California Energy Commission

CONSULTANT REPORT

South Coast Air Basin Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure Guide

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ABSTRACT

The goal of this study is to develop a replicable blueprint for medium- and heavy-duty charging and hydrogen infrastructure within the South Coast Air Basin with a focus on transit, drayage, and long-haul trucking. To that end, this report compiles information crucial to the development of stations, including project timelines, utility programs and rates, as well as codes and standards related to hydrogen fueling and electric vehicle charging. Available data and tools for guidance are listed.

Keywords: Blueprint; infrastructure needs assessment; medium-and heavy-duty vehicles; charging and fueling infrastructure; air quality; disadvantaged communities

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EXECUTIVE SUMMARY

The blueprint is intended to facilitate the adoption of MHD-ZEVs by reducing uncertainty and risk for medium- and heavy-duty fleets seeking to transition in response to grant incentives, education, and climate change, and urban air quality goals. In support of the study goal, this report provides a written guide detailing the decision-making steps in the deployment of charging and hydrogen refueling stations which can be easily adapted for fleets and local jurisdictions.

This report outlines the critical steps of station permitting and commissioning, including average timelines. In general, both charging stations and hydrogen refueling station develop process consists of 1) planning, 2) permit approval, 3) construction, and 4) commissioning. Station commissioning necessitates following federal, state, and local regulations, codes and standards, with particular focus on ensuring public safety. Funding programs often stipulate their own codes and standards as well and may have a list of approved or eligible equipment or vendors. Development timelines can vary greatly depending on the technologies deployed, the size and complexity of the station design, and location-specific constraints, such as how streamlined the permitting process is.

Although there has been significant progress in establishing processes for MH-ZEV infrastructure development, there are still gaps and barriers to charging and hydrogen infrastructure installation. Strategies to overcome barriers and reduce uncertainty include the development of streamlined permitting processes, the culmination of best practices shared among stakeholders, and data and tool sharing. A summary of useful models, tools, and data to support the optimal design and operation of charging/refueling stations, including co-location of station types and resiliency planning is provided in this report.

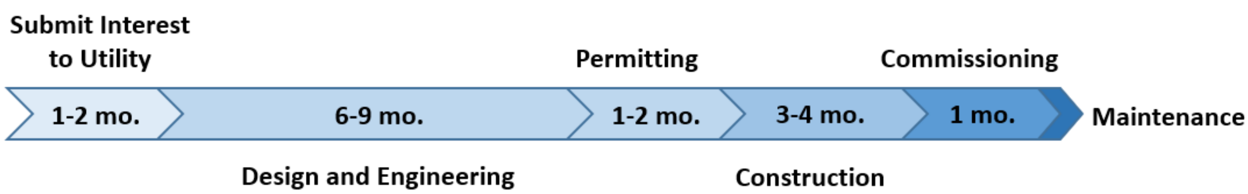
CHAPTER 1: CHARGING INFRASTRUCTURE GUIDE

Permitting Overview

The general steps to commissioning an electric vehicle charging station (EVCS) are: 1) planning (including design review and engineering), 2) permit approval (including local and regional permits as well as any utility required steps), 3) construction, and 4) commissioning. The permitting stage may be integrated into the planning stage. Utilities may request that companies signal their interest in building an EVCS as early in the process as possible so that the utility can determine whether there is adequate local electric grid infrastructure to supply electricity to a charging station.

An average timeline for the deployment of an EVCS is in Figure 1. Times are estimated based on data from San Diego Gas and Electric (SDGE) as well as CALSTART's INSITE tool [1], [2]. The INSITE tool estimates that the total process can take between 3.5 to 29 months [2].

Figure 1. Average Timeline for Battery Electric Vehicle Charging Station Deployment

