Plug-In Hybrid Medium-Duty Truck Demonstration and Evaluation

Final Report, October 2015

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Recipient: South Coast Air Quality Management District

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NOTE

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PRODUCT DESCRIPTION

The Plug-In Hybrid Medium-Duty Truck Demonstration and Evaluation Program was sponsored by the United States Department of Energy (DOE) using American Recovery and Reinvestment Act of 2009 (ARRA) funding. The purpose of the program is to develop a path to migrate plug-in hybrid electric vehicle (PHEV) technology to medium-duty vehicles by demonstrating and evaluating vehicles in diverse applications. The program also provided three production-ready PHEV systems—Odyne Systems, Inc. (Odyne) Class 6 to 8 trucks, VIA Motors, Inc. (VIA) half-ton pickup trucks, and VIA three-quarter-ton vans. The vehicles were designed, developed, validated, produced, and deployed. Data were gathered and tests were run to understand the performance improvements, allow cost reductions, and provide future design changes. A smart charging system was developed and produced during the program.

The partnerships for funding included the DOE; the California Energy Commission (CEC); the South Coast Air Quality Management District (SCAQMD); the Electric Power Research Institute (EPRI); Odyne; VIA; Southern California Edison; and utility and municipal industry participants. The reference project numbers are DOE FOA-28 award number EE0002549 and SCAQMD contract number 10659.

Background

The program has had some new developments over time. Several companies and partners were included, but for various reasons, they dropped out of the program. At the end of the program, both Odyne and VIA had developed PHEV systems.

Objectives

The objectives of the program were to develop three production-ready PHEV systems and to deploy these technologies to the field for evaluation in diverse applications.

Approach

The approach was to locate hybrid developers and develop a PHEV system for medium- and light-duty applications. After developing the system with engineering prowess, the goal was to produce about 280 vehicles and deploy them across the nation in diverse applications. During normal work, data were recorded that were analyzed to determine better designs for the customer, to reduce emissions and costs, and to provide an opportunity for the participant to consider future developments.

Results

The program designed, developed, validated, produced, and deployed a total of 296 PHEVs—119 Class 6 to 8 trucks, 52 three-quarter-ton vans, and 125 half-ton pickup trucks—and remained within budget. Two developers (VIA and Odyne) are now in production with the vehicles produced from this program. The participants are becoming familiar with the new technology and will be increasingly adding these types of trucks to their fleets. One-second data have been gathered during vehicle events, including drive, charge, and stationary events. Data were analyzed, and results were provided. A smart charging system was developed and deployed. Good engineering techniques assisted in each of the developments.

Applications, Value, and Use

Recipients of this report can use these results to evaluate this program and determine next steps for development.

Keywords

Department of Energy (DOE)
Plug-in hybrid electric vehicle (PHEV)
Medium-duty truck
Odyne Systems
VIA Motors

ABSTRACT

The Plug-In Hybrid Medium-Duty Truck Demonstration and Evaluation Program is sponsored by the United States Department of Energy (DOE) using American Recovery and Reinvestment Act of 2009 (ARRA) funding. The purpose of the program is to develop a path to migrate plug-in hybrid vehicle technology to medium-duty vehicles by demonstrating and evaluating vehicles in diverse applications. The program allows the fleets to develop an interest in the technology and understand the infrastructure for the vehicles. The participants are deploying these vehicles in the field with their operators to achieve real-life experience with the vehicles. A total of 296 vehicles were delivered to the field under this program. Two developers were able to make plug-in hybrid pickup trucks, vans, and Class 6 to 8 medium-duty utility trucks for the utility industry. The pickup trucks and vans are plug-in series hybrid vehicles that have more than 40 miles of all-electric range and another 300 miles of gasoline range. The Class 6 to 8 trucks are parallel plug-in hybrid vehicles and can improve fuel economy by up to 50%. These developers now have capabilities to produce more of these vehicles. Cost analysis has been done to understand future cost reduction. An initial survey of the operators was conducted, with positive results.

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1
INTRODUCTION

The original Plug-In Hybrid Medium-Duty Truck Demonstration and Evaluation Program was approved in August 2009 and officially began on November 30, 2009. The program is a $95.8-million program that consists of $45.4 million from the United States Department of Energy (DOE) using American Recovery and Reinvestment Act of 2009 (ARRA) funds, $5 million from the California Energy Commission (CEC), and $45.4 million of cost share from the program participants. The reference project numbers are DOE FOA-28 award number EE0002549 and South Coast Air Quality Management District (SCAQMD) contract number 10659.

1.1 Project Objective

The primary goal of this project is to develop a near-production plug-in hybrid electric vehicle (PHEV) powertrain system that is suitable for widespread utility use in service vehicles. The project required simultaneous execution of two advanced hybrid powertrain development projects along with chassis integration efforts. This project has developed a path to migrate PHEV technology to medium-duty vehicles by accomplishing the following:

- Demonstrating and evaluating vehicles in diverse applications
- Developing two production-ready PHEV systems—one for Class 1 to 2 trucks and vans (less than 10,000 lb gross vehicle weight) and the other for Class 6 to 8 trucks (19,501 lb to greater than 33,001 lb gross vehicle weight)
- Establishing production at a ship-through facility for commercial production and installation of the PHEV system
- Developing production-ready smart charging capability for the vehicles and the supporting charging infrastructure
- Using project results for system development to optimize performance and reduce costs
- Starting the project on November 30, 2009, and ending the project on July 31, 2015

1.2 Project Activities

The early program started with Eaton Corporation (Eaton) being the main hybrid developer. Eaton dropped out, and Odyne Systems, Inc. (Odyne) and Azure Dynamics, Inc. (Azure) became the lead developers of two systems. Azure dropped out, and Odyne, VIA Motors Inc., and Quantum become the developers. Then Quantum dropped out, which left Odyne and VIA were contracted to complete this program (see Appendix E). Both Odyne and VIA had their development funds, but the program also provided funding for development. Both companies went through extensive design, development, validation, manufacturing, and service phases. Design reviews were held to determine the levels of the design and whether to proceed to the next milestone. The VIA developments required getting both United States Environmental Protection Agency (EPA) and California Air Resources Board (CARB) executive orders for emissions. The Odyne system was approved by the EPA, and CARB provided an executive order for the trucks. The trucks are in the field with their owners and will remain in the field until the owners no longer value the trucks. Significant fuel economy benefits have been seen and are described later in this report. Odyne and VIA are now taking orders from new customers for their products.

While changing the developers, the participants also had to rethink their activity in the program. Many participants remained a part of the program, but some left the program due to timing and budget constraints. The original program was developing Class 5 aerial trucks for the utilities. As the program changed over time, the Class 5 trucks were not developed but rather Class 6 to 8 aerial and hydraulic trucks and Class 1 and 2 pickup trucks and vans were delivered. The total number of vehicles delivered is 296 (119 Class 6 to 8 trucks, 125 Class 1 pickup trucks, and 52 Class 2 vans). The cost share for the participants was to purchase the base vehicle and install electric vehicle supply equipment (EVSE) for each vehicle.

Quarterly telecasts or face-to-face meetings were held to keep the participants informed. All vehicles were delivered to the participants in the last year of the program. A smart charging system was developed, produced, and deployed on the vehicles, as well as a data acquisition system that is collecting data. Data will be collected from the vehicles even after the end of the program.

1.3 Organization

- SCAQMD is the prime recipient of the award from the DOE.
- The Electric Power Research Institute (EPRI) was contracted to the SCAQMD for program management, technical guidance, fleet coordination, data collection, and data analysis.
- The CEC provided funds for the program, and the program participants provided the base vehicles and infrastructure.
- Both Odyne and VIA were hybrid system developers and producers.
- Pathway Technologies, Inc., developed and produced the smart charging system.
- Southern California Edison provided the facilities and testing time for the vehicles.

1.4 Summary

This program has accomplished the following:

- Designed, developed, validated, certified, and produced three different PHEVs—the Class 6 to 8 trucks from Odyne Systems, Inc., and the pickup trucks and vans from VIA Motors, Inc.
- Deployed 296 vehicles to 62 different customers (more than $27M worth of base trucks)—52 VIA vans, 125 VIA pickup trucks, and 119 Odyne Class 6 to 8 trucks.
- Producing these vehicles significantly reduced NOx, improved fuel economy, and expanded the types of trucks with PHEV tanker trucks, pickup trucks, and so on.
- Implemented state-of-the-art telematics for analysis and diagnostics.

- Collected and analyzed data from all vehicles and provided raw data to the National Renewable Energy Laboratory and the Idaho National Laboratory.
- Developed, validated, produced, and assembled a smart charging system for the vehicle.
- Completed an operator survey with positive results.
- Laboratory testing on the vehicles was completed by Southern California Edison.
- The participants of the program are beginning to understand the technology and are putting it to good use.
- Higher customer acceptance is causing repeat vehicle orders without subsidies.
- The program officially completed on July 31, 2015, within budget constraints.

2
PARTICIPANTS

Sixty-two different utilities, municipalities, or companies participated from 23 states; Washington, D.C.; British Columbia; and Manitoba. These participants are demonstrating and evaluating 296 vehicles (52 VIA vans, 125 VIA pickup trucks, and 119 Odyne trucks). Special leasing arrangements have been made for a couple of participants through Altec Capital. Data have been collected on each participant's trucks during normal working times to establish data for analysis.

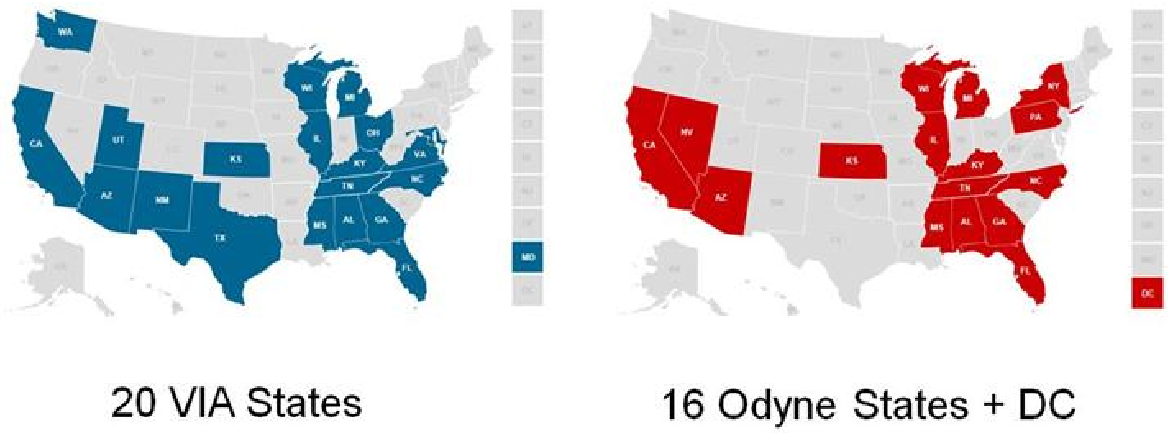

Figure 2-1
States that have program vehicles

The participant responsibilities for the program included the following: 1) Each participant was to order and purchase base trucks without hybrid systems and to purchase and install electric vehicle supply equipment (EVSE) for each truck. 2) The participant was to use the truck as they did others in their fleets, 3) allow for data acquisition, and take a survey. 4) The trucks are owned by the participant. However, upon sale of the trucks, about 50% of the sale will be returned to the federal government unless it is sold for less than US$5,000. The VIA base trucks were purchased by participants in the range of US$25,000 to US$37,000 each, and the Odyne trucks were in the range of US$115,000 to US$450,000 each. The truck and EVSE purchase and installation costs constituted the participants' cost share.

The trucks with the Odyne hybrid system included five types of bodies—bucket trucks, walk-in vans, digger derricks, compressor trucks, and tanker trucks (see Figure 2-2). The bucket trucks represented the largest number of trucks, with 72% of the fleet. The bucket trucks are used to put an operator up onto a pole for repairing or maintaining utility lines. The walk-in vans provide workspace and electric power for a work crew on the job. The digger derricks provide a large drill bit and mechanism for drilling a hole in the ground for a utility pole to be set into and jaws that are used to pick up a pole to set it into the hole. The compressor trucks are used to run an air compressor for providing fresh air into manholes while workers are in the chamber. Three fuel tankers were built, and they are used on the grounds of a nuclear site to dispense fuel into vehicles on the grounds rather than taking the vehicles off the site.

