



**CALIFORNIA  
ENERGY COMMISSION**



California Energy Commission  
Clean Transportation Program

## **FINAL PROJECT REPORT**

# **Charging Infrastructure for Plug-In Hybrid and Electric Vehicle Demonstration with Chrysler**

**Prepared for: California Energy Commission**

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District**

**Gavin Newsom, Governor**

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# California Energy Commission

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# **ACKNOWLEDGEMENTS**

The author wishes to acknowledge the following participants in the project. Each project partner accepted a demonstration vehicle for regular duty use in their fleet, sometimes facing the inconvenience of new technology and the deployment of supporting equipment. Each provided a location and support for the installation of one or more charging stations, including some with advance communication and control capabilities. These provided a platform for the demonstration, experimentation and data collection which were the backbone of the project.

Sacramento Municipal Utility District gratefully acknowledges the participation of the following municipalities:

- City of Citrus Heights
- City of Elk Grove
- City of Galt
- City of Rancho Cordova
- City of Sacramento

# PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to \$20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about \$100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-08-010 to provide funding opportunities under the Clean Transportation Program for demonstration of plug-in hybrid vehicles and deployment of supporting charging infrastructure. In response to PON-08-010, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards August 28, 2009 and the agreement was executed as ARV-10-041 on October 13, 2011.

# ABSTRACT

Sacramento Municipal Utility District partnered with Chrysler Group, LLC to demonstrate plug-in hybrid vehicles in fleet use applications. Chrysler provided Ram 1500 trucks that were up fitted with a plug-in hybrid drive train and a rechargeable lithium ion battery pack. The purpose of the project was to:

- (Task 2) Deploy charging infrastructure
- (Task 3) Demonstrate vehicle operation and accumulate real world mileage
- (Task 4) Demonstrate smart charging and reverse power

The CEC grant funded Task 2 activities, the installation of fourteen Level 2 electric vehicle service equipment (charging stations rated at approximately 6.6 kilowatts) stations. Match funding from Chrysler and Sacramento Municipal Utility District provided the balance of the project budget.

**Keywords:** Alternative Fuel Vehicle, greenhouse gases, plug-in hybrid vehicle, electric vehicle service equipment, Chrysler

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## **EXECUTIVE SUMMARY**

The Sacramento Municipal Utility District (SMUD) was one of several demonstration partners working with Chrysler Group, LLC, to demonstrate advanced plug-in hybrid vehicle technologies. This is part of an overall strategy to accelerate the transition to electric vehicles in the United States. This program is being conducted under contract with the US Department of Energy's (U.S. DOE) Recovery Act- Transportation Electrification DE-FOA 0000028. CEC grant ARV-10-041 funded the portion of SMUD's work involved with charging infrastructure deployment. SMUD collaborated with five municipal customers to deploy 14 Ram 1500 plug-in hybrid vehicles, in total, and installed fleet charging infrastructure at the vehicle users' sites. Additional work involved advancement of technologies needed smart charging and reverse power flow to the grid.



# **CHAPTER 1:**

## **Project Purpose**

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### **Introduction**

SMUD in conjunction with Chrysler Group, LLC worked together to promote a strategy to accelerate the transition to electric vehicles in the United States. SMUD is a publicly owned electric utility that operates independently of other local government and functions as a non-profit entity. SMUD provides electric power to the majority of the Sacramento County as well as a portion of Placer County in Northern California. In total, SMUD service region covers approximately 900 square miles and serves around 550,000 residential customers and 50,000 commercial accounts.

This program is being conducted under contract with the United States Department of Energy's Recovery Act - Transportation Electrification DE-FOA 0000028. A portion of this project effort by SMUD was supported by CEC grant ARV-10-041. The primary focus of the project is the deployment and demonstration of the Ram 1500 plug-in hybrid vehicles (PHEV), and the installation and maintenance of the supporting charging infrastructure.

The key tasks of the project were to deploy Ram 1500 PHEVs with project partners and have them used in regular fleet service. Each partner was provided with one or more electric vehicle service equipment (EVSE) to be installed at their fleet or office location so that the truck could be charged on a regular basis. Additional work was done at select sites to test and refine smart charging and reverse power flow technologies. Figure 1 shows the type of Ram 1500 PHEVs that were deployed in this project.