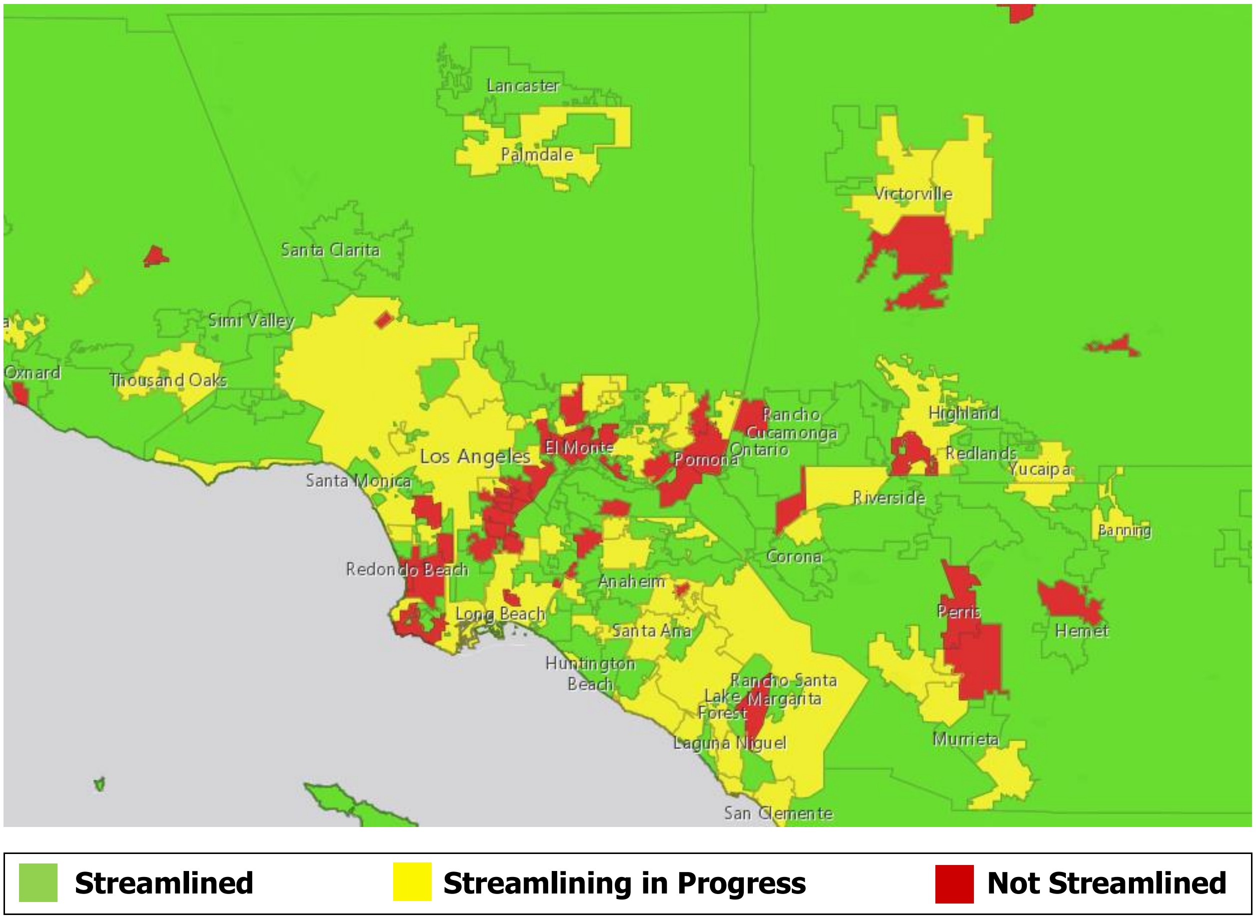


A large challenge in estimating time to completion is the uncertainty in design and construction timelines, as well as the variability in permitting procedures across different regions. A small project may have a shorter completion time for each stage, and any stage can be significantly longer if the project is large, complex, and/or requires additional utility upgrades. If the desired site does not have sufficient capacity to support the peak power of the planned EVCS, a transformer upgrade on the utility side of the meter will be needed. In addition, laying cable may require trenching, which adds time and cost to the design and construction phases.

Permit Streamlining

The state has passed legislation to help streamline permitting. AB 1236 requires city and county general plan for electric vehicle charging station (EVCS) deployment, including an application process to acquire a permit [3]. Standards are required as defined in Article 625 of the National Electrical Code. AB 970 further clarified this process for all cities [4]. California's Governor's Office of Business and Economic Development has released an "EV Charging Station (EVCS) Permit Streamlining Map" that scores cities and counties on their EVCS permitting process and how streamlined it is [5]. Figure 2 presents that scoring results for the South Coast Air Basin (SoCAB) region.

Figure 2. CA Electric Vehicle Charging Station Permit Streamlining Map



Source: https://business.ca.gov/industries/zero-emission-vehicles/plug-in-readiness/

The streamlining score is based on seven criteria: 1) there is an EVCS-specific ordinance to streamline permitting, 2) a permitting checklist is publicly available, 3) approval is based on a non-discretionary permit (i.e., approval is based solely on compliance with requirements), 4) project review scope is based on health and safety only, 5) electronic signatures are allowed, 6) project does not require approval by an association , and 7) one correction letter can be provided in the case of application errors [5].

Codes and Standards Compliance

In the SoCAB region, electric vehicle charging stations (EVCS) must comply with federal and state codes and regulations, as well as local ordinances. Codes and regulations primarily stipulate requirements with public health and safety in mind. Requirements can span equipment specifications (e.g., technologies, performance metrics, cable sizing), system design (e.g., ventilation), and site spacing. Fleets seeking funding to build a hydrogen refueling station may also be required to develop a hydrogen safety plan. General codes and standards are listed in Table 1.

Table 1. General Codes and Standards Required for Battery Electric Vehicle Charging Stations

Code or Standard	Description
NFPA 70	National Electric Code
CCR, Title 4	Tolerances and Specifications for Commercial Weighing and Measuring Devices
Title 24, Part 2	California Building Code
Title 24, Part 3	California Electrical Code
Title 24, Part 6	California Energy Code
Title 24, Part 9	California Fire Code
Title 24, Part 11	EV Capable Infrastructure
California Public Utilities Code (PUC) section 740.20	Regulation of Public Utilities, Rates, EVSE

EVCS must comply with the National Electric Code (NFPA 70) and other national codes that stipulate required safety standards and technical specifications (e.g., cable sizing, ventilation, spacing). In addition, California has its own codes that apply to EVCS installations, including Title 4, Division 9, Article 1 and Title 24 (multiple parts), which both incorporate national codes (e.g., NIST HB 44 and NFPA 70, respectively) with amendments and additional, California-specific requirements [6]. The U.S. and California also have accessibility requirements that need to be met.

Furthermore, California agencies set codes relevant to the scope of their jurisdiction. For example, the California Department of Food and Agriculture, Division of Measurement and Standards oversees accurate accounting of electricity dispensed by EVSE. The California Public Utilities Code section 740.20 stipulates requirements for installation of EVSE and associated infrastructure, including that at least one electrician on-site has completed the Electric Vehicle Infrastructure Training Program certification [7]. Lastly local jurisdictions may have additional ordinances that need to be followed before a station can be commissioned.

Codes for EVSE and EVCS are continuing to evolve, with changes to HB 44 regarding EVSE testing tolerances for electricity delivered already scheduled [8]. With the introduction of megawatt charging systems, it is anticipated that these new systems will need to adhere to existing codes and additional tests may be required. For that reason, MCS standardization efforts already are incorporating testing data and test procedures.

EVCS that receive public funding are also required to follow requirements set by the funding program(s). For example, the federal government, California agencies, regional agencies, and utilities commonly offer incentives or rebates. Relevant current infrastructure funding programs include the National Electric Vehicle Infrastructure

(NEVI) formula program, Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles (EnergIIZE Commercial Vehicles), and Volkswagen Diesel Emissions Environmental Mitigation Trust [9]–[11]. In general, programs will list required codes, standards, and other specifications as a condition of eligibility. To assist potential applicants, funding programs may provide a list of eligible or approved vendors.

Table 2 provides an overview of the charger types available in the U.S. There are both AC and DC options. In general, AC "level 2" chargers provide charging rates up to 19.2 kW, although the newer standard J3068 provides higher charging rates. The more common fast charger is CCS1, which supplies DC power. The most common charging rate configurations include 19.2 kW, 30 kW, 150 kW, and 180 kW, with 450 kW being the highest rated power offered. The higher charging rates are achieved by stacking power modules (30-50 kW per module). An even higher power charger, the Megawatt Charging System (MCS) is currently in development and is expected to meet the charging demands of heavy-duty vehicles and larger, off-road vehicles.

