher vehicle per charge value as shown in the second row of Table 3-2. Intercity charging is currently focused on establishing continuity between cities, even while charger utilization is relatively low. As EV adoption grows and driver confidence in intercity charging availability goes up, utilization is expected to increase. This will present through the number of EVs using intercity charging growing at a faster rate than the number of ports themselves.

Table 3-2. Example Vehicle per Charger Values

Ownership	Charging application	Charging technology	Vehicles per charger current	Vehicles per charger long-term*	Source
Private	LDV Fleet (depot)	DCFC	33	33	Amazon
Public	LDV Fleet (intercity)	DCFC	132	333	† AFDC
Public	Highway Corridor (intercity) (HDV)	DCFC	90.0	100	†
Private	HDV non-Delivery Depot	DCFC	5.0	10	PepsiCo Pilot
Public	Hub (regional) (MDV and HDV)	DCFC	90.0	200	†
Private	Long-Haul Depot (HDV)	DCFC	2.5	5	PepsiCo Pilot
Private	MDV Depot	DCFC	50.0	50	‡
Private	MDV Depot	L2	1.0	1	§

* Long run values assume charging technology maturation in 15-20 years when the vehicle population is roughly 50% electric. Maturation date varies across classes with all MDHD assumed mature in 2037 and LD in 2039 according to IEPR forecast.

† 50% of 2024 vehicle-to-charger ratio in CA based on S&P Global registrations and AFDC.

‡ For delivery trucks and school buses, the low annual VMT and fleet manager interviews suggest they will use L2 charging, likely on a 1-to-1 ratio, with some DCFC backup charging.

§ Amazon has an estimated 10K delivery trucks and 12K charging stations. [24]

[24] https://www.aboutamazon.com/news/transportation/everything-you-need-to-know-about-amazons-electric-delivery-vans-from-rivian

Table 3-3. Vehicles per Charger Input Source, Availability, and Justification

Sources	Availability	Justification
Amazon article	Publicly available through commercial entity	This input differentiates the number of vehicles per charger by charging application, allowing for more precision in analysis. Note that although AB 2127 also has analogous inputs, it does not provide the granularity sought by the TEPP analysis.
PepsiCo Pilot	Publicly available through research agency	
AFDC station locator	Publicly available through public agency	
Bloomberg news article	Publicly available through news agency	
PR Newswire article	Publicly available through news agency	
SFMTA	Publicly available through public agency	

3.2.1 Limitations

Since BEV electrification is still nascent, especially for heavier vehicles, some inputs are based on fleet manager preferences, duty cycle estimates, or pilots. Such inputs may require updating as real-word applications scale and provide insight into how, when, and where BEVs charge.

3.3 Input: Charger Power

The TEPP Modeling I&A will use charger power values by charging application. Most L2 charging is currently assumed to use 12 kW power,[25] and is expected to increase to 22 kW such as those available through ABB.[26] DCFC power levels typically range from 50 kW to 3 MW in power output (see Table 3-4). For example, DCFC power assumptions were taken from existing pilot projects such as PepsiCo's Tesla semi distribution operations. PepsiCo uses 750 kW chargers for their Tesla semi fleet. Similarly, Amazon has 50 kW charging stations for delivery vans as a backup to their preferred L2 ports.

Charger power is expected to vary by charging application, charger technology and time as illustrated in Table 3-4.

[25] This is due to the common configuration of 240v ports on 50-amp breakers. Many vehicles have max AC charging speeds of 11.5 kW, determined by the vehicle's onboard inverter - North America EV charging connector types | Enel X Way

[26] https://new.abb.com/ev-charging

Table 3-4. Current and Long-Run Charging Power Estimates

Ownership	Charging application	Charging technology	Current rated kW	Long run rated kW*	Source
Public	LDV Intercity	DCFC	150	350	CEC
Private	LDV Depot	DCFC	50	100	Amazon
Private	LDV	L2	12	22	AFDC
Private	MDV Depot	L2	12	22	AFDC
Private	MDV Depot	DCFC	50	300	Amazon NREL
Private	HDV non-Delivery Depot	DCFC	350	1000	Forum Mobility
Private	HDV Delivery Depot	L2	12	22	AFDC
Public	Hub (regional)	DCFC	350	1000	AFDC
Private	Transit Bus Depot	DCFC	100	150	FTA Report
Private	School Bus Depot	L2	12	19.2	AFDC
Private	School Bus Depot	DCFC	60	150	School Transportation News
Private	Port (Drayage)	DCFC	350	1000	Forum Mobility
Private	Long-Haul Depot	DCFC	750	1000	PepsiCo Pilot
Public	Highway Corridor (intercity)	DCFC	750	3000	PepsiCo Pilot

* Long run values assume charging technology maturation in 15-20 years when the vehicle population is roughly 50% electric. Maturation date varies across classes with all MDHD assumed mature in 2037 according to IEPR forecast. Values will grow from current-to-long run rated kW in a linear fashion.