### **Charging Infrastructure (Task 2)**

The goal of the charging infrastructure task was to deploy vehicle charging systems to facilitate optimal use of the rechargeable portion of the PHEV battery pack. Each Ram 1500 PHEV was provided with both a Level 1 and a Level 2 EVSE by Chrysler.

### **Vehicle Demonstration (Task 3)**

The goal of the vehicle demonstration task was to put Ram 1500 PHEVs into regular fleet service. Regular maintenance was done by the users and oversight and logistical backup were provided by SMUD.

**Figure 1: Project Kick-off Event at San Francisco City Hall**



Source: SMUD.

### **Data Collection and Smart Charging (Task 4)**

The goal of this task is to accumulate relevant data from all vehicles in the demonstration and report out the findings. Additional work developed smart charging capabilities.

## CHAPTER 2:

# Project Narrative

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### Charging Infrastructure (Task 2)

Each Ram 1500 PHEV came with a Level 1 (Aerovironment Model EVSE-CT) and a Level 2 (Aerovironment model EVSE-RS) EVSE, provided by Chrysler.) The Level 1 EVSE was a unit designed to plug into an ordinary 120 volt wall socket and provide about 1.4 kW of charging power. The Level 2 units had to be hardwired on a dedicated 208 or 240 volt circuit and deliver about 6.6 kW of charging power. SMUD provided design and installation services for the Level 2 EVSEs at the following locations listed in Table 1.

**Table 1: EVSE Installation Plan**

<b>Project Partner</b>	<b>Installation Address</b>	<b>EVSEs</b>
City of Rancho Cordova	2729 Prospect Park Drive	2
	2880 Gold Tailings Ct.	1
City of Citrus Heights	6237 Fountain Square Drive	2
City of Elk Grove	8401 Laguna Palms Way	2
	8400 Laguna Palms Way	1
City of Galt	495 Industrial Dr.	2
	564 Elm Ave., Galt, CA95632	1
City of Sac'to Corp Yard	5730 24th Street	1
SMUD Headquarters	6201 S Street	2
<b>Total</b>		<b>14</b>

Source: SMUD.

Installation of charging infrastructure proved challenging in a number of respects, not the least of which was dealing with various public contracting rules among the partners. Each had its own permitting and inspection protocols. Add to that the novelty of the EVSE hardware and code requirements. There was considerable effort spent in educating the partners regarding National Electric Code Article 625, which governs electric vehicle charging systems.

Cost varied considerably, as well. The cost per EVSE installation depended on factors including, distance to a suitable power supply, whether excavation and paving were part of the work, connectivity with communications hubs, and the complexity of design and construction.

Generally, wall-mounted EVSEs with surface mounted conduit were the least expensive installations. These were accomplished for as little as \$600 per EVSE. Free-standing EVSEs with concrete foundations and buried conduit were considerably more expensive. Cost ranged from about \$2500 to as much as \$8,500 per EVSE installed. These figures are for the contract labor and installation services, only. The cost of EVSE hardware and materials were in addition to the cost of installation, since the EVSEs, proper, were provided by Chrysler. Each type of charger can be seen in Figures 2 and 3.

**Figure 2: Low Cost Installation Wall Mounted with Nearby Power Supply**



Source: SMUD.

**Figure 3: Pedestal-Mounted EVSE**



Source: SMUD.

Significant per-EVSE saving could be achieved by scaling up to greater numbers of EVSEs installed per site. Many of the installation costs would increase by only a small increment with the addition of more EVSEs. One approach to reducing overall cost of future expansion at a given site would be to include breakers, conduit and conductors, installed for future EVSEs; only EVSE hardware would then be needed to expand the number of charging stations.

SMUD developed a detailed EVSE deployment protocol to facilitate more rapid and cost effective installation of EVSEs at project partners' sites. The flow chart for this process is attached as Figure 1.

## Vehicle Demonstration (Task 3)

The vehicle demonstration task was accomplished in two phases. Phase 1 was an extended shake down period (October 2010 – August 2012) with 14 Ram 1500 PHEVs in the field with the project partners. A number of break downs and persistent reliability issues resulted in all 14 trucks being taken back to Chrysler for redesign of the high voltage battery pack.