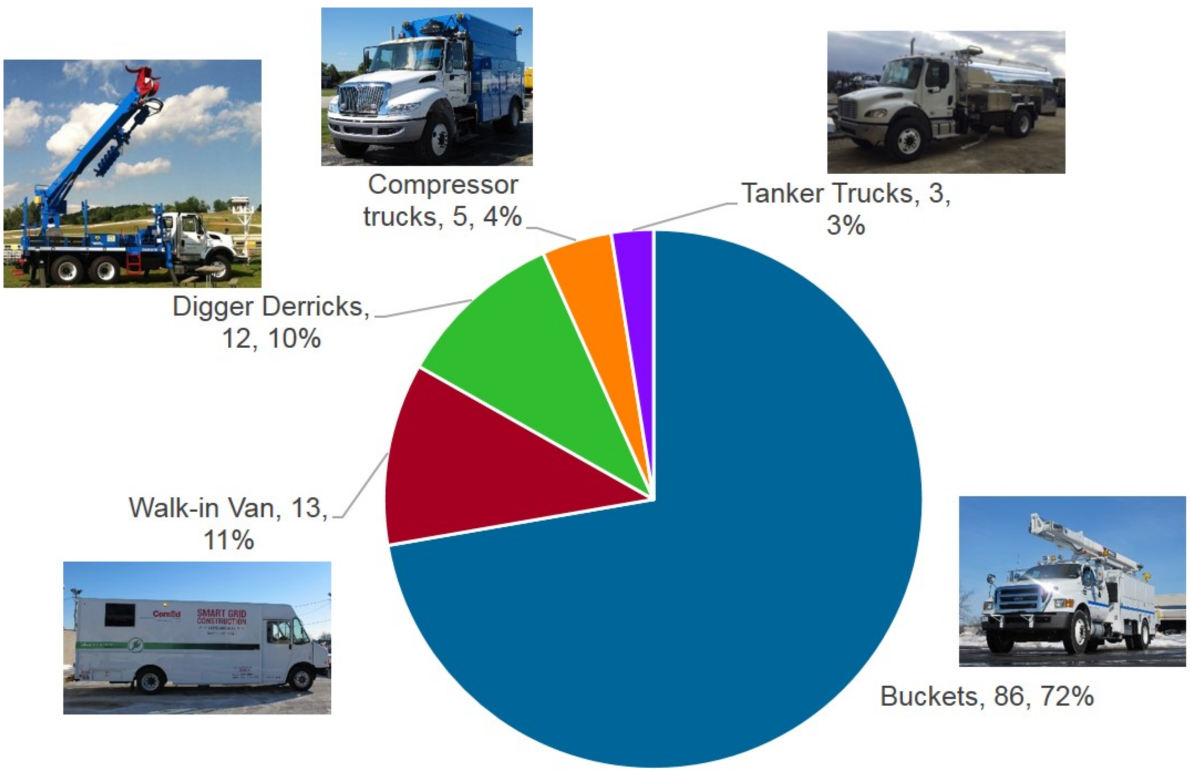

Figure 2-2
Odyne truck body types

The Odyne hybrid system is capable of being installed on numerous original equipment manufacturer (OEM) vehicles. This program has used trucks from four different OEMs—Freightliner, International, Ford, and Kenworth. Figure 2-3 shows the number of units of each that were built for this program. The bodies for these trucks were made by six final-stage manufacturers (FSMs)—Altec, DUECO, Terex, Vanair, Utilimaster, and Amthor.

The participants were responsible to order and purchase the base vehicle and install the charging stations at their locations. The PHEV system and other systems on the vehicles were the responsibility of the program.

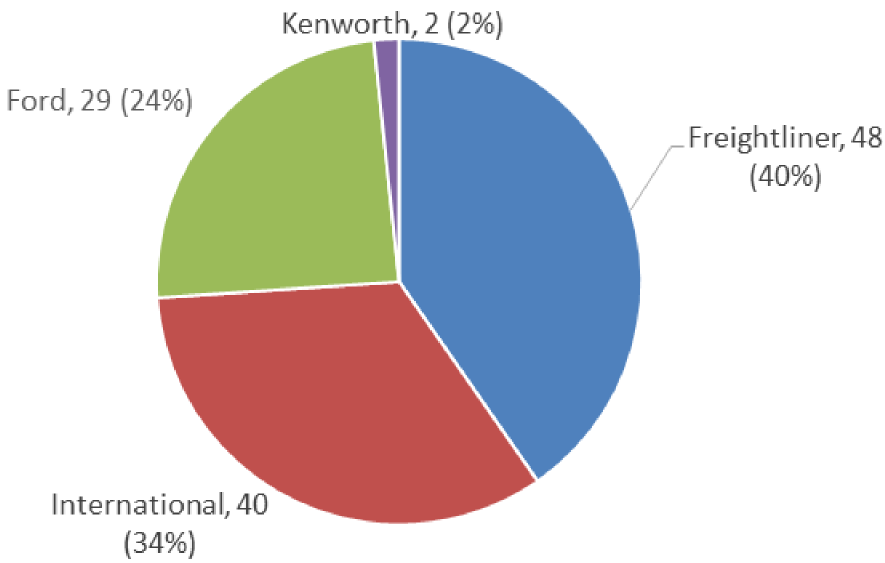

Figure 2-3
Number of Odyne trucks produced, by manufacturer

The participants selected almost 50% of the Odyne fleet as the large Class 8 trucks with Class 7 being the second most (see Figure 2-4). Class 6 trucks have a gross vehicle weight rating (GVWR) of 19,501–26,000 lb, Class 7 trucks have a GVWR of 26,001–33,000 lb, and Class 8 trucks are 33,000 lb and greater.

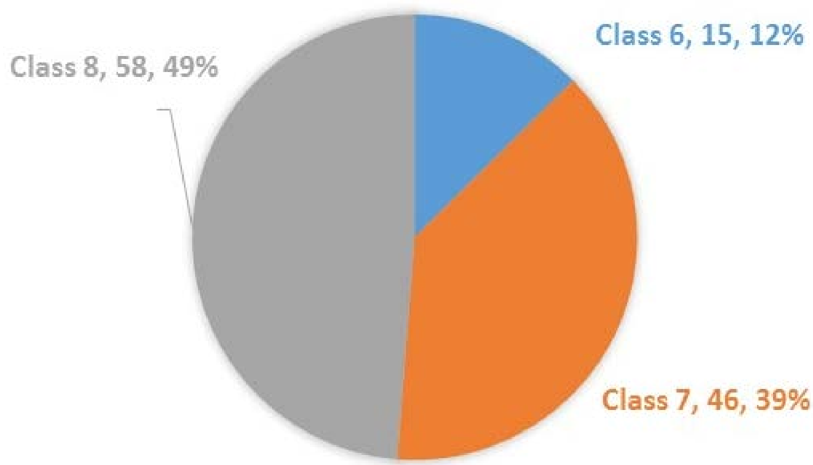

Figure 2-4
Number of Odyne trucks produced, by class

VIA delivered two different body types, a pickup truck and a van. There were more pickup trucks than vans. The vans came in three configurations— a passenger van with multiple seats, a cargo van without extra seats, and an accessible cargo van that has access into the van through the side panels. Figure 2-5 shows the breakdown of the vehicle types.

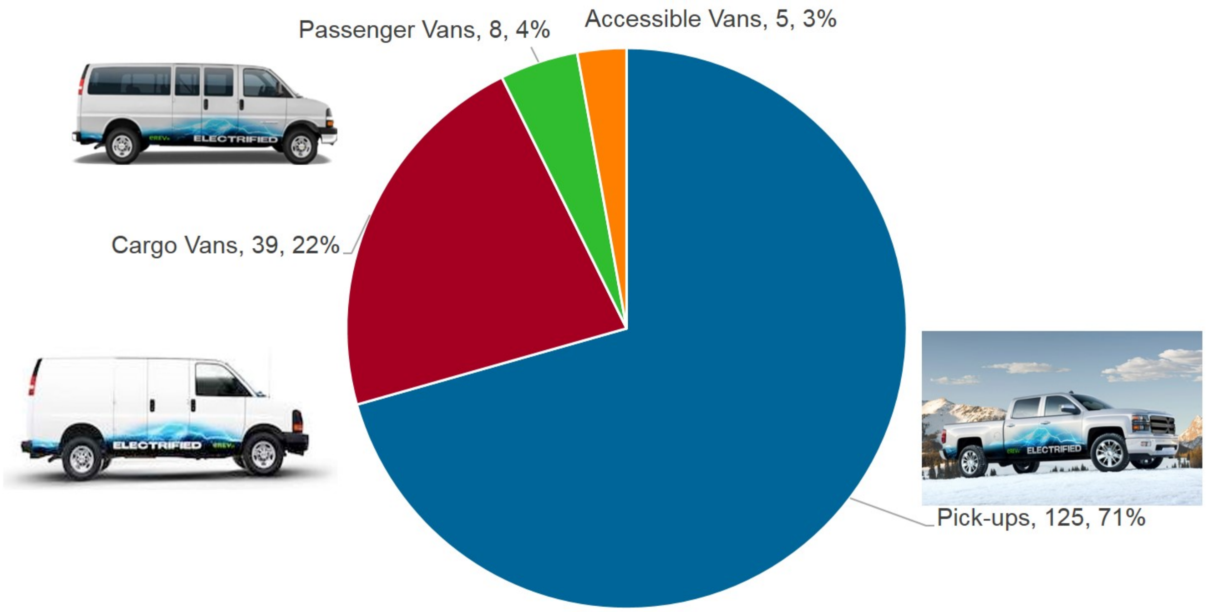

Figure 2-5
VIA van and truck body types produced

3
ODYNE DESIGN, DEVELOPMENT, AND MANUFACTURING

3.1 System Design

The Odyne hybrid system is a simple, parallel hybrid system that allows the torque of the electric motor to augment the torque output of the diesel engine, thus saving fuel. The motor speed is synchronized with the engine speed through the power take-off (PTO) unit. The traction motor drives the PTO, adding torque to the rear axle, or converts torque from the PTO into power to charge the hybrid batteries (see Figures 3-1 and 3-2). Six patents have been granted, and other patents are pending.

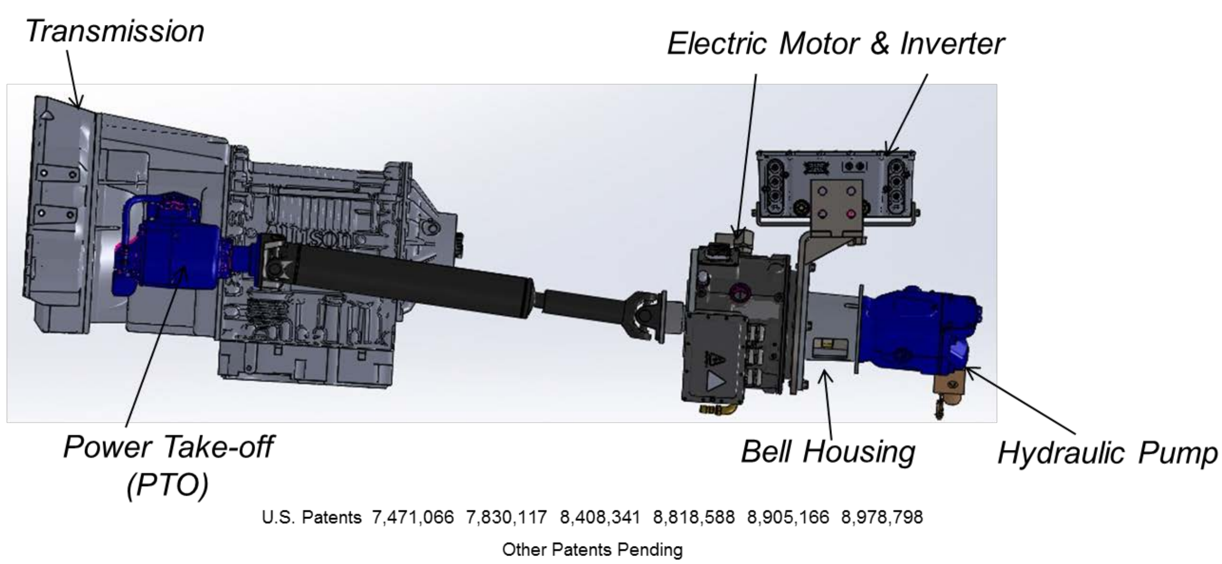

Figure 3-1
Odyne powertrain configuration

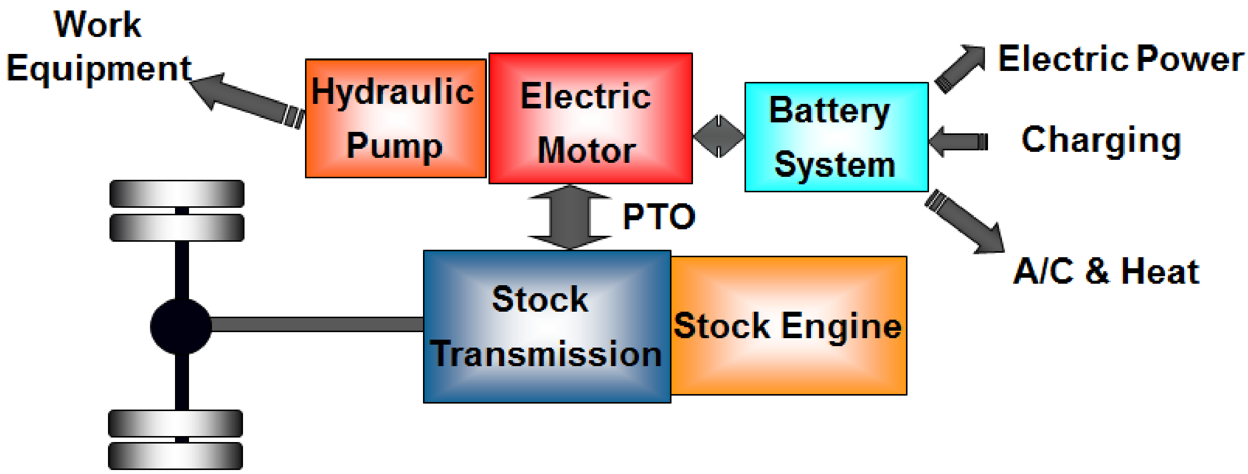

Figure 3-2
Odyne hybrid architecture

The motor can also drive the hydraulic pump that controls the aerial device. A clutch in the PTO allows the motor to drive the hydraulic pump for the aerial device. If the clutch is closed, the diesel engine torque drives the pump and concurrently charges the hybrid batteries through the traction motor.

