Integrating Zero Emission Vehicles into the Caltrans Fleet

April 2022

A Research Report from the National Center for Sustainable Transportation

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16. Abstract

This report details the development and application of a spreadsheet tool which enables the evaluation and use of electric and hydrogen Zero Emission Vehicles (ZEVs) within the Caltrans fleet. The spreadsheet tool assists with both the placement of ZEVs and determining placement of new fueling stations to obtain the maximum benefit. The ZEV tool created as a result of this project allows Caltrans to maximize the usage of ZEVs that will be procured within Caltrans. The ZEV tool enables a strategic adoption of ZEVs within the Caltrans fleet by analyzing: fleet parameters, vehicle technology, vehicle usage, refueling infrastructure development, and operational needs. This report summarizes how available information, trip activity, and EVSE have been integrated within a database tool to analyze ZEV integration possibilities. The ZEV tool development provides Caltrans an architecture to integrate evolving data and fleet characteristics while optimizing ZEV placement and utilization into the future. Caltrans staff will be able to utilize the ZEV tool to strategically select vehicles as ZEV capable based on vehicle specifications, refueling infrastructure, and prior vehicle activity. The ZEV tool provides evaluation techniques by vehicle classification, region or refueling/charging capabilities. Utilization of the tool will assist California in the transition to ZEV platforms that are either battery electric or hydrogen fuel cell. The report serves as a guide to utilize the ZEV tool for deployment of ZEVs in the Caltrans fleet while maintaining or improving the effectiveness of operations. The optimized deployment strategy includes the operational and performance criteria of ZEVs while considering the location of refueling/recharging stations for EVSE (electric vehicle supply equipment) and hydrogen ZEVs.

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Disclaimer

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NCST

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TABLE OF CONTENTS

List of Tables

List of Figures

Integrating Zero Emission Vehicles into the Caltrans Fleet

EXECUTIVE SUMMARY

The main goal of this investigation has been to develop a spreadsheet tool which enables the evaluation and use of ZEVs within the Caltrans fleet. The spreadsheet tool assists with both the placement of ZEV's and determining placement of new fueling stations to obtain the maximum benefit. The ZEV tool created as a result of this project allows Caltrans to maximize the usage of ZEV's that will be coming into the Caltrans fleet, both for environmental reasons as well as to take advantage of fuel credits that accompany Zero Emission Vehicles.

On March 23, 2012, Governor Brown issued Executive Order (EO) B-16-12 ordering "that California's state vehicle fleet increase the number of its zero-emission vehicles (ZEV) through the normal course of fleet replacement so that at least 10 percent of fleet purchases of light-duty vehicles be zero-emission by 2015 and at least 25 percent of fleet purchases of light-duty vehicles be zero-emission by 2020. This directive shall not apply to vehicles that have special performance requirements necessary for the protection of the public safety and welfare." The Governor has issued its 2013 ZEV Action Plan GO ZEV Action Plan. The completion of this project better allows Caltrans to meet statewide ZEV goals.

This final report summarizes the Tasks completed in coordination with Caltrans to meet the goals of the investigation. The literature review focuses on identifying analyzing, characterizing, and summarizing the ZEV relevant information to facilitate the development of a Caltrans ZEV database analysis and planning tool. Tasks 2 through 4 focus on defining the data architecture of the tool and pertinent data sources. Tasks 5 and 6 focus on prioritizing data parameters and creating a database spreadsheet format. Task 7 consisted of creating the ZEV tool according to the structure identified in previous tasks. This final report is the culmination of results from Tasks 1 through 7 detailing the development and usage of the ZEV tool.

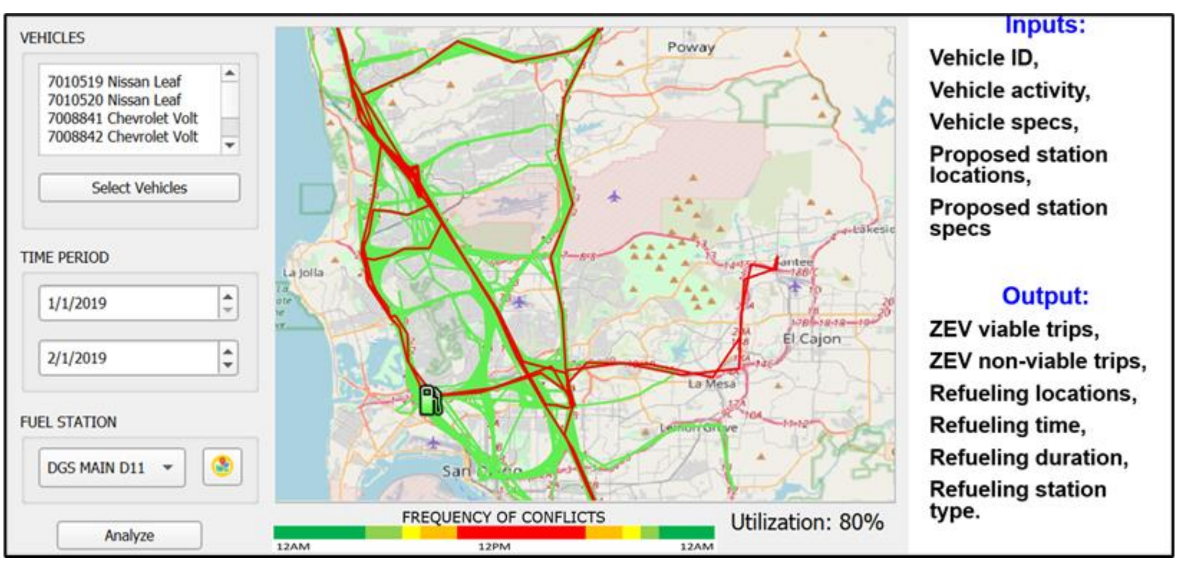


Figure ES-1. Vehicle ZEV compatibility screen with inputs and outputs

The UCR research team has completed the literature review with respect to state purchase and deployment requirements of ZEVs. UCR and Caltrans staff have previously collaborated on an evaluation of vehicle replacement criteria and vehicle acquisition procedures. The research team has utilized this previous expertise when reviewing relevant fleet replacement information and criteria.

The strategic adoption of ZEVs within the Caltrans fleet requires a detailed analysis of fleet parameters, vehicle technology, vehicle usage, refueling infrastructure development, and operational needs coupled with policies, regulations, mandates, and executive orders. This report summarizes how available information, trip activity, and EVSE have been integrated within a database tool to analyze ZEV integration possibilities. The ZEV compatibility map screen is shown in Figure ES-1 and displays the graphical trip detail interface. The ZEV tool development provides Caltrans an architecture to integrate evolving data and fleet characteristics while optimizing ZEV placement and utilization into the future.

Caltrans staff will be able to utilize the ZEV tool to strategically select vehicles as ZEV capable based on vehicle specifications, refueling infrastructure, and prior vehicle activity. The ZEV tool provides evaluation techniques by vehicle classification, region or refueling/charging capabilities. Utilization of the tool will assist the state in the transition to ZEV platforms that are either battery electric or hydrogen fuel cell.

1. Introduction

Ever-increasing transportation activities have raised a range of public concerns such as heavy traffic congestion, degraded air quality, and excessive Green House Gases (GHG). Among many promising remedies, Zero Emissions Vehicles (ZEVs) not only advance individualized mobility, but also provide exceptional GHG and air quality benefits. As a result, government agencies and environmental coalitions around the world are advocating ZEVs with diverse incentivizing strategies. Caltrans has embarked on transitioning its fleet to ZEV and desired to have an analytical spreadsheet tool to assist deployment decisions. The database tool summarized in this report provides Caltrans the means to strategically deploy ZEVs throughout the state.

This project aims to determine how to optimize the deployment of ZEVs in the Caltrans fleet while maintaining or improving the effectiveness of operations. The optimized deployment strategy includes the procurement, operational, and performance criteria of ZEVs while considering the location of refueling/recharging stations for EVSE (electric vehicle supply equipment) and hydrogen ZEVs.

This report focuses on battery electric vehicle (BEV) and hydrogen fuel cell vehicle (HFCV) specifically in representation of ZEVs. Additional ZEV technologies can be included in the ZEV spreadsheet tool as viable technologies becomes available. This project utilizes existing fleet data of over 12,000 department vehicles. The goal of the subsequent literature review is to summarize the current ZEV market and refueling infrastructure and the expected evolution in the foreseeable future. The projects activity and deployment analysis will consider existing and near-term ZEV deployments and trends to identify how Caltrans can optimally transition fleet vehicles to ZEV platforms. The sections following the literature review describe the database selection, database architecture, ZEV tool characteristics, ZEV tool usage, and analysis results. The collaborative efforts of Caltrans staff, ZEV tool development team, and committee member contributions are described in the following chapters.

2. Literature Review

Electric vehicle promotion efforts across the world are increasingly diverse, with many governments, automakers, and advocates pushing to promote awareness and sales of advanced electric-drive vehicles, as well as the necessary regulatory, charging infrastructure, and financial support.

This literature review identifies domestic and international efforts to support ZEV deployment and infrastructure. The literature review addresses the following:

- A review of national and international ZEV deployment efforts implemented by agencies, governments, and regions;
- Relevant fleet management tools, software, databases, and methods;
- Review of existing resources to assist fleets in the ZEV planning process;
- Review of electric BEV and FCEV vehicle supply equipment (EVSE) at state and retail facilities; and,

- Review of status and plans for electric charging stations and hydrogen fueling stations throughout the state.

The global adoption of EVs involves many stakeholders, including government agencies, non-profit advocate organizations, automakers, and the public/consumers. To promote ZEV awareness and sales of ZEVs, the strategies are usually a combination of regulatory policies, financial/mobility incentives, and refueling infrastructure deployment.

The literature research starts with an overview of global ZEV deployment, then focuses on the United States/California ZEV efforts. The literature review also gives special attention to future medium/heavy-duty electric vehicle models and existing vehicle comparison applications to help achieve the project goals: determine how to maximize the deployment of ZEVs in the Caltrans fleet.

2.1 Global ZEV Deployment

The global review of ZEV technology reveals numerous technologies, standards, policies, regulations, and strategies that all focus on ZEV transition and deployment. Table 2.1 gives a detailed summary of the ZEV promotion actions adopted by governments in the most ZEV-pioneering regions and countries: China, Europe, Japan, and United States. Table 2.1 is a direct reference from report 1.

A review of global ZEV efforts reveals numerous trends. First, ZEV deployments are initiated and facilitated by government, regional, and/or local regulations and incentives. The ZEV technology is more costly than traditional platforms and typically requires a combination of mandates and incentives to facilitate the transition. ZEV deployments also require a transition of refueling infrastructure which due to high initial cost requires additional support to facilitate ZEV adoption.

Global ZEV passenger vehicle deployments have been increasing for over a decade in both manufacturer models and quantity. This trend is making the standard ZEV passenger vehicle more cost competitive while also making ZEV refueling infrastructure more available. While there continues to be vehicles and refueling equipment dedicated to regional markets (e.g., Asia, Europe, US) manufacturers are gradually adopting their ZEV platforms for global markets.

The medium and heavy-duty ZEV market is advancing at a much slower pace than the ZEV passenger vehicle market. Global passenger vehicle sales are counted in 100,000’s; while medium and heavy duty ZEV deployments are counted 1000’s. The majority of medium/heavy duty global deployments are in transit bus platforms. The remainder of medium/heavy duty ZEV vehicles are generally specialty vehicles developed for specific applications and/or regions. As the ZEV technology matures for transit bus applications other medium/heavy duty platforms are benefitting from the technology and performance improvements. It is anticipated that the trend will continue and increased medium/heavy duty ZEV deployments are on the horizon.

Table 2.1. ZEV promotion actions from governments in selected areas (adopted from (1), updated)

Area	Action	China	Fra.	Ger.	Jap.	Neth.	Norw.	UK	U.S. (exl CA)	CA
Vehicle manufacturer	Research and development support	X	X	X	X	X	X	X	X	X
	Long-term efficiency standards	X	X	X	X	X	X	X	X	X
	Incentive provisions within efficiency regulations	X	X	X		X	X	X	X	
	Cumulative sales goal	X	X	X		X	X	X	X	X
	Vehicle deployment requirements									X
	Vehicle production subsidy	X								
Consumer purchase	Vehicle purchase subsidy (tax credit)								X	
	Vehicle purchase subsidy (rebate)	X			X			X		X
	Vehicle purchase tax exemption					X	X		/	
	Vehicle fee-bate scheme		X					X		
	Government fleet vehicle purchasing preferences		X		X			X	X	X
	High fuel price and greater fuel savings		X	X		X	X	X		/
Consumer use	Annual vehicle fee exemption			X	X	X	X	/	/	
	Discounted/free electric charging				X	X	X	/	/	X
	Preferential lane (e.g., bus, HOV lane) access			/		X	X		/	X
	Reduced roadway tax or tolls			X	X	X	X	X		
	Preferential parking access		/	/		/	/	/	/	/
Fuel provider, infrastructure	Carbon pricing scheme	X	X	X	X	X	X	X	/	X
	Low carbon fuel incentive for electricity providers							/		X
	Public charging network funding	X	X	X	X	X	X	X	X	X
	Home charging equipment tax incentives		X						/	/
Consumer awareness	Public outreach activities to educate on consumer benefits	X	X	X	X	X	X	X	X	X

"X" denotes national program; "/" signifies smaller regional or local program

2.2 U.S. Nation-wide ZEV Deployment

2.2.1 U.S. State Clean Vehicle Policies and Incentives

Beyond federal tax incentives, there are at least 30 states that have ZEV-related programs, including Clean Energy Vehicle Incentives, ZEV mandates, and other policies. This interactive map (2) hosted by Center for Climate and Energy Solutions provides a clear overview of the states with such programs. The summary table of policies and incentives evaluated for this project are detailed in Section 9 Data Summary. Department of Energy's Alternative Fuels Data Center also provides a complete list of such technology and incentives/regulations (3). Users can choose various topics at state or federal level.

By directly requiring that automakers invest in clean technology, the CA ZEV program is considered one of the nation's most forward-looking climate policies, and a driving force behind an expanding market with more than 30 ZEV models available to the public. The ZEV program assigns each automaker "ZEV credits", and each automaker is required to maintain

ZEV credits equal to a set percentage of non-electric sales. With rules such as "banking and trading ZEV credits", "Travel and pooling provisions (do not apply in CA)", automakers also have flexibility on when and how to achieve the ZEV credits (4).

"Banking and trading ZEV credits" - Manufacturers are allowed to carry over excess credits from one year to the next. Called "banking," the practice has grown since 2012, thanks to extra credits and ZEV sales in California that outpaced the relatively low regulatory starting requirements. In addition, automakers can purchase or trade ZEV credits from other manufacturers (4).

"Travel and pooling provisions (do not apply in CA)" - The travel provision allows automakers to receive credits in all other ZEV states for vehicles sold in California, proportional to the vehicles sales in the states. The pooling provision allows automakers to over-comply in one eastern ZEV state and transfer the extra credits to another eastern ZEV state. Unlike the travel provision, pooling avoids the double-counting issue, and still requires that an actual vehicle is produced and sold before credit is rewarded and transferred (4).

2.2.2 Multi-State ZEV Support

The initial CA ZEV mandate has evolved into multi-state organizations that are committed to advocate ZEVs. For instance, the Multi-State ZEV Task Force, which was formed in 2013, is a nine-state collaborative initiative to support successful implementation of state ZEV programs. The nine states include California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont. Each state has an ambitious plan to reduce GHG, and ZEV implementation is part of the GHG reduction plan. Multi-State ZEV Task Force also maintains the list of all alternative fuel station in each state.

Additional multi-state efforts exist for low emission vehicle (LEV) deployments, alternative fuel standards, and Low Carbon Fuel Standards (LCFS). These programs provide requirements, incentives, and guidance for transitioning traditional vehicle platforms to alternative fuels. Caltrans has played a pivotal role in previously demonstrating the limitations/benefits of: methanol, E85, LNG, RNG, biodiesel, and CNG.

2.2.3 Federal Incentives

In addition to state level ZEV programs, there are a range of federal-level ZEV incentives and several prominent efforts are summarized below (5).

Procurement Preference for Electric and Hybrid Electric Vehicles (6) — The U.S. Department of Defense (DOD) must exhibit a preference for the lease or procurement of motor vehicles with electric or hybrid electric propulsion systems, including plug-in hybrid systems, if the vehicles are commercially available at a cost reasonably comparable to motor vehicles with internal combustion engines. Tactical vehicles designed for use in combat are excluded from the requirement.

Natural Gas Vehicle (NGV) and Plug-In Electric Vehicle (PEV) Weight Exemption (7) — NGVs and PEVs may exceed the federal maximum gross vehicle weight limit for comparable conventional fuel vehicles by up to 2,000 pounds (lbs.). The NGV or PEV must not exceed a maximum gross vehicle weight of 82,000 lbs.

Electric Vehicle Charging on Federal Property (8) — The U.S. General Services Administration (GSA) or any federal agency may install electric vehicle supply equipment (EVSE) for federal employees and others authorized to park at federal facilities to charge their privately owned vehicles. Employees and other users must pay to reimburse federal agencies for the EVSE procurement, installation, and use. Federal agencies may provide EVSE through a contract with a vendor. GSA must submit a report to Congress by December 2018, and annually thereafter for 10 years, on the number of EVSE installed by GSA, the number of EVSE installation requests from other federal agencies, and the status of requests for EVSE from other federal agencies.

Table 2.2. Multi-State ZEV Action Plan: ambitious goals to reduce GHG (from Multi-State ZEV Action Plan 2018 (9))

	2020	2030	2050
CALIFORNIA	0% Below 1990 levels	40% Below 1990 levels	80% Below 1990 levels
CONNECTICUT	10% Below 1990 levels	45% Below 2001 levels	80% Below 2001 levels
MARYLAND	25% Below 2006 levels	40% Below 2006 levels	90% Below 2006 levels
MASSACHUSETTS	25% Below 1990 levels		80% Below 1990 levels
NEW JERSEY	0% Below 1990 levels		80% Below 2006 levels
NEW YORK		40% Below 1990 levels	80% Below 1990 levels
OREGON	10% Below 1990 levels		75% Below 1990 levels
RHODE ISLAND	10% Below 1990 levels	45%* Below 1990 levels	80% Below 1990 levels
VERMONT**	10% Below 1990 levels	50%*** Below 1990 levels	75% Below 1990 levels

** Rhode Island target year 2035*
*** Vermont Statutory goals (shown above) were established by Executive Order in 2005, and passed into law in 2006. The Comprehensive Energy Plan (CEP) goals established in 2016 set Vermont's goals at 40% below 1990 levels by 2030 and 80% to 95% below 1990 levels by 2050*
**** Vermont target year 2028*

Airport Zero Emission Vehicle (ZEV) and Infrastructure Incentives (10) — The Zero Emissions Airport Vehicle and Infrastructure Pilot Program provides funding to airports for up to 50% of the cost to acquire ZEVs and install or modify supporting infrastructure for acquired vehicles. Grant funding must be used for airport-owned, on-road vehicles used exclusively for airport purposes. Vehicles and infrastructure must meet the Federal Aviation Administration's Airport

Improvement Program requirements, including Buy American requirements. To be eligible, an airport must be for public use. The program will give priority to applicants located in nonattainment areas, as defined by the Clean Air Act, and projects that achieve the greatest air quality benefits, as measured by the amount of emissions reduced per dollar of funds spent under the program.

Low and Zero Emission Public Transportation Research, Demonstration, and Deployment Funding (11) — Financial assistance is available to local, state, and federal government entities; public transportation providers; private and non-profit organizations; and higher education institutions for research, demonstration, and deployment projects involving low or zero emission public transportation vehicles.

Qualified Plug-In Electric Vehicle (PEV) Tax Credit (12) — A tax credit is available for the purchase of a new qualified PEV that draws propulsion using a traction battery that has at least five kilowatt-hours (kWh) of capacity, uses an external source of energy to recharge the battery, has a gross vehicle weight rating of up to 14,000 pounds, and meets specified emission standards. The minimum credit amount is $2,500, and the credit may be up to $7,500, based on each vehicle's traction battery capacity and the gross vehicle weight rating. The credit will begin to be phased out for each manufacturer in the second quarter following the calendar quarter in which a minimum of 200,000 qualified PEVs have been sold by that manufacturer for use in the United States. This tax credit applies to vehicles acquired after December 31, 2009.

2.3 California ZEV Regulations and Policies

California has the strictest vehicle emission standards in the U.S. and the most aggressive ZEV programs as introduced in Section 2.2.1. Also, California state legislative has issued a number of mandates regarding ZEV implementation, for example, executive orders, assembly bills, and senate bills, among which the most impactful regulations and policies are listed below.

Senate Bill 32 Global Warming Solutions Act of 2006 — requires that there be a reduction in GHG emissions to 40% below the 1990 levels by 2030. Greenhouse gas emissions include carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons.

Senate Bill 100 California Renewables Portfolio Standard Program — requires the Public Utilities Commission to establish a renewables portfolio standard requiring all retail sellers, as defined, to procure a minimum quantity of electricity products from eligible renewable energy resources, as defined, so that the total kilowatt hours of those products sold to their retail end-use customers achieve 25% of retail sales by December 31, 2016, 33% by December 31, 2020, 40% by December 31, 2024, 45% by December 31, 2027, and 50% by December 31, 2030. It is the policy of the state that eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by December 31, 2045. (13).

Executive Order B-16-12 — pushes the state toward the integration of zero emission vehicles (ZEVs) into the mainstream. It directs the state toward establishing an infrastructure that can support increased public and private sector ZEVs. Specifically, it directs state agencies to replace at least 10% of fleet vehicle purchases with ZEVs by 2015, and at least 25% of fleet vehicle purchases with ZEVs by 2020.

Executive Order B-18-12 — and the Green Building Action Plan require state agencies to reduce environmental impacts of state operations, including GHG emissions, energy, and water use, as well as improving indoor air quality, onsite renewable energy, environmentally preferable purchasing (EPP), and developing the infrastructure for electric vehicle charging stations at state facilities.

California ZEV Action Plan — the plan is a set of documents designed to organize state agency actions to grow the zero emission vehicle market. It provides a roadmap designed to support the Governor's goal of 1.5 million ZEVs on the road by 2025 (Executive Order B-16-12) (14).

Executive Order B-30-15 — establishes a GHG reduction target of 40% below 1990 levels by 2030.

Executive Order B-32-15 — orders the development of a statewide Integrated Freight Action Plan. It orders future investments to upgrade freight vehicles and infrastructure should utilize technologies, energy sources, and fuels that enable greater transportation efficiency while reducing community and environmental impacts.

DGS Management Memo 16-07 — the Department of General Service memo provides direction to all state agencies under the Governor's executive authority on expanded zero-emission vehicle (ZEV) and alternative fuel vehicle (AFV) purchasing and infrastructure support requirements in furtherance of Executive Order B-16-12 and B-18-12, and Public Resources Code §25722.8. It also guides state agencies in their exercise of EO B-16-12's public safety vehicle exemption, as well as an agency's authority for reimbursement during public/employee use of state EV charging infrastructure (15).

Executive Order B-48-18 — implements the Governor's call for a new target of 5 million ZEVs in California by 2030 and 250,000 vehicle charging stations and 200 hydrogen refueling stations by 2025. The proposed funded activities are $134,000,000 for electric vehicle charging infrastructure and $92,000,000 for hydrogen refueling infrastructure.

Assembly Bill 8 — allocates $20 million annually until at least 100 hydrogen fueling stations are available to the public in California (16)

California's policies, laws, and programs pertaining to BEVs and HFCVs have been summarized in tables and are available as detailed in Section 9 Data Summary.

2.4 Caltrans ZEV Efforts

Sustainability, livability, and economy are goals of the Caltrans Strategic Management Plan, with targets for integrating sustainability practices into Caltrans' daily activities. As steward of more than 50,000 highway lane-miles and operator of more than 10,000 service vehicles, Caltrans plays a pivotal role in demonstrating alternative fuel/energy technologies. In the past two years, Caltrans has celebrated many sustainability milestones, including decreased water and energy use, adding zero-emission vehicles to its fleet, and taking steps to maintain a healthy indoor environment at its facilities.

As part of the efforts to achieve sustainability, integrating ZEVs into Caltrans fleet is one of the priority action items. The ZEV state policy framework includes the Senate Bill 32, Executive Order B-16-12, Executive Order B-48-18, and Senate Bill 100, which are introduced in Section 2.3.

Caltrans ZEV deployment program goals and targets are described inTable 2.3. Specific ZEV commitments tasks are identified in Table 2.4. The goal of this project is targeted to effectively integrate ZEVs into Caltrans fleet based on past/current/projected fleet usage, available ZEV models, and EVSE/refueling projections, specifically, the following items:

1. Identify high-priority locations for ZEV deployment (fleet and workplace);
2. Identify locations for the installation of hydrogen/EVSE infrastructure to support fleet vehicles;
3. Identify and characterize outside funding sources for all types of charging;
4. Identify, prioritize, and database ZEV Infrastructure at state owned facilities.