Table 2. EVSE Charging Standards and Specifications

Status	Standard	Current Type	Power Range	Voltage (V)	Current (A)
Current	J1772*	AC	Up to 19.2 kW	120/240 1ϕ	80
	J1772/CCS1 Combo	AC/DC	Up to 350 kW, (450 kW planned)	920 (1000 planned)	380 (rated 500)
	J3105	DC	L1: up to 350 kW L2: up to 1.2 MW	Up to 1000	Up to 1200
	J3068	AC	Up to 133-166 kW	480/600	160 3ϕ (Rated 300)
Proposed	J2954-2+	Inductive	Up to 500 kW	N/A	N/A
	J3271+	DC	Up to 3.75 MW	1250	3000

* DC configuration is defined in J1772: 2017, but has not been implemented in the U.S.

+ Proposed standard, not currently available

All equipment installed need to be certified compliant with required codes and standards. Of particular focus are verification of equipment performance and safety. The main testing standards for EVSE are listed in Table 3.

Table 3. Equipment Testing Standards

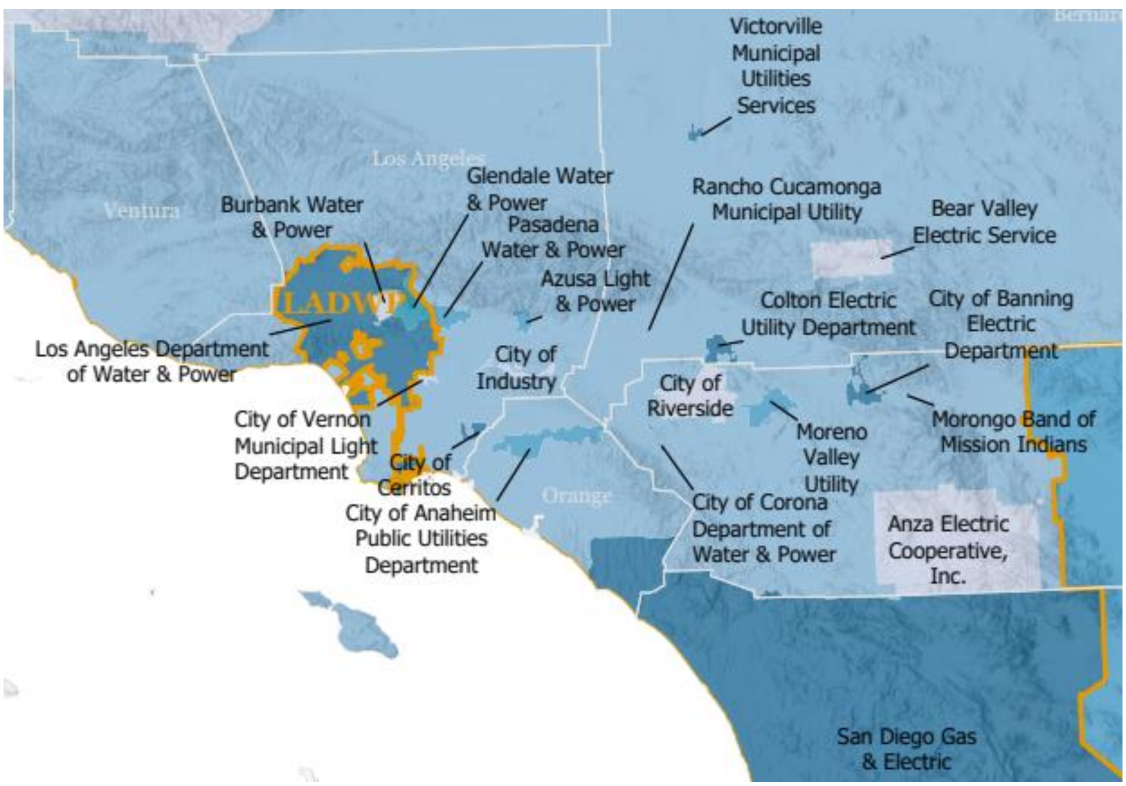
Code or Standard	Scope
UL 1741	Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
UL 2231-1, -2	Standard for Safety Personnel Protection Systems for Electric Vehicle Supply Circuits
UL 2251	Standard Testing for Charging Inlets and Plugs
UL 2594	Standard for Electric Vehicle Supply Equipment
UL 9741	Bidirectional EV Charging System Equipment

There are several testing programs administered at the national and state level that provide testing and certification. Most relevant to this study are the Occupational Safety & Health Administration (OSHA)'s Nationally Recognized Testing Laboratory (NRTL) program, which certifies product compliance with OSHA safety standards [12]; the National Conference on Weights and Measures' National Type Evaluation Program (NTEP), which certifies weighing devices [13]; and the California Type Evaluation Program (CTEP), which participates in the larger NTEP program and certifies weighing and measuring devices corresponding to California laws [14]. For relevant products, companies are required to complete the certification process(es) before making the products commercially available. There are also additional, optional certification programs, such as Energy Star [15].

Utility Programs

Connecting to the grid is an integral step in EVCS deployment. The SoCAB region is divided into several electric utilities, see Figure 3. Each utility operates independently and may have distinct rules for permitting and operating of EVCS. They also may offer different programs to help plan the infrastructure design and offset initial costs.

Figure 3. Electric Utility Territories in the SoCAB Region



Source: California Energy Commission. 2017 California Electric Utility Service Territories and Balancing Authorities. https://cecgis-caenergy.opendata.arcgis.com/documents/2017-california-electric-utility-service-territories-balancing-authorities/explore

The two investor-owned utilities (IOUs) within the SoCAB region, Southern California Edison (SCE) and SDGE, have infrastructure funding programs that coordinate the design and construction of hardware, in front of and behind of the meter required to support EVCS. A summary of the programs is provided in Table 4. Each IOU funding program is 5 years. Applicants must commit to support at least 2 EVs, operate and maintain the vehicles and chargers for a minimum of 10 years, and provide data on charger use for 5 years. SCE has specified that new EVSE should be near a new or existing transformer, with all project EVSE within a single location. EVs should be expected to arrive within 18 months of applying to the program [16]. The utilities also require applicants to rely on eligible or approved product lists in order to ensure safety and performance [1], [16].

Table 4. Investor-Owned Medium- and Heavy-Duty Vehicle Electric Infrastructure

	Southern California Edison	**San Diego Gas and Electric**
Program Name	Charge Ready Transport	Make-Ready Charging Infrastructure
Start Year	2019	2020
Budget	$356.4 million	$107 million
Already Funded	Not reported	1,034 MDHDVs; 47 projects
Total Budgeted	Up to 8,490 MDHDVs; 870 sites	Up to 3,000 MDHDVs; 300+ sites

Sources: Southern California Edison; San Diego Gas and Electric

The other utilities also have programs that cover infrastructure for ZEVs. Some have specific tiers or separate programs for MH-ZEVs, whereas others only define charging level. In the SoCAB region, only the Los Angeles Department of Water and Power (LADWP), in addition to SCE and SDGE, has a MH-ZEV specific program, although others have "commercial" programs. Commercial-oriented programs are oriented towards light-duty vehicles but may have the potential to support some medium- or heavy-duty vehicle needs. Suitability will depend on the charging level, site design (e.g., ingress, egress, height clearance, EVSE spacing, parking spot size), and utility restrictions.