The advantages of the electrically driven hydraulic pump are reduction in sound level at the job site, improved fuel consumption, and reduced emissions. The diesel engine need not idle during the hydraulic pump control. The pump is activated only when the operator provides the control to move the hydraulics. This feature saves energy when the aerial device is being used.

The Odyne parallel hybrid solution provides a redundant system for the operator to minimize any downtime. If the motor or part of the system breaks, the truck can still be used in its conventional way. It provides the ability to retrofit existing trucks in the field and allows for low validation and capital equipment costs.

The Odyne system requires no modifications to the OEM drivetrain. The hybrid system is simply an added system. It is a simplified system with integration with the PTO. The system uses the compatible SAE J1939 “Recommended Practice—Serial Control and Communications Heavy Duty Vehicle Network” vehicle controller-area network (CAN) communications.

The Odyne operational modes are driving mode, stationary mode, and charge mode, as follows:

- **Drive mode.** The launch assist and regenerative braking operate automatically in a charge-depleting condition during normal drive when state of charge (SOC) is greater than 5%. The vehicle enters a charge-sustaining condition when SOC is between 5% and 0%. Drive mode is automatically disabled during an ABS event, and it can be manually disabled by a cab switch.
- **Stationary mode.** Stationary mode—also called *electric PTO (ePTO) operation*—provides engine-off mechanical power through the hybrid motor/battery to run hydraulic or pneumatic equipment. It also provides electric power for equipment or heating and air conditioning through 12 V and 120/240 V inverters. During the stationary mode when the SOC is low, an engine charge occurs. The engine charge is capable of field charging the battery using the vehicle internal combustion engine/hybrid motor. The system provides automatic engine start and power transfer at 5% SOC, and it maintains all work functions while charging from 5% to 30% SOC. When the SOC reaches 30%, the engine is automatically shut down and reverts to full-electric operation. This is done for efficiency and to allow the engine to shut down for noise reasons.
- **Charge mode.** Charge mode is the state in which the vehicle is attached to the grid through the EVSE and power flows to the vehicle through the onboard charger to the batteries.

In the standard configuration, the truck has two battery packs, one on each side of the chassis rails, and the cooling system is mounted at the rear of the cab on the driver's side. The inverter and motor are mounted between the rails, and the smart charging system is mounted to the charger, near the left side battery (see Figure 3-3). Some vehicles may have slightly different configurations due to chassis or application packaging constraints.

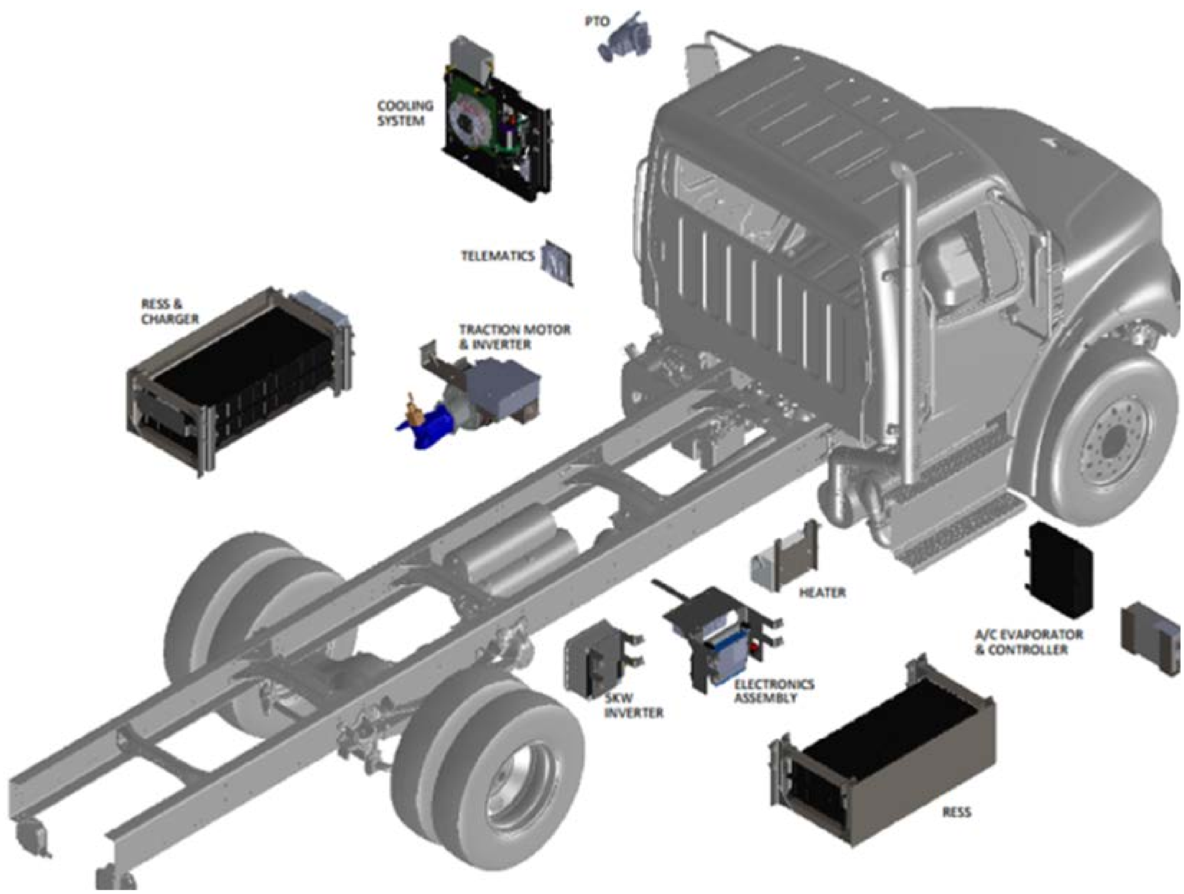

Figure 3-3
Odyne chassis assembly

The Odyne system also provided a 3.0-kW charging system to charge the batteries. During the design phase, discussions were held to determine the required charge time. Most Class 6 to 8 trucks are used during only one shift, leaving up to 12 hours to charge the batteries on the off shifts. Therefore, the 3.0-kW charger was selected for the truck. It requires less than a seven-hour charge time for this configuration, leaving plenty of time until the truck is needed again. The charging connector and interface are compliant with "SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler." Each truck was also provided with a 120-V Level 1 EVSE (cord set).

The Odyne trucks were also provided with a 6-kW, 120/240-V, pure sinusoidal 60-Hz export power. The walk-in trucks all had two 6-kW export power units, providing 12 kW of export power. Each truck had its own export power interface that was provided by the FSM. The Odyne system specifications are listed in Appendix A. Tables 3-1 and 3-2 list the design matrices.

Table 3-1
Matrix of chassis and engine models and transmission series (Allison 2000, 3000, 4000)

Manufacturer	Chassis Model	Engine Model
International	4300/4400	DT, N9
International	7300/7400/7500	DT, N9, N10, ISB6.7, ISL9
Kenworth	T370	PX-9
Ford	F750	ISB6.7
Freightliner	108SD	ISB6.7, ISL9
Freightliner	114SD	ISL9, DD13
FCCC	MT55	ISB6.7

Table 3-2
Matrix of seven primary applications and seven final-stage manufacturers

Primary Power	Application	Final-Stage Manufacturer
Hydraulic	Aerial	Altec, Dueco, Terex
Hydraulic	Digger	Altec, Dueco, Terex
Hydraulic	Fuel pumper	Amthor
Hydraulic	Compressor/vacuum	Cobalt/Vanair
Pneumatic	Boss compressor	Dueco
Pneumatic	Vanair compressor	Cobalt, Hudson Valley
Electric	Walk-in	Utilimaster

During the Odyne design, drawings were obtained from the OEMs for each different truck to determine which truck specifications and dimensions could accommodate the hybrid system. Figure 3-4 shows the approved configurations for this program. Participants could order only the chassis that fit the approved criteria. Typically, the longer the cab-to-axle (CA) dimension, the easier it is to the package.

<table>
<tr><th>Chassis</th><th>Drivetrain</th><th>Cab</th><th>Exhaust</th><th><102" CA</th><th>102" CA</th><th>108" CA</th><th>110-118" CA</th><th>120" CA</th><th>126" CA</th><th>128" CA</th><th>134" CA</th><th>140" CA</th></tr>
<tr><td rowspan="8">International 4300 / 4400</td><td rowspan="6">4 x 2</td><td rowspan="3">Standard</td><td>Vertical</td><td>Not Approved</td><td>Potential Risk</td><td colspan="7">Approved</td></tr>
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<tr><td colspan="3">7BDA</td><td>7BDB</td></tr>
<tr><td rowspan="3">Extended</td><td>Vertical</td><td colspan="2">Not Approved</td><td>Potential Risk</td><td colspan="6">Approved</td></tr>
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<tr><td rowspan="2">6 x 4</td><td rowspan="2">Standard</td><td>Vertical</td><td colspan="7">Not Approved</td><td>Potential Risk</td><td>Approved</td></tr>
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<tr><td rowspan="4">Freightliner M2 106</td><td rowspan="4">4 x 2</td><td rowspan="2">Standard</td><td>Vertical</td><td colspan="3">Not Approved</td><td>Potential Risk</td><td colspan="5">Approved</td></tr>
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<tr><td>Horizontal</td><td colspan="4">Not Approved</td><td colspan="5">Approved</td></tr>
</table>

CA: cab-to-axle length

Figure 3-4
Chassis configurations

The FSMs were required to provide a fiber optic system to insulate the control of the aerial device from the bucket control. The boom itself is insulated from ground to ensure that it does not provide an electrical path to ground if the bucket accidently hits a high power line. Because the PHEV trucks are most efficient as on-demand systems, the hydraulic controls that normally go to the bucket were replaced by a fiber optic control circuit to provide system demand signals while maintaining the insulation of the aerial device. This fiber optic system is an extra cost for the truck because the battery pack is on the truck. This added system should be taken into account with the economics of the trucks.

The controls were a large effort for the vehicle development. A simulation package was used to develop the hybrid control software. Using current industry best practices, failure modes and effects analysis, design reviews, and system simulation, the control systems were totally revamped from the earlier, first-generation Odyne development.

A simple system diagram is shown in Figure 3-5. The system consists of the electric motor, inverter, dc-to-dc converter, charger, hybrid controller, cooling system, battery pack, and battery controller.

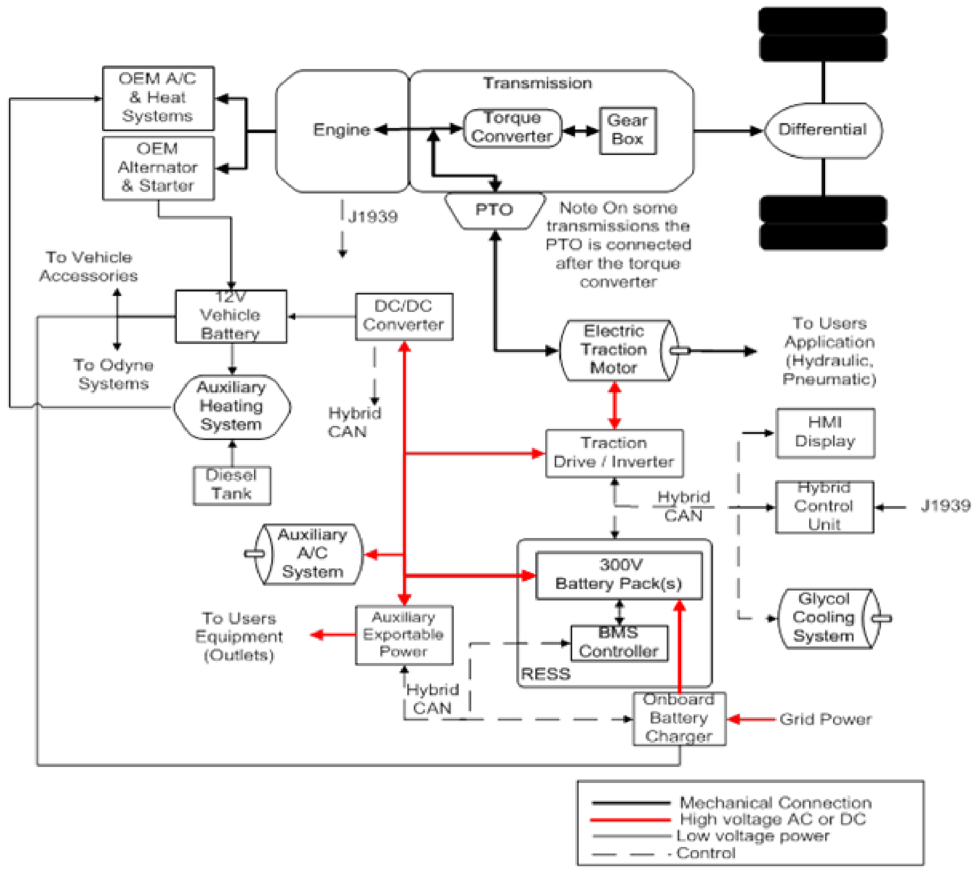


Figure 3-5
Odyne system diagram

3.2 Performance

3.2.1 Mass and Gross Vehicle Weight Rating

The added mass for the hybrid system is 1860 lb (see Table 3-3). This mass reduces the payload by that same amount. The highest mass components are the two battery packs. The battery packs are electrically configured in parallel and are mounted on the outside of the rails on both sides of the truck. Heavy cantilevered brackets are used to house and hold the battery packs. The next design phase should concentrate to eliminate some bracket mass while reliably maintaining the integrity of the system.