Phase II resumed with the redeployment to SMUD of only 5 of the Ram PHEVs (December 2013 – September 2014). During Phase II, the five returned units performed nearly without flaw and drew high praise from all users. The EVSEs installed and phase type in this period can be seen in Table 2.

**Table 2: EVSEs Installed**

<b>Project Partner</b>	<b>Ram 1500 PHEV (Phase I)</b>	<b>Ram 1500 PHEV (Phase II)</b>	<b>EVSEs Installed</b>
SMUD	5	1	2*
City of Citrus Heights	1	-	2
City of Elk Grove	1	-	3
City of Galt	2	2	3*
City of Rancho Cordova	1	2	3*
City of Sacramento	4	-	1
<b>Totals</b>	<b>14</b>	<b>5</b>	<b>14</b>

Source: SMUD.

\* These sites included hardware for communication and reverse power flow in Phase II.

Figure 4 shows the Ram 1500 PHEVs that were used throughout this project.

**Figure 4: Ram 1500 PHEVs**



Source: SMUD.

The service duty of the demonstration vehicle varied widely. Users included dedicated assignment vehicles for 24-hour use by on-call city staff. As such, demonstration vehicles were

often taken to the users' home after hours in case they were called out on emergencies. Plug-in charging was not rigorously performed, especially at home, therefore, there is some variability in the net performance of the vehicle. In the aggregate, the performance highlights from the Phase II demonstration can be seen in Table 3.

**Table 3: Performance Highlights from Phase II Demonstration**

<b>Performance Breakdown</b>	<b>Performance Output</b>
Total miles in Phase II	55,024 miles
Average charging power per vehicle-month	145 kWh
Avg. gasoline MPG in charge depleting mode	25 MPG
Net average gasoline MPG	20 MPG
Engine stop time during driving	39%

Source: SMUD.

Detailed performance evaluation and analysis of the Phase II portion of the demonstration was compiled by Idaho National Lab as part of the Advanced Vehicle Testing program. Their report is attached as Appendix A.

## **Data Collection and Smart Charging (Task 4)**

Smart grid integration was hampered by access issues, primarily owed to cyber security regulations imposed on SMUD as an electric utility to access the Smart Energy Profile 2.0 encryption levels. Due to limited resources, SMUD was unable to deal with these issues directly, but was able to accomplish several of the tasks associated with smart charging by using a local server instead of the server within the SMUD facility (Figure 5). Scheduled charging, demand response and reverse power flow used the Chrysler web- and telemetric-based communications and later an In-Vehicle Display to successfully demonstrate all of these features.

SMUD also hosted the successful original equipment manufacturer (OEM) Central Server demo mid-October, 2014, where the RAM demonstrated the direct communication to the grid using Smart Energy Profile 2.0, as opposed to 6 other OEM's that demonstrated Indirect and combinations of standards using an OEM Central Server with OpenADR2 communications.