It is important to coordinate with the local utility to ensure that the planned EVCS follows all applicable codes and regulations as well as all eligibility requirements for funding/rebates. Also, independent of the utility, companies may be eligible for state and/or federal funding. Table 5 provides an overview of utility programs within the SoCAB region. Table 6 presents an overview of the approved vendors and maximum EVSE power ratings for their MH-ZEV infrastructure funding programs.

Table 5. SoCAB Utility ZEV Infrastructure Funding Programs and Rebates

Utility	Funding	MH-ZEV Program
Anza Electric Co-op	None	No
Azusa Light and Power	Only residential level 2 chargers: $150 per charger	No
Bear Valley Electric Service [17]	Bear Ready Commercial: • 50 level 2 EV chargers	No

Burbank Water and Power [18]	Commercial Electric Vehicle Charging Station Rebate Program:
	• Up to $15,000 per charging station
	• Without utility upgrade
	  ○ $4,000 if in DAC or public access
	  ○ $1,800 if not
	• With utility upgrade
	  ○ $7,500 if in DAC or public access
	  ○ $3,500 if not
	• Limit 40 rebates per commercial customer
		No

City of Anaheim Public Utilities Department [19]	Only residential level 2 chargers: up to $400 or $1,000 depending on utility rate	No
City of Banning Electric Department	None	No
City of Cerritos	None; may be eligible for SCE programs	No
City of Corona Department of Water and Power	None; may be eligible for SCE programs	No
City of Industry	None	No
City of Riverside	EV rebates, but not EVSE.	No
City of Vernon Municipal Light Department	None	No
Colton Electric Utility Department [20]	Electric Vehicle Charger Rebate • $5,000 for charger with separate meter • $2,500 for standard connection Electric Forklift Rebate • $2,000 for forklifts	Forklifts
Glendale Water and Power	Commercial rebate • $6,000 for charger	No
LA Department of Water and Power [21]	Rebate up to $125,000 for DC fast charging EVSE	**Yes**
Moreno Valley Utility	Residential customers with EVs eligible for reduced electricity rate	No
Morongo Band of Mission Indians	None	No
Pasadena Water and Power [22]	Commercial rebate: • $6,000 for charger	No
Rancho Cucamonga Municipal Utility	Commercial rebate: • Up to $5,000 for charger (level 2 or DCFC)	No
San Diego Gas and Electric	Make-Ready Charging Infrastructure 50% of cost or listed value (whichever is less) • $3,000 for up to 19.2 kW • $15,000 for 19.3 – 50 kW • $45,000 for 50.1 – 150 kW • $75,000 for 150.1 kW or greater	**Yes**
Southern California Edison	Charge Ready Transport • $1,700 for up to 19.2 kW • $6,800 for 19.3 kW – 49.9 kW • $20,100 for 50-149.9 kW • $37,000 for 150 kW or greater	**Yes**
Victorville Municipal Utilities Service	None	No

Table 6. SCE and SDGE Approved Vendors

Supplier	EVSE Charging Rate			
	< 19.2 kW	19.3 – 50 kW	50 – 150 kW	>150 kW
ABB	✓	✓	✓	✓
Advanced Charging Technologies	X	X		
Blink	✓	✓		
BTCPower	✓	✓	✓	✓
BYD Coach & Bus	X			
Charge America				✓
ChargePoint	✓	✓		
Clipper Creek	✓			
Cyber Switching	✓			
Delta	✓	✓	✓	✓
EcoTec	X			
EFACEC	✓	✓		✓
Electrify America				✓
Enatel	X	X		
Enel X	✓			
Enersys	X	X		
EverCharge	✓			
EV Passport	✓			
EVRange	✓			
Freewire Technologies			✓	
Heliox				✓
InCharge		✓	✓	✓
ioTecha	✓			
JuiceBox	✓			
KIGT Inc.	✓			
Konnectronix	✓			
Loop	✓			
Noodoe	✓			✓
Nuuve	✓			
Phihong	✓	✓	✓	✓
Power Designers Sibex	X	X		
Power Electronics				✓
PowerFlex	✓			
Proterra			✓	
Rhombus			✓	
SemaConnect	✓			
Siemens	✓	✓		✓
Signet HP				✓
Stryten	X	X		
Tellus Power		✓	✓	✓
Tritium		✓	✓	✓
TurnOnGreen		✓		
Wallbox	✓			
Webasto	✓			

✓ = rebate eligible, X = not rebate eligible, black = SCE, yellow = SDGE, green = SCE & SDGE

Challenges and Data Gaps for Electric Vehicle Charging Stations

The EVSE market has grown significantly over the last 10 years with over 40 companies currently supplying EVSE. As the technology has matured, best practices are being adopted, expediting deployments and improving performance. However, there remain several challenges and data gaps that cause customer uncertainty and slow adoption.

For example, COVID-19 and other global events have impacted EVSE supply chains. Lead times on equipment are still prolonged and may impact expected timelines for EVCS construction. Timing the purchase of MH-ZEVs in coordination with the commissioning of new EVCS can be challenging, especially if funding programs set time restrictions for receiving vehicles or constructing infrastructure.

Another challenge being addressed is low EVSE Reliability. Approximately 30% of charging sessions fail [23]. Sessions can fail for a number of reasons, including hardware and software malfunctions. These include interoperability issues, challenges with payment systems, hardware failure, and communication failures (e.g., failed start-up sequence). The large number of product offerings has contributed to interoperability issues between EVSE and vehicles. MHDV charging will require a greater level of reliability due to the MHDV's commercial purposes. Failed charging sessions can lead to reduced vehicle availability, increased operating costs, and lower consumer confidence in the technology.