Table 3-3
Odyne payload analysis

Item	Standard (lb)	Hybrid (lb)
Gross vehicle weight rating	36,220	36,220
Bare chassis	11,740	11,740
Hybrid system	n/a	1,860
Body and equipment	15,520	15,520
Finished bucket truck	27,260	29,120
Payload	8,960	7,100

Payload change: $\frac{1860}{7100 + 1860}$ = (21%)

The mass study results are shown in Figure 3-6.

- Chassis (Extended Cab)
  - FA: 7,253 lb
  - RA: 4,487 lb
  - Total: 11,740 lb
  - HCG (RA): 133 in.
- Hybrid Chassis
  - FA: 7,826 lb
  - RA: 5,774 lb
  - Total: 13,600 lb
  - HCG (RA): 124 in.
- Odyne Hybrid System
  - FA: 573 lb
  - RA: 1,287 lb
  - Total: 1,860 lb
  - HCG (RA): 66 in.

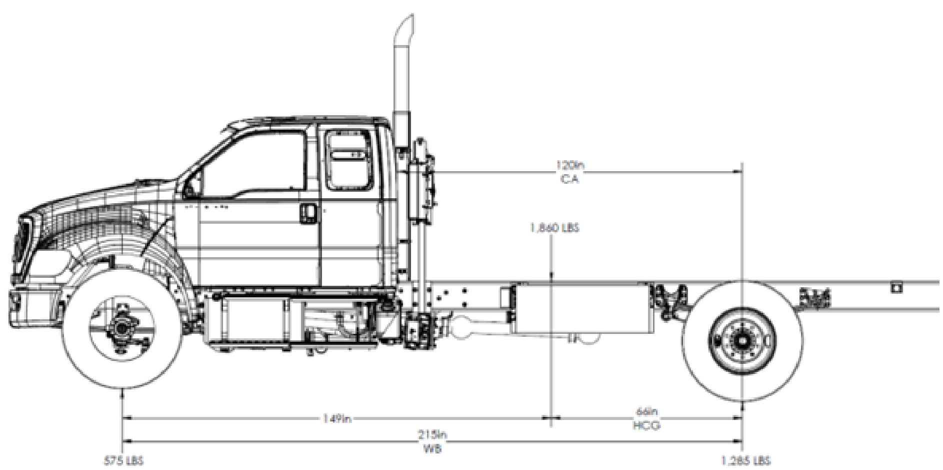


Figure 3-6
Mass study results

3.2.2 Fuel Economy and Emissions

The fuel economy of these vehicles depends on whether the vehicle is charged frequently and whether the vehicle uses all the electric energy available during the daily operation. Obviously, if more electric energy is used, less diesel fuel will be used.

Two calibrations were completed for the Odyne vehicles. One calibration was considered aggressive (strong), and the other was considered mild. The difference is that the aggressive calibration caused the battery energy to be depleted more quickly during the drive phase to the job site than did the mild calibration. The mild calibration would allow more battery energy to be used at the job site than the aggressive calibration. The objective was to determine which one would be used more.

The calibration is changeable through the telematics system, but the operator cannot change it. The trucks with the calibrations were determined quite randomly but with some judgement. Some participants have requested that the other calibration be used.

The mild calibration applies less motor torque and limits the amount of launch assist to save more energy for the job site later. The aggressive calibration has a higher torque limit and increases the amount of launch assist to increase fuel economy benefits while driving (see Figure 3-7).

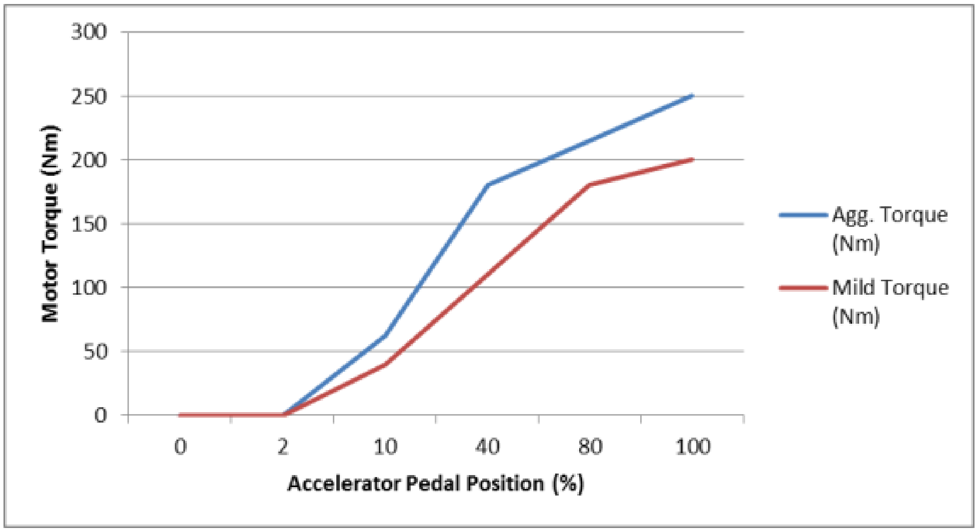


Figure 3-7
Mild versus aggressive performance—acceleration

The mild calibration focuses on lower-speed operation and limits the speed range of launch assist to save energy for the job site. The aggressive calibration extends to higher vehicle speeds. It extends the range of launch assist to cover more driving conditions and increase fuel economy benefits while driving (see Figure 3-8).

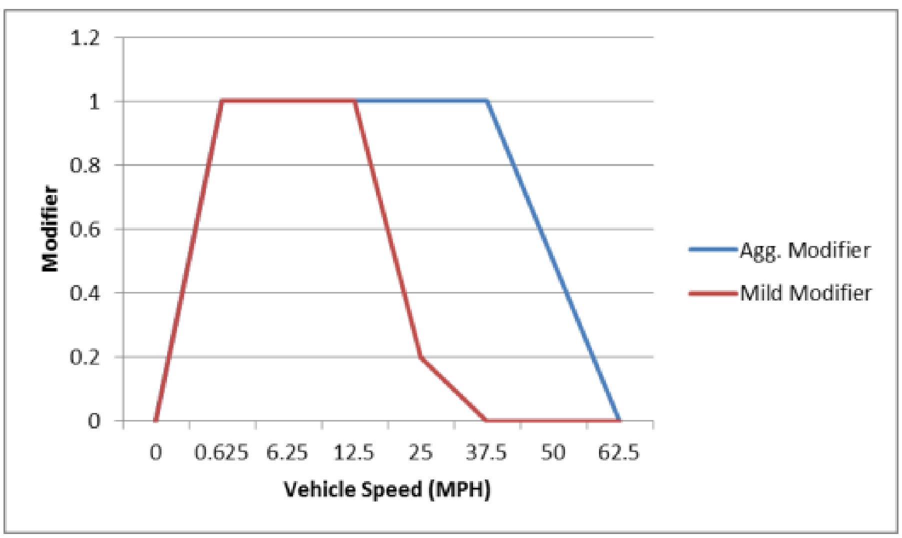


Figure 3-8
Mild versus aggressive performance—vehicle speed

During the charge-sustained mode, as the battery SOC approaches 0%, the system reduces the torque available for launch by the percentage indicated by the modifier graph in Figure 3-9. Regeneration rates remain the same. This method allows the vehicle to dynamically sustain charge, usually around 1% to 2% SOC.

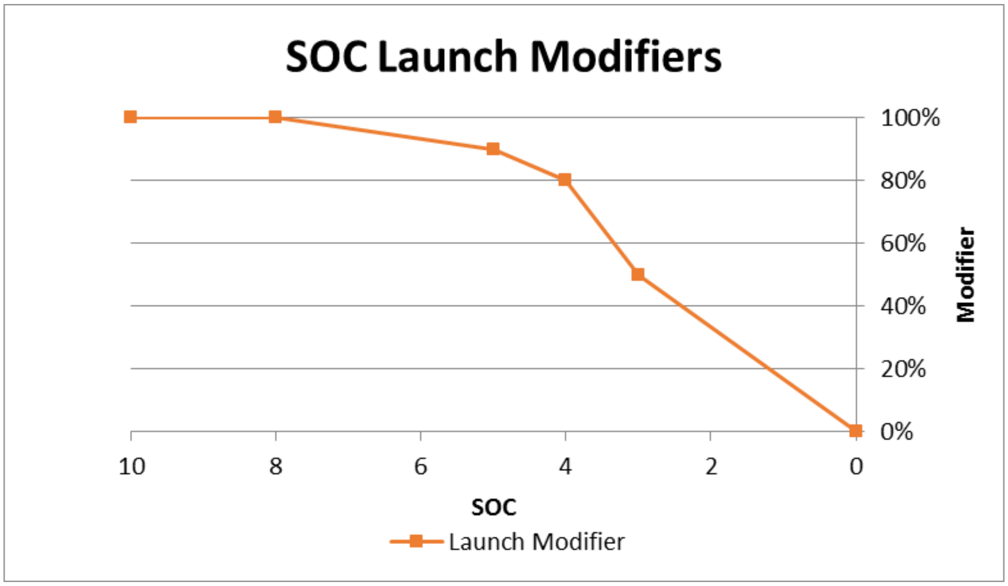


Figure 3-9
Charge-sustained mode modifier

Development tests were performed at Southwest Research Institute. Four drive cycles representing the range of utility industry driving were evaluated—the Combined International Local and Commuter Cycle (CILCC), which was developed under EPA for the utility service industry; the Heavy-Heavy Duty Diesel Truck emissions test (HHDDT), which was originally recommended by the California Air Resources Board (CARB); the Orange County Transportation Authority (OCTA) test, which represents city applications; and the EPA Heavy-Duty Urban Dynamometer Driving Schedule (HDUDDS), which also represents city driving conditions. See Appendix C for drive cycles. Testing was performed on the same vehicle in conventional and hybrid modes under both driving and job site conditions. The results shown in Table 3-4 are the average of three valid test runs. The results indicate that there is improvement with both the aggressive and mild calibrations. The mild calibration improved fuel economy by 12% to 15%, and the aggressive calibration had a 30% to 46% improvement.

Table 3-4
Fuel economy for drive cycles

Cummins/Ford G2V2 December 2013	Fuel Economy (mpg)	Improvement
CILCC cycle		
Average conventional	5.27	
Average hybrid mild calibration	6.07	15.2%
Average hybrid aggressive calibration	7.72	46.5%
OCTA cycle		
Average conventional	3.96	
Average hybrid mild calibration	4.44	12.1%
Average hybrid aggressive calibration	5.57	40.7%
HHDDT transient cycle		
Average conventional	4.81	
Average hybrid mild calibration	5.46	13.5%
Average hybrid aggressive calibration	7.09	32.2%

One of the benefits of the Odyne system is to combine the fuel and emissions savings while driving with the engine-off benefits of hybrid job site operation. To accurately assess the system, the combined benefits are calculated in the full day work cycle. Using the data that were gathered on the fleet, an average day's parameters can be calculated. These data are shown in Figures 3-10 through 3-13. The average drive distance is 26 miles, the average stationary work is complete in 2.8 hours, and the average idle time is 1.6 hours.