Table 3-5. Charger Power Input Source, Availability, and Justification

Sources	Availability	Justification
CEC	Publicly available through public agency	This input differentiates charger power by vehicle use cases, allowing for more precision in analysis. Note that although AB 2127 also has analogous inputs, it does not provide the granularity sought by the TEPP analysis.
AFDC	Publicly available through public agency	
Amazon	Publicly available through news agency	
NREL whitepaper	Publicly available through research agency	
FTA Research	Publicly available through public agency	
School Transport News	Publicly available through news agency	
Forum Mobility	Publicly available through news agency	
ChargePoint MW Charging announcement	Publicly available through commercial entity	
PepsiCo Pilot	Publicly available through research agency	

3.3.1 Limitations

The key question for charger power is whether assumptions about future charger power will be accurate. MDHD BEV DCFC power levels are expected to increase in the future just as observed in the case of LD BEV DCFC. Initial LD BEV DCFC had a maximum limit of 50 kW, but now is available up to 350 kW.[27,28] Higher charging in the MW range is already being explored but will be slow to install, quite costly, and will require substantial investment in transmission and distribution.[29] It's possible that transmission and distribution challenges or solutions could make future charging either lower or higher than assumed. As successful business models for private and especially public charging emerge, assumptions regarding future charger power in the TEPP Modeling I&A can be further refined.

[27] R&D Insights for Extreme Fast Charging of Medium- and Heavy-Duty Vehicles: Insights from the NREL Commercial Vehicles and Extreme Fast Charging Research Needs Workshop (energy.gov)

[28] Alternative Fuels Data Center: Procurement and Installation for Electric Vehicle Charging Infrastructure (energy.gov)

[29] The power of moving loads: Cost analysis of megawatt charging in Europe (raponline.org)

4. Grid Impacts

This section provides I&A for estimating the energy demand associated with BEV operations. The energy needed to power electric vehicles can be calculated by multiplying a vehicle's fuel efficiency and VMT (see Figure 4-1 below). That energy will then be allocated to different charging use cases with public charging filling in for trips that are beyond vehicles' range from charging at depots. Trip data will provide an indication of the proportion of a vehicle's VMT that could be expected to require public charging. This energy for public and private charging will then be allocated to time of day according to load shapes by charging use case (e.g., school bus depot or highway corridor charging).

Figure 4-1. Vehicle Energy Calculation

Class (a)	Powertrain (c)	Annual VMT # (d)	Fuel Efficiency # (e)	Total Vehicles# (f)	Energy* (kWh = d*e*f)
Passenger Car	BEV	10,000 miles	0.3 kWh/mile	1,089,000	3,267 GWh

4.1 Input: "Fuel" Efficiency

The TEPP Modeling I&A will use BEV "fuel" efficiency values from the CEC. Fuel efficiency is a measure of the number of miles a vehicle can travel per kWh consumed. Values vary by vehicle use case and duty with smaller vehicles able to drive multiple miles per kWh, while semi-trucks travel less than one.

Table 4-1 provides fuel efficiency estimates by vehicle use case.

Table 4-1. Fuel Efficiency by Vehicle Use Case

Duty	Vehicle Use Case	Fuel Efficiency kWh/mile (2024)	Fuel Efficiency kWh/mile (2045)	Source
LD	Light Truck (Personal and Commercial)	0.433	0.410	CEC
LD	Passenger Car (Personal and Commercial)	0.281	0.287	CEC
MDHD	GVWR3 Pickup	0.586	0.586	CEC
MDHD	GVWR 4-6 Delivery	1.061	1.032	CEC
MDHD	GVWR 7-8 Delivery	1.068	1.016	CEC
MDHD	Short-Haul Truck	1.804	1.764	CEC
MDHD	Vocational Truck	1.807	1.755	CEC
MDHD	CA Long Haul Truck	1.818	1.773	CEC
MDHD	OOS Long Haul Truck	0.000	1.773	CEC
MDHD	School Bus	1.804	1.804	CEC
MDHD	Transit Bus	1.634	1.634	CEC
MDHD	Drayage	1.786	1.750	CEC

Table 4-2. Fuel Efficiency Input Source, Availability, and Justification

Source	Availability	Justification
CEC	Publicly available through public agency	These inputs provide transparent, publicly accessible, and traceable fuel efficiency figures derived from telemetry data.

4.1.1 Limitations

The key limitation around fuel efficiency is the accuracy of future estimates. These estimates are based on historical improvements and anticipated research and development investments but are still uncertain, especially toward the end of the study analysis. Current estimates also are dependent on the existing vehicle mix, including drag coefficient and weight. These may change over time as consumer preferences, technology, and OEM designs change.

4.2 Input: Vehicle Miles Traveled

The TEPP Modeling I&A will use vehicle miles traveled (VMT) values that are specific to California from CEC's IEPR 2023 forecast. VMT estimates will be used to calculate per-vehicle energy impacts. They indicate the number of miles a vehicle travels in a year. VMT, along with other indicators of vehicle lifetime costs such as fuel efficiency, fuel price, and maintenance cost, determines operating expenditure estimates. VMT plays a crucial role in the downstream effects of estimating overall Total Cost of Ownership (TCO) and powertrain market share.

Table 4-3 provides VMT values by vehicle duty and use case. Calendar Year refers to the year in which energy impacts are calculated. The complete set of VMT values is available in the Library.