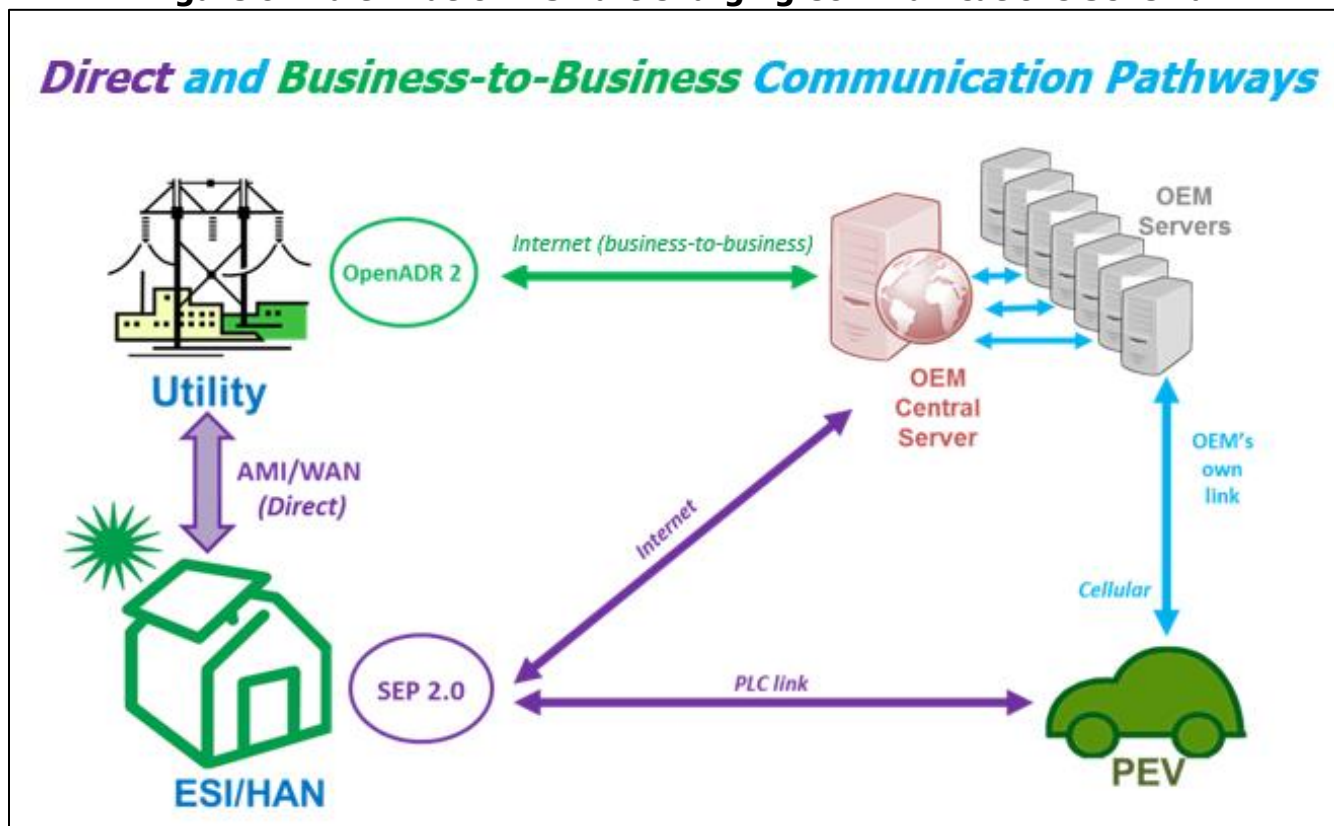
Advancements in both communication (including business-to-business) and control technologies will enable future application to demand response, smart charging (including managed, shared, scheduled and cost-optimized charging), and reverse power flow (sometimes referred to as vehicle-to-grid). This communication can be seen in Figure 6.

**Figure 5: Multi-OEM Smart Charging Demonstration at SMUD**



Source: SMUD.

**Figure 6: Multi-Platform Smart Charging Communications Schema**



Source: SMUD.

## CHAPTER 3:

# Project Financials

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Table 4 shows the final expenses of this project.

**Table 4: Final Expenses**

<b>Task</b>	<b>CEC</b>	<b>Chrysler Match</b>	<b>SMUD Match</b>	<b>SMUD In-Kind</b>	<b>Total</b>
Task 2	69,829.26	108,899.48	40,105.59	-	<b>\$218,834.33</b>
Task 3	-	48,135.07	49,124.52	443,613.72	<b>540,873.31</b>
Task 4	-	23,141.45	51,027.85	-	<b>74,169.30</b>
<b>Total</b>	<b>69,829.26</b>	<b>180,176.00</b>	<b>140,257.96</b>	<b>443,613.72</b>	<b>\$833,876.94</b>

Source: SMUD.

### Contractors and Suppliers

3D Datacom

11365 Sunrise Gold Circle, Rancho Cordova, CA 95742

EVSE Installation services

EETS, Inc.