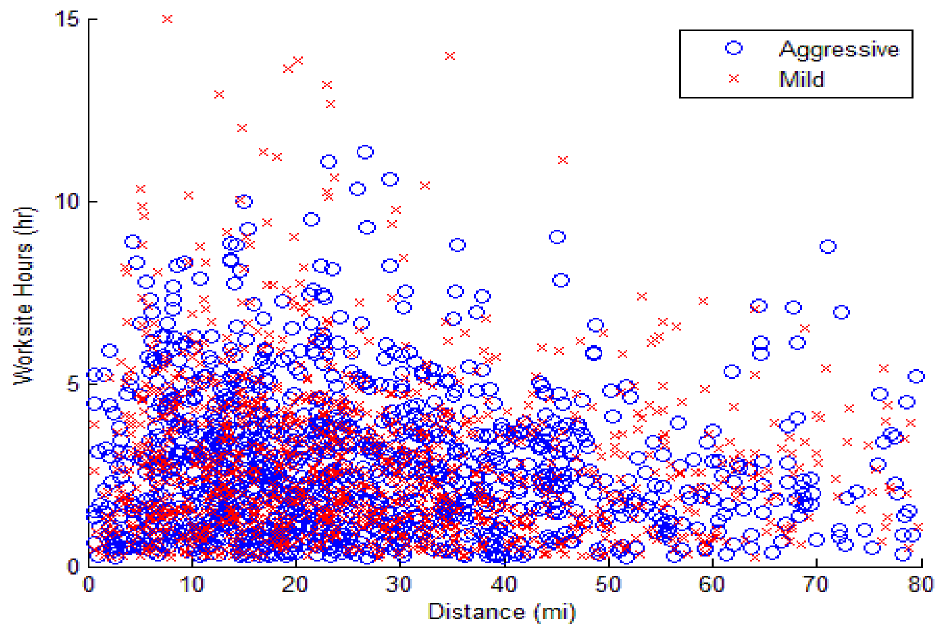


Figure 3-10
Plot of real data for work time versus distance

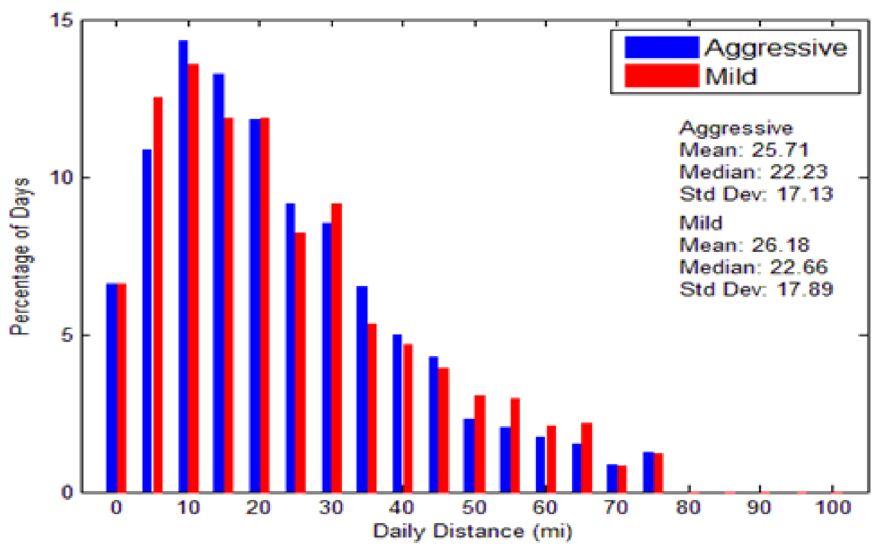


Figure 3-11
Histogram of drive distance

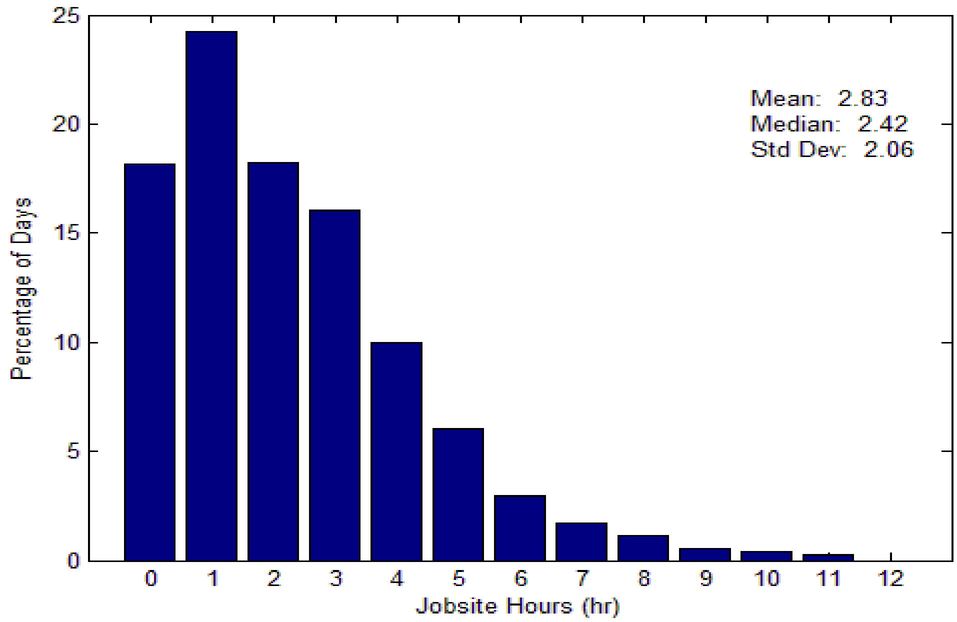


Figure 3-12
Histogram of stationary work time

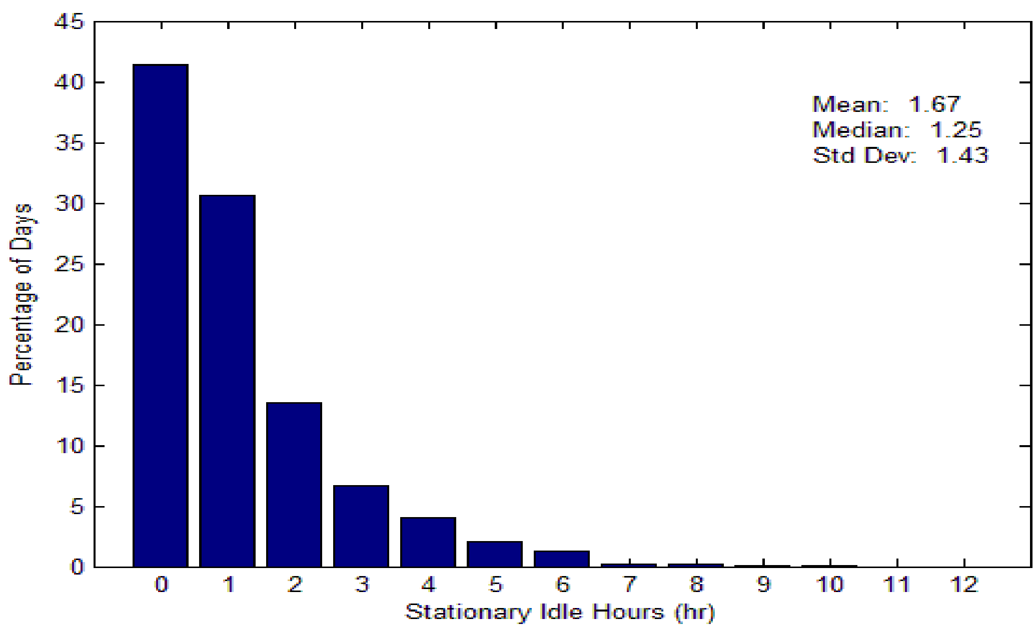


Figure 3-13
Histogram of idle time

Using the fuel and emissions test results from the dynamometer testing and the average use case, Odyne system benefits can be calculated as shown in Table 3-5 and Figures 3-14 through 3-16 for a full-day work cycle. The results are the following:

- Reduces full-day fuel use by 50% or more
- Reduces greenhouse gas emissions by 50% or more
- Reduces NO*x* emissions by 80% or more

Table 3-5
Odyne fuel consumption

Mode	Baseline Vehicle	Odyne Mild Calibration	Odyne Aggressive Calibration
Driving (26 miles/day)	3.52	3.23	2.58
ePTO at job site (2.8 hours/day)	3.07	0	0
Idle at job site (1.7 hours/day	0.70	0	0
Engine charge (if needed)	N/A	0	0
Workday total	7.29	3.23	2.58
Total savings (gal)		4.06	4.71
Total savings (%)		55.7%	64.6%