Table 4-3. Example Vehicle Miles Traveled by Duty and Vehicle Use Case for BEVs

Duty	Vehicle Use Case	Calendar Year	Vehicle Miles Traveled	Source
LD	CVC (Commercial)	2024	13,433	CEC
LD	PVC (Personal)	2024	13,690	CEC
MDHD	GVWR3 Pickup	2024	14,595	CEC
MDHD	GVWR 4-6 Delivery	2024	15,992	CEC
MDHD	GVWR 7-8 Delivery	2024	19,981	CEC
MDHD	Short-Haul Truck	2024	28,757	CEC
MDHD	Vocational Truck	2024	15,250	CEC
MDHD	CA Long Haul Truck	2024	92,341	CEC
MDHD	School Bus	2024	10,382	CEC
MDHD	Transit Bus	2024	25,118	CEC
MDHD	Drayage	2024	30,824	CEC

Table 4-4. Vehicle Miles Traveled Input Source, Availability, and Justification

Sources	Availability	Justification
CEC, IEPR, AATE 3 vehicle forecast scenario*	Publicly available through public agency	AATE Scenario 3 recommended for TEPP because it is included in the “single forecast set” used by CPUC, CEC, and California Independent System Operator (CAISO).

* *2023 Integrated Energy Policy Report*

4.2.1 Limitations

While the industry has credible VMT estimates for light-duty BEVs, there is more uncertainty regarding assumptions for electrified MDHD BEVs. This is due to the lack of real-world evidence for larger electrified MDHD BEVs and how their trip lengths, on average, may be impacted over time.

4.3 Input: Driving Range

The TEPP Modeling I&A will use electric driving range values by vehicle use case from the DOE’s AFDC. Driving range indicates the expected miles a vehicle can travel based on its battery size, capacity, and efficiency. Driving range will play a key role in determining how far BEVs can travel (in miles) before needing to recharge.

Table 4-5 provides assumptions on the driving range for electric vehicles by duty and use case. Research for this I&A did not find any future projections for MDHD range. Subsequently, this I&A chose to keep MDHD range static while the market matures and determines successful business models. Future updates to the I&A could adjust range values once there is more clarity around whether MDHDs charge at depots or public stations, the co-evolution of charging preference with public charging targeted to MDHDs, and whether fleet managers are willing to pay more for increased driving range.

Table 4-5. BEV Driving Range by Duty and Vehicle Use Case

Duty	Vehicle Use Case	2024 Driving Range (Miles)	2030 Driving Range (Miles)	Source[30]
LDV	Personal	250	350	AFDC BNEF
LDV	Commercial	250	350	
MDV	GVWR 4-6 Delivery	200	200	
MDV	GVWR3 Pickup	200	200	
HDV	GVWR 7-8 Delivery	150	150	
HDV	Short-Haul Truck	150	150	
HDV	Vocational Truck	150	150	
HDV	CA Long Haul Truck	300	300	
HDV	OOS Long Haul Truck	300	300	
HDV	School Bus	120	120	
HDV	Transit Bus	200	200	
HDV	Drayage	150	150	

Table 4-6. BEV Driving Range Input Source, Availability, and Justification

Source	Availability	Justification
AFDC	Publicly available through public agency	Data set provides driving range values for most BEVs in the US.

4.3.1 Limitations

This input assumes that driving range is similar for passenger cars and light trucks based on research reviewing vehicle model specifications provided by AFDC. Range is determined by variables such as weight, drag, elevation, and driving speed, which contribute to efficiency, and battery capacity. There is considerable variation in driving range across MDHD BEV types and use cases. For example, the Tesla Semi has an estimated range of 500 miles while the Freightliner eCascadia has an estimated range of 230 miles.[31] It may be a challenge to capture variation in driving range within the same vehicle use case, especially as cargo weight can vary dramatically. Eventually, long-haul trucks are expected to have a range closer to 500 miles in order to drive on cross-country routes. Like other inputs, this will also depend on technology

[30] 2024 values are from AFDC and 2030 values are from BNEF. The 2030 BNEF values were the latest identified through researching future driving ranges.

[31] https://afdc.energy.gov/vehicles/search

improvements over time, which are inherently uncertain. It's also possible that future LDVs will have different driving ranges based on use case. Delivery trucks that only drive 100 miles in a day may have less range (and associated lower battery costs) than personal vehicles where customers expect similar range to ICEVs.

4.4 Input: Trip Data

The TEPP Modeling I&A will use fleet trip data that includes telemetry outputs from more than 100,000 vehicles and individually owned trip data from Oak Ridge National Laboratory's (ORNL) National Household Transportation Survey. This data provides the distribution of trips for different vehicle types and use cases. The distribution of VMT by trip length identifies trips that could not be conducted on the basis for allocating energy to depot or public charging, in a process explained in Section 4.5. Trip data combined with domicile/registration location and traffic data determines where vehicles are traveling along highway corridors and where they would likely need to recharge.

Table 4-7. Trip Data Input Source, Availability, and Justification

Source	Availability	Justification
Oak Ridge National Lab National Household Transportation Survey (NHTS)	Publicly available through public agency	Represents the best-known source for personal vehicle trip data.
Geotab	Due to contractual obligations with commercial providers raw aggregate data inputs from those data sets cannot be made publicly available. These sources and data sets are the best available at the time of this research, and are subject to change.	Represents the best-known source for commercial vehicle trip data

4.4.1 Limitations

The trip data is based on ICEV trips, so it assumes that electric BEV will make similar trips.