6060 Sunrise Vista Drive #3450, Citrus Heights, CA 95610

EVSE installation design services

AeroVironment

181 West Huntington Drive #202, Monrovia, CA 91016

EVSE hardware and appurtenances

Gerlinger Steel

1510 Tanforan Ave, Woodland, CA 95776

Misc. steel materials for EVSE installation

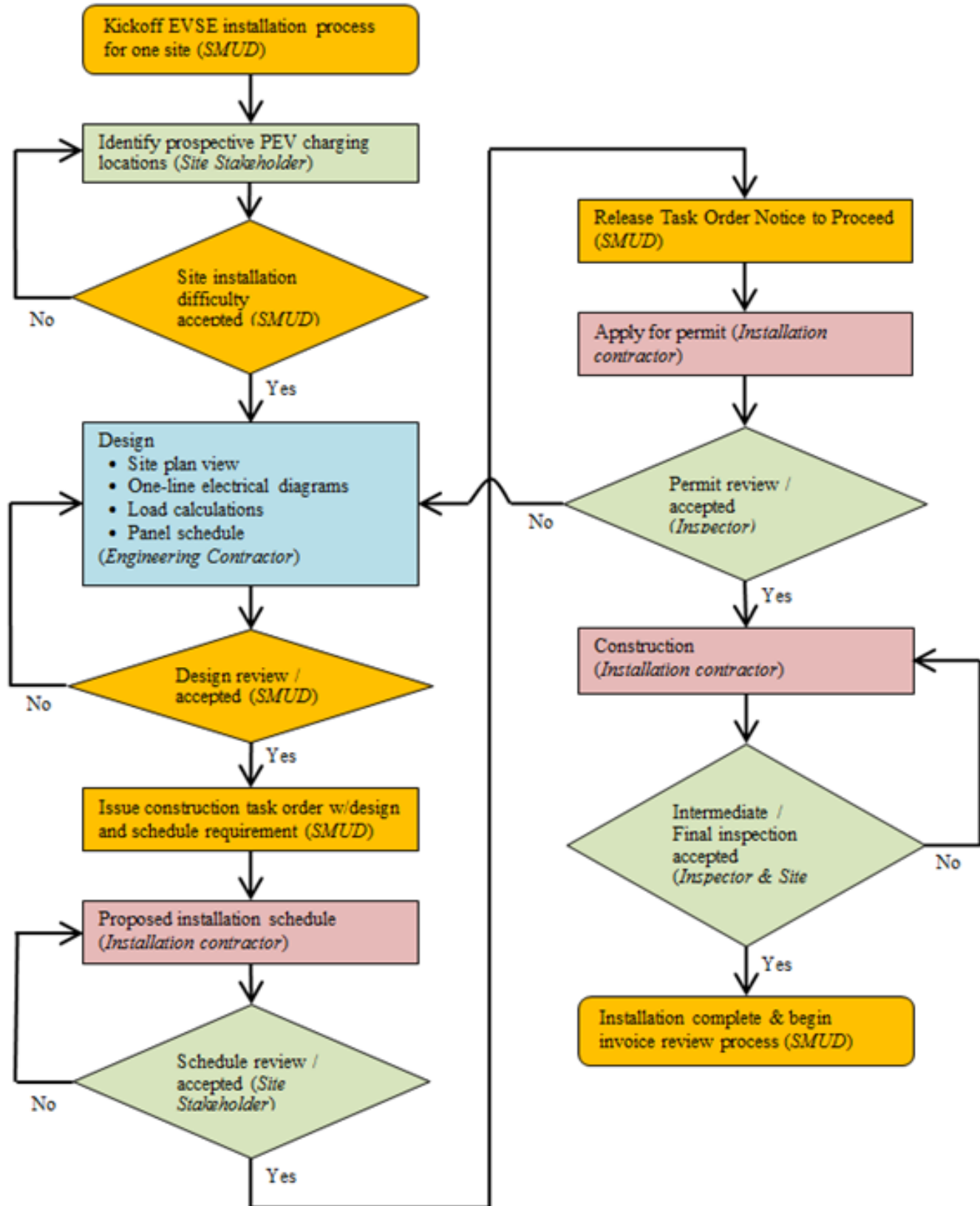
Graybar Electric

1211 Fee Drive, Sacramento, CA 95815

Misc. electrical supplies for EVSE installation

Figure 7 shows the EVSE Installation Decision Flow Chart used through this project.

**Figure 7: EVSE Installation Decision Flow Chart**



Source: SMUD.

## GLOSSARY

**ALTERNATIVE-FUEL VEHICLE (AFV)** – A vehicle designed to operate on an alternative fuel (e.g., compressed natural gas, methane blend, electricity). The vehicle could be either a dedicated vehicle designed to operate exclusively on alternative fuel or a nondedicated vehicle designed to operate on alternative fuel and/or a traditional fuel.