Table 2.3. Caltrans ZEV Program (from (17))

Public Charging	Public charging for general public use on Caltrans right-of-way
Workplace	Charging for private vehicles owned by Caltrans employees
Partnering	Activities to support development and deployment of ZEV technologies working with others
Fleet	Integrating vehicles and charging infrastructure into the Caltrans light, medium, and heavy duty fleet
Freight	Support for sustainable freight technology adoption for spectrum of freight activities

Table 2.4. Caltrans ZEV Commitments (from (18))

I-6 ZEV: Identify, increase, and streamline Zero Emission Vehicle infrastructure and operations		
Commitment	**Participating Department Units**	**Deadline**
I-6.C1: Lead the Department's activities relating to fleet, equipment, and workplace charging, including coordinating District activities.	Equipment (Lead)	Ongoing
I-6.C2: Develop and disseminate Department policy on workplace charging.	Business Operations	Draft Policy for review by 4/1/18
I-6.C3: Continue to represent the Department in Administration-wide and industry activities including the ZEV Inter-Agency Task Force.	Sustainability	Ongoing
I-6.C4: Sponsor an internal "ZEVFest" educational and decision-making workshop in Spring 2018 to accelerate ZEV policy development and resolve specific implementation barriers.	Sustainability	Workshop in Spring 2018
I-6.C5: Develop communications and training material focused on climate adaptation and resilience in connection with the Department's sustainability priority "Advance clean vehicles, fuels and materials."	Sustainability	12/31/18

2.5 Fleet Management Tools

Caltrans has utilized software and technology to perform fleet management functions for decades. The current practices allow Caltrans to: track maintenance, manage procurements, manage operation/assignments, evaluate operational costs, track mileage/usage, track fuel, evaluate performance, and justify vehicle acquisitions. These functions are achieved through a variety of software tools and hardware technologies.

Fleet management databases are integrated statewide and allow Caltrans staff to maintain continuous vehicle records from fleet acquisition through vehicle disposal. The fleet management tools are tightly integrated with maintenance and service departments to track operational maintenance with respect to miles and/or service hours. The fleet management tools provide a complete history of each vehicle's assignment/maintenance/usage history since fleet inception. The fleet management database also details the vehicle class/model/specifications of each vehicle to determine if equivalent ZEV platforms exist within the marketplace.

In addition to fleet management software systems, Caltrans operates fuel management access/accounting system to manage and track fuel use across the fleet. The fuel system allows staff to determine overall fuel use and cost throughout the fleet. The fuel tracking provides detail refueling information per event: fuel type, location, quantity, vehicle and cost. This information when combined with the fleet management database provides a detailed characterization of fuel and energy use per vehicle.

Caltrans has also deployed fleet tracking technology to further characterize individual vehicle activity. The fleet tracking software allows for GPS based location information to be recorded on a trip-by-trip basis. The vehicle location and trip information is wirelessly transmitted to servers and available to fleet management staff. The fleet location and trip information is the most valuable for determining the suitability of a specific vehicle being transitioned to a ZEV platform. The vehicle travel patterns can be evaluated to determine trip length, parking locations, refueling options, energy needs and overall ZEV suitability.

This project will integrate the fleet management, fuel, and telematics databases to allow for a thorough analysis of individual vehicle suitability for ZEV operation. The relevant fields from each database will be merged into a single database which allows for a full characterization of vehicle performance related activity. Database tools and functions will be developed which allow for continued fleet analysis as the fleet and vehicle activity evolves.

2.6 BEV Status

Currently, more than 40 manufactures offer a range of models of battery electric vehicles (BEVs) in the U.S. market. As of end of 2020, there are more than 369,000 BEVs on road in California (19), and the new BEV sales in 2021 is on a rapid increase. A complete list of all-battery light duty, SUVs, and vans are available at the U.S. Department of Energy website (20).

2.7 HFCV Status

A Hydrogen Fuel Cell Vehicle (HFCV) runs on compressed hydrogen fed into a fuel cell "stack" that generates electricity to power the vehicle. In additional to environmental benefits, HFCVs possess fast refueling and long driving range compared to commercially available BEVs. An arguable advantage is the energy security of hydrogen due to its manufacture, transportation, storage, and resilience when compared with electricity and fossil fuel (21). Table 2.5 compares the three available passenger HFCV models on the market.

Table 2.5. Light duty HFCV available on market

	Toyota Mirai (2021)	Hyundai Nexo (2021)	Honda Clarity (2021)
Vehicle Class	Sedan	SUV	Sedan
Range (miles)	400	354 - 380	360
Power (hp) Torque (lb-ft)	179 221	161 291	174 221
MPGe Combined	66	57 - 61	68
Curb Weight (lb)	4,075	3,990 – 4,116	4,134
Tank Capacity (L) / (kg)	122.4/5.6	156.6 / 6.3	135.7 / 5.46
MSRP ($)	starting $ 49,500	58,935	lease starting at **$379**/month for 36 months.

Since the fuel cell technology is nascent, there are only about 7,000 HFCVs on road now in California and projected to be more than 47,200 by 2024 (22).

In addition to the fuel cell passenger vehicles, the fuel cell heavy-duty vehicles are gaining momentum in the ZEV heavy duty market, especially transit buses. As of December 2018, there are 32 fuel cell buses operating in US, and more than 30 planned to be deployed in the near future. (23, 24).

Table 2.6. Fuel Cell Transit Buses in Active Service in the United States (from 24)

	Bus Operator	Location	Active Buses[b]	Technology Description
1	AC Transit, ZEBA[a]	San Francisco Bay Area, CA	13	Van Hool bus and hybrid system integration, US Hybrid support for fuel cell
2	SunLine Transit Agency[a] (AFCB prototype)	Thousand Palms, CA	1	ENC/BAE Systems/Ballard next-generation advanced design to meet "Buy America" requirements
3	SunLine Transit Agency[c]	Thousand Palms, CA	3	ENC/BAE Systems/Ballard updated AFCB design
4	SunLine Transit Agency	Thousand Palms, CA	1	ENC/BAE Systems/US Hybrid battery-dominant AFCB design
5	SunLine Transit Agency[d]	Thousand Palms, CA	5	AFCB (3 of 5 are in service)
6	University of California at Irvine (UCI)	Irvine, CA	1	AFCB
7	Orange County Transportation Authority (OCTA)	Santa Ana, CA	1	AFCB
8	Stark Area Regional Transit Authority (SARTA)[a,d]	Canton, OH	6	AFCB, one bus operated by Ohio State University for a year
9	Flint Mass Transportation Authority[c]	Flint, MI	1	AFCB
		Total	**32**	

[a] *Project received funding through the NFCBP*
[b] *Total buses delivered or in service as of August 2018*
[c] *Project received funding through TIGGER*
[d] *Project received funding through Low-No Program*

Table 2.7. New Fuel Cell Transit Buses Planned in the United States (from 24)

Bus Operator	Program	Location	Number of Buses	Technology Description	Actual Estimated Service Start
AC Transit (CALSTART)	NFCBP	Oakland, CA	1	New Flyer 60-ft bus with next-generation Ballard fuel cell, Siemens hybrid propulsion system	October 2018
SARTA	NFCBP	Canton, Columbus, OH	1	AFCB	Q4 2018
SunLine	CEC	Thousand Palms, CA	1	New Flyer Xcelsior 40-ft bus, Hydrogenics fuel cell	Q4 2018
SARTA	Low-No (2016/17)	Canton, OH	5	AFCB	TBD
AC Transit, OCTA	CARB	Oakland, Santa Ana, CA	20	New Flyer bus with Ballard fuel cell, 10 buses for each agency	Q4 2018
SunLine	CARB	Thousand Palms, CA	5	New Flyer bus with Ballard fuel cell	Q4 2018
Champaign-Urbana Mass Transit District	Low-No (2017)	Champaign-Urbana, IL	2	New Flyer 60-ft bus with Ballard fuel cell	2020
		Total	**35**		

2.8 Zero-Emission Medium to Heavy Duty

As light-duty BEVs global adoption and acceptance increases, there continues to be limited availability zero-emission medium and heavy-duty vehicles on the market. Many MD and HD vehicles are still being developed and deployed at the demonstration level. Currently, motor companies and vehicle upfitting companies are pushing the electrification of medium to heavy duty fleet. This section will briefly introduce such companies and their products with a summary table below. The products include the models mentioned on the official websites, and those appeared only in promotional news were not included in this summary. Shuttle buses, transit buses, and school buses are not included in the table, since the Caltrans operations do not focus on bus and transit vehicle platforms.

Table 2.8. Summary of Zero-Emission Medium to Heavy Duty Vehicles

Manufacturer	Model	Duty Class	CurbWeight (lb.)	GVWR (lb.)	Est. range per charge/refuel (mile)	Battery cap. (kWh)	Test/release year
Atlis Motor	Atlis XT pickup truck	Medium		35,000	300, 400, 500		2020
Bollinger Motors	B1 SUV, B2 pick up truck	Medium	5,000	10,000	200	120	
BYD	A range of trucks	Heavy	Up to 25,000	Up to 105,000	124 -167	Up to 435	In use
Freightliner	eCascadia Class 8 tractor	Heavy			250	550	2021
Freightliner	eM2 106 truck	Medium			230	325	2021
Havelaar	Bison	Medium			186		
Lion	Lion8 Class 8 truck	Heavy	24,600	54,600	250	480	
Mack Trucks	Mack LR refuse truck	Heavy		35,000-72,000			2020
Mercedes-Benz	eActros	Heavy	~40,000		125	240	in use
Mitsubishi FUSO	eCANTER	Medium	6,615	15,995		83	in use
Morgan Olson	Walk-in van	Medium	-	-	-	-	in use
Nikola*	Nikola One	Heavy	20,000 – 23,000	80,000	500 – 750		2020
Nikola	Nikola Two/Tre	Heavy	20,000 – 23,000	80,000	500 – 750	250	2020
OrangeEV	T-series terminal truck	Heavy		81,000	customized	customized	
Peterbilt	Class 8 Model 579 day cab tractor	Heavy			200	350-440	
Peterbilt	520 refuse trucks	Heavy			80	352	
Phoenix Motorcars	flat bed, utility vehicle	Medium		14,500	110	105	in use
Rivan	RT1	Medium	2,670	3,470	230 - 400	105 -180	
ROUSH CleanTech	Upfitted F-650	Medium			120		in use
Utilimaster	Walk-in Van	Medium			customized	customized	
Volvo	Class 8 truck	Heavy		33,000			2020
Van Hool	A300L Fuel Cell	Heavy			300		
Workhorse Trucks	W-15 PHEV pick up truck	Medium		7,200	80 all-electric range		
Xos Trucks	ET-One	Heavy		80,000	300		
Xos Trucks	Delivery truck	Medium			200		
ZeroTruck	A range of utility vehicles	Medium		12,000-19,500	70 - 75		in use

* The blue-color highlighted Nikola One and Van Hool are the only HFCVs in the summary, all others are BEV.

ADOMANI (https://adomanielectric.com/) — ADOMANI is a provider of advanced zero-emission and hybrid vehicle drivetrain solutions and purpose-built electric vehicles. ADOMANI offers zero-emission commercial trucks, chassis, and vans to businesses and schools. For example, ADOMANI provides zero-emission electric drivetrain systems for electric school buses built by Blue Bird, Inc.

Atlis Motor (https://www.atlismotorvehicles.com/xt) — Atlis XT is an all-electric pickup truck with a range of 300 miles, 400 miles, or 500 miles based on users' choice. It is stated that a Atlis XT can be charged at an Atlis Motor Vehicles Advanced Charging station within just 15 minutes.

Bollinger Motors (https://bollingermotors.com/bollinger-b2/) — Bollinger B1 All- Electric SUV has 200 miles of range with 120 kWh battery pack, 4,800 lb curb weight, and 10,001 lb GVWR. Bollinger B2 All-Electric Pickup Truck has 200 miles of range with 120 kWh battery pack, 5,000 lb curb weight, 10,001 lb GVWR, 5,000 lb payload capacity, and 7,500 lb towing capacity.

BYD (https://en.byd.com/truck/) — In addition to passenger ZEVs, BYD has developed a wide range of practical and economical EV solutions. It has launched commercial vehicles that cover ten market segments: buses, coaches and taxis; logistics, construction and sanitation vehicles; and vehicles for warehousing, port, airport and mining operations.

Dana (http://www.dana.com/) — Dana provides engineered solutions for improving the efficiency, performance, and sustainability of powered vehicles and machinery. The recent acquisition of a control company positions Dana as the only supplier capable of producing all core components of a complete, fully-integrated e-Drive system, including Electrified Drivetrain Components, Motor, Power Inverter, and Controls Components, Thermal Management Components, and Fully-Integrated e-Drive Systems. For example, Dana recently introduced a commercially viable electric drivetrain showing a Class 6 Peterbilt 220 delivery truck (100 mile range and 93 kWh battery pack) fitted with Dana's equipment. It also covers all vehicle market, including light duty vehicle, commercial vehicle, and off-road equipment.

Ecotuned Automobile (http://ecotuned.com/accueil/) — Ecotuned technology transforms light trucks with the manufacturer's expired warranty to a clean electric vehicle. By leveraging the longevity of the electric motor, the system is designed to be easily reused at least three times in a row in another vehicle. By saving every time the expensive renewal of a vehicle, this ecological gesture saves more than 50,000 USD.

Freightliner (https://freightliner.com/e-mobility/) — Freightliner manufactures commercial semi trucks since 1942. The eCascadia, built on North America's bestselling class-8 on-highway platform, is an all-electric heavy duty highway tractor designed for local and regional distribution and drayage with 250 miles of range, 550 kWh usable battery capacity, and 90% recharge within 90 minutes. The eM2 106 (230 miles of range, 325 kWh, and 80% charge within 60 minutes) is an all-electric medium duty truck designed for local distribution, pickup and delivery, food and beverage delivery and last mile logistics applications.

GreenPower Bus (https://www.greenpowerbus.com/) — GreenPower Motor Company is a zero-emissions bus manufacturer that offers a full line of battery-electric vehicles that cater to the transportation needs of public transit agencies, school districts, and private sector operations. GreenPower was founded in 2010 with the purpose of bringing the most compelling zero-emissions buses to market.

The GreenPower EV Star is a purpose-built, zero-emission minibus in its class. Multi-functional, the 25-feet Min-eBus can be deployed for transit, executive shuttle, paratransit, vanpool, and many other operations. GreenPower delivered the first EV Star in 2018, and has sold these vehicles to a number of customers, including UC San Francisco, the Port of Oakland, Sacramento Regional Transit, Creative Bus Sales and others. The GreenPower EV550 is an all-electric double decker. Two of them have been deployed in Victoria, Canada since 2016.

Havelaar (https://www.havelaarcanada.com/) — Havelaar has developed a suite of technologies for zero-emission electric vehicles. Their powertrain technology optimizes battery performance and significantly cuts charging time, which also allows for bidirectional charging, as well as charging directly from renewable energy sources like wind and solar. Havelaar built the 'world's first all-electric pickup truck' – the Bison, which can go186 miles on a single charge.

Mack Trucks (https://www.macktrucks.com/) — Mack is one of North America's largest producers of heavy-duty trucks, sold and serviced through an extensive distribution network in more than 45 countries. Mack Trucks has introduced its Mack LR all-electric refuse truck, which it plans to test on the streets of New York City in 2020. The Mack LR BEV uses Mack's integrated electric powertrain, featuring two 130 kW motors producing a combined 496 peak horsepower and 4,051 lb.-ft. of torque. Power is sent through a two-speed Mack Powershift transmission. Mack LR uses four NMC lithium-ion batteries which charge at up to 150 kW, and the hydraulic systems on the truck are electrically driven as well.

Meritor (https://www.meritor.com/) — Meritor is a leading global supplier of drivetrain, mobility, braking, and aftermarket solutions for commercial vehicle and industrial markets. Meritor has 22 electrification programs with global OEMs that is expected to put at least 130 fully electric medium- and heavy-duty commercial trucks on the road through 2020.

Mitsubishi FUSO Trucks (https://www.mitfuso.com/en-us/models/ecanter) — eCANTER box truck is "the world's first purely electric-powered light truck." With a state-of-the-art modular HV battery pack and permanent synchronous e-motor, the eCanter delivers an output of 185 kW and powerful torque. Estimated 6,615 lb. curb weight, 15,995 lb. GVWR, and 82.8 kWh battery pack.

Morgan Olson (https://morganolson.com/) — Morgan Olson is the leading walk-in van body manufacturer in North America. Their walk-in van bodies are custom built to meet exact specifications and delivery needs. They upfit first all-electric walk-in van, first hydraulic hybrid walk-in van, first ROUSH propane walk-in van, first LIGHTNING hybrid walk-in van, first CROSSPOINT kinetic walk-in van.

Nikola (https://nikolamotor.com/motor) — Nikola Motor Company focuses in electric heavy-duty applications. Nikola One is a hydrogen fuel cell electric sleeper semi-truck, available in North America. Nikola Two is a fully-electric and hydrogen fuel cell electric day cab semi-truck, available in North America. Nikola Tre is a fully-electric and hydrogen fuel cell electric day cab semi-truck, available in Europe, Asia and Australia.

Nordresa (https://nordresa.com/en) — Nordresa develops, manufactures, and commercializes electric drivetrains for commercial vehicles. The company now introduces the NEC50, a conversion drivetrain for Ford E-350 or E-450 chassis. The fully-electric powertrain meets the most demanding requirements of the North American market and is sold at a price that will ease the decision making process.

Peterbilt Motors Company (https://www.peterbilt.com/) — Peterbilt Motors Company is the leading manufacturer and provider of natural-gas powered commercial vehicles. Peterbilt currently leads the industry with approximately 30 percent of all Class 6-8 natural gas truck sales and offers a broad range of models, engines, and fuel systems.

Recently, Peterbilt becomes the latest truck maker with an all-electric class 8 truck program. The truck maker announced a partnership with Meritor and TransPower, who will supply all-electric drivetrain systems for two Peterbilt vehicle platforms. They will produce the electric powertrains for "12 Peterbilt all-electric Class 8 Model 579 day cab tractors and three Model 520 refuse trucks."

Phoenix Motorcars (http://www.phoenixmotorcars.com/products/) — Phoenix aims at the electrification of transportation. Specific areas of experience include design, development, manufacturing of EV components, sub-systems and complete vehicles for sales in U.S. and export markets. The product includes ZEUS electric shuttle bus, electric flatbed, and electric utility vehicle.

Proterra (https://www.proterra.com/products/) — Proterra is an American automotive and energy storage company that designs and manufactures electric transit buses and electric charging systems. Proterra's Catalyst series includes transit buses ranging from 35 feet to 40 feet in length and various battery configurations.

Rivan (https://products.rivian.com/) — US-based automotive startup Rivian has debuted its first electric vehicle: a five-passenger pickup truck called the R1T. The result is a quad-motor electric pickup truck capable of up to over 400 miles of range that's able to reach 60 miles per hour in three seconds.

ROUSH CleanTech (https://www.roushcleantech.com/roush-cleantech-enters-electric-vehicle-market-with-the-ford-f-650/) — ROUSH CleanTech announced its newest zero emission vehicle – an all-electric Ford F-650. Built on the Ford F-650 chassis, ROUSH CleanTech's new fully electric vehicles will have a lithium ion battery system of up to 225 kilowatt hours and 700 volts. Depending on the vehicle's GVWR, the average range will be up to 120 miles with a top speed of 75 miles per hour. The AC permanent magnet motor will have a continuous-rated power of 150 kilowatts (200 horsepower), with a peak-rated power of 250 kilowatts (335 horsepower).

The Lion Electric Co. (https://thelionelectric.com/en) — The company creates, designs and manufactures all-electric school buses and minibuses for paratransit, urban transportation and commercial uses. Lion is the OEM leader of North American electric school buses. Recently, they officially launched the expansion starting with the Lion8, an all-electric urban class 8 truck with a range of "up to 250 miles".

Volvo (https://www.volvotrucks.us/news-and-stories/press-releases/2018/september/volvo-trucks-to-introduce-all-electric-trucks-in-north-america/) — As part of an innovative partnership between the Volvo Group, California's South Coast Air Quality Management District (SCAQMD), and industry leaders in transportation and electrical charging infrastructure, Volvo Trucks will introduce all-electric truck demonstrators in California next year, and commercialize them in North America in 2020. Volvo Trucks will deploy eight multi-configuration battery Class 8 electric demonstration units (GVW +15 tons), and an additional 15 precommercial and commercial units, throughout California's South Coast Air Basin. The project will also integrate non-truck battery-electric equipment, non-proprietary chargers, and solar energy production equipment. The project will reduce an estimated 3.57 tons of criteria pollutants (defined air pollutants) and 3,020 tons of greenhouse gases annually.

Workhorse Trucks (https://workhorse.com/) — Workhorse manufactures the new W-88, 88 inch-wide chassis, and the venerable W-62 chassis at its Indiana plant and offers an array of fuel options including two different electric drive trains both powered by Panasonic 18650 Li-Ion cells. The patent-pending E-GEN drive train has a 60kWh battery and a 2200 nm TM4 electric motor coupled to a small gas engine that drives the electric motor as a generator to charge the battery when its SOC reaches a preset level, the vehicle is in PARK, and the key off. E-GEN can be great local delivery trucks where, on a typical day, the truck would complete its route on battery power. Workhorse will exhibit its HorseFly™ UAV, which is fully integrated into the Workhorse truck and autonomously delivers packages to hard-to-access locations. The Workhorse W-15 is the first plug-in range extended electric pickup built from the ground up by an OEM. Lithium ion battery cells from Panasonic provide an 80 mile all-electric range, while the onboard generator works to recharge while driving to get the job done.

XL (https://www.xlfleet.com/) — XL offers hybrid and plug-in hybrid electrification systems and on-board telematics for commercial and municipal fleets. The XL Plug-in system installs seamlessly onto Ford F-150 and F-250 pickup trucks, delivering a 50% MPG increase and a 33% reduction in CO_2 emissions*. Performance, meet sustainability. The XL Hybrid system delivers a 25% MPG increase and a 20% reduction in CO_2 emissions for Class 2-6 fleets*. Available on major OEM platforms, including Ford, Chevy, GM and Isuzu.

Xos Trucks (previous Thor Trucks) (https://xostrucks.com/) — A Los Angeles-based transportation lab making electric commercial vehicle fleets a reality. ET-One is an all-electric class 8 tractor with 80,000-pound carrying capacity with up to 300 miles of range for short haul and regional tractors and trucks. Xos Trucks also proposes to make electric delivery vans up to more than 200 miles of range on a single charge that can be configured for a variety of applications including parcel delivery, food & beverage transportation, textile & linen transportation, utility vans, tool trucks, and refrigerated transport, among others.

ZeroTruck (http://zerotruck.com/our-fleet/) — ZeroTruck works with industry-leading EV integrators to produce innovative passenger and commercial electric vehicles for fleets and special events that have a range envelope under 70 miles. With an optional fast charger, the ZeroTruck can be fully charged in under 2 hours. The green fleet options include utility, dry freight, stake bed, tow, sweeper, landscaper, water services, dump, container delivery, and refuse trucks for a full range applications.

2.9 EVSE Status

Electric Vehicle Supply Equipment (EVSE) refers to EV charging and HFCV refueling facilities, and it is also a protocol to help keep EV users and EVs safe while charging. Caltrans not only plans to implement EVSE to support Caltrans fleet and employee ZEV charging, but also facilitate statewide EVSE for the public charging. The deployment of refueling infrastructure is critical for fleet operations and ZEV deployment. Numerous hardware configurations have been developed and deployed to refuel ZEV vehicles. The successful transition to a ZEV fleet requires broad adoption of compatible refueling infrastructure to allow commercial entities to develop vehicles with matching specifications, connectors, and protocols.

2.9.1 BEV Charging

California leads the country on BEV EVSE facilities deployed and operational. Continued regulations, programs, subsidies, and mandates continue to provide the BEV industry with confidence for light duty vehicle applications. The EVSE for light duty BEV continues to mature with standards developed and many competing technologies providing consumer options. The power transfer capacity of light duty EVSE continues to increase with 150 kW chargers being deployed and 250 kW chargers being developed for future deployments. The increased energy transfer capacity of EVSE equipment is allowing BEV light duty vehicles to obtain 100 miles of driving range in 20 minutes. While EVSE BEV advancements are reaching near equivalence for light duty combustion refueling, the medium/heavy duty BEV market still faces headwinds. The energy transfer for a medium/heavy duty BEV vehicle requires continued development and evolution of the EVSE market to reach industry wide standards, protocols, and methods. The EVSE market for medium/heavy duty BEV will continue to develop and evolve. Table 2.9 lists the EV charging stations within Caltrans facilities.