4.5 Input: Public vs Private Charging Allocation

To determine whether vehicles will use public or private charging, the TEPP Modeling I&A will use values from NREL, Federal Highway Administration (FHWA), and Federal Transit Authority (FTA), supplemented with additional telemetry data from Geotab. As identified earlier, fleet managers interviewed by Guidehouse indicated a preference to charge at depots to ensure operational effectiveness. However, an analysis of vehicle trip distance and expected driving range using Geotab's telemetry data indicated a proportion of trips for different vehicle use cases (e.g., LD fleet vehicles, transit buses and delivery trucks) are expected to require recharging mid-trip. This charging is assumed to occur at public stations. In Table 4-8, for example, HD BEV delivery trucks are assumed to charge 90% at private depots and 10% at public ports.[32] The complete set of charging allocation assumptions are available in the Library.

According to NREL's EVI Pro-Lite tool, currently 99% of charging for personally owned vehicles (IEPR class 'PVC') occurs at local charging ports (e.g., home, work, market[33]), while 1% uses intercity charging such as Telsa's superchargers. This proportion of intercity charging is expected to increase to 3% by 2045 as more high-speed charging ports are installed and used along highway corridors. Most charging for long-haul trucks is expected to come from public charging ports since they don't return to depots in the same day and trips may extend multiple days, or even weeks. The analysis indicated a 29% / 71% split between private and public charging for long-haul vehicles. HDV BEV completing shorter trips such as short-haul trucks have an 89% / 11% private versus public charging allocation. Pilot projects from transit buses have reflected 82% of charging at private bus depots and 18% at public chargers. Advances in charging infrastructure for these buses allows for wireless charging at bus stops, so these vehicles can get a top-off on their regular route. School buses are assumed to charge primarily at private depots, given that these vehicles have significant down-time outside of school hours. Current assumptions for delivery trucks, and specialized vocational vehicles (e.g., refuse trucks) is that most recharging will occur at private depots. Recent port electrification plans indicate some drayage vehicle charging will occur at ports. This value could be updated based on interviews with fleet managers to determine their charging preferences (depot vs public) and charging infrastructure availability.[34] [35] [36]

This input is based on ICEV trip data and assumes that BEV driving behavior remains similar to that of ICEVs. For that reason, most allocation values do not change between 2024 and 2045. However, that reasoning does not hold for personal vehicles where driving behavior for BEVs and ICEVs is expected to change along with the installation of more intercity charging. This input assumes an increasing proportion of personal[37] long-distance travel will use EVs and is in-line with the CEC's California Electric Vehicle Infrastructure for Long-Distance Travel.[38]

32 All vehicle charging allocation should sum up to 1

33 Market charging is at locations such as pharmacies or grocery stores

34 https://ngtnews.com/california-ports-will-invest-25-million-in-truck-charging

35 aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2023annualreport_2024planupdate_final.pdf?sfvrsn=8

36 California Ports Will Invest $25 Million to Boost Truck Charging Infrastructure - NGT News

37 Personally owned vehicles (IEPR class 'PVC')

38 California Electric Vehicle Infrastructure for Long-Distance Travel

Table 4-8. Example Allocation of Vehicle Energy to Public and Private Ports

Vehicle Duty	Vehicle Use Case*	Charging Use Case	Charger Ownership	2024 Charging Allocation	2045 Charging Allocation	Source
LDV	Commercial	Intercity	Public	3%	3%	Geotab
LDV	Personal	Intercity	Public	1%	4%	NREL[39]
HDV	GVWR 7-8 Delivery	Delivery Truck Depot	Private	90%	90%	Geotab
HDV	GVWR 7-8 Delivery	Hub	Public	10%	10%	Geotab
MDV	GVWR 4-6 Delivery	Delivery Truck Depot	Private	96%	96%	Geotab
MDV	GVWR 4-6 Delivery	Hub	Public	4%	4%	Geotab
HDV	Drayage	Port Depot	Private	50%	50%	FHWA
HDV	Drayage	Hub	Public	50%	50%	FHWA
HDV	CA Long-Haul Truck	Long-Haul Depot	Private	29%	29%	FHWA
HDV	CA Long-Haul Truck	Highway Corridor	Public	71%	71%	FHWA
HDV	Short-Haul Truck	HDV Depot	Private	89%	89%	FHWA
HDV	Short-Haul Truck	Hub	Public	11%	11%	FHWA
HDV	Transit Bus	Transit Bus Depot	Private	82%	82%	FTA Research Report
HDV	Transit Bus	Hub	Public	18%	18%	FTA Research Report

* Rows are shaded to indicate charging for the same vehicle. For example, HDV delivery trucks are assumed to charge 94% at depots and 6% at public ports.

[39] Evi Pro Lite (nrel.gov)
2024 value assumed 100% access to home charging
2045 results assumed 50% access to home charging

Table 4-9. Allocation of Vehicle Energy Input Source, Availability, and Justification

Source	Availability	Justification
NREL	Publicly available through public agency	These sources represent the best known for vehicle trip data which provide the underlying assumptions for public vs depot charging. Note that although AB 2127 also has analogous inputs, it does not provide the granularity sought by the TEPP analysis.
FHWA	Publicly available through public agency	
FTA	Publicly available through public agency	
Geotab	Due to contractual obligations with commercial providers raw aggregate data inputs from those data sets cannot be made publicly available. These sources and data sets are the best available at the time of this research, and are subject to change.	