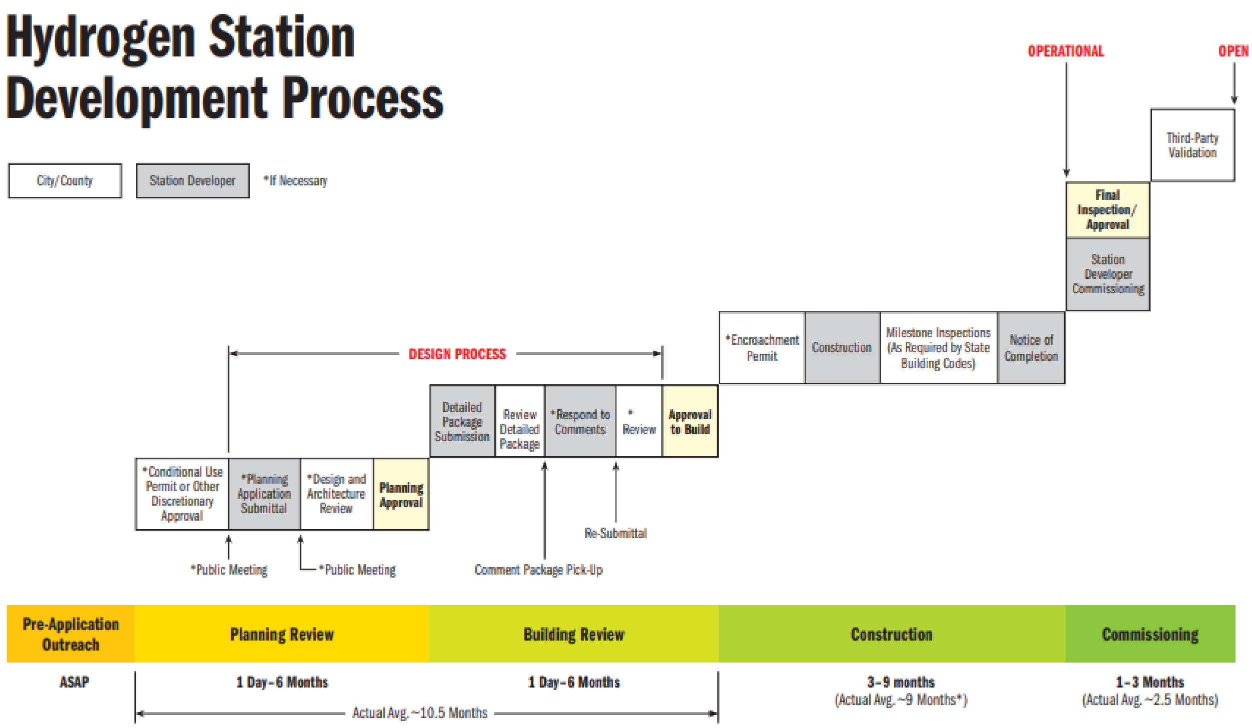
High capital costs also remain a challenge. Transitioning to MH-ZEVs is a major undertaking. There are significant long-term implications when deciding the charging infrastructure specifications, including site location(s), technologies and charging rates, and utility transformer upgrade needs. Higher charging rate can mean faster charging times and greater operational flexibility; however, it also means higher upfront costs as well as potentially higher demand charges from the electric utility. A fleet should consider several factors in selecting the proper charger type(s), including vehicle operations, energy demand, electricity costs, EVSE costs, and space available for EVSE [6], [24].

CHAPTER 2:
HYDROGEN FUELING INFRASTRUCTURE GUIDE

Permitting Overview

Hydrogen refueling stations have the same general stages as EVCS: 1) planning (including design review and engineering), 2) permitting (including local and regional permits as well as any utility required steps), 3) construction, and 4) commissioning. Again, permitting can be integrated into the planning stage.

Figure 4. Overview of Hydrogen Refueling Station Development Process



Source: https://static.business.ca.gov/wp-content/uploads/2019/12/GO-Biz_Hydrogen-Station-Permitting-Guidebook_Sept-2020.pdf

The permits required for a hydrogen refueling station are listed in Table 7. Permitting spans building and electrical requirements, fire safety, and environmental impacts (water and air). The permit streamlining initiate by AB 1236 did not apply to hydrogen refueling stations.

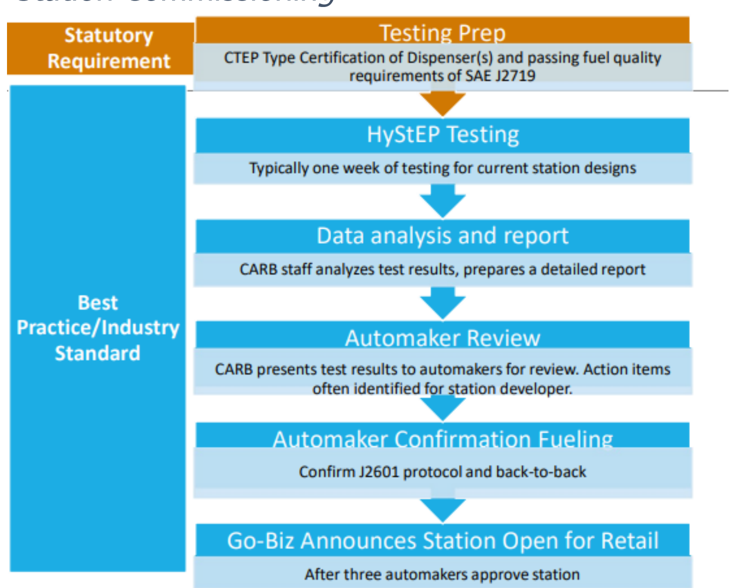
Table 7. Permit Requirements for Hydrogen Refueling Stations in the South Coast Air Basin Region

Permit	Agency	Permit/Permit Scope
Construction	Building Department	Permit to Construct General/Address safety construction issues
Drainage	Engineering Department	Permit to Construct Drainage/Modification to sewer drainage
Site grading	Engineering Department	Permit to Construct Grading/Modification to site elevation
Electrical	Building/Electrical Department	Electrical Permit/Modification to electrical service
Demolition	Building Department	Construction permit/Demolish structures required for dispenser construction
Air emission impacts	South Coast Air Quality Management District	Air Quality permit or no impact declaration
Fire safety	Fire Department Plans Review Office	Fire safety permit/general fire code compliance
Water Quality	Water Quality Management Agency	Liquid discharges to the environment

Source: National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy13osti/56223.pdf

The final commissioning stage consists of multiple steps to verify station compliance with all legal requirements. Verification is conducted by the California Air Resources Board as well as automakers. In general, testing may require multiple rounds to address identified issues. The general commissioning process for stations is outlined in Figure 5. In the future, it is possible that new testing methods will be applied to HDV stations in line with new high flow fueling equipment and protocols.