Table 2.9. Caltrans EV Charging Stations – Locations and Quantity (as of year 2018)

Region	In Use (permanent stations)	Solar Chargers In Use	Future Plan
North region (D1,2,3 & HQ)	17	4	7
Central (D4,5,6,&10)	35	5	30
South (D7,8,11&12)	32	8	41
Summary	84	17	78

Based on data provided by the Multi-State ZEV Task Force (25), the estimated number of statewide electric vehicle chargers by networks is summarized in Table 2.10. The number of sites and chargers in each Caltrans District is summarized in Table 2.11. An overview of charging sites in each Caltrans District is presented in Figure 2.1.

Table 2.10. Number of electric vehicle chargers by charging network in California as of August 2021

POWERFLEX			
Provider	**Level 1**	**Level 2**	**DCFC**
AMPUP		2	
Blink Network		916	52
ChargePoint Network	106	15,537	483
Electrify America		98	805
EV Connect		2,034	143
EVCS		34	18
EVGATEWAY		74	4
eVgo Network		176	780
FLO		195	
Greenlots	57	1,255	83
Non-Networked	532	5,796	375
OpConnect	6	127	
POWERFLEX		1,502	13
SemaCharge Network		1,364	
Tesla			3,422
Tesla Destination		3,007	
Volta		565	1
SUM	701	32,682	6,179

Table 2.11. Number of sites and chargers in each Caltrans District

Caltrans District	Sum of Sites	Level 1	Level 2	DCFC
1	145	0	244	73
2	62	1	85	79
3	701	109	1,503	492
4	4,868	273	11,516	1,813
5	530	18	1,030	310
6	498	13	967	496
7	3,612	245	9,822	1,092
8	811	14	1,662	654
9	40	0	58	62
10	205	12	414	199
11	1,065	7	2,575	410
12	1,462	9	2,806	499
SUM	13,977	701	32,682	6,179

Figure 2.1. Overview of EV Charging Sites in Each Caltrans District

Table 2.12 summarizes the charger's connector type per charging site. For specific number of connector type at each site, please refer to https://www.plugshare.com/.

As more and more ZEVs hit the road in California, there is a substantial increase in charging/refueling demand. Therefore, establishing DC fast charging stations and hydrogen refueling stations becomes an integral component of ZEV deployment strategy. Figure 2.2 displays a map of the planned DC fast-charging stations statewide. These fast-charging stations are planned along major travel corridors as part of the ZEV implementation.

Charging stations are equipped with several type of charging connectors to accommodate a range of electric vehicles. Table 2.12 summarizes the charging connectors for light duty vehicles.

Table 2.12. Light-Duty charging connectors

Connector	Charging Level	Notes and plug pinout
Nema 5-15, Nema 5-20	1	Wall plug, charger required  
Nema 14-50 (RV plug)	2	Wall plug, charger required 
Nema 6-50	2	Wall plug, charger required 
J1772	1 or 2	Tesla can charge with an adapter 
Tesla HPWC	2	Tesla only
CHAdeMO	3	Tesla can charge with an adapter 
SAE Combo CCS	3	Does not apply to Tesla 
Tesla Supercharger	3	Tesla only

Figure 2.2. Proposed 30 in 30 DC Fast Charging Stations Plan (from (26))

As detailed in Section 2.8, the electric medium-to-heavy duty vehicles require significantly higher battery capacity compared with light duty vehicles. Therefore, the EVSE equipment for medium-to-heavy duty are different than that of the light duty. Figure 2.3 illustrates the power requirements for different classes of EVs.

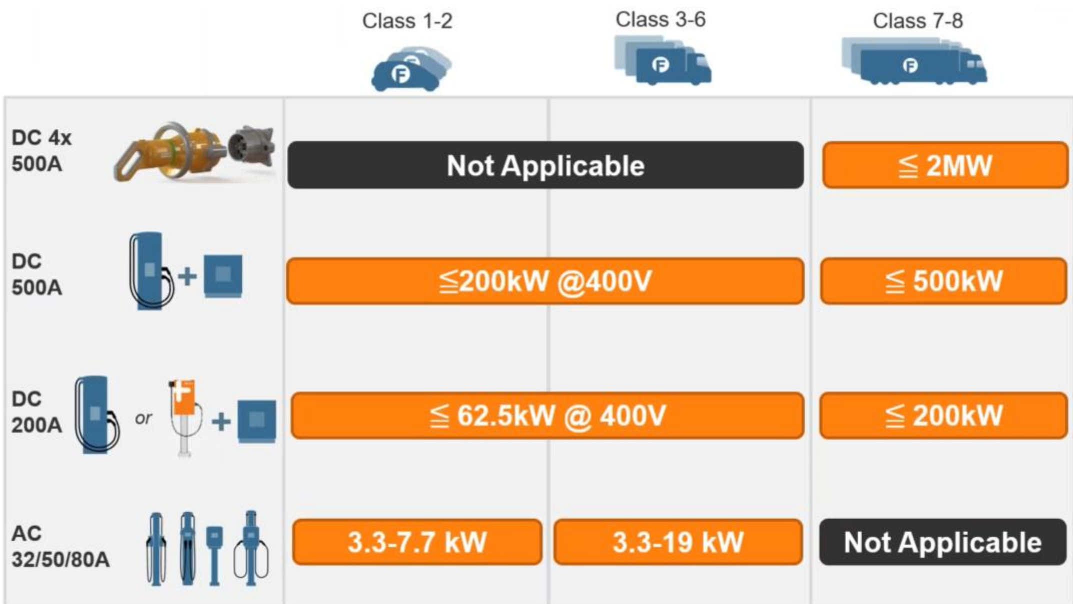
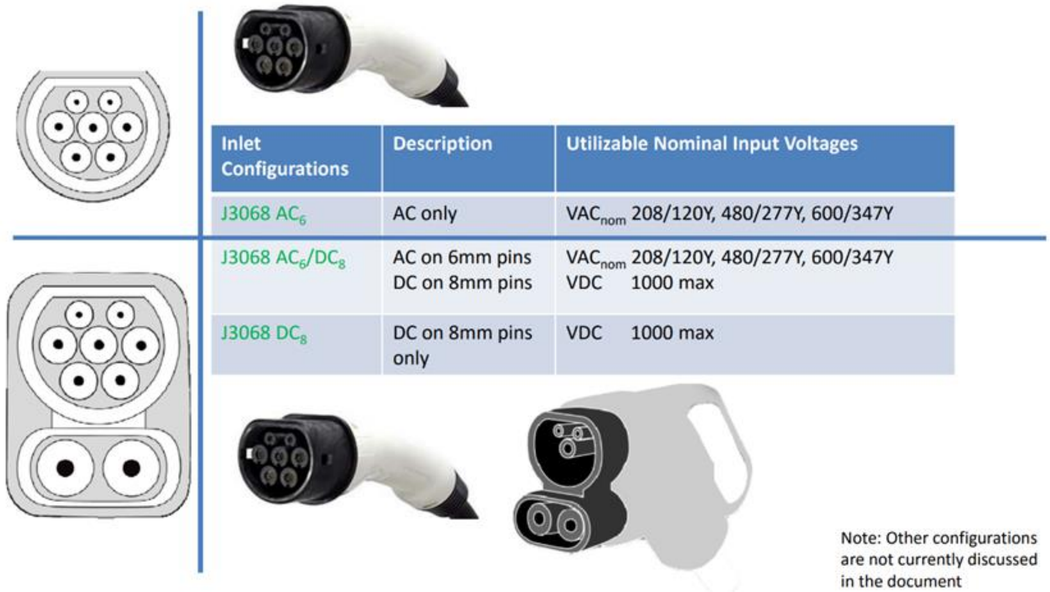


Figure 2.3. Power Requirements for Different Classes of EVs (27, 28)

SAE (Society of Automotive Engineers) International just released specifications for the SAE J3068 (29), which is similar to the European IEC 62196 (Type 2 or CCS Combo). J3068 is adopted by SAE to charge large-capacity EVs. The reason behind SAE J3068 is that SAE J1772 or its combo version (SAE J1772 Combo) doesn't support three-phase charging, and single-phase charging was limited to 19.2 kW. Many commercial and industrial locations in the U.S. and Canada are equipped with three-phase power and the SAE J3068 enables the use of three-phase 480 V (up to 133 kW at 160A), as well as 600 V AC (up to 166 kW at 160A). In additional to the handheld J3068, the overhead DC J3105 is in the development process (30). Figure 2.4 shows part of the specification for J3068 (31).



Inlet Configurations	Description	Utilizable Nominal Input Voltages
J3068 AC_6	AC only	VAC_{nom} 208/120Y, 480/277Y, 600/347Y
J3068 AC_6/DC_8	AC on 6mm pins DC on 8mm pins	VAC_{nom} 208/120Y, 480/277Y, 600/347Y VDC 1000 max
J3068 DC_8	DC on 8mm pins only	VDC 1000 max

Figure 2.4. Part of Specifications for J3068

2.9.2 HFCV Hydrogen Refueling

Based on Alternative Fuel Data Center, there are 39 retail hydrogen stations in California as of 2018, and the number rises to 47 as of August 2021, with a dozen more planned for future development. 5 stations in the process of commissioning, 4 stations under commissioning, and 16 more stations in development.

An overview map of hydrogen fuel stations are shown in Figure 2.5. (32).

The common practices of current hydrogen station technology are:

- Half-pressure H35 (35 MPa, 350 bar, ~5,076 psi)
- Full-pressure H70 (70 MPa, 700 bar, ~10,152 psi)
- Trucks and buses mostly use H35 (Toyota Portal truck uses H70) (33)
- Passenger vehicles now use H70
- Newer stations only have H70
- Trucks and buses will likely use a separate station or dispenser
- Research suggested that significant cost reductions would be achieved by the 2014–2016 timeframe, when early commercial stations with an estimated average capacity of 450 kg/day will be installed at a capital cost of $2.8 million per station (34). While costs are continuing to decline, additional cost reductions are still anticipated as facility deployments develop.

Figure 2.5. Map of Hydrogen Stations in California as of August 2021

2.10 Cost/Emission Research

A range of applications have been developed and are available to assist industry and consumers evaluate the cost and feasibility of ZEV adoption. These applications consider numerous factors associated with the driver's travel profile, vehicle requirements, and economic needs. The calculators will provide the emissions, energy, and cost benefits associated with specific vehicle options. The team has reviewed some of the available software to determine applicability and suitability relative to Caltrans' needs.

MyGreenCar Mobile APP — MyGreenCar Mobile APP is developed by the Berkeley Lawrence National Lab (35). In MyGreenCar APP, the user can choose preferred vehicles and enable the function of driving detection. The APP will detect when the user is driving and record user trips. Then the APP automatically calculates the selected vehicles' costs in terms of purchase price, fuel consumption, maintenance, insurance, and tax. The fuel consumption and GHG emission are calculated based on vehicle energy models and collected data of driving trips. Screenshots of the APP user interface are shown in Figure 2.6.

The APP includes almost all vehicles available on the market. It gives an excellent option of comparing individual vehicles with real-world driving records, and in this project, it could be ZEVs. However, one limitation is that the APP could not evaluate multiple vehicles, or a fleet collectively, hence it is difficult to optimize the ZEV integration into a fleet of thousands of vehicles.

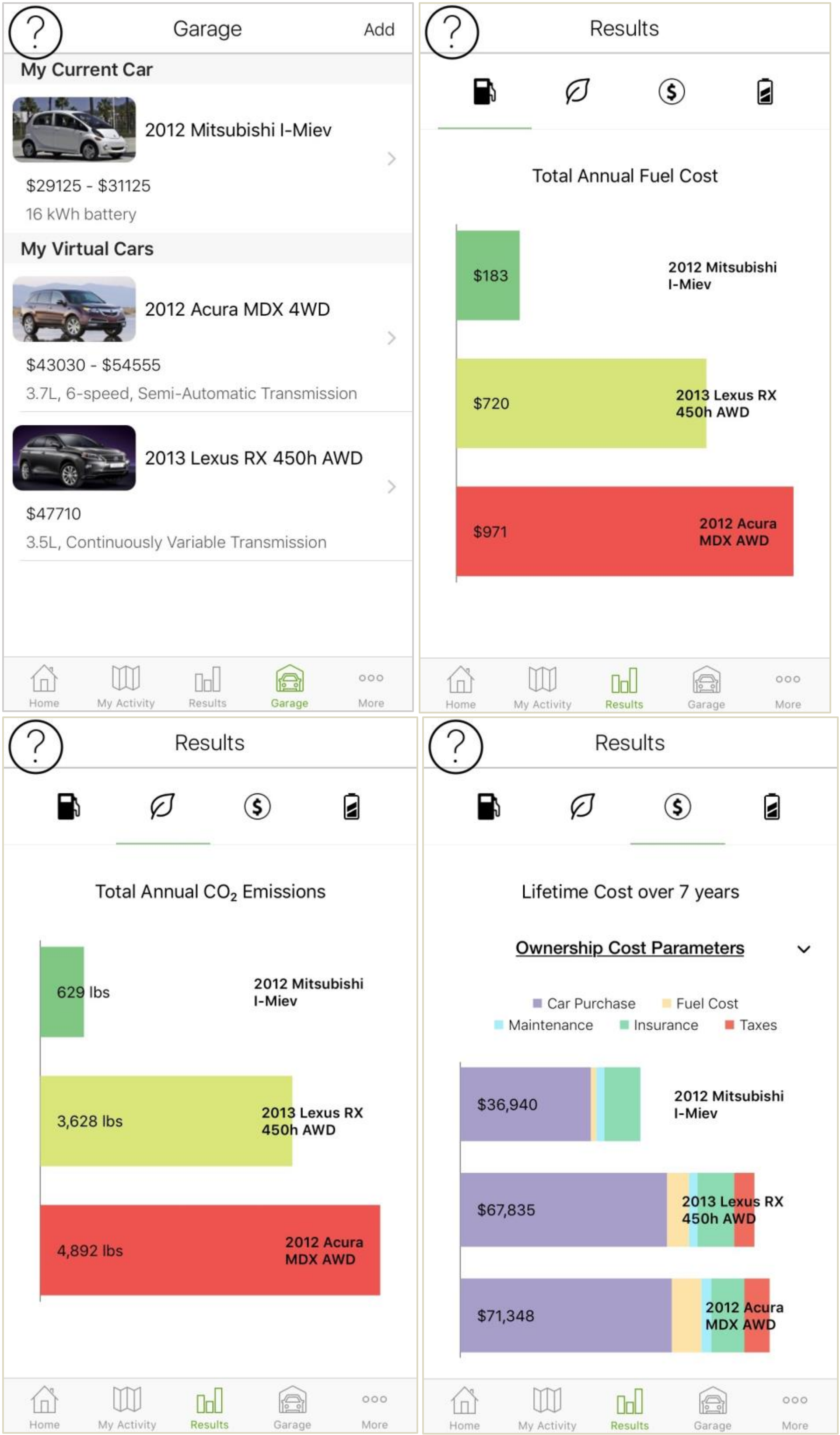


Figure 2.6. An Example Application of MyGreenCar APP

DOE’s ZEV Calculation Tool — Department of Energy also has a similar web-based ZEV comparison tool (36). Further, the DOE website provides information regarding how to rightsize vehicle fleet to conserve fuel, and how to create a sustainable green fleet policy (37). The DOE tool does not have the function of driving trajectory collection as the MyGreenCar, however, users are able to input their preferred vehicle, annual mileage, percentage highway, and other parameters. The tool will then estimate the annual fuel/electricity use, fuel/electricity cost, operating cost, cost per mile, and GHG emissions. Screenshots of the tool is provided below. This tool also supports multi-vehicle comparison. The limitation is similar with that of the MyGreenCar Mobile APP - it is not straightforward to optimize the ZEV integration into a fleet of thousands of vehicles.

Vehicle Cost Calculator

This tool uses basic information about your driving habits to calculate total cost of ownership and emissions for makes and models of most vehicles, including alternative fuel and advanced technology vehicles. Also see the cost calculator widgets.

ASSUMPTIONS

Choose vehicles to compare

Select up to eight vehicles to compare from the makes and models below or create your own custom vehicle.

2013 ▾ | Lexus ▾ | RX 450h 6cyl 3.5L Automatic (AV-S6) Hybrid ▾ | ADD >>

Create Custom Vehicle

		Vehicle	Price	Fuel Economy (City/Hwy)	Fuel Type
⊗		2012 Mitsubishi i-MiEV Automatic (A1) EV	$ 29,125 Tax credit?	27/34 kWh/100m	Electric
⊗		2012 Acura MDX 4WD 6cyl 3.7L Automatic (S6) Gasoline	$ 42,930	16/21 mpg	Gasoline
⊗		2013 Lexus RX 450h 6cyl 3.5L Automatic (AV-S6) Hybrid	$ 45,910 Tax credit?	31/28 mpg	Hybrid

Fuel Prices

Gasoline

$ 3.88 /gal

Tell us how you use your car

Because vehicle efficiencies vary depending on how you use your car, this information allows the tool to more accurately calculate fuel usage.

Normal Daily Use

Average daily driving distance 20 miles

Days per week 5

Weeks per year 49

Percent highway 45

Annual Driving Distance **8496 miles**
City Distance **4853 miles**
Highway Distance **3643 miles**

Other Trips

Annual mileage 3596 miles

Percent highway 40

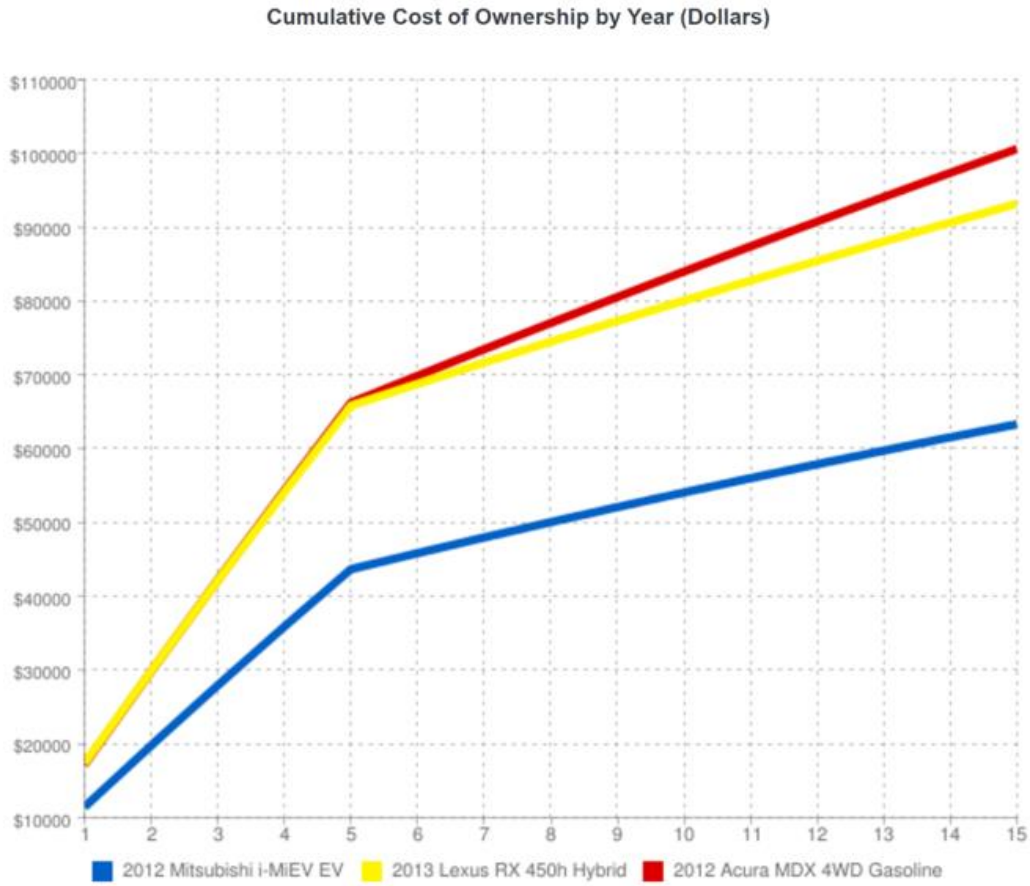
Electricity Use

Select a state so we can find the electricity price and calculate the emissions from generating electricity in your area.

California ▾

Results

Vehicle	Annual Fuel Use	Annual Electricity Use	Annual Fuel/Elec Cost	Annual Operating Cost	Cost Per Mile	Annual Emissions (lbs CO2)
2012 Mitsubishi i-MiEV EV	0 gal	2,549 kWh	$482	$2,446	$0.29	1,452
2012 Acura MDX 4WD Gasoline	477 gal	0 kWh	$1,850	$3,923	$0.46	11,443
2013 Lexus RX 450h Hybrid	287 gal	0 kWh	$1,112	$3,185	$0.37	6,880
	Graph	Graph	Graph	Graph	Graph	Graph



This graph shows the cumulative cost of ownership by year for each vehicle, including fuel, tires, maintenance, registration, license, insurance, and loan payment. The tool assumes a five-year loan with a 10% down payment. Year one on the graph represents the 10 percent down payment plus the first year's total operating costs. For more information on this graph and other calculations, see the assumptions page.

Disclaimer:
The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) do not endorse any companies or products described on the Vehicle Cost Calculator. Vehicle prices and specifications change frequently. Not all data have been verified by DOE or NREL, which manages the site. Consult a dealer or vehicle manufacturer before making purchasing decisions.

Figure 2.7. An Example Application of DOE Vehicle Cost Calculation Tool

Medium Duty Battery EV Ownership Cost Calculator — This calculator tool is developed by North American Council for Freight Efficiency (NACFE). The spreadsheet tool can be downloaded in the link (38) maintained by NACFE. The tool compares the cost of medium-duty diesel trucks and their electric counterparts based on the duty cycle factors (e.g., average/max daily mileage, annual mileage), baseline diesel/gasoline truck information (e.g., ownership period, retail price, trade-in values, insurance, maintenance, etc.), electric vehicle truck information (e.g., battery efficiency, rebate, battery replacement cost, etc.), charging infrastructure, and finance condition. The tool also includes lookup tables and suggested values to aid with the evaluation.

3. ZEV Tool Conceptual Model and Data Resources

The UCR research team collaborated with Caltrans staff to identify needs, opportunities, and constraints associated with ZEV acquisitions and deployments. Caltrans goals, requirements, and needs were clearly identified and prioritized. Caltrans and the UCR research team collaboratively discussed and identified a model concept and database architecture. Finally, the team considered and evaluated mutual state agency benefits and opportunities which could evolve from utilization of the ZEV tool.

The UCR research team utilized expertise and knowledge developed in previous projects to identify existing fleet data and operational resources. The UCR research team developed a fleet database summary architecture which considered: vehicle activity, vehicle specifications, vehicle classifications, refueling, charging, vehicle usage history, and additional parameters identified through evaluation of existing databases. The UCR research team coordinated with Caltrans to obtain access to existing databases and resources. The UCR research team identified which pertinent data sources were available and which required additional data collection efforts.

The ZEV Team utilized Caltrans existing telematics services and contracts to obtain relevant vehicle activity data. The evaluation and acquisition of telematics based vehicle activity included the following:

- Identification of relevant ZEV data fields;
- Download of vehicle activity data for the estimated 13000 vehicles;
- Parsing of significant data parameters;
- Development of a vehicle ID indexed database;
- Database development of Caltrans vehicle trips, and;
- Evaluation methods to estimate other relevant trip characteristics (e.g., idle time).

The UCR team utilized prior and existing database tools and analysis techniques to refine the database parameters. Figure 3.1 shows initial GIS techniques to geo-match vehicle activity and refueling operations. UCR integrated GIS tools and existing databases to filter and process ZEV relevant data.