4.5.1 Limitations

Assumptions about private vs public charging preference are based on expected BEV duty cycles. However, duty cycles are not a perfect indicator. Fleet managers could change duty cycles to prioritize depot charging, reducing the need for public charging. Conversely, lengthy permitting and grid installation periods may force fleet managers to rely on public charging as opposed to their stated preference for depot charging. For LD, it is unclear whether individuals will have similar driving patterns with BEV as they do for ICEV, and the extent to which drivers will utilize DCFC charging at highway corridors for local trips.

4.6 Input: Load Shapes

The TEPP Modeling I&A includes the CEC's hourly power demand load shapes for BEV by use case (e.g., long-haul truck and transit bus), and by month and day of week (weekday/weekend). Load shapes allocate energy to the hour of day.

Hub and long-haul depot load shapes are based on NREL data, and all other use cases are based on 2024 IEPR data, which blends charging technologies (L1, L2, and DCFC).

Table 4-10. Load Shape Input Source, Availability, and Justification

Source	Availability	Justification
CEC	Public	These inputs provide transparent, publicly accessible, and traceable hourly load shape data broken out by use case and TAC area (Transmission Access Charge)

* CPUC 2023, Joint IOU Electric Vehicle Load Research and Charging Infrastructure Cost Report and EV Infrastructure Rule Data 11th Report Filed on March 31, 2023.

4.6.1 Limitations

MDHD EV load shapes are based on ICEV trips and assume BEVs will have similar driving behavior as their ICEV counterparts. LD load shapes assume future intercity charging will be similar to current-day behavior.

Empirically derived load shapes are based on actual charging session data, and as such, are a product of technological, behavioral, social systems that can change over time. Changes in electric rates, battery technology, charger technology, commute behavior, etc. can all affect load shapes in important ways.

These load shapes also blend charging technologies (L1, L2, DCFC), which may make more granular analysis challenging.

4.7 Input: State of Charge (SOC)

The TEPP Modeling I&A includes inputs for customer charging preferences with respect to state of change (SOC[40]). SOC, together with the vehicle's driving range (Section 4.3) and distance-to-destination trip data (Section 4.4), will influence the vehicle's demand for charging along a highway corridor.

The influence of state of charge of a vehicle on the vehicle owners' public charging behavior has been simulated or evaluated in academic settings for personally owned vehicles[41] with no clear generalizable conclusion that can be found at this time. Charging behavior has also been shown to be influenced by socioeconomic attributes, risk tolerance, and "charging inertia," as well as trip and vehicle related variables.[42] As fleet driving needs and charging behavior are region dependent, Guidehouse recommends using available data gathered from the state of California to inform charging behavior assumptions. In this I&A, SOC assumptions are consistent across commercial LD and MDHD vehicles. Personally owned vehicles are assumed to be more variable, with SOC dipping below 20%. For commercial vehicles, research indicates fleet managers require charging before vehicle SOC reaches 20%.

The "Advanced Plug-in Electric Vehicle Travel and Charging Behavior Final Report," conducted by UC Davis and funded under CARB Contract 12-319 provides a reference for the average state of charge associated with public DCFC charging in the state of California.

[40] SOC represents an electric vehicle battery's energy levels as a percentage, and is analogous to the fuel gauge of a gasoline-powered vehicle
[41] https://www.sciencedirect.com/science/article/abs/pii/S1361920922003169
[42] https://onlinelibrary.wiley.com/doi/10.1155/2024/9926334

The probability of charging at public stations associated with the state of charge of the vehicle can be used to inform the likelihood of public charging need and corresponding load estimates. The ‘Modeling Charging Behavior of Battery Electric Vehicle Drivers: A Cumulative Prospect Theory Based Approach’ study conducted by Oak Ridge National Laboratory provides a reference for the density of charging associated with a vehicle’s initial state of charge. Guidehouse leverages this study’s density curve to directly inform the probability distribution of public charging given states of charge for individually owned vehicles. Given the relative lack of public charging data for commercially owned vehicles, Guidehouse developed a probability distribution of public charging. Guidehouse deduced the probability of charge at different states of charge for commercially owned vehicles by modifying the individually owned probability distribution to fit the constraints identified in the North American Council for Freight Efficiency (NACFE) study.

Figure 4-2. Charging Behavior Source, Availability, and Justification

Assumption Item	Value	Source	Availability	Justification
Average state of charge (SOC) at start of public charging session	35%	UC Davis	Publicly available through public agency	Provides California-based evidence for state of charge associated with actual public charging behavior
Probability of charging below 20% SOC	<1%	North American Council for Freight Efficiency (NACFE)	Publicly available through research agency	Provides reference for state of charge associated with truck trips based on real-world trucking demonstrations
Probability of charging above 90% SOC	<1%	North American Council for Freight Efficiency (NACFE)	Publicly available through research agency	Provides reference for state of charge associated with truck trips based on real-world trucking demonstrations

4.7.1 Limitations

The ‘Advanced Plug-in Electric Vehicle Travel and Charging Behavior Final Report’ covers personally owned vehicles, not commercially owned vehicles. As studies indicate that public charging preferences are driven by a variety of factors including socioeconomic and risk tolerance factors rather than SOC, there is uncertainty with the extent to which SOC and charging behavior data can solely be used to predict likelihood of public charging.