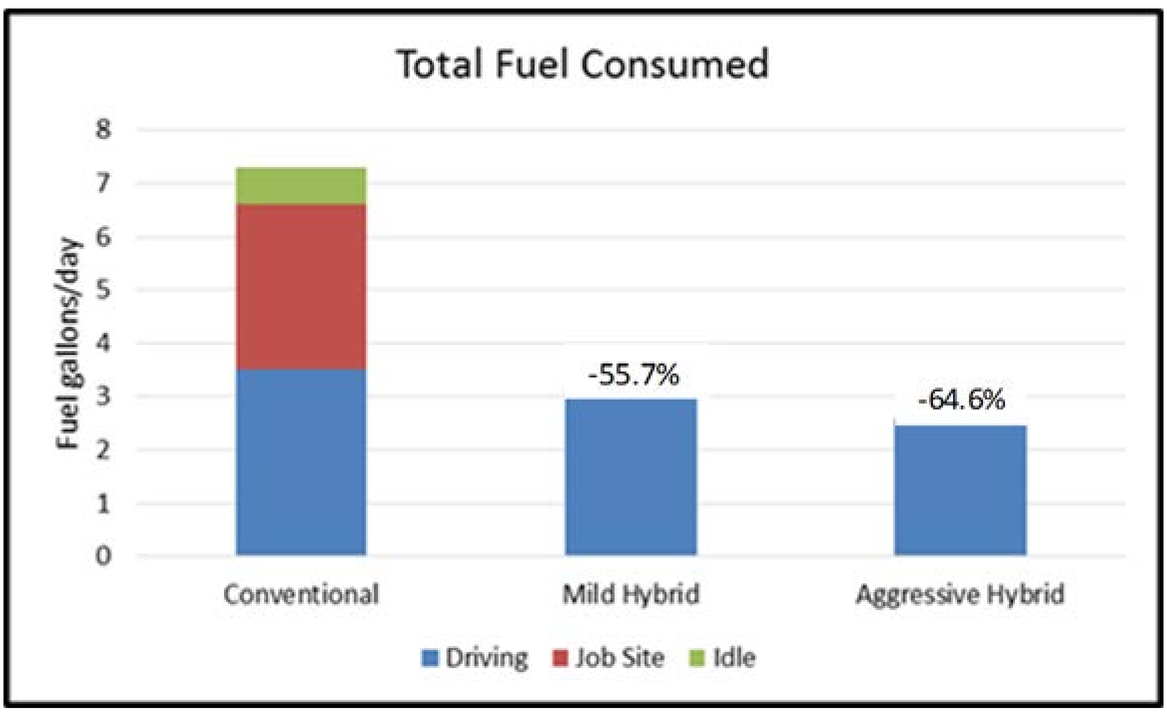


Figure 3-14
Odyne fuel consumption

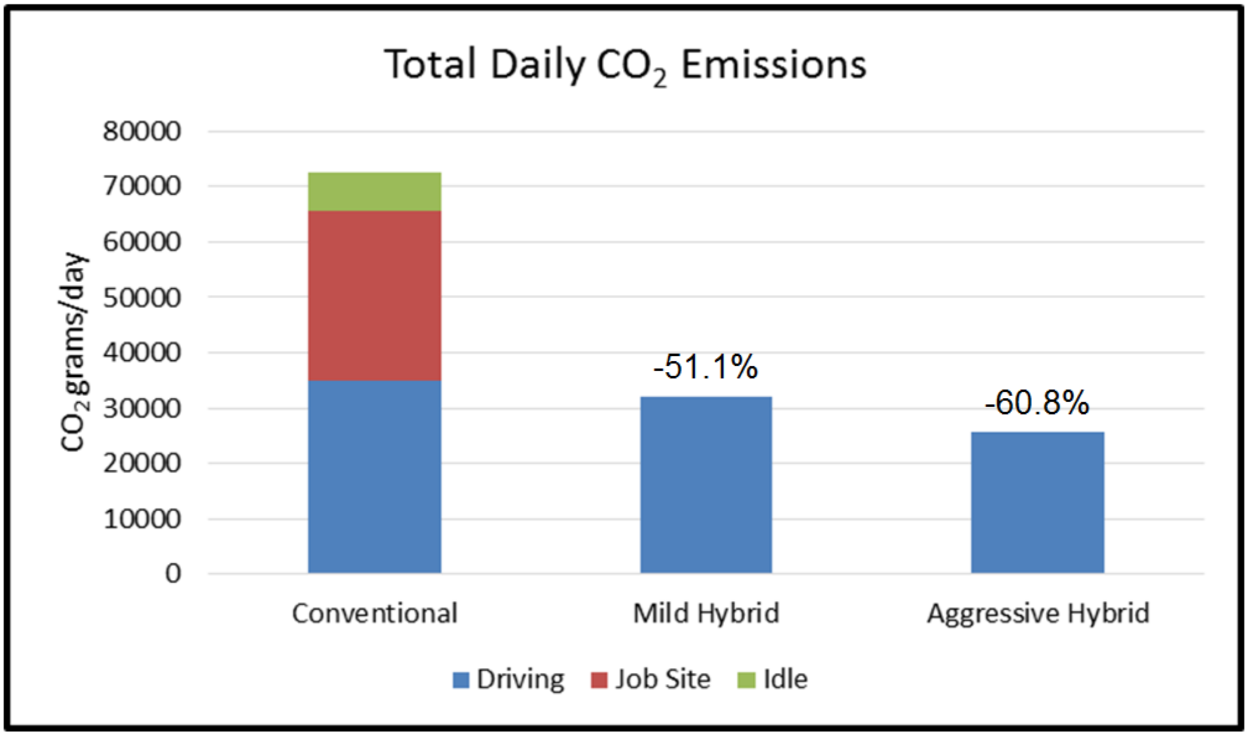


Figure 3-15
Odyne carbon dioxide emissions

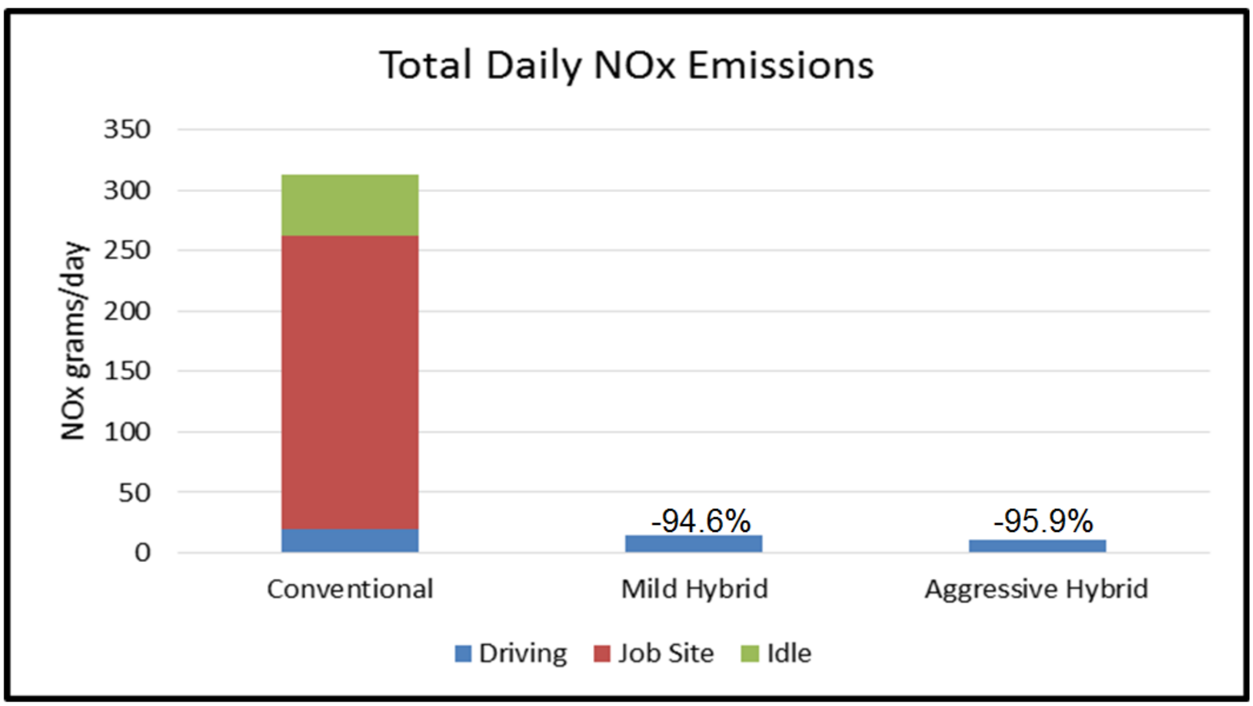


Figure 3-16
Odyne nitrogen oxide emissions

Testing for CARB certification submission was performed at the University of California–Riverside's Center for Environmental Research and Technology test facility. The results are a workday summary consisting of weighted Urban Dynamometer Driving Schedule (UDDS), consisting of cold and hot start cycles, and stationary cycle (two-hour idle plus 30-minute engine charge). Two project vehicles were used for testing. Only mild calibration was tested and submitted. Using CARB-recommended procedures, the Odyne system delivered a full-day fuel and CO_2 reduction of 40% to 50% and a NO*x* reduction of 70% to 80%, including a field engine charge (see Table 3-6).

Table 3-6
Air Resources Board test results

	CO_2 (grams per test)	NO*x* (grams per test)	Fuel Usage (gallons per test)
Vehicle 1			
Conventional	49,415	64.882	4.976
Hybrid	23,823	18.440	2.399
Difference	-51.8%	-71.6%	-51.8%
Vehicle 2			
Conventional	40,792	198.404	4.108
Hybrid	24,148	39.409	2.430
Difference	-40.8%	-80.1%	-40.8%

The Odyne system was reviewed with EPA in January 2014. It was agreed that no further review or information was needed for Odyne to proceed with production. Odyne is now beginning development of system enhancements to meet the 2017 EPA heavy-duty vehicle onboard diagnostics requirements.

Odyne has submitted an application for exemption from the prohibition of California Vehicle Code Sections 27156 and 38391. Odyne was sent the test letter in October 2014. The test letter explained that two vehicles over two drive cycles should be planned to cover the Odyne range of engine families. Odyne began testing in February 2015 and submitted data in the middle of March 2015. The NO*x* increases while driving were duly noted. A revised test plan established by CARB including a stationary cycle was received in July 2015. Results were submitted and accepted, and vehicles were released. Odyne has received an Executive Order from CARB for the final approval; the Odyne system was found not to reduce the effectiveness of the applicable vehicle pollution control system. The fifteen trucks in the field with only hydraulic control and without traction assist will now have the software changed to enable the traction control.

Odyne Certification Observations

Current certification paradigms did not fit the Odyne system, which has made approval more difficult for both Odyne and CARB in the following ways:

- Experimental exemption. This requires removal of the system after one year, which is not economically viable for Odyne or advantageous for the customer.
- Certification. Odyne is not certifying an engine family but applying an auxiliary assist mechanism (during driving) across many engine platforms that are customer and application driven.
  - Odyne would not have the resources to perform full engine certification for so many engines.
  - The initial volume for one engine family is not sufficient to interest OEMs at this time.
- Aftermarket exemption.
  - Written for much smaller aftermarket components. The CARB and Odyne struggled in applying all the deliverables (installation manuals, parts lists, and so on) to such as a large system.
  - Technically, Odyne is an intermediate-stage manufacturer, as defined by Federal Motor Vehicle Safety Standards (FMVSS); therefore, the commercial rules for aftermarket have proven to be challenging. Odyne cannot ship a PHEV vehicle to some customers because it would then violate the aftermarket definition.
  - Test procedures and facility capabilities were not available. Odyne has co-developed with CARB and facilities during the process.
    - Test-to-test variation is still questionable.
    - Full-day cycle is just now being defines.
    - Facilities do not have the capability to do a good job on stationary cycles.

3.2.3 Crash and Safety

Safety is an important design feature. Odyne uses a high-voltage interlock loop (HVIL) and isolation fault protection that will disable the hybrid system if an electrical fault is detected. In addition, an inertia switch will disable the system if a crash event is detected. Odyne had no direct requirements to crash the vehicles.

3.3 Odyne Engineering Process

Odyne's engineering process was complete with development, validation, and production (DVP) plans, design failure modes and effects analysis (DFMEA), risk assessments, and bills of materials (BOM). The BOM has more than 760 lines, which included 183 new parts and 17 unique subassemblies. Design reviews were held periodically during the engineering process (see Table 3-7).

Table 3-7
Odyne design reviews

Design Review	Title
O1	Technical program kickoff
O1a	System requirements and design
O1b	System requirements and design and long-lead release review
O2	Production validation and release review
O3	Production validation complete
O4	Production release review
O5	Initial hybridization of production chassis
O6	Delivery of 12 production chassis

3.4 Odyne Manufacturing Accomplishments

The manufacturing process that Odyne is using adds another step to the typical process for Class 6 to 8 trucks. Conventionally, the customer orders the chassis from one of the major OEMs and it is sent directly to an FSM that adds the body to chassis for the end product that is sent to the customer. In the hybridization process, the chassis is first sent to Odyne, where Odyne modifies and adds the hybrid components and makes the truck driveable as a chassis only. The hybridized chassis is then sent to the FSM for final body completion. Figure 3-17 shows the chassis as received from the OEM with the hybrid system installed, and Figure 3-18 shows the final configuration as a digger derrick.

Figure 3-17
Chassis with hybrid system installed

Figure 3-18
Final configuration as a digger derrick

Odyne manufacturing was completed by Inland Power Group–Allison transmission dealer/service center in Butler, Wisconsin. Odyne contracted the facility to install the Odyne hybrid systems on the Class 6 to 8 trucks. Inland is a manufacturer within 15 minutes of Odyne's Waukesha engineering offices and development area. Inland has had good experience with Allison and has provided modifications to Allison transmissions before sending them to the Janesville General Motors Assembly Plant. The facility handles three truck build sites, one test site, and a sick bay. Up to 20 trucks per month can be produced at this facility. Chassis were accepted at the Odyne facility and transported to the Inland site for hybrid installation. All parts were delivered to Inland, and subassemblies were made for the trucks. The build began at the end of July 2013. The last vehicle was delivered to the FSM in October 2014. The original development builds were slow, but Odyne achieved their production rate when production began. Figures 3-19 and 3-20 show the Inland Power Group facility and the manufacturing floor. Figure 3-21 shows technicians installing a battery pack.

Figure 3-19
Inland Power Group–Allison Transmission dealer/service center in Butler, Wisconsin

Figure 3-20
Manufacturing floor at Inland

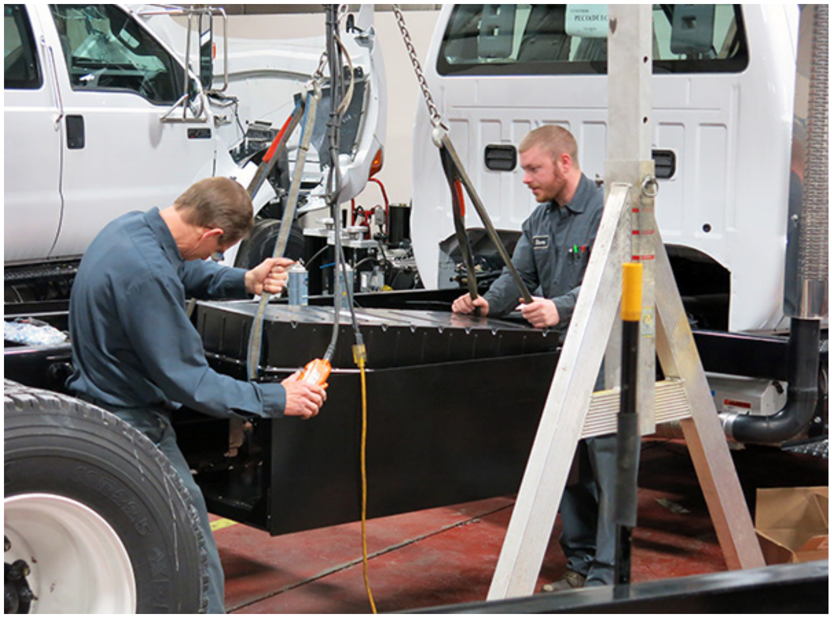


Figure 3-21
Installing a battery onto a chassis

3.5 Odyne Vehicle Manufacturing Testing

An automatic tester was installed in the test stall that would cycle the vehicles through all modes of operation, including beeping the horn when the test was completed (see Figure 3-22). This equipment was highly effective in its execution of the test and could identify any issues to be repaired and provide a report for successful completion of the test.

Figure 3-22
Using the automatic tester for testing the final assembled hybrid system

Each truck was verified using the automatic test procedure, which takes 60–90 minutes to complete (see Figures 3-23 and 3-24). The procedure includes hydraulic loads to discharge the battery. Each accessory—including heater, air conditioner, and export power—is tested. CAN messages and performance are measured and analyzed before acceptance of the test.

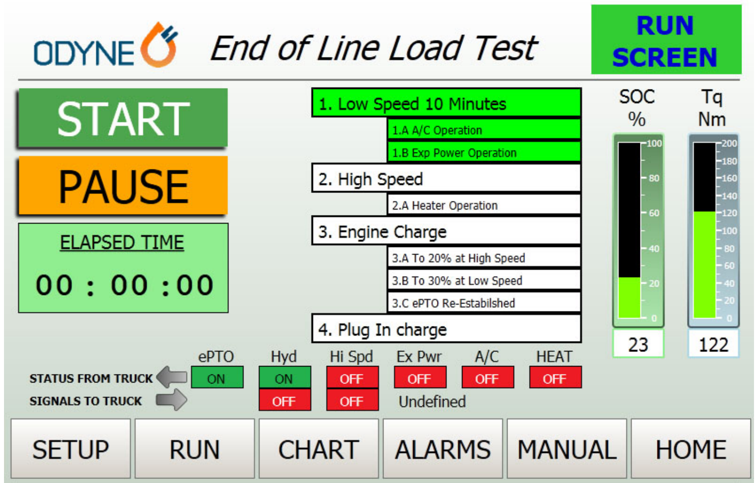


Figure 3-23
End of line load test—run screen

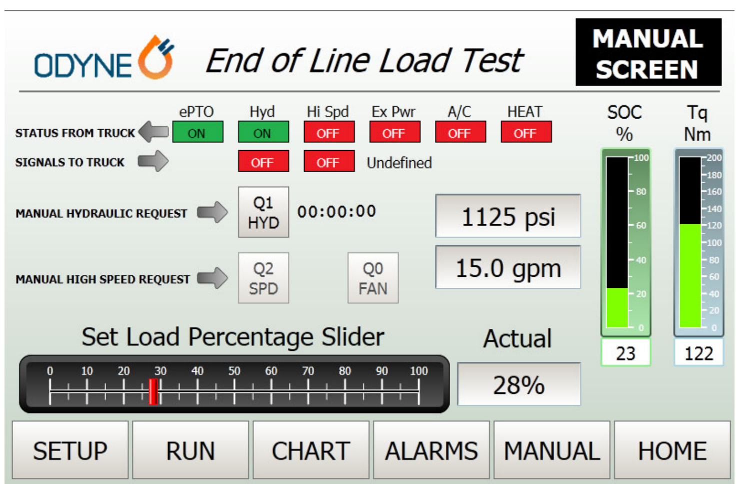


Figure 3-24
End of line load test—manual screen

3.6 Odyne Cost Analysis

Odyne performed a cost analysis of their PHEV system. The current system is at low volume and is based on recent shop orders. The cost of 15 components make up 93% of the component material cost. Increasing the volume to 5000 units can reduce the costs by 21%. The battery pack has the largest cost of the entire system, at about 38% of the cost (see Figure 3-25). Figure 3-25 shows costs for both 28-kWh and the 14-kWh systems at various production volumes. The cost analysis does not include the cost of the fiber-optic system that is required for this system by the FSMs.