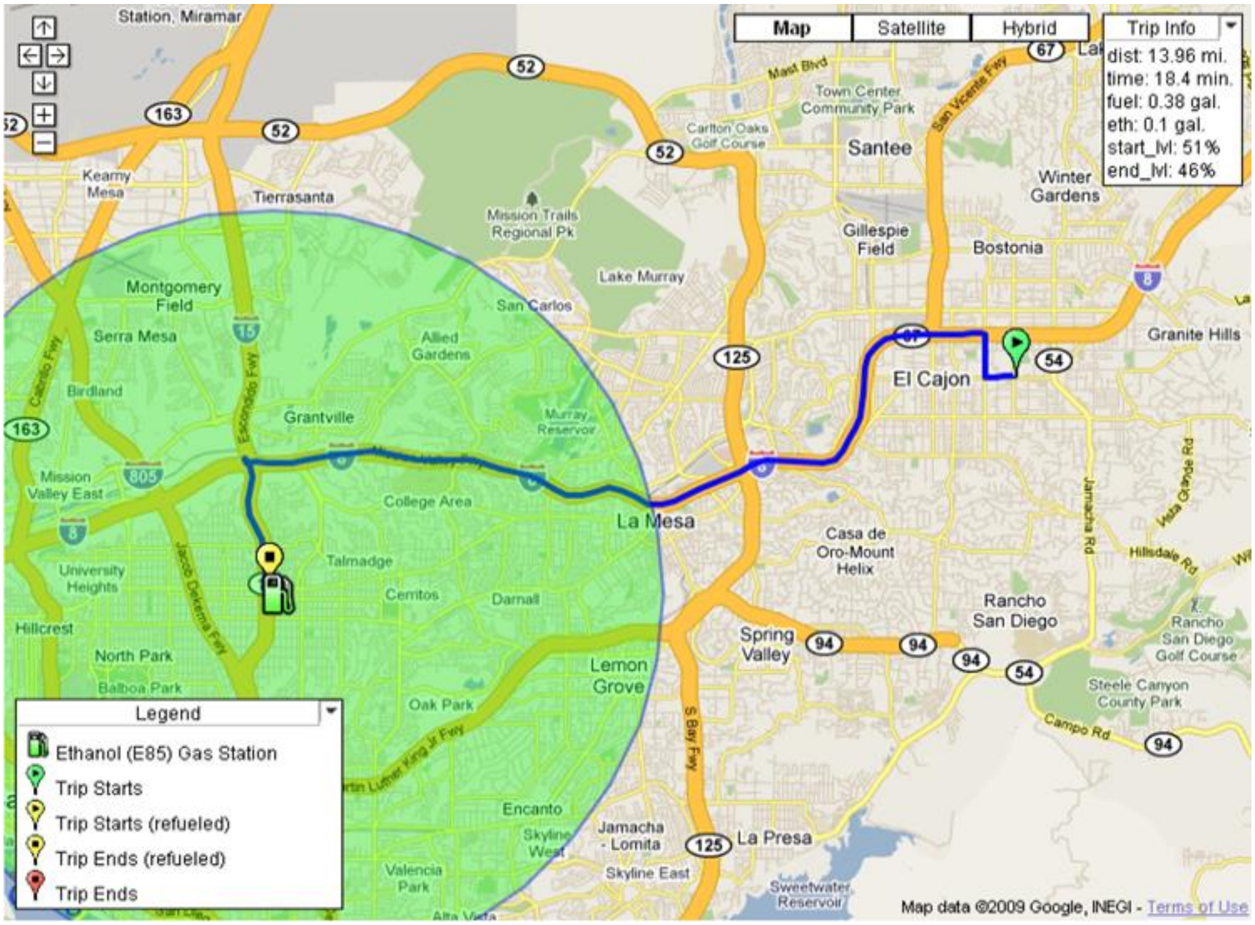


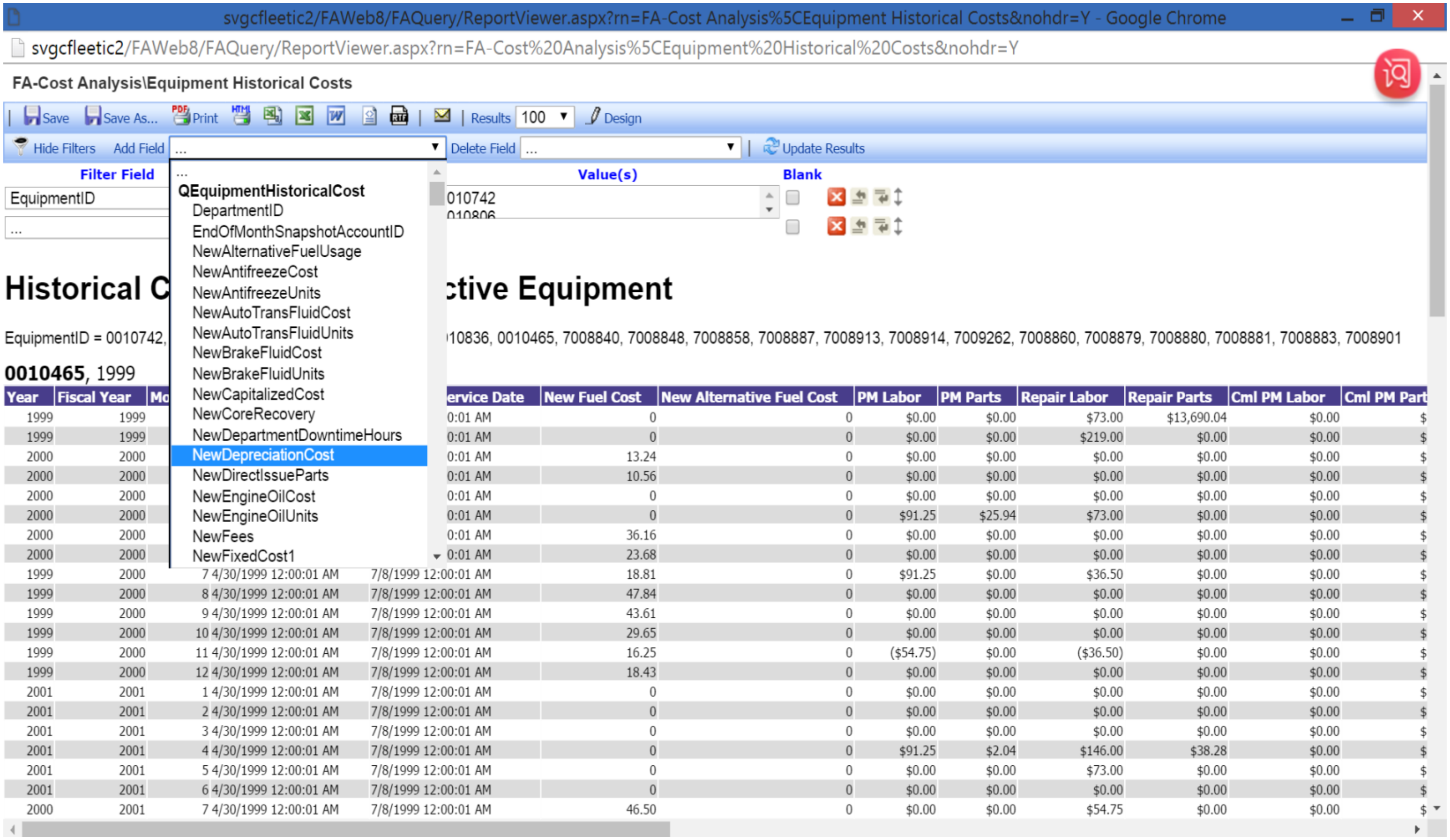
Figure 3.1. Refueling vehicle activity geo-matched with refueling location

3.1 Caltrans Equipment Databases

Caltrans currently utilizes numerous vehicle database systems and methods to manage fleet maintenance, operations, fueling, vehicle activity, and vehicle acquisitions. The development team and Caltrans coordinated on selecting data parameters, vehicle variables, and relevant vehicle activity utilized to identify relevant vehicle parameters and database fields.

One of the primary database utilized by Caltrans operations and maintenance is Assetworks. Figure 3.2 shows an example of the Assetworks vehicle spreadsheet. The Assetworks database tool lists vehicle information relevant to vehicle costs and maintenance throughout the vehicle's presence in the Caltrans fleet. The Assetworks database is valuable in aligning vehicle identification parameters (vehicle ID, year, make, model, classification, etc.) with operational and maintenance costs. The development team evaluated the available tables and data fields available throughout the Assetworks utility. While the database provides extensive information of vehicle costs, repairs, maintenance, reliability, and service requirements the most valuable data fields for the ZEV tool did not require continued updates or downloads from the Assetworks database.

The most relevant static vehicle parameters are populated across numerous existing databases and only require updates when vehicles are newly acquired or change assignments. Table 3.1 provides vehicle information indexed by Equipment ID. The vehicle year, make, model, maintenance class, district, and assigned department are all variables determined to be necessary for reference within the ZEV tool architecture. These parameters are considered static parameters within the ZEV database and are frequently intended to be utilized for vehicle selection procedures within the ZEV tool database.



Year	Fiscal Year	Mo		ervice Date	New Fuel Cost	New Alternative Fuel Cost	PM Labor	PM Parts	Repair Labor	Repair Parts	Cml PM Labor	Cml PM Part
1999	1999			0:01 AM	0	0	$0.00	$0.00	$73.00	$13,690.04	$0.00	$
1999	1999			0:01 AM	0	0	$0.00	$0.00	$219.00	$0.00	$0.00	$
2000	2000			0:01 AM	13.24	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2000	2000			0:01 AM	10.56	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2000	2000			0:01 AM	0	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2000	2000			0:01 AM	0	0	$91.25	$25.94	$73.00	$0.00	$0.00	$
2000	2000			0:01 AM	36.16	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2000	2000			0:01 AM	23.68	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
1999	2000	7	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	18.81	0	$91.25	$0.00	$36.50	$0.00	$0.00	$
1999	2000	8	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	47.84	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
1999	2000	9	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	43.61	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
1999	2000	10	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	29.65	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
1999	2000	11	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	16.25	0	($54.75)	$0.00	($36.50)	$0.00	$0.00	$
1999	2000	12	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	18.43	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2001	2001	1	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2001	2001	2	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2001	2001	3	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2001	2001	4	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$91.25	$2.04	$146.00	$38.28	$0.00	$
2001	2001	5	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$0.00	$0.00	$73.00	$0.00	$0.00	$
2001	2001	6	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	0	0	$0.00	$0.00	$0.00	$0.00	$0.00	$
2000	2001	7	4/30/1999 12:00:01 AM	7/8/1999 12:00:01 AM	46.50	0	$0.00	$0.00	$54.75	$0.00	$0.00	$

Figure 3.2. Assetworks vehicle repair cost table.

Table 3.1. Equipment ID indexed vehicle static parameter table

Equipment ID	Model Year	Manufacturer ID	Model ID	Equipment description	License No	Asset Number	Department ID
0010052	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1351726		371758
0010602	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1038468		04-1042
0010606	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1038141		33055
0010910	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1063640		839542
0010914	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1075624		178818
0010915	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1075625		56-3482
0010917	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1076086		03-0516
0010918	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1076087		03-0516
0011603	2002	DODGE	B3500	VAN MAINTENANCE FULL SIZE	1123121		04-1049
0011605	2002	DODGE	B3500	VAN MAINTENANCE FULL SIZE	1324262		06-1334
0011606	2002	DODGE	B3500	VAN MAINTENANCE FULL SIZE	1123084		38534
0014444	2000	GMC	G3500	VAN MAINTENANCE FULL SIZE	1075628		06-1644
0020081	1998	FORD	E350	VAN MAINTENANCE FULL SIZE	963134		263615
0020610	1999	GMC	G3500	VAN MAINTENANCE FULL SIZE	1038218		01-0077
0020612	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1038168		03-0495
0020614	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1038266		06-1626
0020615	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1038142		32690
0020616	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1035566		30133
0020618	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1035568		50587
0020621	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1035571		22828
0020622	1999	GENERAL MOTORS	G3500	VAN MAINTENANCE FULL SIZE	1035572		72137

3.2 ZEV Refueling Databases

One of the primary functions of the ZEV tool is to evaluate vehicle refueling requirements based on existing vehicle trip patterns and trip activity. Evaluation of vehicle refueling requires knowledge of existing refueling infrastructure for both battery electric and hydrogen fuel cell vehicles. The development team reviewed numerous sources for EVSE infrastructure. Some of the key requirements for EVSE were connection specifications, such as, Level II, Fast DC, J1772, CHAdeMO, CCS, Tesla. Additionally, knowing if the EVSE infrastructure was publicly accessible or private. More specifically, the team also gathered information of Caltrans owned or operated EVSE infrastructure. Since specific models of battery electric ZEVs can only utilize compatible EVSE equipment knowledge of available EVSE is vital for accurate ZEV analysis.

The development team focused on ZEV EVSE tools that provided up to date infrastructure information with the ability to download relevant database data fields. One of the available tools was the NREL CEC EV Infrastructure tool shown in Figure 3.3. This tool provided valuable information at the county level with projections and estimates of charger usage. An additional database is the alternative fuels station map shown in Figure 3.4. The development found characteristics of each tool to provide some beneficial characteristics for integrating within the Caltrans ZEV tool database.

In addition to EVSE infrastructure characteristics the ZEV tool database required Hydrogen refueling station data. Hydrogen refueling infrastructure consists of either 350 bar or 700 bar delivery pressure. The preferred refueling station database would provide georectified information that would allow placement on maps along with GPS based vehicle trip information. The preferred EVSE and hydrogen refueling database became the DOE AFDC database shown in Table 3.2.

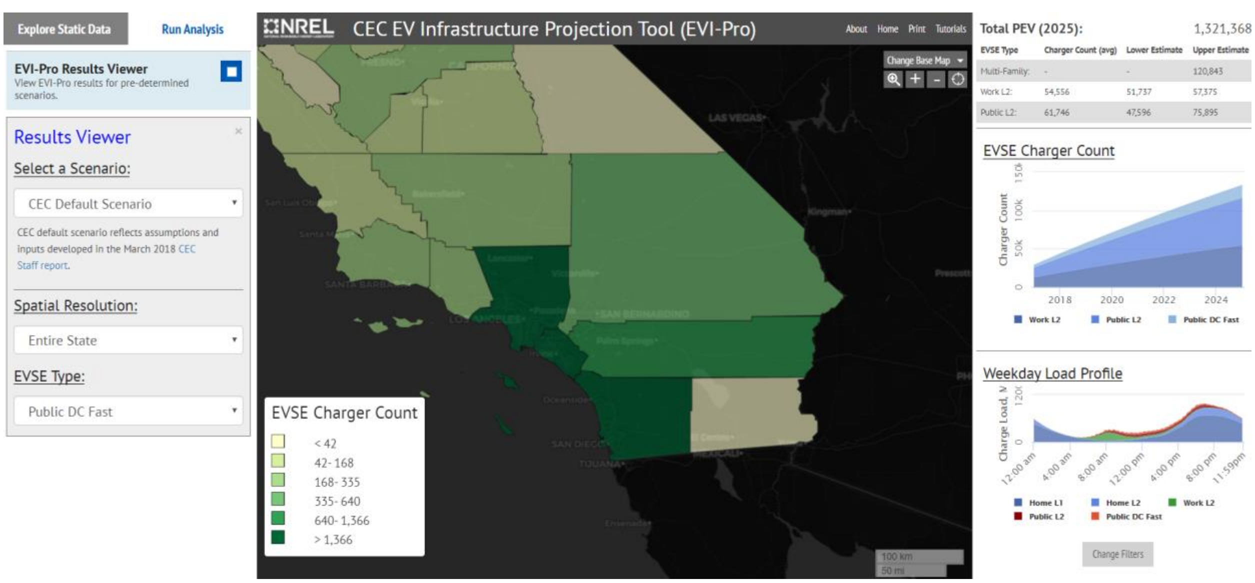


Figure 3.3. NREL electric vehicle suppl equipment database tool

ALTERNATIVE FUEL STATION LOCATOR

- Western Riverside County Alternative Fuel and Advanced Technology Station Map (PDF)

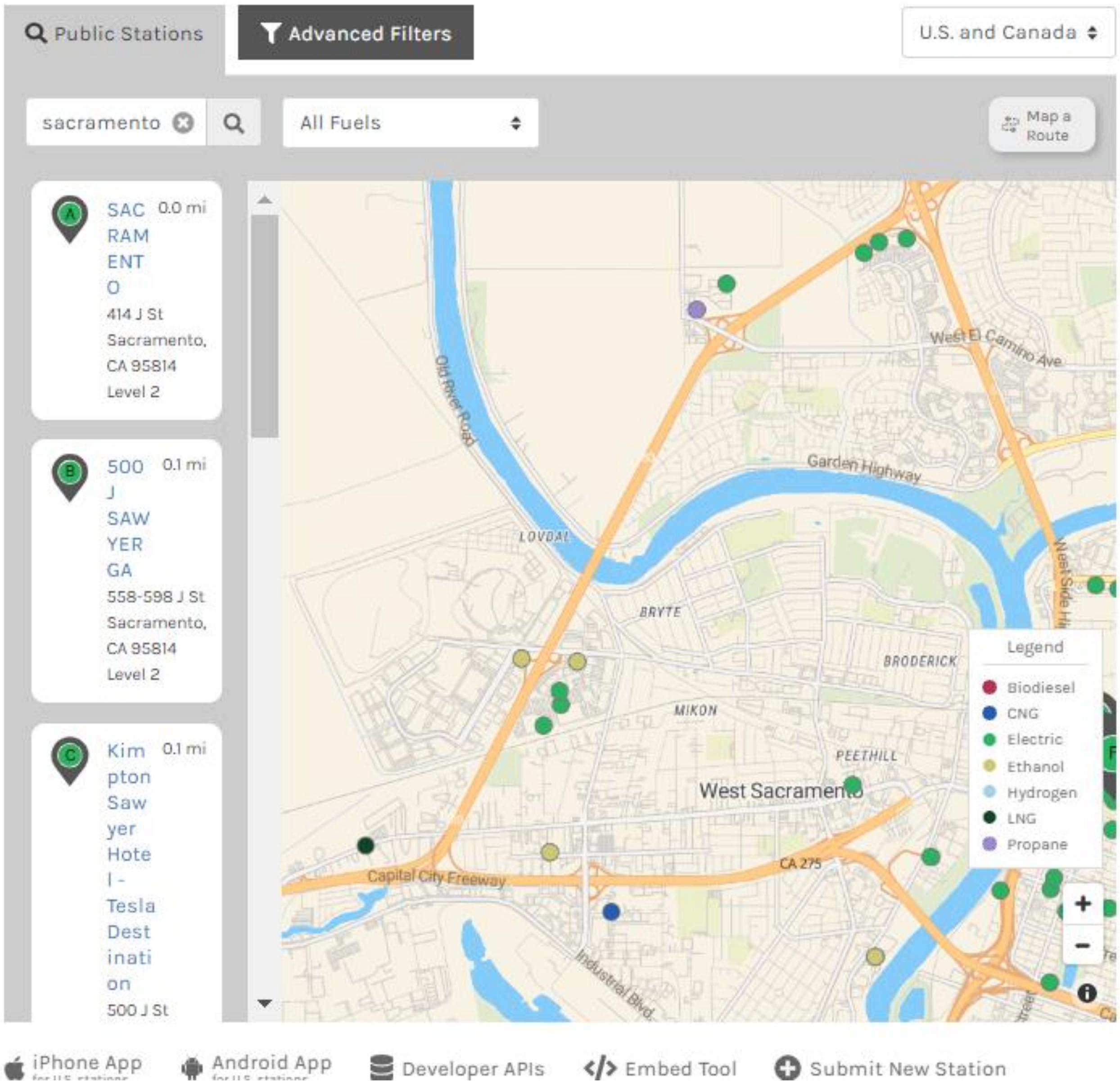


Figure 3.4. Alternative Fuel Station Locator Map hosted by WRCOG.

Table 3.2. DOE AFDC alternative fuel vehicle station database

Station Counts by State and Fuel Type																
State	Biodiesel	CNG	E85	Electric[a]					Hydrogen[b]			LNG	Propane[c]			Total[d]
				Station locations	EVSE ports	Level 1	Level 2	DC Fast	Retail	Non-Retail	Total		Primary	Secondary	Total	
California	9	164	234	13,272	34,088	295	27,664	6,092	47	0	47	17	134	88	222	34,781
Colorado	4	18	81	1,395	3,299	61	2,739	499	0	0	0	0	27	19	46	3,448
Connecticut	0	7	3	459	1,218	21	909	286	0	0	0	0	10	9	19	1,247
Delaware	0	1	0	105	261	2	178	81	0	0	0	0	7	2	9	271
District of Columbia	0	0	1	236	660	18	603	39	0	0	0	0	0	0	0	661
Florida	1	26	105	2,268	5,624	36	4,537	1,051	0	0	0	2	75	43	118	5,876
Georgia	1	24	52	1,509	3,766	200	3,013	553	0	0	0	4	35	40	75	3,922
Hawaii	7	0	0	363	747	5	658	84	1	0	1	0	1	0	1	756
Idaho	0	2	3	104	261	0	181	80	0	0	0	0	10	14	24	290

[a] *Includes legacy chargers but does not include residential electric vehicle charging infrastructure.*

[b] *Retail hydrogen stations accept payment at the point of sale. Non-retail hydrogen stations are only available to a certain subset of customers (e.g., require an access card, PIN, or training).*

[c] *Primary propane stations offer vehicle-specific fueling capabilities. Secondary propane stations have fuel available for use in vehicles but limited vehicle fueling services*

[d] *Totals are the number of station locations for all fuel types combined. Individual stations count multiple times if the station offers more than one fuel type. For electric, the total includes EVSE ports rather than station locations. For hydrogen, the total includes all (retail and non-retail) stations. For propane, the total includes all (primary and secondary) stations.*

3.3 Vehicle Activity Databases

Determining the viability and feasibility of transitioning a vehicle to an ZEV powertrain is heavily dependent on vehicle usage conditions. Passenger vehicles that always travel short distances and park in the vicinity of appropriate refueling infrastructure could easily transition to ZEV. Alternatively, specialty vehicles (sweepers, snowplows, cone trucks, etc.) that travel many miles per day have limited options due to availability of needed vehicle specifications and availability of refueling infrastructure. The Caltrans fleet has been equipped for years with GPS based vehicle activity monitoring systems. The initial 3 years deployment consisted of Networkfleet followed by a transition to Geotab beginning in 2020. The development team determined that the existing and future vehicle activity databases would be necessary to determine ZEV compatibility.

3.3.1 NetworkFleet Vehicle Activity Data

Networkfleet utilizes a GPS based vehicle telematics unit connected to a vehicle's OBDII data port connection. The telematics device collects trip by trip information and stores the data into vehicle specific data files. The Networkfleet data files provide: trip start time, trip start location, trip end time, trip end location, trip travel time, trip distance, and trip path in 2 minute increments. The location data is reported in GPS location format suitable for geospatial analysis.

3.3.2 Geotab Vehicle Activity Data

Geotab also utilizes a GPS based vehicle telematics unit connected to a vehicle's OBDII data port connection. The telematics device collects trip by trip information and stores the data into two vehicle specific data files. Geotab data files consist of a trip summary file detailing: vehicle information, trip length, trip time, average speed, idle time, and maximum speed. The second Geotab data files provide GPS trip path in path detailed based on speed and turning movements. An example of Geotab location based trip information is provided in Table 3.3 for a single vehicle's trip activity on March 12, 2019. The vehicle completed several trips as detailed by the Ignition/Status field and Odometer field. The data in the trip activity table forms the basis for the mapping function displayed in Figure 3.5. The Geotab trip mapping function provides a cloud based interface to visualize trip origins, destinations, and routes. Geotab also provides a cross reference vehicle information table of Caltrans vehicle ID, make, model, year and classification as shown in Table 3.4. The table also lists vehicle type and odometer when available. Trip information is also summarized in the Geotab trip summary table with an example shown in Table 3.5. Trip summary information details each trip as a row in the table with pertinent data (start, stop, duration, idling, distance) as columns. Geotab trip activity data reporting interval is based on changes in speed and location. This characteristic provides variation in reporting frequency as shown in Figure 3.6. The figure shows increased reporting in proportion to changes in vehicle speed. The cloud-based Geotab interface provides trip activity details that have been transferred through an Application Programming Interface (API) to the ZEV tool for more detailed analysis capabilities.