4.8 Input: Tract Drayage Operations

Since drayage operations typically use semi-trucks with higher annual VMT values (e.g., 45,000 miles), they represent a vehicle class with potentially large public charging needs. Furthermore, since the drayage market has a higher prevalence of small fleets and owner-operators,[43] this segment is expected to rely more on public charging than large corporate shipping companies with well-financed fleet depots.

Geotab vehicle classes and vocations do not specifically identify drayage operations, so the I&A uses US Census business type and employment data to determine where drayage vehicles would be domiciled. This approach identifies ZCTA’s with NAICS codes that indicate drayage operations (e.g., 483113 – costal and great lakes freight transportation) and allocates drayage vehicles from the IEPR forecast to those geographic areas. The accompanying I&A Library includes the full table of Census Tract to NAICS Code mapped values under its ‘Tract Drayage Operations’ tab.

[43] Companies with 20 trucks or fewer account for 72% of the operators and one-quarter of the drayage trucks serving the Ports of Los Angeles and Long Beach - https://labusinesscouncil.org/wp-content/uploads/2024/09/LABC-ACF-Report-Full-Report-5.pdf

Table 4-11. Drayage Operations Source, Availability, and Justification

Assumption Item	Source	Availability	Justification
Drayage operations location	Census	Publicly available through public agency	Provides an indication of where drayage operations occur, and associated vehicles would be domiciled.

4.8.1 Limitations

Drayage operations employment data does not necessarily indicate where drayage vehicles would be domiciled, so there is some uncertainty about the accuracy of allocating vehicles to these census tracts. A future research consideration to address this uncertainty could be to interview drayage operators to understand where drayage vehicles are actually domiciled, as compared to where they may be registered.

5. Geospatial Layers

This section provides I&A for ten[44] geospatial layers that provide geographic granularity and locational characteristics for California highway corridor segments and nearby communities. The layers include geospatial data, air quality indicators, utility service territories, environmental and social justice attributes, and charging infrastructure. .

5.1 Input: California Counties

TEPP will address corridors for 58 California counties. Table 5-1. California Counties Source, Availability, and Justification

Source	Availability	Justification
Census Tiger Lines	Publicly available through public agency	This is a commonly used geographic information system (GIS) shapefile for county borders.

5.1.1 Limitations

No known limitations for county boundary files. Technical documentation of these files is available through the U.S. Census.[45]

5.2 Input: Freight Analysis Framework 5 Model

The TEPP Modeling I&A will include the Federal Highway Administration's Freight Analysis Framework, Version 5 (FAF 5) Model, specifically the FAF 5 Network Links and FAF 5 Estimates of Truck Flow for Year 2022 – Base Line Scenario and will use the FAF5 annual projections of traffic volume out to 2050. The FAF 5 Network Links is a geodatabase that includes all roads in the National Highway System and the National Highway Freight Network, showing traffic flows by highway corridor segment at five-mile increments. This geodatabase will be combined with the FAF 5 Estimates of Truck Flow for Year 2022 – Base Line Scenario to associate the roads with daily truck trips flow (AADT). The resulting linear shapefile will identify a comprehensive road network in California and the travel patterns of MDHD BEVs along those roads.

Table 5-2. FAF 5 Source, Availability, and Justification

Source	Availability	Justification
FHWA	Publicly available through public agency	The FAF 5 highway network provides a comprehensive picture of the corridors along which traffic moves by all modes of transportation.

5.2.1 Limitations

FAF 5 uses vehicle weight (million ton-miles) as a proxy for VMT. This may lead to false precision for long haul truck VMT. For example, the ton-miles for a fully loaded truck would be

[44] Additional geospatial layers could be added based on stakeholder feedback.
[45] TIGER/Line Shapefiles and TIGER/Line Files Technical Documentation (census.gov)

different from the ton-miles of an empty truck along the same route, even though the VMTs should be equal.

5.3 Input: LD Average Annual Daily Traffic (AADT)

The TEPP Modeling I&A will include 2024 Traffic Volumes (Annual Average Daily Traffic) shape file of the California Department of Transportation state highway network. This shape file will provide traffic patterns along California highway segments for LD vehicles.

Table 5-3. LDV AADT Source, Availability, and Justification

Source	Availability	Justification
Caltrans	Publicly available through public agency	This is a commonly used geographic information system (GIS) shapefile for county borders.

5.3.1 Limitations

This data set includes all duties and is not limited to LD. However, since the vast majority of vehicles on the road are LD, it provides a good indication of LD traffic volumes.

5.4 Input: Investor-Owned Utilities/Publicly Owned Utilities Service Areas

The TEPP Modeling I&A will include IOU and Publicly Owned Utilities (POU) geographic layers. Knowledge of these territories will identify which highway corridor segments are associated with specific IOUs and POUs.

Table 5-4. IOU/POU Service Areas Source, Availability, and Justification

Source	Availability	Justification
CEC	Publicly available through public agency	Up-to-date GIS shapefiles for IOU and POU service areas required to indicate territory lines.