**ALTERNATIVE AND RENEWABLE FUELS AND VEHICLE TECHNOLOGY PROGRAM (ARFVTP)** – Also known as the Clean Transportation Program, created by Assembly Bill 118 (Nunez, Chapter 750, Statutes of 2007), with an annual budget of about \$100 million. Supports projects that develop and improve alternative and renewable low-carbon fuels, improve alternative and renewable fuels for existing and developing engine technologies, and expand transit and transportation infrastructures. Also establishes workforce training programs, conducts public education and promotion, and creates technology centers, among other tasks.

**AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)** – An international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

**CALIFORNIA ENERGY COMMISSION (CEC)** – The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

- Forecasting future statewide energy needs
- Licensing power plants sufficient to meet those needs
- Promoting energy conservation and efficiency measures
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
- Planning for and directing state response to energy emergencies

Funding for the Commission's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account and other sources.

**CALIFORNIA CODE OF REGULATIONS (CCR)** – The official compilation and publication of the regulations adopted, amended, or repealed by state agencies pursuant to the Administrative Procedure Act (APA). Properly adopted regulations that have been filed with the Secretary of State have the force of law. The CCR is compiled into Titles and organized into Divisions containing the regulations of state agencies.<sup>1</sup>

**CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA - pronounced See' quah)** – Enacted in 1970 and amended through 1983, established state policy to maintain a high-quality environment in California and set up regulations to inhibit degradation of the environment.

**ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)** – Infrastructure designed to supply power to EVs. EVSE can charge a wide variety of EVs including BEVs and PHEVs.

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<sup>1</sup> [California Office of Administrative Law](https://oal.ca.gov/) (<https://oal.ca.gov/>)

**GREENHOUSE GASES (GHG)** – Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), halogenated fluorocarbons (HCFCs), ozone (O<sub>3</sub>), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

**KILOWATT (kW)** – One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

**ORIGINAL EQUIPMENT MANUFACTURER (OEM)** – a company that purchases parts and equipment that may be manufactured by another company.<sup>2</sup>

**PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)** – PHEVs are powered by an internal combustion engine and an electric motor that uses energy stored in a battery. The vehicle can be plugged in to an electric power source to charge the battery. Some can travel nearly 100 miles on electricity alone, and all can operate solely on gasoline (similar to a conventional hybrid).

**SACRAMENTO MUNICIPAL UTILITY DISTRICT (SMUD)** –The acronym for the Sacramento Municipal Utility District, an electric utility serving the greater Sacramento, California, region.

**UNITED STATES DEPARTMENT OF ENERGY (U.S. DOE)** – The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA)** – A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting, and enforcement activities.

**VOLT (V)** – A unit of electromotive force. It is the amount of force required to drive a steady current of one ampere through a resistance of one ohm. Electrical systems of most homes and offices have 120 volts.

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<sup>2</sup> [Original Equipment Manufacturer Wikipedia](https://en.wikipedia.org/wiki/Original_equipment_manufacturer) (https://en.wikipedia.org/wiki/Original\_equipment\_manufacturer)

# APPENDIX A:

## Phase II Demonstration Performance Report

### Idaho National Lab Advanced Vehicle Testing

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NOTE: The Idaho National Lab report uses terms of art for how the battery is utilized in PHEV operation on a trip by trip basis. These terms and acronyms may be understood as follows.

**Table A-1: PHEV Battery Utilization Description**

Operating Mode	Acronym	Description
Charge Depleting	CD	Trips in direct current mode mean that the plug-in rechargeable portion of the battery was used to achieve maximum gasoline efficiency. This could include all-electric operation, without the engine running. CD mode can only operate if the battery is above some preset state of charge.
Mixed Operation	CD/CS	Trips in this mode included both CD and CS operation. This means that the plug-in rechargeable portion of the battery capacity was spent at some point in the trip and the system automatically switched to CS mode.
Charge Sustaining	CS	Trips in CS mode happen when the battery is at or below the lowest allowed state of charge. The mode balances engine efficiency by alternately charging and discharging the battery. CS mode is designed to keep the battery in a narrow band near the lowest allowable state of charge.

Source: SMUD.