Table 3.3. Geotab application cloud based trip activity table

Label	VIN	Date	Ignition/Status	Latitude	Longitude	Odometer	Avg Spd (mph)	Max Spd (mph)	Posted Spd (mph)	Groups
0010402	JT2BK12U81003204	3/12/19 8:34:14 AM	On	35.134435	-120.619875	158,392.7	0	0	45	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:36:14 AM	On	35.135786	-120.621937	158,392.8	4	30	45	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:38:15 AM	On	35.147591	-120.645546	158,394.5	50	61	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:40:16 AM	On	35.161102	-120.679893	158,396.7	63	67	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:42:16 AM	On	35.183004	-120.701226	158,398.7	61	66	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:44:17 AM	On	35.212017	-120.696675	158,400.7	61	66	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:46:19 AM	On	35.238542	-120.68352	158,402.8	61	65	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:48:20 AM	On	35.242311	-120.676408	158,403.4	20	63	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:49:56 AM	Off	35.245511	-120.673493	158,403.7	11	32	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:55:28 AM	On	35.245511	-120.673493	158,403.7	0	0	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:57:29 AM	On	35.245511	-120.673422	158,403.7	0	0	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 8:59:29 AM	On	35.245511	-120.674204	158,403.7	1	17	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 9:01:30 AM	On	35.257315	-120.668515	158,404.6	26	41	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 9:03:14 AM	Off	35.261795	-120.667733	158,404.9	11	39	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:31:38 PM	On	35.261795	-120.667733	158,404.9	0	0	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:33:38 PM	On	35.267982	-120.670364	158,405.4	16	40	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:35:39 PM	On	35.267128	-120.670862	158,405.7	7	24	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:36:49 PM	Off	35.267626	-120.671004	158,405.7	1	11	35	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:39:58 PM	On	35.267626	-120.671004	158,405.7	0	0	35	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:41:59 PM	On	35.261795	-120.667875	158,406.3	19	39	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 1:42:38 PM	Off	35.261795	-120.667733	158,406.3	0	0	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:06:31 PM	On	35.261795	-120.667733	158,406.3	0	0	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:08:32 PM	On	35.266204	-120.670435	158,406.7	12	40	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:10:32 PM	On	35.267768	-120.670364	158,406.8	2	34	--	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:12:33 PM	On	35.264853	-120.6752	158,407.2	11	36	35	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:14:34 PM	On	35.242808	-120.683377	158,408.9	51	65	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:16:34 PM	On	35.214648	-120.696746	158,411.1	66	68	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:18:35 PM	On	35.188124	-120.701297	158,413.0	55	65	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:20:37 PM	On	35.162808	-120.6848	158,415.0	61	67	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY
0010402	JT2BK12U81003204	3/12/19 5:22:38 PM	On	35.153493	-120.661191	158,416.5	43	56	65	06-1330 | 06-1573 | ADMINISTRATION (5000) | CAPITAL OUTLAY

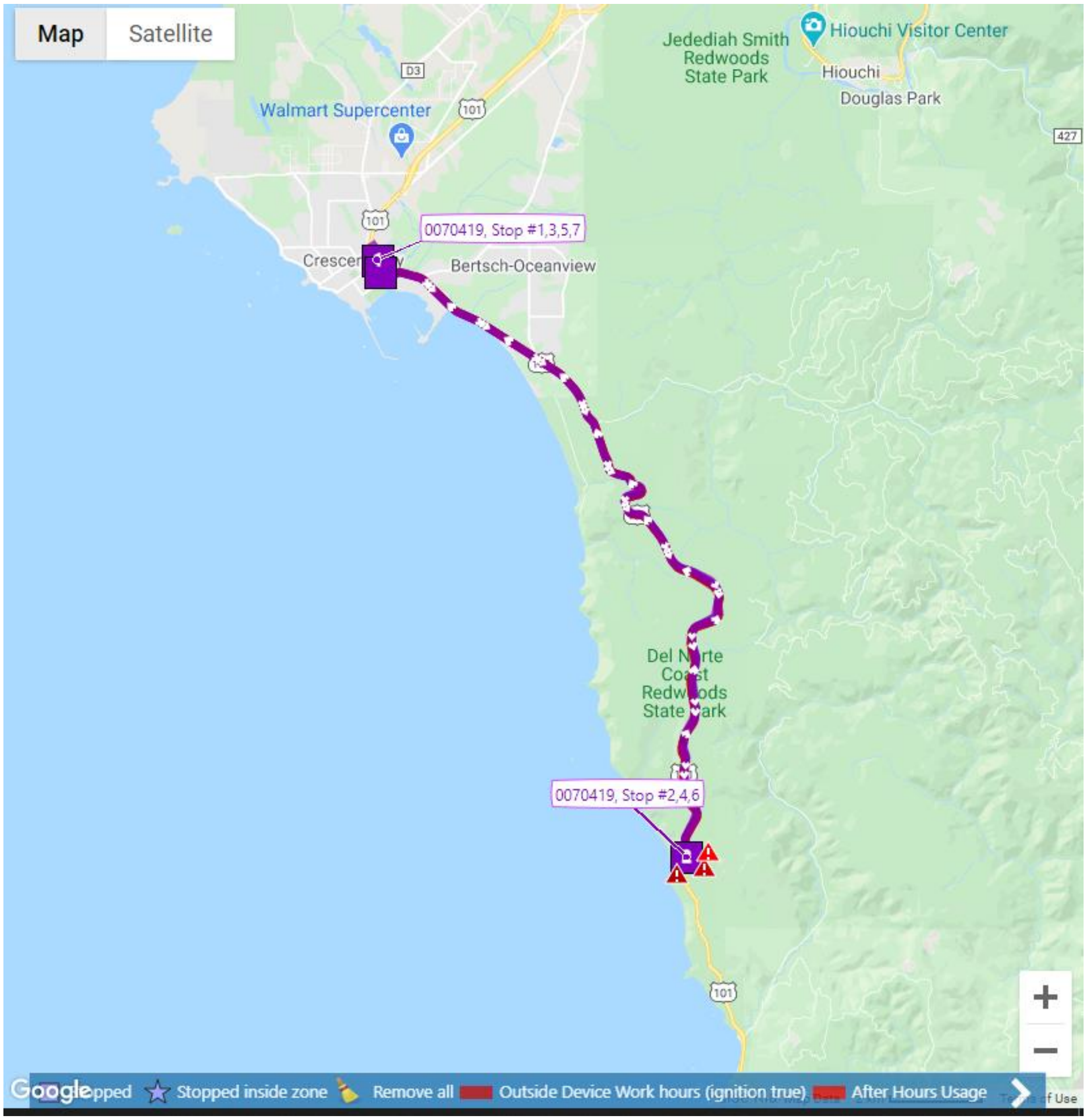


Figure 3.5. Geotab application cloud-based mapping function

Table 3.4. Geotab vehicle information table

Vehicle	Make	Model	Year	Vehicle Type	Class	Odometer
0010402	Toyota	Prius	2001	Passenger Car	No Class	8
0010917	GMC	Savanna	2000		Class H (9001 -10000 lbs)	408
0010918	GMC	Savanna	2000		Class H (9001 -10000 lbs)	0
0010921	Dodge	Caravan / Grand Caravan	2002		Class D (5001 -6000 lbs)	191560
0010929	Dodge	Caravan / Grand Caravan	2002		Class D (5001 -6000 lbs)	112344
0010932	Dodge	Caravan / Grand Caravan	2002		Class D (5001 -6000 lbs)	0
0010945	Dodge	Caravan / Grand Caravan	2002		Class D (5001 -6000 lbs)	217072
0011605	Dodge	Ram Wagon / Ram Van	2002	Bus	No Class	857
0012026	Toyota	Prius	2002	Passenger Car	No Class	3251
0014444	GMC	Savanna	2000		Class H (9001 -10000 lbs)	1728
0016010	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	406
0016022	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	1709
0016026	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	1688
0016030	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	1188
0017027	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	2086
0017038	GMC	Safari Van	2000		Class D (5001 -6000 lbs)	404

Table 3.5. Geotab vehicle trip summary table

Device	Driver	Start Date	Driving Duration	Stop Date	Distance	Stop Duration	Location	Idling Duration	Maximum Speed
7003595	328211	Dec 03, 2020 4:10:37 PM	0:01	Dec 03, 2020 4:11:40 PM	0	0:20	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0:00	9
7003595	328211	Dec 03, 2020 4:31:54 PM	0:52	Dec 03, 2020 5:24:32 PM	40	12:54	6688 Central Ave, Ukiah, CA 95482, USA	0:12	63
7003595	328211	Dec 04, 2020 6:19:19 AM	0:07	Dec 04, 2020 6:26:55 AM	4	0:44	3188 N State St, Ukiah, CA 95482, USA	0:00	69
7003595	328211	Dec 04, 2020 7:11:18 AM	0:00	Dec 04, 2020 7:11:46 AM	0	4:55	Hamby Ford Rd, Ukiah, CA 95482, USA	0:00	10
7003595	328211	Dec 04, 2020 12:07:09 PM	0:08	Dec 04, 2020 12:15:28 PM	4	19:06	6688 Central Ave, Ukiah, CA 95482, USA	0:14	66
7003595	328211	Dec 05, 2020 7:21:30 AM	0:50	Dec 05, 2020 8:12:22 AM	40	1:29	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0.25	66
7003595	328211	Dec 05, 2020 9:42:16 AM	0:50	Dec 05, 2020 10:32:56 AM	40	42:14	6688 Central Ave, Ukiah, CA 95482, USA	0.25	66
7003595	328211	Dec 07, 2020 4:47:13 AM	0:48	Dec 07, 2020 5:35:38 AM	40	0:50	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0:00	66
7003595	328211	Dec 07, 2020 6:26:18 AM	0:00	Dec 07, 2020 6:26:46 AM	0	1:48	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0:00	9
7003595	328211	Dec 07, 2020 8:15:32 AM	0:00	Dec 07, 2020 8:16:13 AM	0	0:31	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0:00	0
7003595	328211	Dec 07, 2020 8:47:30 AM	0:00	Dec 07, 2020 8:47:58 AM	0	64:02	13070 State Hwy 20, Clearlake Oaks, CA 95423, USA	0:00	4

Figure 3.6. Geotab application cloud-based speed mapping function

4. Database Creation and Prioritization

Utilizing the databases described in the previous section, the UCR research team created a database of relevant fleet and infrastructure information. The database serves as the foundation for ZEV based analysis and spreadsheet tools. The database creation includes the following:

- Relevant Caltrans data from Caltrans owned or accessible sources;
- Caltrans accessible charging stations and hydrogen stations;
- Caltrans facilities;
- Database of available ZEVs and attributes; and,
- Number of Occupants (based on available information).

Utilizing the data and information gathered in previous tasks the UCR research team developed a prioritized list of ZEV integration factors in coordination with Caltrans staff. The prioritized factors identify the parameters required for anticipated statewide ZEV deployment which meets State and regulatory requirements. Figure 4.1 shows the database input components and ZEV tool architecture. Figure 4.2 displays the majority of parameters utilized in the ZEV tool.

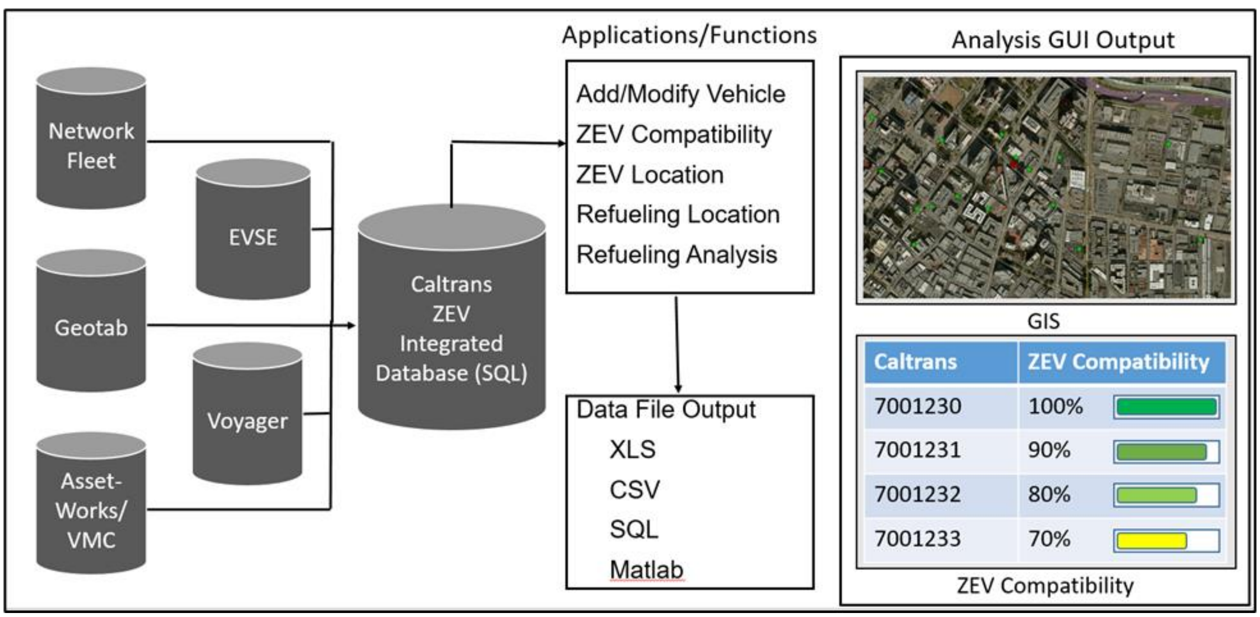


Figure 4.1. Caltrans ZEV tool database architecture

	EQUIP ID	Year	Make	Model	Trips	Non-Idle Trips	Idle Trips	Miles	Avg Miles/Trip	Max Miles/Trip	Avg Miles/Day	Max Miles/Trip	Avg Miles/Day	Max Miles/Day	Hours	Idle	Avg Idle/Trip	Max Idle/Trip	Avg Idle/Day	Max Idle/Day	ZEV	non-ZEV	% ZEV
1	0337336	2004	INTL TRUCK	4400	478	357	121	1798.6	5.0	84.6	14.7	175.8	14.7	175.8	169.0	8.5	0.1	0.6	0.1	0.6	471	7	98
2	7002044	2005	FREIGHTLINER	M2106	276	201	75	3424.0	17.0	119.0	39.8	189.4	39.8	189.4	269.5	8.8	0.1	0.9	0.1	0.9	255	21	92
3	0252388	2004	INTL TRUCK	4300	274	182	92	2821.8	15.5	95.2	27.9	189.7	27.9	189.7	213.3	22.2	0.2	2.3	0.2	2.9	269	5	98
4	7003609	2008	INTL TRUCK	4400	823	641	182	10929.7	17.1	142.2	53.1	194.8	53.1	194.8	1019.8	17.7	0.1	4.1	0.1	4.1	767	56	93
5	0252399	2004	INTL TRUCK	4400	558	419	139	8385.6	20.0	185.7	43.7	185.9	43.7	185.9	800.5	13.5	0.1	1.6	0.1	2.1	518	40	92
6	0256346	1995	INTL HARVESTER	4700	574	551	23	3614.2	6.6	70.7	31.4	138.7	31.4	138.7	136.6	10.7	0.5	7.0	0.1	7.0	554	20	96
7	7004514	2010	INTL TRUCK	4400	993	762	231	10074.4	13.2	112.6	47.1	209.1	47.1	209.1	1091.6	22.2	0.1	1.6	0.1	1.6	925	68	93
8	0257546	2000	NAVISTAR	4900	104	92	12	1934.9	21.0	110.6	56.9	151.8	56.9	151.8	188.4	1.0	0.1	0.3	0.0	0.3	88	16	84
9	0257047	1997	INTL HARVESTER	4900	300	277	23	5265.9	19.0	112.3	45.8	157.1	45.8	157.1	517.2	0.9	0.0	0.2	0.0	0.2	268	32	89
10	0257051	1997	INTL HARVESTER	4900	244	201	43	6216.5	30.9	187.2	73.1	205.7	73.1	205.7	329.5	4.0	0.1	1.2	0.0	1.2	193	51	79
11	0339200	2000	NAVISTAR	4900	686	389	297	5029.5	12.9	88.1	28.4	167.1	28.4	167.1	257.1	32.3	0.1	2.2	0.2	2.4	652	34	95
12	7006439	2013	INTL TRUCK	4400	330	132	198	6099.3	46.2	254.4	44.8	254.4	44.8	254.4	791.6	395.0	2.0	10.5	2.9	10.5	277	53	83
13	0258220	1999	KODIAK	CR45	651	405	246	6738.5	16.6	166.8	48.5	166.8	48.5	166.8	583.9	25.4	0.1	1.6	0.2	2.6	616	35	94
14	7006020	2010	INTL TRUCK	4400	190	159	31	3962.4	24.9	116.3	74.8	266.2	74.8	266.2	403.8	1.9	0.1	0.2	0.0	0.8	126	64	66
15	0335845	1993	FORD	F700	340	300	40	6417.8	21.4	241.2	72.1	258.7	72.1	258.7	435.2	4.2	0.1	0.9	0.0	0.9	298	42	87
16	7005832	2013	INTL TRUCK	4400	1234	976	258	16119.6	16.5	266.2	103.3	308.8	103.3	308.8	487.7	13.0	0.1	0.6	0.1	0.8	1058	176	85
17	0256712	1996	WHITE	FE42	249	118	131	2332.4	19.8	98.4	37.6	175.8	37.6	175.8	180.3	12.3	0.1	1.2	0.2	1.4	233	16	93
18	0257601	2001	INTL TRUCK	4900	647	418	229	12112.5	29.0	183.0	83.5	209.8	83.5	209.8	583.9	41.5	0.2	3.1	0.3	3.1	580	67	89
19	0335844	1993	FORD	F700	128	95	33	1046.8	11.0	48.6	20.1	74.7	20.1	74.7	118.9	4.6	0.1	1.6	0.1	1.6	128	0	100
20	0257343	1999	GMC	C7H042	480	443	37	3679.6	8.3	89.0	29.7	130.8	29.7	130.8	464.1	3.6	0.1	0.5	0.0	0.5	474	6	98
21	0338220	1999	NAVISTAR	4900	254	183	71	3552.3	19.4	165.5	48.7	409.7	48.7	409.7	100.7	3.0	0.0	0.2	0.0	0.2	228	26	89

EQUIP ID - Caltrans Equipment ID

Year - Vehicle year

Make - Vehicle make

Model - Vehicle model

Trips - Total trips (key on to off) in selected time period

Non-Idle Trips - Non-idle trips

Idle Trips - Trips that has a distance of 0

- Miles - Total miles traveled in selected time period
- Avg Miles/Trip - Average miles per non-idle trip
- Max Miles/Trip - Maximum miles traveled in a trip
- Avg Miles/Day - Average miles traveled per operating day
- Max Miles/Day - Maximum miles traveled per day
- Hours - Total hour duration of non-idle trips
- Idle - Total hour duration of idle trips
- Avg Idle/Trip - Average hours per idle trip
- Max Idle/Trip - Maximum hours in an idling trip
- Avg Idle/Day - Average hours of idle trip per day
- Max Idle/Day - Maximum hours of idle trip per day
- ZEV - ZEV-compatible trips
- non-ZEV - non-ZEV compatible trips
- ZEV % - ZEV-compatible percentage

Figure 4.2. Caltrans ZEV tool database fields

4.1 Trip Activity Spatial Representation

Utilizing vehicle activity databases the development team was able to spatially represent travel patterns regionally and throughout the state. Caltrans GPS based trip activity was processed to determine which locations were most frequently travelled and which locations were least travelled. The travel patterns were also evaluated relative to EVSE locations and hydrogen refueling stations. Figure 4.3 provides a statewide representation of geo-location travel frequency as a heat map. The red squares represent the highest frequency of travel. The blue squares represent the lowest amount of trip frequency. The orange and yellow squares represent moderate and low frequency, respectively. The heat map vehicle activity representation has been utilized to visualize extensive GPS data sets. The heat map methodology has also been utilized for regional analysis. Figure 4.4 shows District 3 sedan trip activity in the Sacramento region with EVSE chargers shown as black dots. Regions that portray a high trip activity with many red squares should ideally possess a larger presence of EVSE (black dots).

Figure 4.5, Figure 4.6, and Figure 4.7 display heat maps for District 7 sedan trips. The red squares represent the highest frequency of travel. The blue squares represent the lowest amount of trip frequency. The orange and yellow squares represent moderate and low frequency, respectively. The CCS compliant DC fast chargers are shown a plus signs. The Tesla fast DC chargers are displayed a lightning bolts. Figure 4.6 shows blue highlighted squares that are colored red but lacking CCS compatible EVSE within 4 miles. Figure 4.7 shows blue highlighted squares that are colored red but lacking Tesla compatible EVSE within 10 miles. The Tesla distance was selected as 10 miles due to the extended range of the Tesla vehicles over most CCS compatible vehicles. Figure 4.6 and Figure 4.7 are examples of analysis methods to identify regions which may need to be considered for additional EVSE deployment.

Figure 4.3. District 3 sedan vehicle activity GPS travel heat map

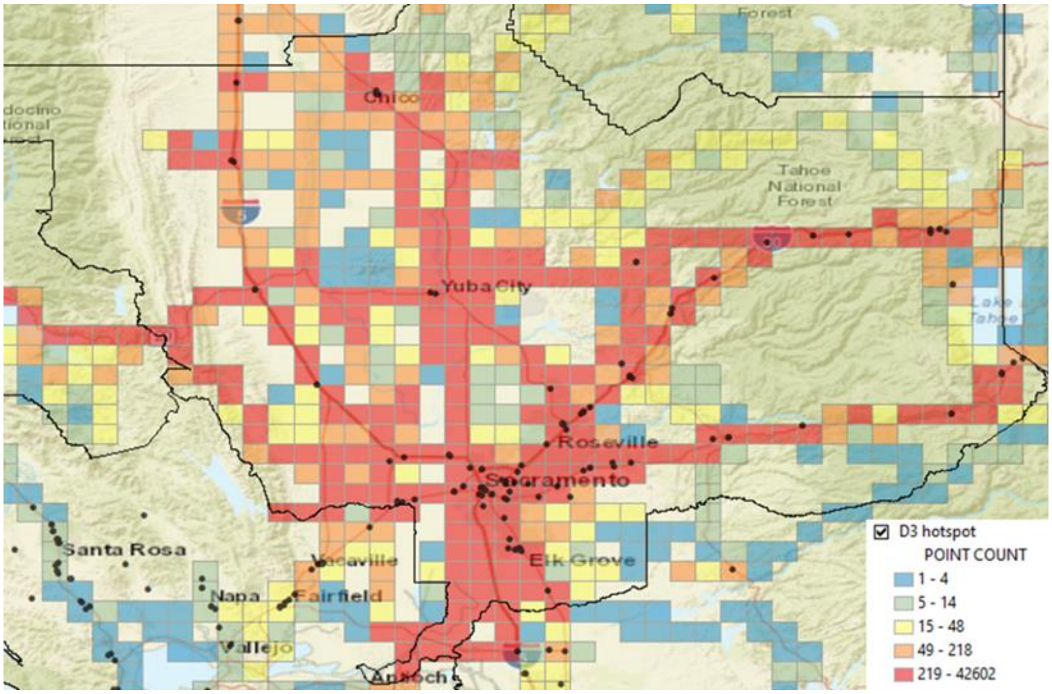


Figure 4.4. District 3 regional sedan vehicle activity GPS travel heat map

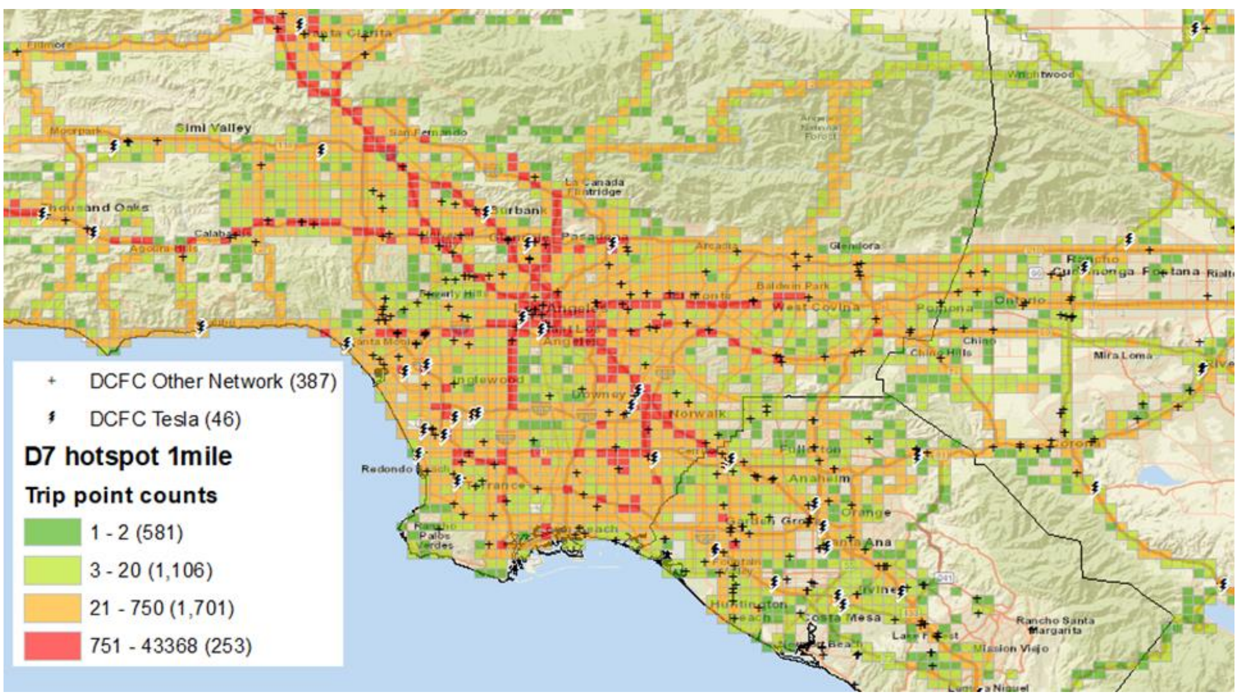


Figure 4.5. District 7 regional sedan vehicle activity GPS travel heat map

Figure 4.6. District 7 regional sedan vehicle activity GPS travel heat map with CCS and CHAdeMO