Figure 5. Steps for Station Commissioning



Source: California Air Resources Board, Assessment of a Hydrogen Station Verification Requirement for Public Hydrogen Stations (2018) https://ww2.arb.ca.gov/sites/default/files/2020-05/carb_presentation_0_ac.pdf

To expedite the certification process, the Department of Energy commissioned the development of Hydrogen Station Equipment Performance (HyStEP) device can be used at a hydrogen refueling station to validate that the hydrogen dispensers operate within the tolerance limits defined within the relevant codes and standards [25]. HyStEP was designed for and is currently being used at light-duty hydrogen refueling stations. New methods for testing HDV high flow fueling protocols are under development.

The timeline for station development is dependent on the station location, size, and type. Average time from planning to commissioning completion is currently one year. The estimated timeline range for hydrogen refueling stations is listed in Table 8 for different station hydrogen delivery assumptions. The timeline can vary depending on the proposed location of the station, with permitting taking longer in places that do not have previous experience with hydrogen.

Table 8. Estimated Timeline for Hydrogen Refueling Station Commissioning

Station Type	**Estimated Timeline**
Gaseous or Liquid Delivery	9.5 – 22 months
On-site Electrolysis	3.5 – 11 months
On-site Steam Methane Reformation	7 – 13 months

Source: Infrastructure Insite, https://insitetool.org/design_hydrogen

Codes and Standards Compliance

Several federal and state codes and regulations, as well as local ordinances are used in concert to define specific requirements of a given hydrogen refueling station, see Table 9. The key focus is on public health and safety. Safety codes and standards include general building considerations, electrical systems, energy systems, fire safety, hazardous materials, and accurate accounting of hydrogen dispensed. All equipment and built stations require testing and certification. Testing can include interoperability testing across multiple and comparable standards. Proof of compliance generally occurs right after construction during the station commissioning stage [26].

A key safety standard referenced is NFPA 2, which defines primary safeguards needed across the hydrogen supply chain, spanning storage and handling, generation, delivery, use [27]. NFPA 2 covers gaseous and liquid hydrogen systems, describing safety considerations when planning the design of a station (e.g., ventilation, spacing) to address health and safety risks of hydrogen. Compliance with NFPA 2 is required for all hydrogen refueling stations within California [26].

Additional standards and codes required that address safety include OSHA's Reg. 29 CFR 1910 Subpart H (1910.103), which covers safety requirements during hydrogen delivery, storage, and use with a focus on worker safety [28]; California's Health and

Safety Code Section 25510(a), which covers hazardous materials release ; and CCR Title 24. NFPA safety documents that are relevant to FCEVs but are outside the scope of the current project are NFPA 70, which describes electrical safety requirements for the powertrain and NFPA 55, which provides safety requirements for handling, storage, and use of hydrogen.

Table 9. Codes and Standards for Hydrogen Refueling Station Testing and Certification

Code or Standard	Scope
NFPA 2	Hydrogen Technologies Code
NFPA 55	Compressed Gases and Cryogenic Fluids Code
NFPA 70	National Electrical Code
California Health and Safety Code Section 25510(a)	Hazardous Materials Release Response Plans and Inventory: Business and Area Plans
California Code of Regulations (CCR) Title 4, Division 9, Chapter 1	Tolerances and Specifications for Commercial Weighing and Measuring Devices
CSA/ANSI HGV 4.3	Test Methods for Hydrogen Fueling
CSA/ANSI HGV 4.9	Hydrogen Fueling Stations
CGA G-5.3	Commodity Specification for Hydrogen
ISO/IEC 18000-3	Conformance tests for Air interface communications
ISO/IEC 18046	Test methods for RFID tag performance
NIST Handbook 44	Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices
NIST Handbook 130	Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality
OSHA's Reg. 29 CFR 1910 Subpart H (1910.103)	Worker safety requirements for hydrogen supply chain
California Code of Regulations (CCR), Title 4, Division 9	Weights And Measures Field Reference Manual
CCR, Title 24, Part 2	California Building Code
CCR, Title 24, Part 3	California Electrical Code
CCR, Title 24, Part 6	California Energy Code
CCR, Title 24, Part 9	California Fire Code
UL 2075	Standard for Safety Gas and Vapor Detectors and Sensors

Other standards include CSA/ANSI HGV 4.9, which provides an overarching specification that encompasses requirements for the design, construction, operation, and maintenance of hydrogen refueling stations (gaseous) [29]. Elements of a station that require testing include hydrogen fuel quality, communications, fault detection, and fueling accuracy. CGA G-5.3 serves as a specification for hydrogen quality verification at a hydrogen refueling station [30]. Hydrogen fuel quality requirements, as defined in SAE J2719, include the minimum molar hydrogen content required ($\geq$ 99.97%), as well as the maximum concentrations of contaminants of concern [31]. ANSI/CSA HGV 4.3 defines testing for evaluating hydrogen fueling dispenser compliance against J2601 (fueling) and J2799 (communications) [32]. CCR Title 4, Division 9, Chapter 1 includes national definitions (NIST Handbook 44), exceptions, and additional technical requirements and measuring devices [33].

In addition to codes, standards, and regulations, there are government-developed tools available to support the safe and secure deployment of hydrogen as a transportation fuel. Some examples include H2Tools, a suite of tools to promote hydrogen best practices [34], HyRAM, a toolkit for quantitative risk assessment and consequence analysis for hydrogen infrastructure [35], and H2FillS, a simulation tool for modeling hydrogen flow behavior during refueling to support safety and compliance with codes and standards [36].

Fueling Protocols and Fueling Pressure

Gaseous hydrogen refueling is offered at 350 and 700 bar. A survey of industry stakeholders found that current high-fill vehicles (>30 kg) are being refueled using a variety of methods [37]. Figure 6 presents the available fueling methods for 350 bar (H35) refueling, and Figure 7 presents the scope of current and proposed 700 bar fueling methods used in California.

The main fueling protocol for LDVs is SAE J2601, which was harmonized for the European market as ISO 19880-1 [38] and adapted for the Japanese Market as JPEC-S 0003 [39]. SAE J2601-2 was adopted for the first HDV market of fuel cell electric buses. SAE J2601-2 is a guidance document that requires a custom protocol that considers specific vehicles that fuel at the station. It is intended for private fueling stations, where the vehicles fueling are known. For other MHDVs that rely on 700 bar refueling, several options have been deployed, including J2601 (Category D), JPEC-S 0003, and other custom average pressure ramp rate (APRR)-based protocols [37].