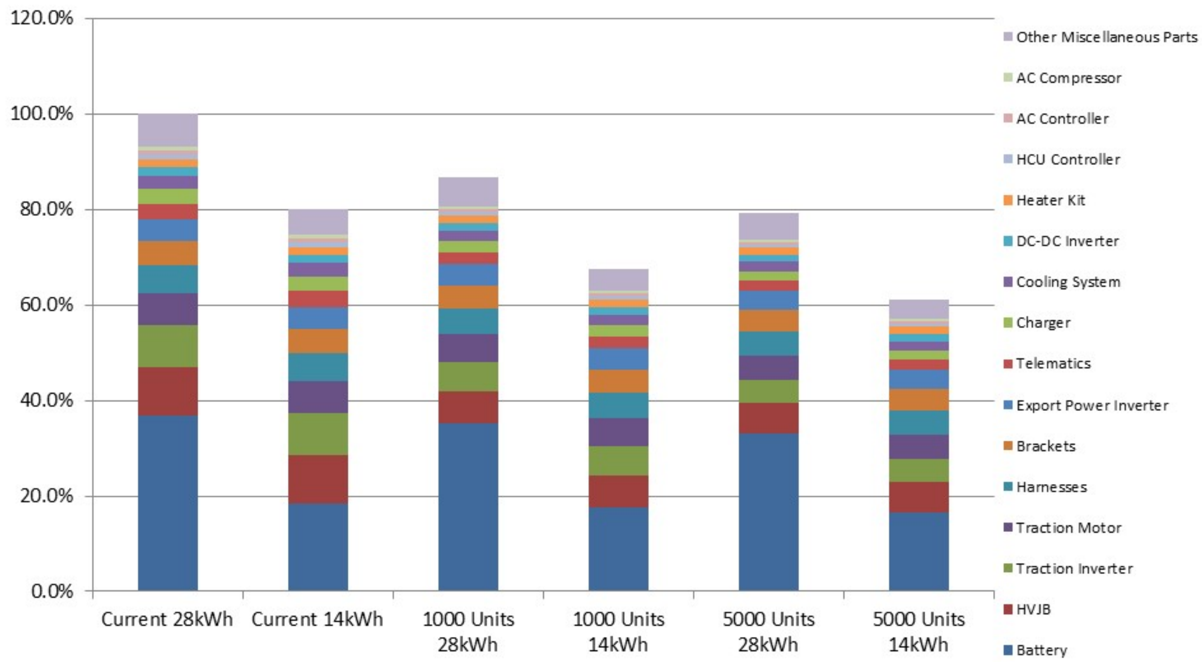


Figure 3-25
Odyne cost analysis

Odyne has continued to work on reducing the cost of the system. The first step in the process was to determine if there were any quick or easy adaptations. Figure 3-26 shows that a majority of the duty cycles do not require the full 28-kWh system and could possibly be handled by a 14-kWh system. This led to considering a 14-kWh system as a method of reducing the capital cost of the system. The ability to offer a system with one less battery pack was fairly significant. The data show that the cost could be reduced by about 20% if only half the battery energy was required. Calculations indicate that the net cost of ownership can be reduced in these applications by using a single battery pack with a slight increase in engine charging events.

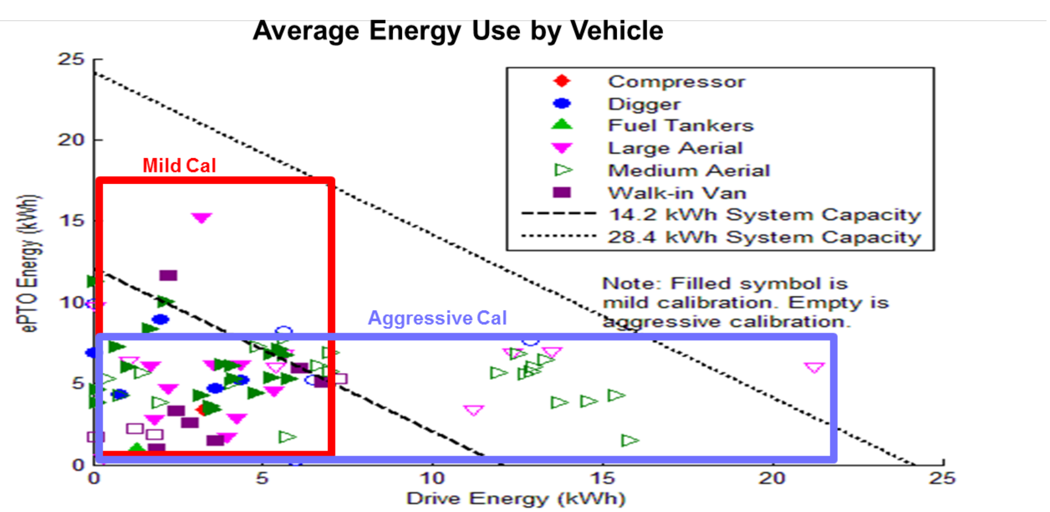


Figure 3-26
Battery energy tradeoff

The costs experienced to date are based on low production volumes. Odyne's suppliers have provided pricing on components based on the economies of scale associated with higher volumes. If the volumes reach higher levels (see Figure 3-25) the component cost reductions will translate to a lower sale price.

Odyne has been working with third-party installers to reduce the hours required to install a system. There has been a significant drop from the start of the program to the most recent units built.

Odyne will be working on a full system redesign in 2015–2016. They plan to use the lessons learned from the current system to help design a less costly system. The current system may continue to be a product offering for certain duty cycles, but Odyne is convinced that many customers would be better served by a system designed for their lower duty cycles.

3.7 Odyne Data Analysis

Data were collected using the data acquisition system described in Section 5.1, as well as Odyne's data acquisition system. The results are described in this section.

All 119 Odyne vehicles are equipped with a data acquisition system that collects data at a rate of up to 1 Hz. Data are collected during the day and sent to the server daily. Data collected include the following:

- Motor current and voltage
- Battery current and voltage
- Charger current and voltage
- Motor and engine torque and speed
- Export power current and voltage
- Odometer
- Vehicle speed
- Accelerator and brake pedal position
- Fuel used
- Charger time
- Software and calibration level

Data for the year include 150,366 miles driven in more than 7,267 hours, with a total of 12,412 job site hours. Of the total distance traveled, 95% was charge depleting.

Figure 3-27 presents the fleet summary totals, and Figure 3-28 presents the mean plus or minus standard deviation.

	All Applications			Digger		Medium Aerial		Large Aerial	
	Both	Mild	Agg	Mild	Agg	Mild	Agg	Mild	Agg
# Vehicles	95.0	51.0	44.0	7.0	5.0	21.0	24.0	12.0	10.0
# Vehicle-Days	11278.0	5618.0	5660.0	513.0	615.0	3918.0	3153.0	807.0	1161.0
Net Distance (mi)	150365.7	73561.1	76804.5	3802.5	3652.6	43685.1	58769.6	18798.9	10254.1
Net Distance CD (mi)	143308.3	72974.7	70333.6	3631.8	3403.5	43348.3	52766.2	18726.3	10046.1
Net Distance CS (mi)	7423.8	527.0	6896.9	168.6	246.5	327.8	6361.7	15.1	281.5
Net Charge Energy (kWh)	59287.3	23599.3	35688.1	2125.9	2102.5	14909.8	28444.1	5079.3	4440.1
Net Drive Energy (kWh)	30323.2	9482.4	20840.8	557.3	1250.1	5938.1	16519.2	2220.9	2625.9
Net ePTO Energy (kWh)	25284.6	13100.8	12183.8	1001.9	866.5	7984.3	9082.8	2912.5	1797.1
Net Eng. Charge Energy (kWh)	4399.3	1385.8	3013.4	133.0	165.5	865.5	2513.6	153.2	317.1
Net Plug-In Hours	163007.7	78911.1	84096.6	8872.8	8842.4	42375.1	57360.3	16139.3	11884.7
Net Driving Hour	7267.0	3704.5	3562.5	170.2	138.8	2170.1	2853.0	973.5	418.7
Net Jobsite Hour	12412.3	6226.3	6186.0	266.0	274.6	3908.4	4551.3	1085.7	687.2
Net Stat. Idle Hours	11369.1	5116.3	6252.8	272.6	287.3	3183.4	4527.1	1203.6	1156.1
Net Drive Fuel (gal)	24956.3	12482.8	12473.6	775.0	676.8	7493.6	9761.1	3358.7	1625.1
Net Eng Charge Fuel (gal)	693.9	216.6	477.3	22.6	27.2	136.4	397.9	31.4	51.4
Net Stat. Idle Fuel (gal)	5967.7	2745.9	3221.8	145.5	160.0	1784.0	2346.9	607.6	602.3

Figure 3-27
Fleet summary—totals

	All Applications			Digger		Medium Aerial		Large Aerial	
Note: all averages are daily	Both	Mild	Agg	Mild	Agg	Mild	Agg	Mild	Agg
# Vehicles	95.0	51.0	44.0	7.0	5.0	21.0	24.0	12.0	10.0
# Vehicle-Days	11278.0	5618.0	5660.0	513.0	615.0	3918.0	3153.0	807.0	1161.0
Ave. Distance (mi)	23.8±16.8	23.8±17.3	23.7±16.3	18.8±15.5	20.5± 15.6	22.7±16.5	23.9± 15.7	29.9±19.9	26.6± 18.2
Ave. Distance CD (mi)	22.9±16.4	23.8±17.3	22.1±15.5	18.1±15.5	19.3± 14.1	22.7±16.5	21.8± 14.9	30.4±19.7	26.6± 17.8
Ave. Distance CS (mi)	10.30±10.79	6.51±7.25	10.78±11.07	0.84±4.57	1.40±3.98	0.17±1.24	2.63±7.31	0.02±0.43	0.74±2.92
Ave. Charge Energy (kWh)	10.1±7.8	8.2±6.3	11.8±8.6	8.3±7.6	10.4± 7.9	8.8±6.4	12.4± 8.7	8.0±5.9	12.3± 8.0
Ave. Drive Energy (kWh)	6.2±5.8	3.9±2.8	8.6±7.0	3.7±3.2	9.1± 6.2	4.1±3.1	8.9± 7.1	3.9±2.3	9.2± 6.7
Ave. ePTO Energy (kWh)	5.2±4.6	5.3±5.1	5.0±4.2	6.7±5.3	6.3± 5.2	5.5±4.8	4.9± 4.1	5.1±5.0	6.3± 4.2
Ave. Eng. Charge Energy (kWh)	5.7±4.2	5.1±4.1	6.0±4.3	0.9±2.2	1.2± 2.5	0.6±2.0	1.4± 3.3	0.3±1.5	1.1± 2.8
Ave. Plug-In Hours	15.9±6.9	15.4±7.0	16.3±6.8	15.7±8.4	18.6± 6.5	15.2±6.9	15.9± 6.8	14.8±6.8	16.5± 6.8
Ave. Driving Hour	1.5±0.9	1.5±1.0	1.4±0.8	1.3±0.7	1.1± 0.5	1.4±0.9	1.5± 0.8	1.9±1.0	1.4± 0.8
Ave. Jobsite Hour	2.6±1.8	2.6±1.9	2.5±1.8	1.9±1.3	2.0± 1.4	2.6±1.8	2.4± 1.7	2.4±1.7	2.5± 1.7
Ave. Stat. Idle Hours	2.0±1.7	1.9±1.7	2.1±1.7	1.6±1.4	1.7± 1.5	1.8±1.7	2.0± 1.6	2.2±2.0	2.9± 2.2
Ave. Drive Fuel (gal)	4.0±2.7	4.1±2.8	3.9±2.6	3.9±2.9	3.8± 2.7	3.9±2.6	4.0± 2.5	5.4±3.5	4.3± 2.7
Ave. Eng Charge Fuel (gal)	1.0±0.7	0.9±0.6	1.1±0.7	0.2±0.4	0.2± 0.4	0.1±0.3	0.2± 0.5	0.1±0.3	0.2± 0.5
Ave. Stat. Idle Fuel (gal)	1.0±1.0	0.9±0.9	1.0±1.0	0.8±0.8	0.9± 0.8	1.0±1.0	1.0± 1.0	1.0±0.9	1.5± 1.3
Ave. KI (1/mi)	1.9±1.5	1.8±1.5	1.9±1.5	2.3±1.9	1.6± 1.6	1.9±1.6	2.1± 1.5	1.3±1.0	1.0± 1.0
Ave. Fuel Economy (mpg)	5.9±1.5	5.8±1.5	6.1±1.6	4.6±0.9	5.2± 1.1	5.6±1.2	5.9± 1.3	5.5±1.0	6.1± 1.5
Ave. Drive Energy/Distance (kWh/mi)	0.4±0.3	0.2±0.2	0.5±0.4	0.4±0.3	0.5± 0.3	0.3±0.3	0.5± 0.4	0.2±0.2	0.5± 0.4

Figure 3-28
Fleet summary—mean plus or minus standard deviation

Figures 3-29 through 3-31 show examples of typical days for the trucks. The charts plot the SOC of the battery against the time of day on the horizontal axis. Several modes are illustrated, including SOC while plugged in, SOC change due to the PTO, engine charge SOC, drive SOC, and idle SOC. These charts have become known as *SOC V charts* because, under optimum conditions, the plot looks like a V. Ideally, the V would start at or near the 100% SOC point, go to 0%, and then return to 100%. The left side of the V uses the energy from the battery to drive or move the hydraulics, and the right side is the battery charge.