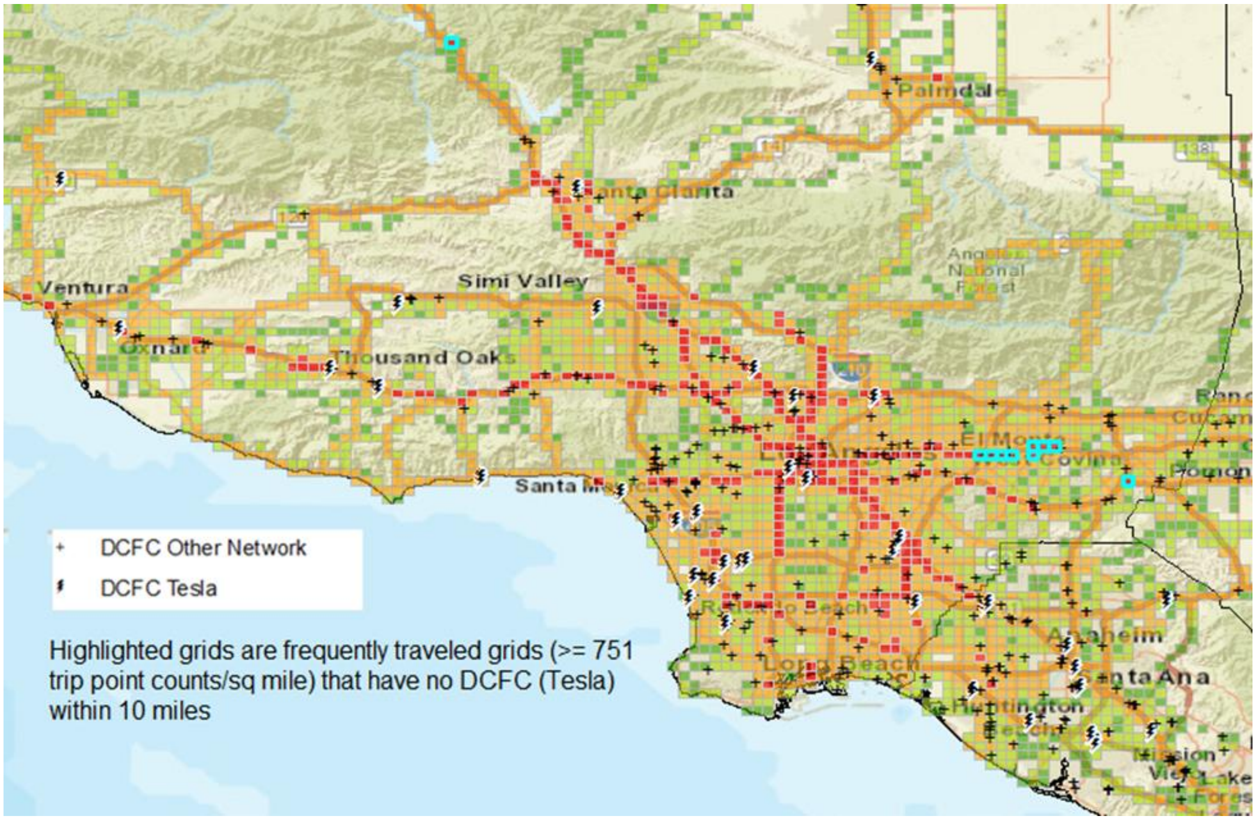


Figure 4.7. District 7 regional sedan vehicle activity GPS travel heat map with Tesla fast DC

5. ZEV Tool Creation

The UCR research team created a database spreadsheet Graphical User Interface (GUI) which allows for Caltrans staff to interact with the ZEV database. The GUI allows users to interface with the database to input, select, and identify vehicles for ZEV analysis. The vehicle specifications determine to what extent the associated trips are complimentary with associated refueling facilities. The abilities and functions of the spreadsheet tool have been collaboratively defined between the UCR research team and Caltrans representatives. The home screen of the ZEV tool is shown in Figure 5.1. The ZEV tool has five primary functions selectable on the main dashboard:

1) ZEV Spreadsheet tool for viewing and editing ZEV specifications;
2) ZEV Compatibility function to analyze single vehicle activity;
3) ZEV Refueling function to evaluate refueling station activity;
4) ZEV Fueling station spreadsheet; and
5) Comparative ZEV function to create analysis results for a group of vehicles.

The capabilities and characteristics of these functions are further detailed below.

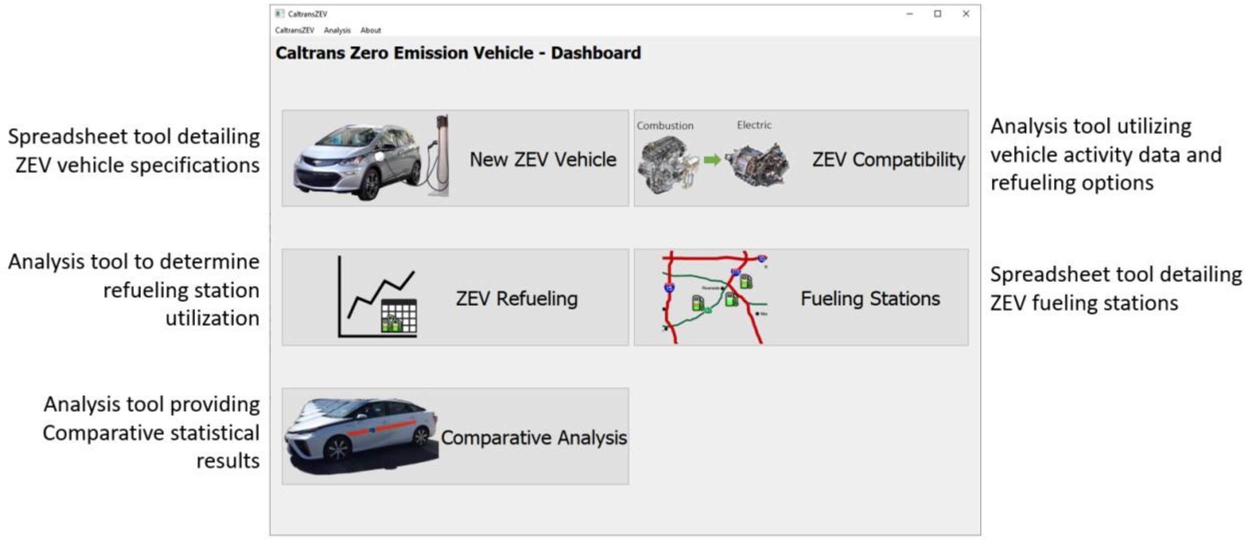


Figure 5.1. Caltrans ZEV tool GUI dashboard identifying functions and analysis options

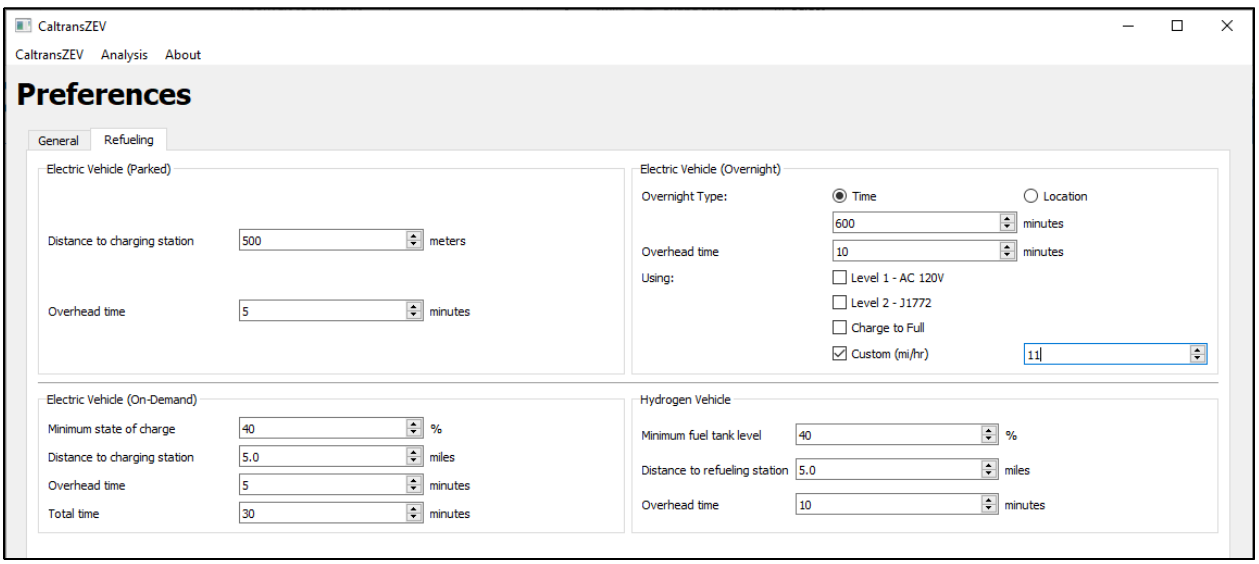


Figure 5.2. Caltrans ZEV tool GUI dashboard preference tab

5.1 New ZEV Specification Spreadsheet

The new ZEV vehicle tab allows the user to identify or input ZEV specifications into the ZEV tool. The ZEV specifications listed in the ZEV vehicle tab are utilized for compatibility analysis. To initiate ZEV compatibility based on a ZEV specifications listed in the table a user would select the ZEV in the table and then select an analysis option at the bottom of the page.

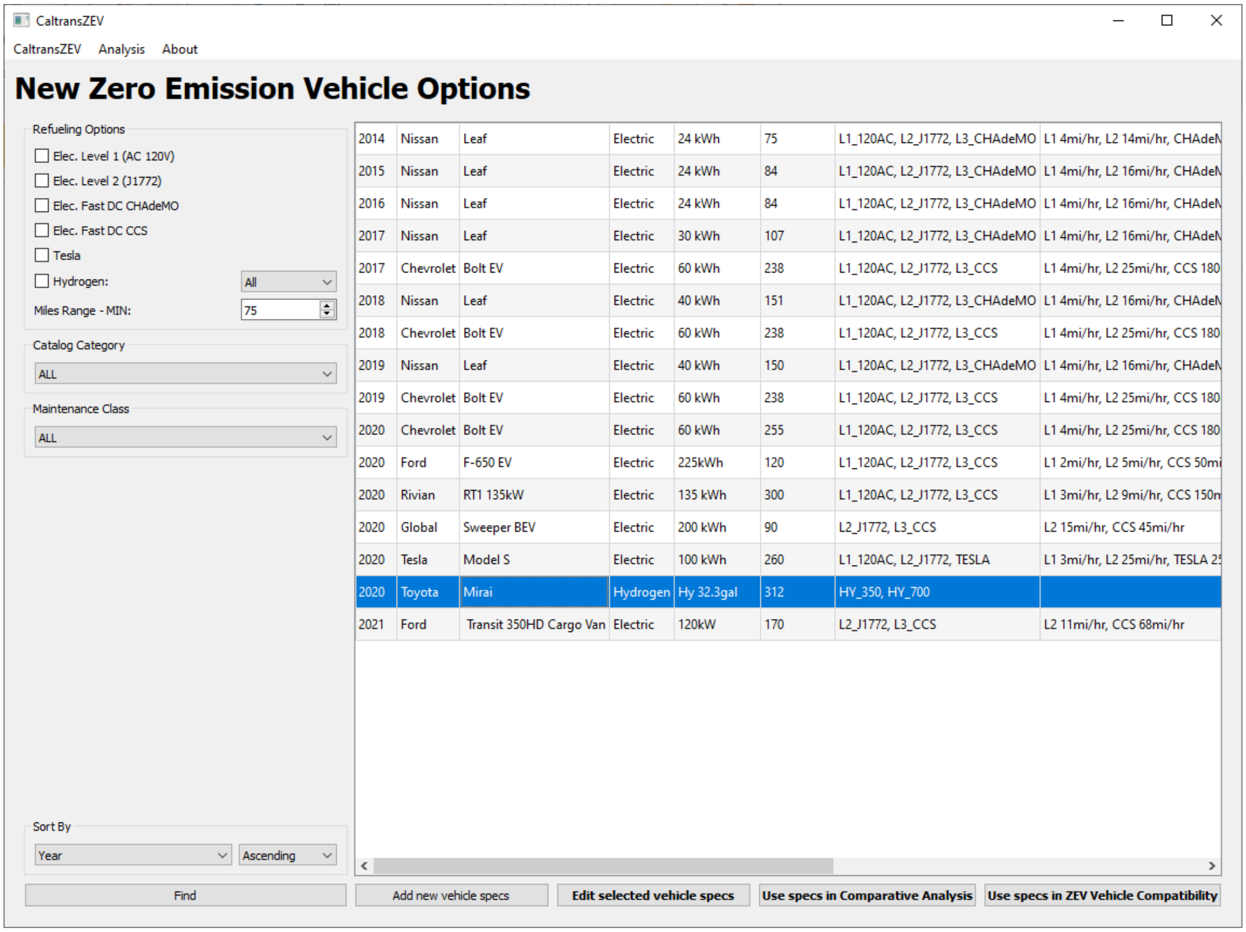


Figure 5.3. ZEV spreadsheet to input and identify vehicle options

5.2 ZEV Compatibility Analysis

The ZEV tool provides the option of evaluating all the trip of a single vehicle for determining ZEV compatibility. The single vehicle analysis reviews all the trip activity for a selected vehicle during the identified time period. The vehicle selection for ZEV compatibility analysis is either accomplished by directly typing the equipment ID or clicking the select button. The select button opens an additional window which can be used for vehicle selection as an alternate to the equipment ID. The vehicle selection window is shown in Figure 5.4.

Subsequent to selecting a time period and vehicle ID the user can modify the refueling and charging options. If the user had previously selected ZEV specifications the charging/refueling and range will auto populate. The user can modify the auto populated variables and selected additional charging/refueling conditions. Once the user has completed the selections the analyze button will commence the comparative analysis function. The results will be a map with ZEV successful trips colored green and ZEV non-compatible trips colored red. Figure 5.5 displays the results for a single vehicle analysis transitioning to a battery electric vehicle. Figure 5.6 shows the analysis of a vehicle's proposed transition to a hydrogen fuel cell vehicle.

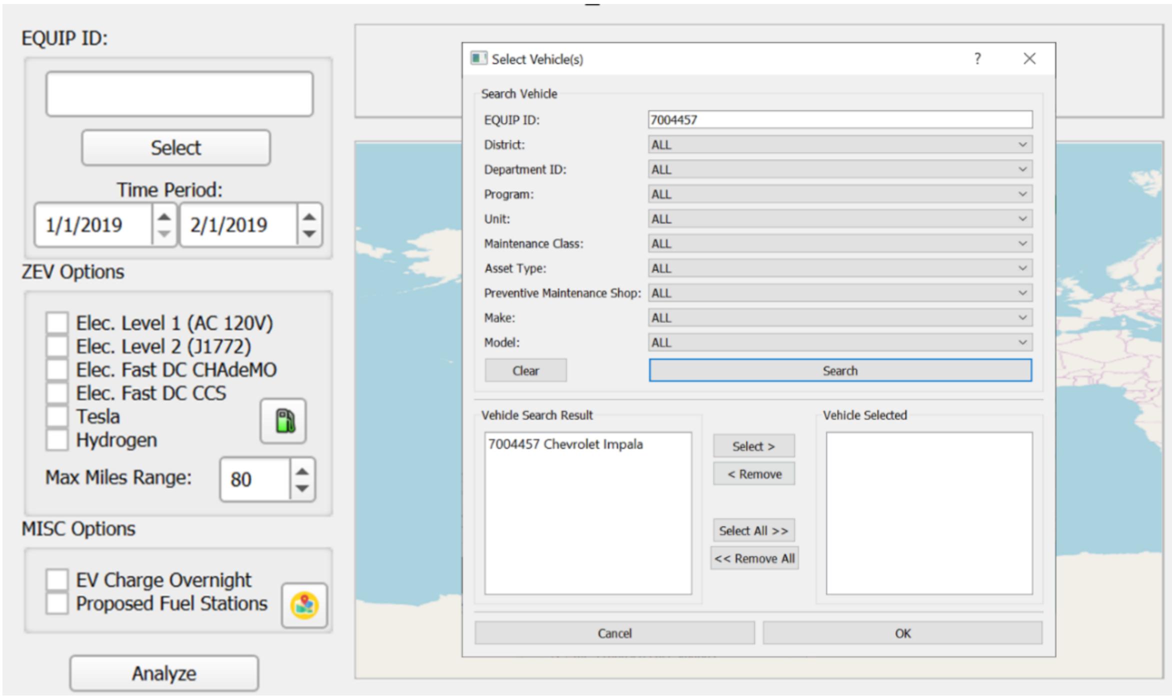


Figure 5.4. Vehicle selection options to initiate ZEV compatibility analysis.

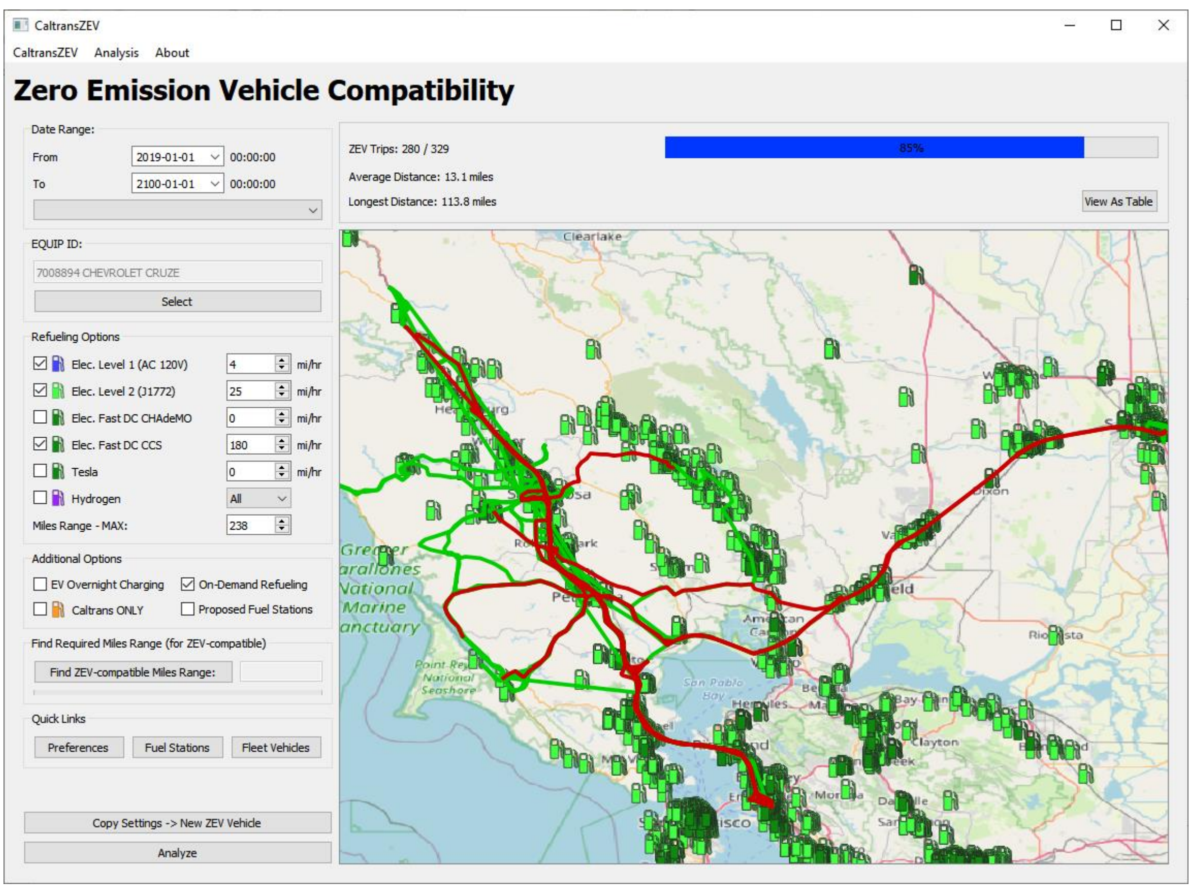


Figure 5.5. ZEV compatibility analysis for battery electric evaluation

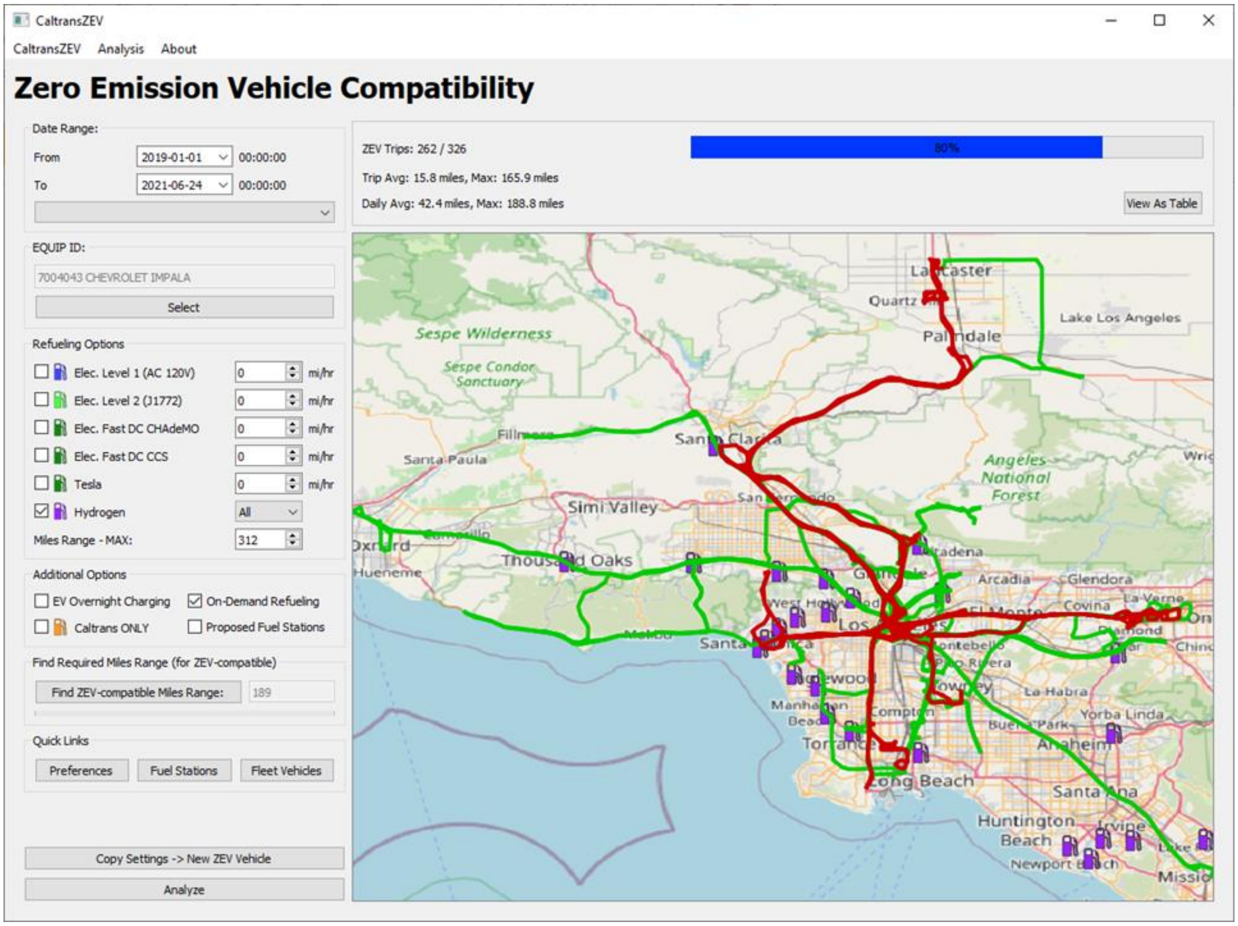


Figure 5.6. ZEV compatibility analysis for hydrogen fuel cell electric evaluation

5.3 ZEV Refueling

The ZEV tool evaluates and identifies the occurrence, location, and type of refueling event. A vehicle's need for refueling is determined from the vehicles trip characteristics, estimated SOC, and type of refueling conditions selected by the user. The refueling analysis window is shown in Figure 5.7. The refueling locations considered for a given hydrogen analysis are shown in Figure 5.8. Hydrogen refueling events are shown as blue in Figure 5.9. Battery electric refueling events are shown in Figure 5.10.