Figure 6. 350 Bar Hydrogen Fueling Standards Scope

		Fueling Rate (kg/min)		
		1.8	3.6	7.2
CHSS (kg)	1.19-2.39	J2601 Category A		
	2.39-4.18	J2601 Category B		
	4.18-5.97	J2601 Category C		
	5.97-10			
	10+	J2601-2 Slow Fueling Option C	J2601-2 Normal Fueling Option B	J2601-2 Fast Fueling Option A

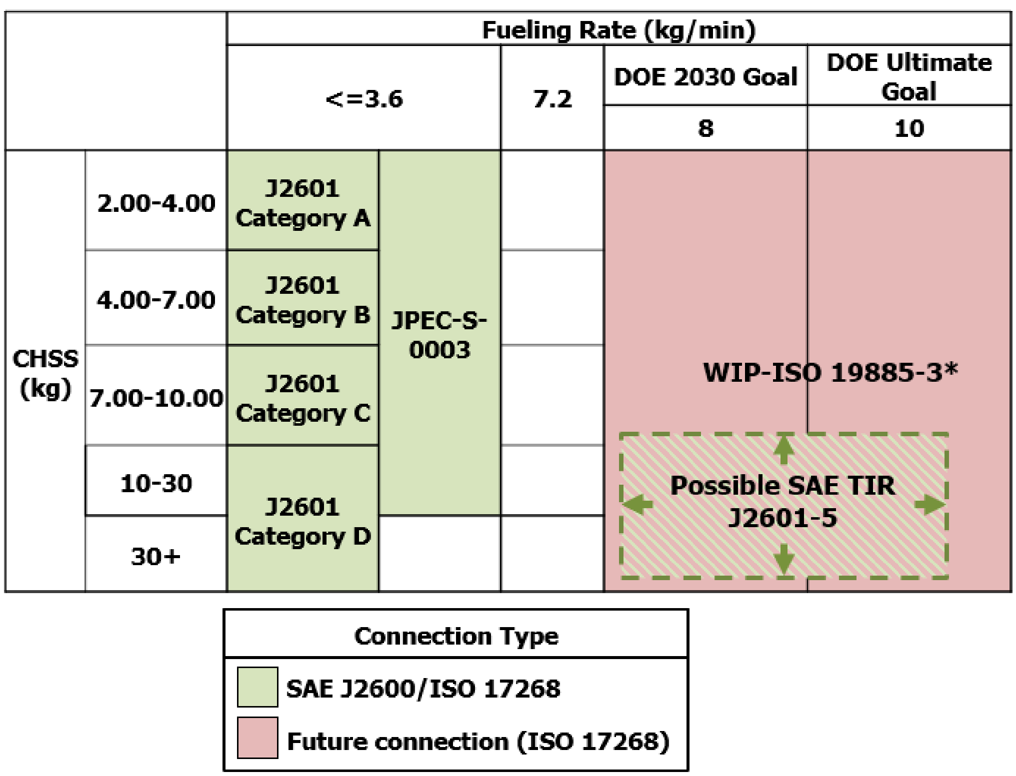
Connection Type
SAE J2600/ISO 17268
ISO 17268:2012 HDHSV

CHSS = compressed hydrogen storage system, HDHSV = heavy duty hydrogen surface vehicle
Note: J2601-2 is a recommended practice and not a full standard

A main priority of heavy-duty hydrogen refueling research is the development of a high flow 700 bar (H70) HDV refueling standard in order to support MH-FCEV refueling needs effectively and ideally achieving parity with diesel refueling performance (80 kg hydrogen dispensed in 10 to 15 minutes). There are several standards under development within the International Standards Organization (ISO) in order to achieve this target, including the development of new nozzle, break away, and hose, as well as advanced fueling protocol(s) that support high flow refueling. The current timeline for standard development is completion by 2023. There is a plan to harmonize the completed ISO standards with SAE International standards [40].

Given the immediate need for a standardized high flow fueling protocol, there is discussion to accelerate dissemination of high flow fueling data and methods through the development of a SAE Technical Information Report (TIR). This TIR "SAE J2601-5" would describe potentially high flow fueling protocols using the MC Formula in combination with nozzles with similar specs to the current standard but a larger bore size to allow for higher flow. The timeline for completion of the TIR, if it moves forward, is summer 2023.

Figure 7. 700 Bar Hydrogen Fueling Standards Scope



Challenges and Data Gaps for Hydrogen Refueling Stations

Similar to BEV charging, emergency response teams have limited experience with hydrogen refueling stations. As the number and capacity of hydrogen stations increase, it is important that safety guidelines (e.g., NFPA 2) are more broadly understood. Local and regional variability in station permitting, hydrogen understanding, and emergency response training leads to longer commissioning times and a slower growth of MH-FCEV deployment. Lead times can also affect project costs and overall feasibility. While there have been several state initiatives on the EVSE-side to streamline permitting (e.g., through AB 1236), there has been less progress on streamlining hydrogen refueling station permitting.

Faster refueling is limited by current dispenser equipment and the existing standards. The current protocols are designed for LDVs. Applying these same protocols to MHDV applications is not optimal and results in slow fill times and difficulty achieving 100% SOC. This difficulty stems from SAE J2601's overly conservative approach. The HDV-specific high flow protocol is still in development and any delay in its release may hinder efforts to accelerate MH-FCEV deployment in the next few years.

Lastly, current procedures for commissioning hydrogen refueling stations are designed for light-duty vehicle stations. It is probable that new procedures and devices are needed to accommodate differences in fueling protocols, station equipment, and vehicle design. There are several concurrent efforts developing devices, test methods, and validation procedures. It is anticipated that these procedures will be standardized within new ISO and SAE standards once documents for high flow protocols (ISO 19885-3, SAE J2601-5) are finalized. Again, the timing of the release of these procedures can affect MH-FCEV deployment.

CHAPTER 3: DATA AND TOOLS

Over the years, several surveys have been conducted at the state and federal levels to capture the travel behavior of on-road vehicles. For this study, surveys including medium- and heavy-duty vehicles can provide insight into vehicle composition and travel patterns. Some recent surveys and datasets are listed in Table 10.