5.4.1 Limitations

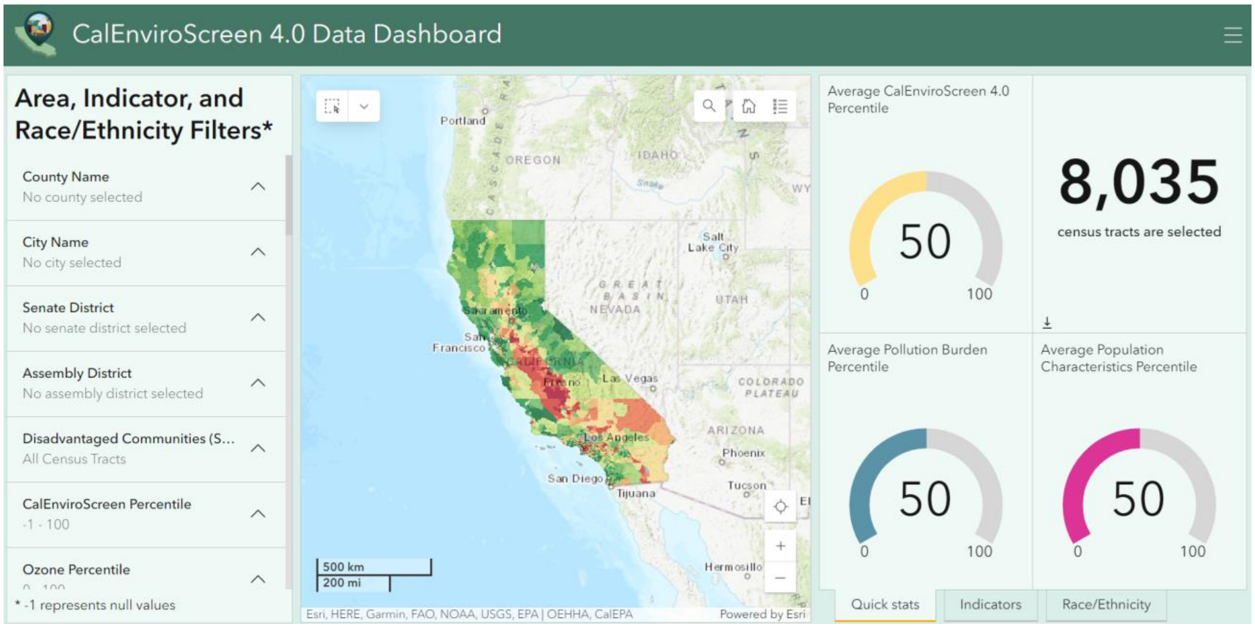
Distribution service territories are typically drawn as an approximating representation of the customers and customer meters served by the utility. These can change over time and may not encompass all the physical assets of the IOU or POU.

5.5 Input: Disadvantaged Communities

The TEPP Modeling I&A will include California Office of Environmental Health Hazard Assessment's (OEHAA) CalEnviroScreen[46] locations through associated shape files. Disadvantaged Communities (DAC) are disproportionally affected by vehicle pollution, so improving air quality is an important equity issue for many stakeholders.

Figure 5-1 provides an example of the user interface based on this geographic data.

Figure 5-1. CalEnviroScreen Dashboard



Source: CalEnviroScreen

Table 5-5. DAC Source, Availability, and Justification

Source	Availability	Justification
CalEnviroScreen from California Office of Environmental Health Hazard Assessment (OEHHA)	Publicly available through public agency	CalEnviroScreen is a state resource used to identify DACs, which leverages pollution and income indicators. OEHAA maintains DAC shapefiles for California.

5.5.1 Limitations

Disadvantaged Communities' boundaries may shift over time, and these DAC shapefiles may not reflect current conditions. While CalEnviroScreen is one important way to look at pollution and population to identify equity needs, it does not capture areas that may have equity needs but don't register on all the necessary indicators, such as rural areas with low populations and low economic indicators.

[46] CalEnviroScreen 4.0 Data Dashboard

5.6 Input: PM2.5 and Ozone Non-Attainment Areas

The TEPP Modeling I&A will include Particulate Matter 2.5 (PM2.5) and Ozone Non-Attainment Areas (NAA) geographic layers that will be used to associate highway corridor segments with non-attainment areas. According to the EPA, this is defined as any area that does not meet (or that contributes to ambient air quality in nearby area that does not meet) the national primary or secondary ambient air quality standards for National Ambient Air Quality (NAAQ)[47]. It is not uncommon to have PM 2.5 or Ozone NAA in or near DACs.

Table 5-6. PM2.5 and Ozone NAA Source, Availability, and Justification

Source	Availability	Justification
EPA	Publicly available through public agency	The EPA maintains PM 2.5 and Ozone NAA GIS shapefiles.

5.6.1 Limitations

Non-Attainment Areas may shift over time, and these NAA shapefiles may not reflect current conditions.

5.7 Input: Planned & Existing Public Infrastructure

The TEPP Modeling I&A will include a geographic spatial layer that identifies where (latitude/longitude coordinates) planned and currently existing public charging infrastructure will be, and are currently, located. The advanced filters applied will include available and planned station status for electric fuel types in California. This layer will include the number of ports, associated charging power, and accessibility (public/private).