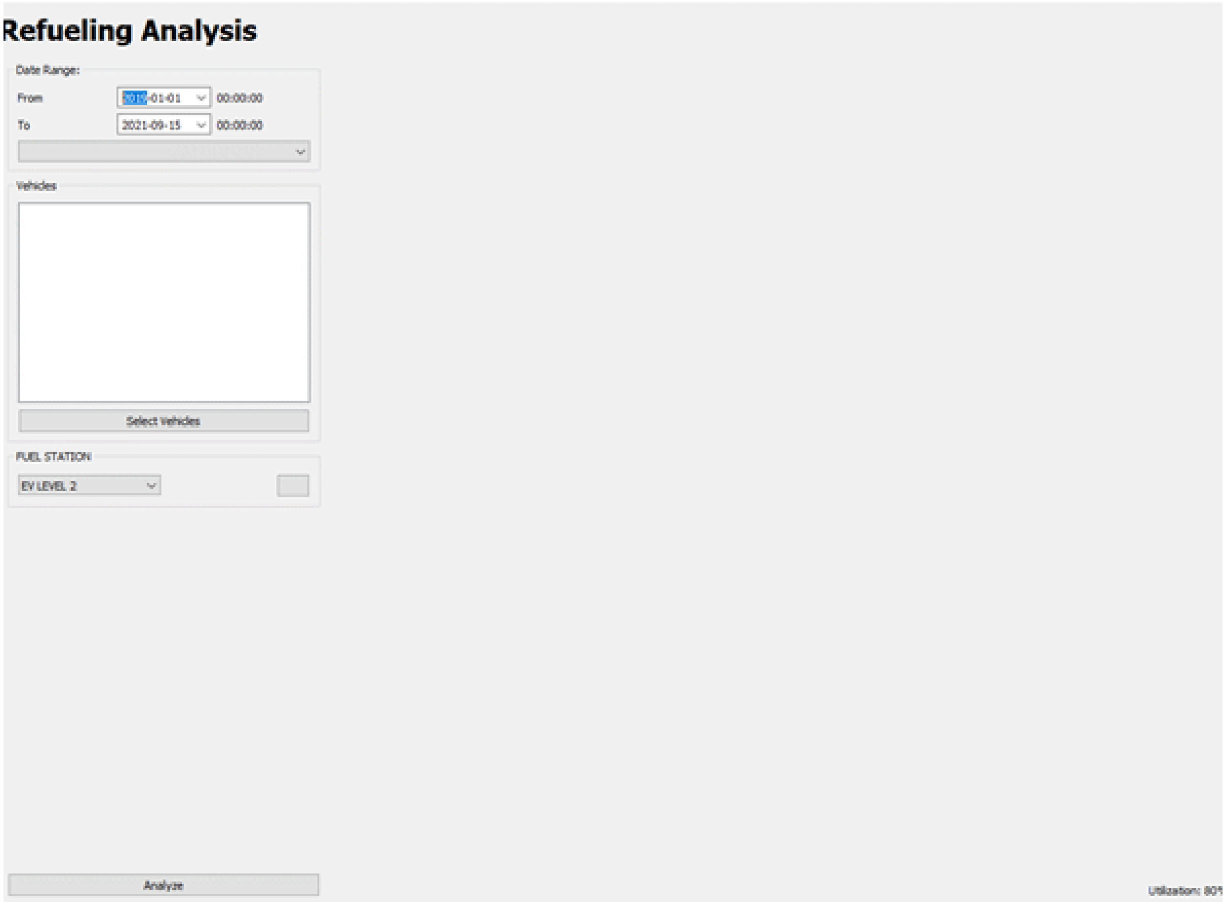


Figure 5.7. Refueling analysis window for ZEV tool

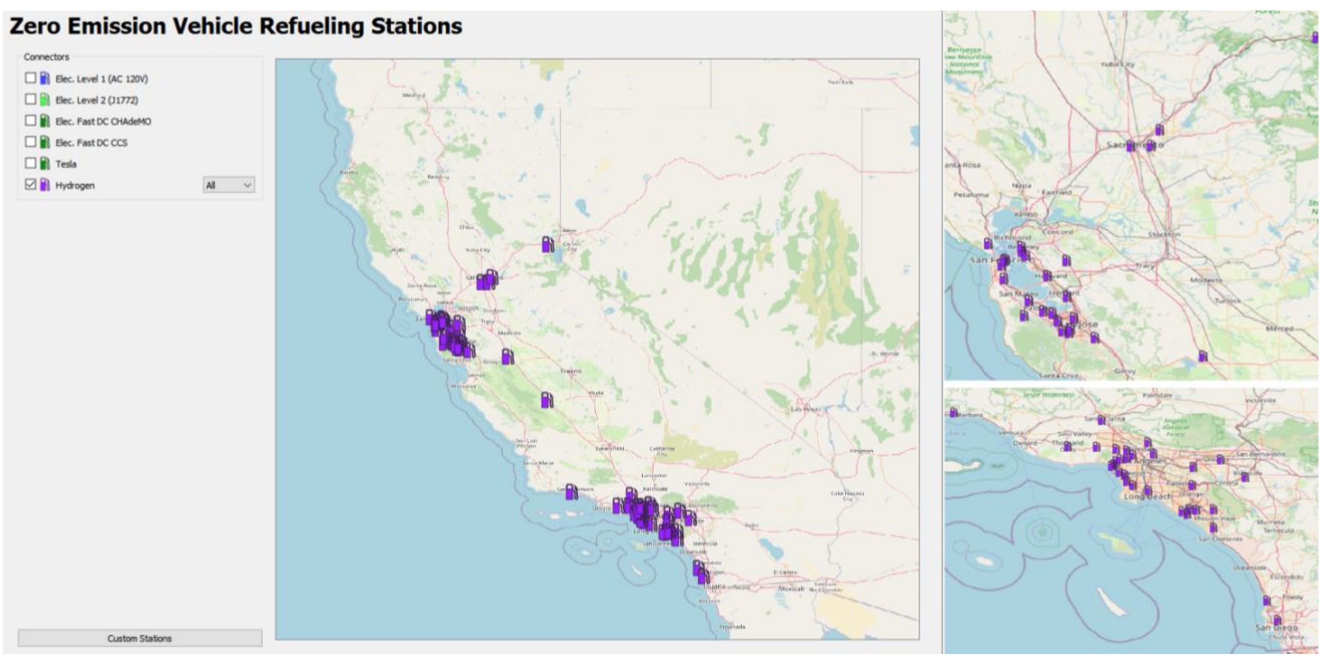


Figure 5.8. Hydrogen refueling stations for ZEV tool

	Event	Description	Duration	Distance	Start Range	End Range	Start DateTime	End DateTime	Start Location	End Location
81	Trip	TripID: 78	0.48	13.4	198.5	185.1	2019-09-16 06:51:21	2019-09-16 07:20:13	-118.238435,34.024675	-118.306204,34.173866
82	Trip	TripID: 79	0.02	0.1	185.1	184.9	2019-09-16 10:01:56	2019-09-16 10:03:21	-118.306204,34.173866	-118.306275,34.17408
83	Trip	TripID: 80	0.27	9.1	184.9	175.8	2019-09-16 10:26:20	2019-09-16 10:42:25	-118.306275,34.17408	-118.222435,34.083057
84	Trip	TripID: 81	0.31	5.6	175.8	170.2	2019-09-16 10:51:40	2019-09-16 11:10:12	-118.222435,34.083057	-118.219377,34.042808
85	Trip	TripID: 82	0.16	2.2	170.2	168.0	2019-09-16 11:12:50	2019-09-16 11:22:10	-118.219377,34.042808	-118.242062,34.051271
86	Refuel	Hydrogen (Mid-Trip)	0.08	168.0						
87	Trip	TripID: 83	2.16	58.1	312.0	253.9	2019-09-16 13:15:00	2019-09-16 15:24:34	-118.242062,34.051271	-118.243128,34.051128
88	Trip	TripID: 84	1.39	32.2	253.9	221.7	2019-09-16 16:02:00	2019-09-16 17:25:06	-118.243128,34.051128	-117.745564,34.022471
89	Trip	TripID: 85	1.13	41.9	221.7	179.8	2019-09-17 05:07:55	2019-09-17 06:15:45	-117.745564,34.022471	-118.306204,34.174009
90	Trip	TripID: 86	0.02	0.0	179.8	179.8	2019-09-17 06:16:18	2019-09-17 06:17:46	-118.306204,34.174009	-118.306489,34.174009
91	Trip	TripID: 87	0.01	0.0	179.8	179.8	2019-09-17 06:40:38	2019-09-17 06:41:24	-118.306489,34.174009	-118.305991,34.173938
92	Trip	TripID: 88	0.02	0.0	179.8	179.8	2019-09-17 06:43:58	2019-09-17 06:44:54	-118.305991,34.173938	-118.306347,34.17408
93	Trip	TripID: 89	0.09	1.2	179.8	178.5	2019-09-17 10:46:10	2019-09-17 10:51:48	-118.306347,34.17408	-118.3136,34.163484
94	Trip	TripID: 90	0.09	1.3	178.5	177.2	2019-09-17 11:31:07	2019-09-17 11:36:36	-118.3136,34.163484	-118.306418,34.17408
95	Trip	TripID: 91	1.45	42.0	177.2	135.2	2019-09-17 14:30:27	2019-09-17 15:57:38	-118.306418,34.17408	-117.745564,34.022471
96	Refuel	Hydrogen (Mid-Trip)	0.08	171.9						
97	Trip	TripID: 92	1.06	41.8	312.0	270.2	2019-09-18 05:21:08	2019-09-18 06:24:36	-117.745564,34.022471	-118.306347,34.174009
98	Trip	TripID: 93	0.12	1.1	270.2	269.1	2019-09-18 11:25:18	2019-09-18 11:32:22	-118.306347,34.174009	-118.313529,34.163627
99	Trip	TripID: 94	0.08	1.3	269.1	267.8	2019-09-18 12:20:36	2019-09-18 12:25:38	-118.313529,34.163627	-118.306347,34.17408
100	Trip	TripID: 95	1.34	42.2	267.8	225.6	2019-09-18 14:34:33	2019-09-18 15:55:10	-118.306347,34.17408	-117.745564,34.022471
101	Trip	TripID: 96	1.14	41.6	225.6	184.0	2019-09-19 05:21:26	2019-09-19 06:29:56	-117.745564,34.022471	-118.306418,34.17408
102	Trip	TripID: 97	0.58	11.9	184.0	172.1	2019-09-19 10:30:20	2019-09-19 11:05:19	-118.306418,34.17408	-118.242489,34.051484

Figure 5.9. Hydrogen refueling based on vehicle activity

CaltransZEV

CaltransZEV Analysis About

Zero Emission Vehicle Compatibility

	Event	Description	Duration	Distance	Start Range	End Range	Start DateTime	End DateTime	Start Location	End Location
265	Trip	TripID: 204	2.27	64.7	151.0	86.3	2019-12-03 09:44:48	2019-12-03 12:00:53	[-118.242488, 34.050986]	[-118.062293, 34.040391]
266	Trip	TripID: 205	0.04	0.2	86.3	86.1	2019-12-03 12:05:36	2019-12-03 12:07:58	[-118.062293, 34.040391]	[-118.05888, 34.04032]
267	Trip	TripID: 206	0.83	19.4	86.1	66.7	2019-12-03 12:22:33	2019-12-03 13:12:04	[-118.05888, 34.04032]	[-118.243128, 34.0512]
268	Refuel	Level 3 - CHAdeMO	0.33	40.0						
269	Trip	TripID: 207	0.41	11.1	106.7	95.6	2019-12-05 09:28:05	2019-12-05 09:52:36	[-118.243128, 34.0512]	[-118.07296, 34.076302]
270	Trip	TripID: 208	0.25	7.4	95.6	88.3	2019-12-05 10:33:08	2019-12-05 10:48:24	[-118.07296, 34.076302]	[-117.979235, 34.070328]
271	Trip	TripID: 209	1.73	42.0	88.3	46.3	2019-12-05 11:16:28	2019-12-05 13:00:11	[-117.979235, 34.070328]	[-118.242915, 34.051057]
272	Refuel	Level 3 - CHAdeMO	0.33	40.0						
273	Trip	TripID: 210	2.06	63.9	86.3	22.4	2019-12-09 12:58:21	2019-12-09 15:02:15	[-118.242915, 34.051057]	[-118.064711, 34.051413]
274	Trip	TripID: 211	0.69	17.2	22.4	5.1	2019-12-09 15:09:05	2019-12-09 15:50:20	[-118.064711, 34.051413]	[-118.11584, 33.839004]
275	Trip	TripID: 212	5.04	141.0	5.1		2019-12-10 06:51:38	2019-12-10 11:54:01	[-118.11584, 33.839004]	[-118.242986, 34.051057]
276	Refuel	Level 3 - CHAdeMO	0.33	40.0						
277	Trip	TripID: 213	1.82	43.8	45.1	1.4	2019-12-11 09:39:44	2019-12-11 11:28:58	[-118.242987, 34.051058]	[-118.125369, 34.078862]
278	Trip	TripID: 214	0.44	8.0	1.4		2019-12-11 12:27:37	2019-12-11 12:54:18	[-118.125369, 34.078862]	[-118.243058, 34.0512]
279	Refuel	Level 3 - CHAdeMO	0.33	40.0						
280	Trip	TripID: 215	0.79	11.5	41.4	29.9	2019-12-12 09:59:57	2019-12-12 10:47:07	[-118.243057, 34.0512]	[-118.144071, 34.14464]
281	Trip	TripID: 216	0.55	11.1	29.9	18.8	2019-12-12 13:29:10	2019-12-12 14:02:15	[-118.144071, 34.14464]	[-118.242915, 34.051057]
282	Refuel	Level 3 - CHAdeMO	0.33	40.0						
283	Trip	TripID: 217	0.1	0.5	58.8	58.3	2019-12-13 09:36:05	2019-12-13 09:41:52	[-118.242916, 34.051058]	[-118.244053, 34.050916]
284	Trip	TripID: 218	0.17	0.5	58.3	57.8	2019-12-13 10:21:02	2019-12-13 10:31:09	[-118.244053, 34.050916]	[-118.242773, 34.051129]
285	Refuel	Level 3 - CHAdeMO	0.33	40.0						
286	Trip	TripID: 219	1.57	41.9	97.8	55.9	2019-12-13 12:27:23	2019-12-13 14:01:50	[-118.242773, 34.051129]	[-118.390044, 33.824782]

Back to ZEV Vehicle Analysis

View Event

Figure 5.10. Battery EV refueling based on vehicle activity

5.4 Refueling Stations

The refueling stations tab allows for a user to review station availability within a given region. The tab opens a map window which displays ZEV refueling infrastructure based on type (Figure 5.11). There are options for selecting Level 1, Level 2, or fast DC EV charging infrastructure. For Fast DC there are options for CHAdeMO, CCS, or Tesla. Hydrogen refueling infrastructure is also selectable with 350 or 700 bar being selectable. The refueling stations tab provides the option for entering new station locations. The input of a new station allows the user to select type of refueling and specifications as shown in Figure 5.12.

Each analysis scenario (compatibility or comparative) utilizes the existing refueling infrastructure as a baseline. Planned or future EVSE or hydrogen refueling infrastructure is added within the tool manually utilizing the “Fueling Stations” option. The user selects the location, EVSE type, and/or hydrogen pressures. The addition of fueling stations would carry over into the compatibility or comparative analysis. This methodology allows layered analysis either with or without additional EVSE or hydrogen refueling capacities.

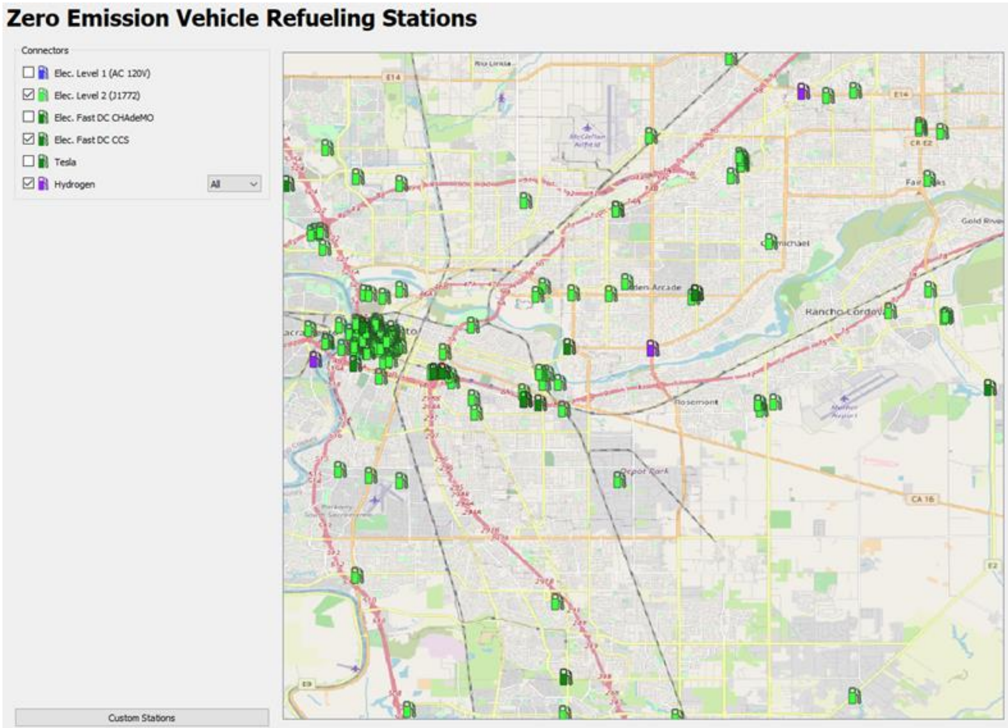


Figure 5.11. Map interface for ZEV tool refueling stations

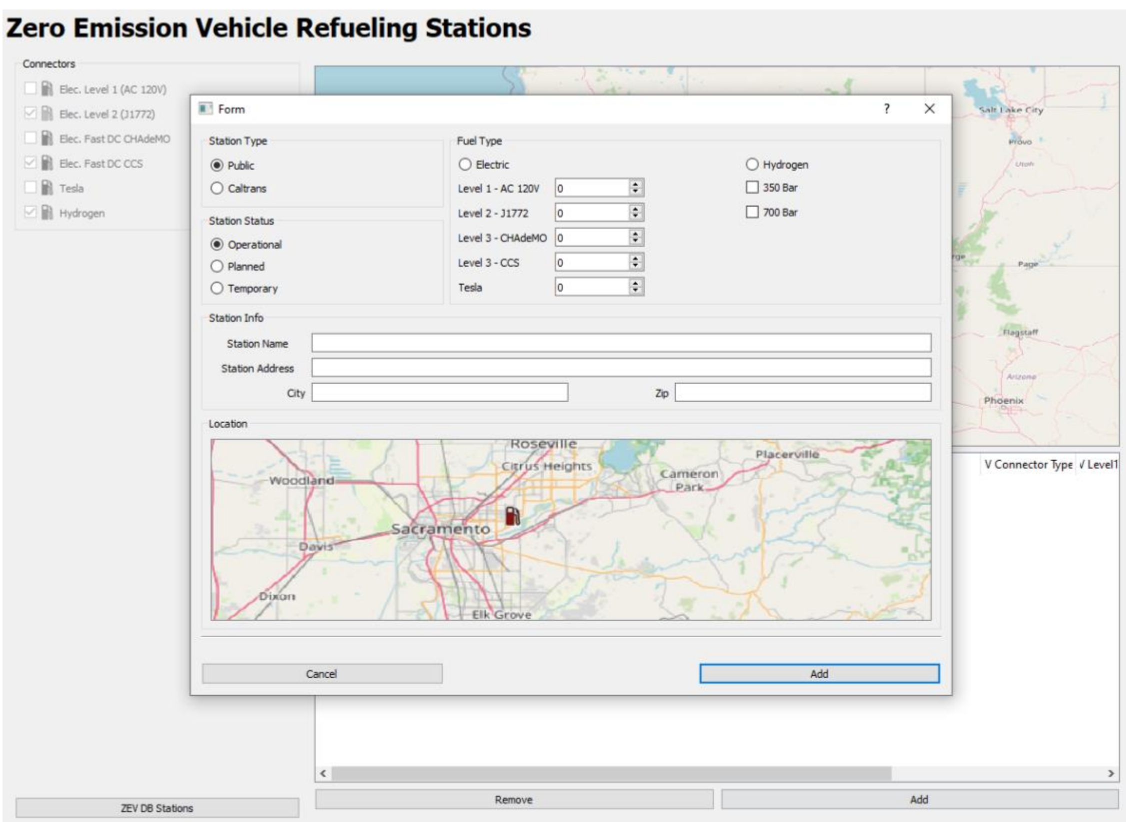
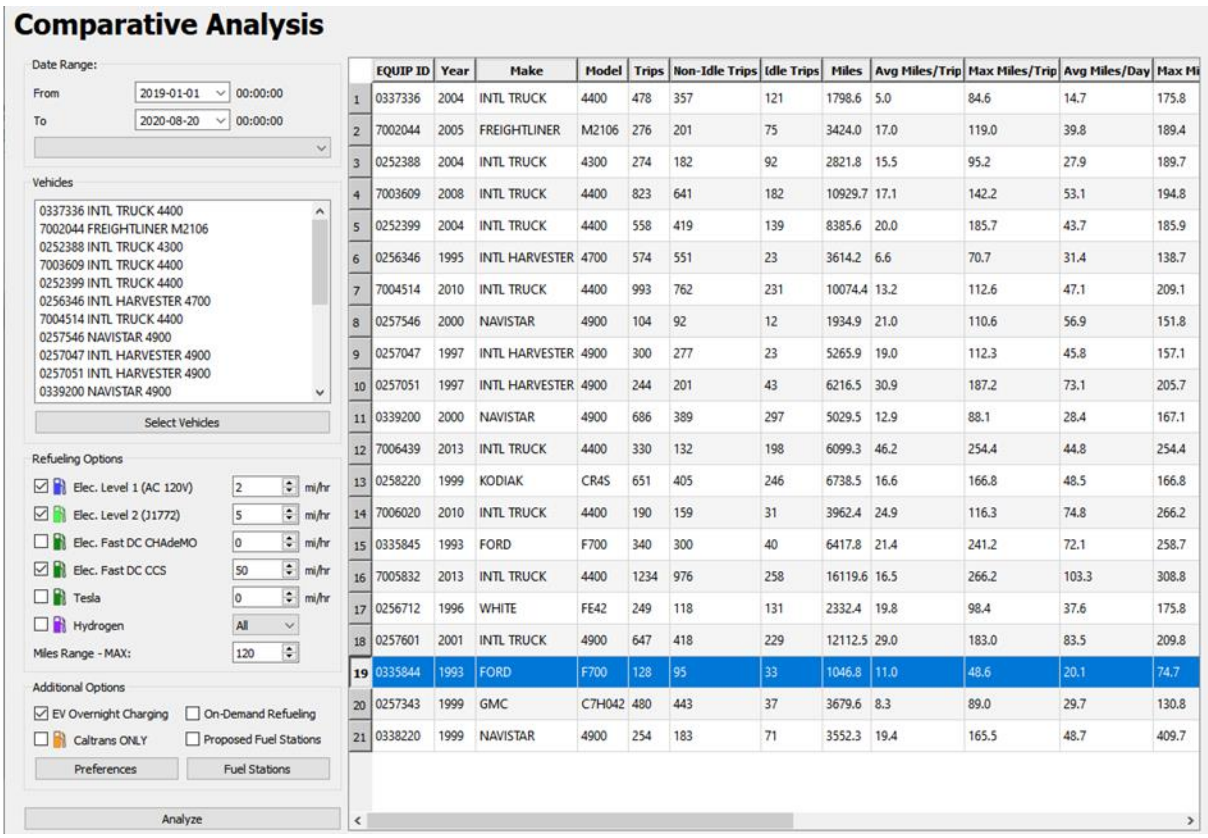


Figure 5.12. Pop-up window for new refueling station input parameters

5.5 Comparative Analysis

The comparative analysis tab allows for a group of vehicles to be simultaneously evaluated for ZEV compatibility. The analysis methodology is similar to a single vehicle analysis described previously. The comparative analysis lists each vehicle results as a row in the results. A sample comparative analysis results table is shown in Figure 5.13. The table lists the relevant vehicle information, such as, ID, year, make, and model. Additionally, significant trip summary results are provided. Finally, the table lists the percent of ZEV trips which can be completed based on the selected vehicle specs, refueling availability, and trip activity. The comparative analysis output table is also exported to a CSV data file for further evaluation.