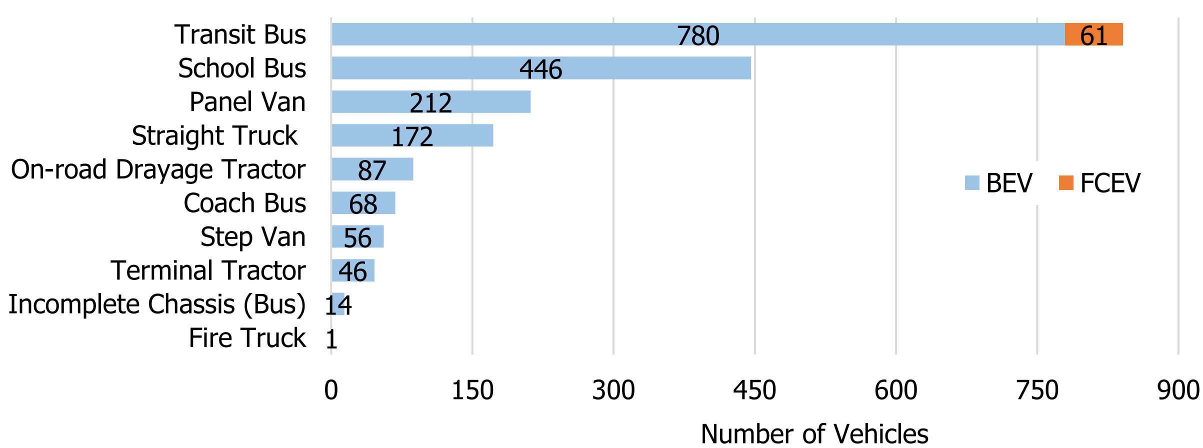
Table 10. Medium- and Heavy-Duty Vehicle Surveys and Datasets

Survey	Scope	Conducted by	Year(s)
California Hybrid, Efficient and Advanced Truck Research Center (CalHEAT) Medium- and Heavy-Duty Truck Study	MHDVs	CALSTART	2013
California Household Travel Survey	Personal/Private Transportation	California DOT and Metropolitan Planning Agencies (MPOs)	2017*
California Vehicle Inventory and Use Survey (CA-VIUS)	Commercial Vehicles	Caltrans	2016-2017
Fleet DNA	Limited Vocations	National Renewable Energy Laboratory	2014
Medium- and Heavy-Duty Zero Emission Vehicles in California Dashboard	MH-ZEV population and sales data	California Energy Commission	Present
Vehicle Inventory and Use Survey (VIUS)	Trucks (personal and commercial)	Bureau of Transportation Statistics	2021*

* Survey has been conducted repeatedly. Latest survey as of the publication of this report is listed.

The MHDV sectors consist of a diverse collection of vehicle types that provide a variety of services, including goods movement, construction, refuse, transit, last mile delivery, and emergency services. The current MH-ZEV market is predominantly buses, but has been expanding to include vehicles of all MHDV classes, see Figure 8, data from [41].

Figure 8. California MH-ZEV Population



Key parameters such as daily vehicle miles traveled, fuel efficiency, hours operated, and proximity to a home base or public infrastructure depends greatly on the vehicle class and type/purpose [42]–[44]. Understanding a fleet's needs is necessary to determine the optimal ZEV technology for the fleet. In general, BEVs may suit fleets with relatively short daily trips and sufficient time to recharge. FCEVs may be a preferable option for fleets that require long distance travel with little downtime, so they can take advantage of shorter refueling times and a greater vehicle range.

The number of models, calculators, and other tools to support the deployment of MH-ZEVs and their infrastructure has significantly grown over the last few years. These tools can be instrumental in assisting fleets in transitioning to MH-ZEVs, by removing uncertainty in terms of design requirements, costs, project timelines, and expected station performance. In addition to site-specific tools, the state and federal governments have developed tools that model the transportation sector as well as its associated emissions, which can also provide insight into MH-ZEV planning, such as determining optimal station siting and evaluating the potential impacts of MH-ZEVs. A list of relevant tools is provided in Table 11.

Table 11. Models and Other Tools

Model Name	Technology	Source	Description
AERMOD + AERSCREEN	Both	U.S. Environmental Protection Agency	Air quality modeling
AFLEET	BEV	Argonne National Laboratory	Charging station energy consumption and impact on emissions
ALOHA	FCEV	U.S. Environmental Protection Agency	Gas and liquid hazard modeling
CA Electric Vehicle Charging Station Permit Streamlining Map	BEV	Governor's Office of Business and Economic Development	Scoring of city and county EVCS policies and procedures in terms of streamlining approval
California Statewide Freight Forecasting Model	Freight vehicles	Caltrans	Spatial freight transportation tool that projects freight travel demand and cargo totals based on future economic scenarios.
Distributed Energy Resource Interconnection Map (DERiM)	Distributed energy resources	Southern California Energy	Spatial tool that models the electric grid down to the substation level.
Distribution Resource Plan External Portal (DRPEP)	BEV	Southern California Edison	SCE distribution lines and substation status
Electric Fleet Fuel Savings Calculator	BEV	Southern California Edison	Calculate electricity cost and savings (compared to diesel) over 10 years with BEV charging.
EMFAC	Both	California Air Resources Board	Vehicle emissions model that includes projections for vehicle population, vehicle miles traveled, criteria air pollutant emissions, and greenhouse gas emissions
Freight Analysis Framework	Freight vehicles	Federal Highway Administration; Bureau	Spatial freight data, including origin-destination, commodities, and tonnage.

		of Transportation Statistics	
Fuel Savings Calculator	BEV	Pacific Gas and Electric	Calculate difference in fuel costs between diesel and electric fuel consumption per year
Funding Finder Tool	Both	CALSTART	Find available funding programs for alternative fuel vehicles and infrastructure
HEVI-LOAD	BEV	California Energy Commission	MHDV charging infrastructure deployment
H2FillS	FCEV	NREL	Refueling Simulation
HDSAM	FCEV	U.S. DOE	Delivery Cost
HRSAM	FCEV	U.S. DOE	LDV refueling cost
HDRSAM	FCEV	U.S. DOE	HDV refueling cost
HyRAM	FCEV	Sandia National Laboratories	Quantitative risk assessment and consequence analysis for hydrogen infrastructure
INSITE	Both	CALSTART	Station planning including equipment and costs
Total Cost Calculator	BEV	Pacific Gas and Electric	Calculate total cost of building and operating BEV charging infrastructure. Also includes eligible funding programs.

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