Table 5-7. Planned & Existing Public Infrastructure Source, Availability, and Justification

Source	Availability	Justification
AFDC	Publicly available through public agency	Understanding current and pending charging infrastructure identifies current nodes in the charging network and where there may be gaps for optimal charging locations. AFDC keeps updated BEV infrastructure data sets.

5.7.1 Limitations

Planned and existing public infrastructure that are submitted to ADFC may not include all publicly available charging stations. Port status and reliability is not included.

[47] Ozone Designation and Classification Information | US EPA

5.8 Input: Truck Stops

The TEPP Modeling I&A will include a geographic layer that identifies the location of existing California truck stops. These have the potential to offer insight into where electric semis might recharge at public stations along highway corridors.

Table 5-8. Truck Stops Source, Availability, and Justification

Source	Availability	Justification
Find my fuels	Publicly available through commercial entity	More comprehensive list of California truck stops that complements those included in CTC's SB 671 Clean Freight Corridor Assessment.

5.8.1 Limitations

Use of this layer as a proxy for electric vehicle charging stations assumes electric long-haul and short-haul trucks have similar trips as diesel-powered semis. The layer also assumes that utilities have the necessary electrical infrastructure in place (transmission/distribution) to energize potentially rural and inaccessible truck stops.

This input layer also focuses on existing truck stop locations, many of which are known to have inadequate parking infrastructure. This input assumes that trucks will expand parking to make space for overnight charging and associated revenue. Future updates to the TEPP Modeling I&A could consider planned and potential truck stops and input from truck stop and fleet manager interviews.

5.9 Input: Rest Stops

The TEPP Modeling I&A will include a geographic layer that identifies the location of California rest stops. These have the potential to offer insight into where personally owned cars (IEPR class 'PVC'), and potentially fleet vehicles might recharge at public stations along highway corridors.

Table 5-9. Rest Stops Source, Availability, and Justification

Source	Availability	Justification
Caltrans	Publicly available through public agency	Rest stops provide an indication of where public charging for long-distance trips may occur.

5.9.1 Limitations

While rest stops currently provide refueling ICEVs, it is unclear to what extent they would be used for recharging BEVs, and especially MDHD BEVs.

5.10 Input: Fleet Depots

The TEPP Modeling I&A will include a geographic layer that identifies the location of major California fleet depots. These have the potential to offer increased precision for where electric vehicles are domiciled and subsequently where their routes start and end.

Table 5-10. Fleet Depots Source, Availability, and Justification

Source	Availability	Justification
RigDig by Fusable	Due to contractual obligations with commercial providers raw aggregate data inputs from those data sets cannot be made publicly available. These sources and data sets are the best available at the time of this research, and are subject to change.	Improved accuracy in fleet domicile location offers better precision in determining where public charging infrastructure should be located to facilitate fleet routes

5.10.1 Limitations

Fleet depot data is historically sparce and can sometimes report an office location rather than the depot serving the vehicle. While accurate fleet depot data would improve the precision of related depot and public charging, this enhancement is limited by data quality. In previous investigations, fleet depot data required validation with substantial manual web searches and satellite image analysis.

The data source proposed by this report has relatively robust MDHD fleet depot data, but LD fleet depot data is much more limited. Though there are several commercially available data sets that can be used to determine MDHD fleet depot locations, there currently are no known comprehensive data sets for LD depot locations.

Appendix A. L2-DCFC Split Calculation

Year	Duty	Class	Average Yearly VMT	kWh per mile	Annual Energy (kWh)	Consumption per weekday (kWh)*	Charge hours with 12 kW L2 port	Assumed available hours to charge for L2†	Compatible with L2 charging
2024	LDV	Personal PC	10,713	0.29	3,107	11.95	12	1.00	Yes
2024	LDV	Personal LT	10,713	0.47	5,035	19.37	12	1.61	Yes
2024	LDV	Commercial PC	8,828	0.29	2,560	9.85	12	0.82	Yes
2024	LDV	Commercial LT	8,828	0.47	4,149	15.96	12	1.33	Yes
2024	MDV	GVWR3 Pickup	17,966	0.47	8,444	32.48	12	2.71	Yes
2024	MDV	GVWR 4-6 Delivery	18,004	0.96	17,284	66.48	12	5.54	Yes
2024	HDV	GVWR 7-8 Delivery	33,868	1.22	41,319	158.92	12	13.24	Yes
2024	HDV	Short-Haul Truck	32,365	2.27	73,469	282.57	12	23.55	No
2024	HDV	CA Long Haul Truck	77,044	2.33	179,513	690.43	12	57.54	No
2024	HDV	OOS Long Haul Truck	94,489	2.33	220,159	846.77	12	70.56	No
2024	HDV	Drayage	34,695	2.27	78,758	302.92	12	25.24	No
2024	HDV	Vocational Truck	23,487	1.90	44,625	171.63	12	14.30	No
2024	HDV	Transit Bus	20,122	2.22	44,671	171.81	12	14.32	No
2024	HDV	School Bus	9,791	1.33	13,022	50.08	12	4.17	Yes

* This value is estimated by dividing the annual energy by the number of weekdays in the year (260).

† These are the working assumptions based on analysis of trip data. We will review whether they need to be updated after analyzing more extensive trip

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