	EQUIP ID	Year	Make	Model	Trips	Non-Idle Trips	Idle Trips	Miles	Avg Miles/Trip	Max Miles/Trip	Avg Miles/Day	Max Mi
1	0337336	2004	INTL TRUCK	4400	478	357	121	1798.6	5.0	84.6	14.7	175.8
2	7002044	2005	FREIGHTLINER	M2106	276	201	75	3424.0	17.0	119.0	39.8	189.4
3	0252388	2004	INTL TRUCK	4300	274	182	92	2821.8	15.5	95.2	27.9	189.7
4	7003609	2008	INTL TRUCK	4400	823	641	182	10929.7	17.1	142.2	53.1	194.8
5	0252399	2004	INTL TRUCK	4400	558	419	139	8385.6	20.0	185.7	43.7	185.9
6	0256346	1995	INTL HARVESTER	4700	574	551	23	3614.2	6.6	70.7	31.4	138.7
7	7004514	2010	INTL TRUCK	4400	993	762	231	10074.4	13.2	112.6	47.1	209.1
8	0257546	2000	NAVISTAR	4900	104	92	12	1934.9	21.0	110.6	56.9	151.8
9	0257047	1997	INTL HARVESTER	4900	300	277	23	5265.9	19.0	112.3	45.8	157.1
10	0257051	1997	INTL HARVESTER	4900	244	201	43	6216.5	30.9	187.2	73.1	205.7
11	0339200	2000	NAVISTAR	4900	686	389	297	5029.5	12.9	88.1	28.4	167.1
12	7006439	2013	INTL TRUCK	4400	330	132	198	6099.3	46.2	254.4	44.8	254.4
13	0258220	1999	KODIAK	CR4S	651	405	246	6738.5	16.6	166.8	48.5	166.8
14	7006020	2010	INTL TRUCK	4400	190	159	31	3962.4	24.9	116.3	74.8	266.2
15	0335845	1993	FORD	F700	340	300	40	6417.8	21.4	241.2	72.1	258.7
16	7005832	2013	INTL TRUCK	4400	1234	976	258	16119.6	16.5	266.2	103.3	308.8
17	0256712	1996	WHITE	FE42	249	118	131	2332.4	19.8	98.4	37.6	175.8
18	0257601	2001	INTL TRUCK	4900	647	418	229	12112.5	29.0	183.0	83.5	209.8
19	0335844	1993	FORD	F700	128	95	33	1046.8	11.0	48.6	20.1	74.7
20	0257343	1999	GMC	C7H042	480	443	37	3679.6	8.3	89.0	29.7	130.8
21	0338220	1999	NAVISTAR	4900	254	183	71	3552.3	19.4	165.5	48.7	409.7

Figure 5.13. Comparative analysis results window

6. ZEV Tool Analysis Results

The ZEV tool has proven valuable to perform comparative analysis for numerous scenarios. The comparative analysis provides spreadsheet based output for a group of vehicles. One such analysis was completed for street sweepers being considered for battery electric transition potential. The sweeper comparative analysis consisted of 47 sweepers throughout the state. Both a 60 mile range and a 90 mile range were considered. Full recharging was proposed to occur in the maintenance yard when park over 8 hours. The resulting comparative analysis is shown in Table 6.1.

Table 6.1. Battery electric sweeper comparative analysis

EQIP ID	Year	Make	Model	Trips	Trips_NonIdle	Trips_Idle	Miles	Miles_AvgTrip	Miles_LongestTrip	Miles_AvgTripDay	Miles_LongestTripDay	Hours_NonIdle	Hours_Idle	Hours_AvgIdleTrip	Hours_MaxIdleTrip	Hours_AvgIdleDay	Hours_MaxIdleDay	ZEV	Non-ZEV	ZEV%
7002026	2006	JOHNSTON	4000	520	156	364	1177.9	7.6	44.5	9.8	56.2	287.5	82.4	0.2	2.1	0.7	5.8	520	0	100
7003680	2007	JOHNSTON	4000	441	272	169	1755.1	6.5	46.5	12.1	64.3	327	12	0.1	0.6	0.1	0.6	439	2	99
7004908	2009	JOHNSTON	4000	427	303	124	2529.1	8.3	57.5	18.1	76.6	354.9	10.4	0.1	0.6	0.1	0.6	422	5	98
7004906	2009	JOHNSTON	4000	565	381	184	3444.3	9	63	20.4	71.2	384.9	15.7	0.1	2.8	0.1	2.8	561	4	99
7008047	2012	GLOBAL	M4	829	601	228	3687.7	6.1	62.2	17.6	70.7	532.3	10.9	0	0.6	0.1	0.7	819	10	98
7006048	2012	GLOBAL	M4	757	578	179	5659.3	9.8	67.8	27.7	89.3	817.1	18.9	0.1	3.1	0.1	3.1	736	21	97
7004611	2009	JOHNSTON	4000	534	366	168	449.6	12	66.5	30.6	97.9	620.2	11.5	0.1	0.7	0.1	0.7	509	25	95
7003686	2007	JOHNSTON	4000	729	579	150	5083	8.8	83.5	25.8	94.3	655.4	11.9	0.1	0.9	0.1	0.9	715	14	98
7010240	2014	GLOBAL	M4	418	265	153	2107	8	81.7	16.6	104.9	293.4	14.6	0.1	0.8	0.1	1.7	412	6	98
7010241	2014	GLOBAL	M4	764	545	219	3753.9	6.9	57.9	22	72.6	530.1	22.4	0.1	0.8	0.1	1.8	756	8	98
7010244	2014	GLOBAL	M4	494	355	139	1698.3	4.8	40.7	12.8	76.7	280.4	8.6	0.1	1.7	0.1	1.7	493	1	99
7003798	2007	JOHNSTON	4000	404	275	129	1966.2	7.1	65.3	19.5	76.8	251.5	12.2	0.1	1.5	0.1	1.6	394	10	97
7003698	2007	JOHNSTON	4000	484	325	159	2536.2	7.8	66.9	19.2	85.8	296.1	11.7	0.1	0.5	0.1	0.9	469	15	96
7003797	2007	JOHNSTON	4000	121	28	93	137.7	4.9	33.7	2.8	38.2	46.7	17.4	0.2	2.2	0.3	3.1	121	0	100
7010239	2014	GLOBAL	M4	502	180	322	1667	9.3	50.9	9.2	50.9	638.9	354.1	1.1	7.2	2	8.6	502	0	100
7010247	2014	GLOBAL	M4	897	112	785	69.7	0.6	11	0.4	17	646.9	468.7	0.6	6.3	2.5	9.8	897	0	100
7010242	2014	GLOBAL	M4	766	141	625	41.4	0.3	2.4	0.2	2.4	671.7	292.2	0.5	6.6	1.6	9.1	766	0	100
7003700	2007	JOHNSTON	4000	9	9	0	1938.5	215.4	905.1	215.4	905.1	11445.4	0	0	0	0	0	5	4	55
7003703	2007	JOHNSTON	4000	372	215	157	2038.8	9.5	58.9	17.9	95.8	288.7	15.8	0.1	1.7	0.1	1.9	361	11	97
7004243	2007	JOHNSTON	4000	351	227	124	2465.4	10.9	108.4	23.3	155.1	1431.9	843.5	6.8	312.9	8	312.9	338	13	96
7004613	2009	JOHNSTON	4000	448	290	158	3050.3	10.5	73.4	25.4	73.4	361.2	9.8	0.1	1	0.1	1	438	10	97

An additional comparative analysis was completed on 43 compactors. The vehicle specifications consisted of 396 kWh battery pack with a 250 mile range. Both Level 2 and Fast DC refueling/recharging conditions were considered (20kw and 150kw). The refueling/refueling were proposed to occur in the maintenance yard when parked. The resulting comparative analysis is shown in Table 6.2. The two rightmost columns in Table 6.2 list the percent of trips which can be successfully completed by the vehicle in the corresponding row. The majority of vehicles can complete 100% of their trips whether they utilize Level 2 or fast DC charging. The first two vehicles show a slight increase in the ZEV% when utilizing 150kW fast DC charging.

Table 6.2. Battery electric compactor comparative analysis

EQIP ID	Year	Make	Model	Trips	Trips_Idle	Miles	Miles_AvgTrip	Miles_LongestTrip	Miles_AvgTripDay	Miles_LongestTripDay	ZEV	Non-ZEV	ZEV%	150 DC ZEV%
7012462	2020	FREIGHTLINER	M2 112	314	34	10153.4	36.3	230.9	59	251.2	225	89	71	74
7012467	2020	FREIGHTLINER	M2 112	580	36	8733.9	16.1	94.7	41.2	146.7	520	60	89	90
7005943	2017	FREIGHTLINER	M2 112	408	35	7083.9	19	90.7	44.3	176.7	401	7	98	98
7003969	2008	AUTOCAR	WX42	356	79	8598.1	31	193.1	48.6	193.3	354	2	99	99
338749	2001	FREIGHTLINER	FL70	1180	337	2654.9	3.1	48.4	14.7	67.7	1180	0	100	100
33729	1995	INTL HAREVSTER	4900	856	290	4868.1	8.6	53.2	19.8	69.4	856	0	100	100
336703	1996	INTL HARVESTER	4900	962	33	5794	6.2	33.7	34.1	115.3	962	0	100	100
7000056	2004	INTL TRUCK	4400	583	141	3467.3	7.8	67.8	20.8	67.8	583	0	100	100
7004804	2011	FREIGHTLINER	M2106	659	131	7424.4	14.1	182.8	36.9	182.9	659	0	100	100
7008057	2013	INTL TRUCK	7400	660	105	11228.4	20.2	166.8	46	189.6	660	0	100	100
7004702	2009	AUTOCAR	ACX42	492	116	6271.1	16.7	160.1	33.7	175.4	492	0	100	100
7005448	2011	FREIGHTLINER	M2106	892	186	10692.9	15.1	102	40.4	147	892	0	100	100
7005446	2011	FREIGHTLINER	M2106	813	181	9691.3	15.3	143.3	39.4	151.4	813	0	100	100
7002349	2007	INTL TRUCK	4400	510	134	4935.8	13.1	89.8	23.8	102.6	510	0	100	100

The comparative analysis tool can be utilized iteratively to evaluate the same group of vehicles and corresponding vehicle activity. A group of 24 vans were considered for battery electric transition. Different charging/refueling conditions were evaluated without changing the vehicles, range, activity, or timeframe. The only parameters that were modified were the charging/refueling conditions. The charging conditions being evaluated were utilizing:

1) L2 – utilizing existing level 2 chargers located within a quarter mile of stop locations;
2) Overnight – charging the vehicle fully when parked more than 8 hours;
3) L2 + Overnight – combining the two options 1 and 2; and,
4) Fast DC – utilizing 1, 2, and 3 above and fast DC chargers in the vicinity of the trip path.

The tabular results in Table 6.3 show the most significant improvement in ZEV% can be attributed to overnight charging. The existing Level 2 infrastructure is not prevalent enough to make option 1 very effective. The fast DC charging also does not significantly increase the ZEV%. The results of Table 6.3 show the significance of having charging available at locations where battery electric vehicles park for extended periods.

Table 6.3. Battery Electric Van Analysis

EQIP ID	Year	Make	Model	Trips	Trips_NonIdle	Miles	L2_only	Overnight_Only	L2+Overnight	" +FastDCMidTrip"
7004843	2009	FORD	E350	4526	4388	48265.1	17	86	87	100
25075	2002	GMC	SAVANNA	1003	951	31864.8	15	91	91	93
7005520	2008	FORD	E350	820	775	28834.5	34	88	88	91
7012100	2018	FORD	TRANSIT	625	566	28736.1	13	89	89	91
14444	2000	GMC	G3500	1039	984	22207	35	96	96	97
7010821	2016	CHEVROLET	EXPRESS 3500	1073	1011	21944.4	12	91	91	98
20610	1999	GMC	G3500	1140	1093	21827.7	7	98	98	99
25053	2002	GMC	SAVANNA	584	547	19342.3	11	91	91	94
7010816	2016	CHEVROLET	EXPRESS 3500	1054	1009	19114.9	14	90	90	99
7012102	2018	FORD	TRANSIT	1787	1551	18584.5	15	99	99	100
7012099	2018	FORD	TRANSIT	1616	1574	16991.7	4	99	99	100
7008952	2014	CHEVROLET	EXPRESS 3500	1194	1085	16382.4	13	99	99	99
25055	2002	GMC	SAVANNA	476	435	16304.9	12	94	94	96
7008950	2014	CHEVROLET	EXPRESS 3500	892	830	15533.2	11	98	98	99
7000721	2005	FORD	E350	663	636	15497.5	22	95	95	96
7004541	2007	CHEVROLET	EXPRESS 3500	1024	919	15343.9	30	99	99	99
7001590	2006	FORD	E350	1182	1073	14897.6	11	99	99	99
7008962	2014	CHEVROLET	EXPRESS 3500	1013	927	14726.1	10	99	99	99
7008949	2014	CHEVROLET	EXPRESS 3500	410	389	14532	12	98	98	99
7005180	2009	FORD	E350	1318	1202	14100.4	10	100	100	100
7005209	2009	FORD	E350	1042	902	14076.5	40	99	99	99
7004936	2008	FORD	E350	713	671	13838.6	9	95	95	97
7008957	2014	CHEVROLET	EXPRESS 3500	925	850	13602.8	11	98	98	99
7008958	2014	CHEVROLET	EXPRESS 3500	1212	1011	13576.6	23	98	96	97

An additional comparative analysis was completed on 249 cargo body and dump body trucks operating within the South Coast AQMD. The vehicle specifications consisted of either a 100 or

200 mile range. The refueling/recharging were proposed to occur in the maintenance yard when parked. The two rightmost columns in Table 6.4 list the percent of trips which can be successfully completed by the vehicle with a 100 and 200 mile range (respectively). Vehicles unable to complete 100% percent of their trips with a 100 mile range only show about a 5 to 10% improvement with a 200 mile range.

Table 6.4. Battery Electric SCAQMD Truck Analysis

EQIP ID	Year	Make	Model	Trips	Trips_NonIdle	Trips_Idle	Miles	Miles_AvgTrip	Miles_LongestTrip	Miles_AvgTripDay	Miles_LongestTrip Day	ZEV	Non-ZEV	100 Mile ZEV%	200 Mile ZEV%
1374010	2004	INTL TRUCK	5500I 4X4	1251	1177	74	17170.5	14.6	147.9	72.1	317.1	933	318	74	80
1371413	2002	INTL TRUCK	5500	912	619	293	15197.4	24.6	226	91.6	468.4	702	210	76	81
338712	1999	NAVISTAR	4900	504	430	74	13174.1	30.6	285.2	86.7	425	370	134	73	81
1378360	2001	VOLVO	WG42	1330	1035	295	11315.8	10.9	138.3	60.8	413.1	1032	298	77	84
1378363	2001	VOLVO	WG42	1240	921	319	11101.4	12.1	158	55.5	350.5	1013	227	81	85
337219	1993	INTL HARVESTER	4900	587	446	141	11235.2	252	170.5	63.1	456.3	486	101	82	87
1377011	1998	NAVISTAR	5000	903	625	278	12211.2	19.5	206	79.8	508.9	759	144	84	87
1371414	2002	INTL TRUCK	5500	825	632	193	11683.2	18.5	214.2	62.5	425.1	671	154	81	87
237448	2000	NAVISTAR	4900	1192	964	228	9058.2	9.4	92.8	44	138.1	858	334	71	88
1377298	1999	VOLVO	WG44	284	179	105	3544.9	19.8	150.3	46.6	325.9	241	43	84	89
1374008	2004	INTL TRUCK	5500I 4X4	1068	718	350	11811.5	16.5	247.2	57.6	407.8	917	151	85	89
1377296	1999	VOLVO	WG44	533	298	235	4320.5	14.5	116.8	41.9	251.3	455	78	85	89
257550	1992	ROLBA	S1000	646	426	220	10761.7	25.3	161.4	56.1	301.6	548	98	84	90
330103	1999	NAVISTAR	4900	660	452	208	9392.6	20.8	226.4	58	546	565	95	85	90
1378361	2001	VOLVO	WG42	540	423	117	3787.8	9	97.2	49.8	227.9	458	82	84	90

A statewide battery electric sedan analysis was completed comparing transition to Chevy Bolt vehicles or Tesla Model 3. The vehicle specifications consisted of either a 260 mile range Tesla or 200 mile range Bolt. The DC recharging were proposed to occur at either Tesla locations for the Model 3 or Level CCS locations for the Bolt. The overnight refueling consisted of full recharge when parked over 8 hours. Overnight charging (ON) proved to provide the greatest ZEV% for both the Tesla and the Bolt. The Tesla scenario had slightly better overnight ZEV% results due to greater vehicle range. The 30 mile near parking scenario represents the availability of fast DC chargers in proximity to destination locations. These results were highly variable since fast DC chargers are not sufficiently prevalent for either Tesla or CCS. The ZEV tool ultimately helps identify which vehicles are the best candidates to transition to ZEV.

Table 6.5. Chevy Bolt and Tesla Model 3 sedan analysis

EQIP ID	Year	Make	Model	Trips	Miles	Miles_AvgTrip	Miles_LongestTrip	Miles_AvgTripDay	Miles_LongestTrip	ZEV	Non-ZEV	Tesla ON ZEV%	Tesla 30 ZEV%	Bolt ON ZEV%	Bolt 30 ZEV%
7005059	2008	CHEVROLET	IMPALA	568	6025.8	11.2	77.7	31.7	112	568	0	100	83	100	67
7000518	2003	FORD	FOCUS	555	4500.1	9.5	88.5	32.8	122.6	555	0	100	46	100	31
7005061	2008	CHEVROLET	IMPALA	304	11458.8	39.8	229.5	138.1	351.7	281	23	92	66	86	37
11465	2000	FORD	TAURUS	786	12025.5	16	183.4	59.2	260.7	785	1	99	57	99	33
7003891	2007	CHEVROLET	IMPALA	422	10287.7	25.9	211.9	87.2	372.3	406	16	96	19	95	9
7006071	2009	CHEVROLET	MALIBU	1396	16200.6	12.8	130.5	54.2	289.2	1395	1	99	45	99	71
7003398	2006	CHEVROLET	IMPALA	1322	17543.9	14.9	120.9	78.3	280.9	1320	2	99	50	99	51
7003892	2007	CHEVROLET	IMPALA	573	8802.5	16.4	170.3	59.1	341.5	572	1	99	46	99	55
7003394	2006	CHEVROLET	IMPALA	705	8758.9	14.5	128.1	46.1	314.8	702	3	99	25	99	18
7002775	2005	FORD	FOCUS	474	11283.5	24.4	98.3	85.5	218.4	474	0	100	92	99	82
7002779	2005	FORD	FOCUS	635	14222.4	23.3	189.5	86.7	441.3	604	31	95	37	91	50
7002782	2005	FORD	FOCUS	662	7048.1	11.7	79.3	51.1	190	662	0	100	59	100	70
7003495	2007	FORD	FOCUS	664	16156.2	25.2	222.7	94.5	433.7	657	7	98	31	94	23

7. Conclusions and Recommendations

The strategic adoption of ZEVs within the Caltrans fleet requires a detailed analysis of fleet parameters, vehicle technology, vehicle usage, refueling infrastructure development, and operational needs coupled with policies, regulations, mandates, and executive orders. This report summarizes how available information, trip activity, and EVSE have been integrated within a database tool to analyze ZEV integration possibilities. The ZEV tool compatibility analysis functions provide users an objective comparison of potential ZEV deployment solutions. The analysis results are displayed graphically in maps and tables while providing spreadsheet output for further analysis. The ZEV tool development provides Caltrans an architecture to integrate evolving data and fleet characteristics while optimizing ZEV placement and utilization into the future.

Caltrans staff are able to utilize the ZEV tool to strategically select vehicles as ZEV capable based on vehicle specifications, refueling infrastructure, and prior vehicle activity. The ZEV tool provides evaluation techniques by vehicle classification, region or refueling/charging capabilities. Utilization of the tool will assist the state in the transition to ZEV vehicle platforms that are either battery electric or hydrogen fuel cell.

The team utilized available information and developed the ZEV database and GUI to provide Caltrans with a user interface to facilitate ZEV integration. The analysis scenarios completed to date have demonstrated the need for expanded ZEV refueling/recharging infrastructure. The infrastructure need is independent of vehicle supplier, charger specifications, or energy form (battery electric or hydrogen). The scenario evaluations have also demonstrated the benefits of refueling/recharging infrastructure being available at or near extended parking locations.

Utilizing existing Caltrans vehicle activity data has proven invaluable in characterizing the feasibility of transitioning to ZEV platforms. Additionally, the ZEV tool provides method to evaluate the impact of refueling/recharging and vehicle range improvements. These benefits will aid in the State’s successful transition to Zero Emission Vehicle platforms.

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9. Data Summary

Products of Research

The research team utilized Caltrans existing telematics services and contracts to obtain relevant vehicle activity data. This project referenced existing datasets to perform trip based ZEV deployment analysis. The acquisition and evaluation of telematics based vehicle activity included the following:

- Identification the ZEV relevant vehicle activity data.
- Access to available trip data for the estimated 2000 Caltrans owned vehicles.
- Parsing of vehicle trips for vehicle activity relevant to ZEV trip analysis.
- Referencing of Caltrans fleet database for relevant vehicle information.
- Development of algorithms to identify Caltrans trips with relevance to ZEV capabilities.

The team processed trip data to allow analysis of ZEV relevant trip characteristics which may not directly exist as a data parameter. The research team referenced publicly available databases of EVSE and hydrogen refueling infrastructure to evaluate deployment scenarios. The databases served as the foundation for ZEV based analysis and spreadsheet calculation. The research analysis included the following:

- Identification of trip origins, destinations, and routes relative to ZEV refueling infrastructure.
- Refueling analysis of Caltrans accessible charging stations and FCV stations.
- Identification of trip activity that could be successfully completed with ZEVs.
- Creation of a Graphical User Interface (GUI) that displays ZEV analysis results.

The research team utilized APIs with proper authorization to access trip activity information. The geospatial information of travel paths, refueling locations, origins, destinations, and activity locations were analyzed and translated to a GIS GUI for displaying in maps, tables, and geographical representations.

Portions of data identifying an individual and their respective travel patterns will not be made available in a public database. Identification of individual traveler's will be transitions to numerical values and provide anonymity. Additionally, travel patterns of individuals will not be made available which would allow trips to be identified to an individual's residence or employment location.

The research team compiled three data tables that reference policies and incentives for ZEV deployments. The first data table is a nationwide summary itemized by state. The second and third data tables are California specific and provide BEV and FCEV program information.

Data Format and Content

The Caltrans fleet has been equipped for years with GPS based vehicle activity monitoring systems. The initial 3 years deployment consisted of Networkfleet followed by a transition to

Geotab beginning in 2020. The research team utilized the existing and future vehicle activity databases as inputs into the ZEV tool.

Networkfleet utilizes a GPS based vehicle telematics unit connected to a vehicle's OBDII data port connection. The telematics device collects trip by trip information and stores the data into vehicle specific data files. The Networkfleet data files provide: trip start time, trip start location, trip end time, trip end location, trip travel time, trip distance, and trip path in 2 minute increments. The location data is reported in GPS location format suitable for geospatial analysis. The data access utilized Networkfleet API procedures with Caltrans acquisition approval.

Geotab also utilizes a GPS based vehicle telematics unit connected to a vehicle's OBDII data port connection. The telematics device collects trip by trip information and stores the data into two vehicle specific data files. Geotab data files consist of a trip summary file detailing: vehicle information, trip length, trip time, average speed, idle time, and maximum speed. The second Geotab data files provide GPS trip path in path detailed based on speed and turning. The data access for Geotab utilized API procedures with Caltrans acquisition approval.

Additional spreadsheet tables were created to summarize ZEV information for the Caltrans ZEV tool development. The ”US States ZEV Programs” table details the ZEV programs by state throughout the US. Each state is listed in a row with the program name, description, and website reference. The "CA BEV Laws and Incentives" table was created to summarize CA BEV information for the Caltrans ZEV tool development. The spreadsheet details CA BEV incentives and programs. Each incentive or program is listed in a row with the program name, bill number, bill name, implementation date, description, and website reference. An additional spreadsheet titled "CA HFCV Laws and Incentives" was created to summarize CA HFCV information for the Caltrans ZEV tool development. Each HFCV incentive or program is listed in a row with the program name, bill number, bill name, implementation date, description, and website reference.

Data Access and Sharing

The research team acquired and reviewed state Caltrans acquired datasets which contain individual travel patterns. The travel patterns are the result of existing vehicle telematic files collected by cellular based gps devices installed in state owned vehicles. The research team utilized vehicle identification, make, model, classification, assignment, and vehicle activity as analysis variables. The vehicle identity was not linked to individual employees and trip origins and destinations are only utilized to evaluate potential for EVSE or hydrogen refueling operations.

The vehicle datasets were only accessible to individual researchers with approved access and participation on the project. Individual trip data is considered restricted and was stored on non-networked computers and/or hard drive storage with password protections only accessible by the approved research team. Data sharing throughout the duration of the project consisted of summarized results in tables, graphs, charts, and geospatial maps presented in progress reports and the final project report. Individual travel patterns or individual trip patterns have not been identified, analyzed, or disseminated as part of this project. Sensitive data has not been presented within results throughout the duration of this project.

Existing datasets were accessed for the purpose of trip analysis for ZEV compatibility. Results are displayed utilizing the ZEV tool GUI created by the research team. DOT staff are able to utilize the ZEV tool to review a vehicle's potential to transition to ZEV. Trip activity data access and sharing would be arranged through Caltrans pending approvals and authorizations.

New data tables were created for policies and incentives for states and California. The tables are available on the Zenodo repository as follows:

> Todd, Michael (2022), Compilation of California and US Zero Emission Vehicle Programs, Laws, and Incentives, Zenodo, Compilation, https://doi.org/10.5281/zenodo.6863075

Reuse and Redistribution

The information, analysis, and results provided in this report are accessible for reuse and redistribution subject to citation guidelines. The data utilized by the team to produce the results in the report are subject to Caltrans approval and authorization for use and distribution. The tables detailing policies and incentives are located in the Zenodo repository and available for access or reference.