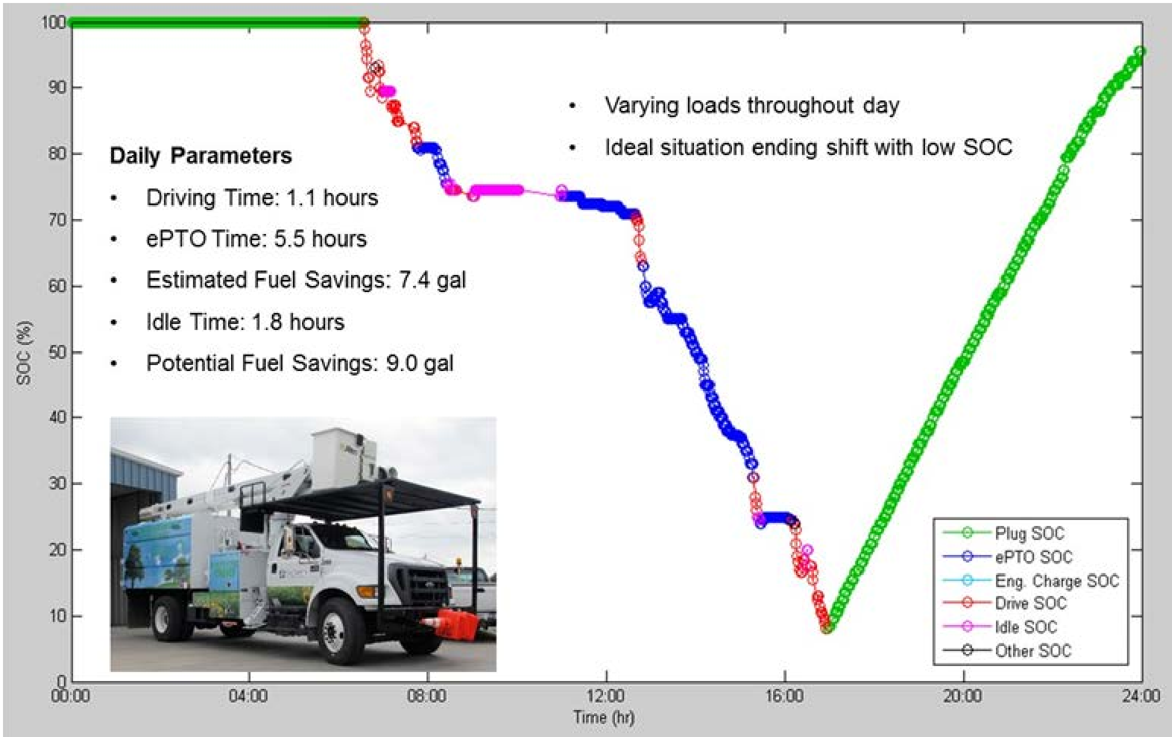


Figure 3-29
State of charge, large aerial truck example

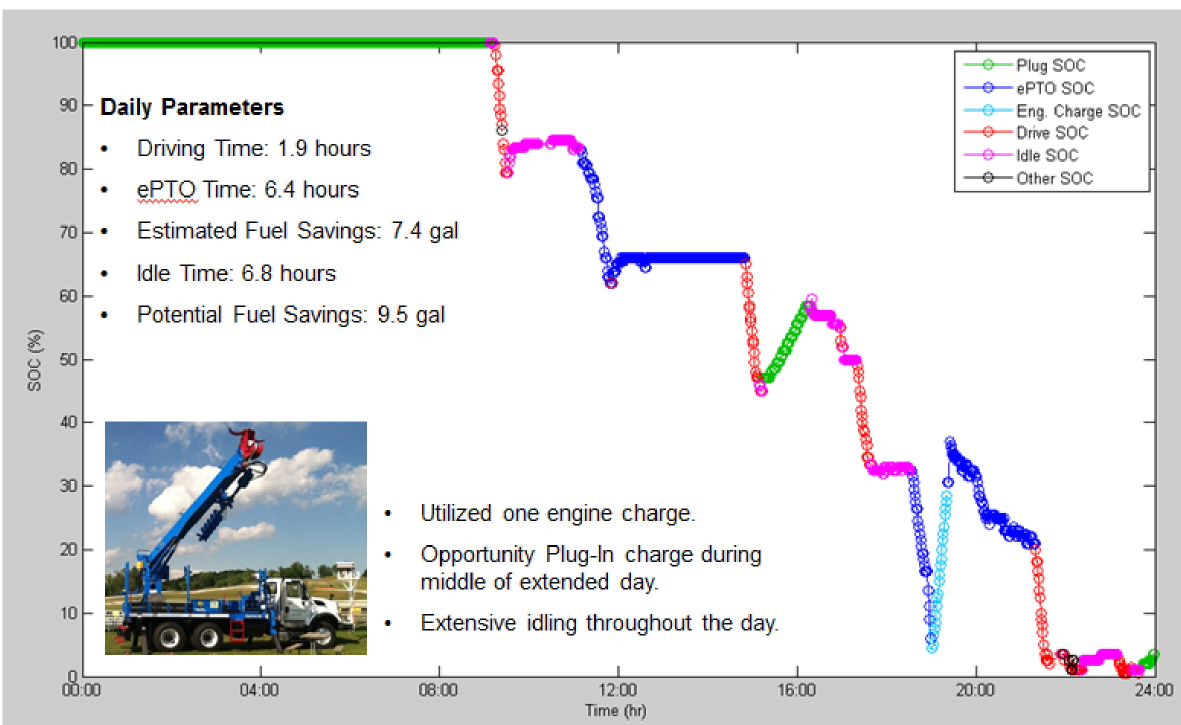


Figure 3-30
State of charge, digger derrick example

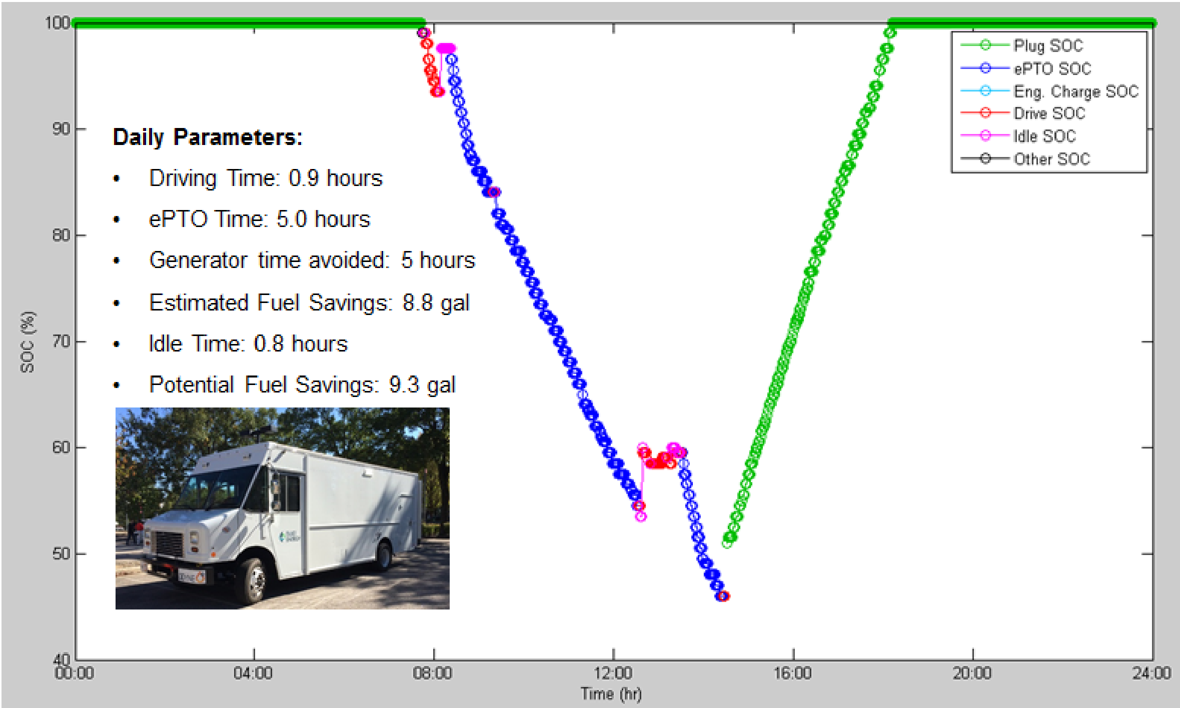


Figure 3-31
State of charge, walk-in van example

As one can see from Figures 3-29 through 3-31, there was some unwanted idle time that was not necessary because it is a hybrid and does not require idle time. If the idle time can be eliminated, there is a potential to achieve more fuel savings, as shown in the figures. In Figure 3-29, it is estimated that 7.4 gallons of fuel were saved over a conventional vehicle. If the idle time could be eliminated, a total of 9.0 gallons of diesel fuel could be saved. Figures 3-30 and 3-31 show other examples of this. Figure 3-30 has an example of an engine charge. The truck was run until the battery energy was gone, and then the engine came on near the 19:00 hours mark to charge the battery.

Simple charts like Figure 3-32 show how the vehicles are being used. The layout of the data is by day of the month, like a calendar. The data shown are SOC versus time of day, or an SOC V chart, as defined earlier. The data shown in Figure 3-32 compare the SOC of two project vehicles for one month. Vehicle A shows little activity, whereas vehicle B shows much more activity, including many full charges. The project contains a mix of high- and low-use vehicles; however, usage appears to be increasing with time. To provide reasonable payback, hybrid systems should be targeted toward more high-usage applications.

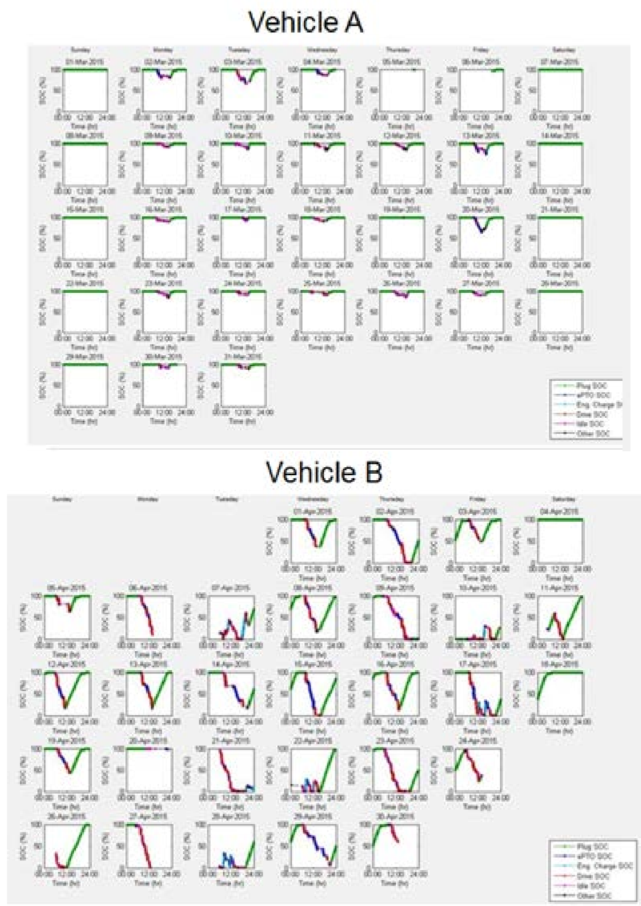


Figure 3-32
Comparison of state of charge for a low-usage and a high-usage vehicle

Table 3-8 shows data for the most recent quarter (the second quarter of 2015). Many fleets took weeks or months to put their hybrid vehicles into regular use. Some contributing factors to the delay were licensing, registration, facility assignment, crew assignment, training, and equipment transfer. Sporadic early use results in low usage averages.

Table 3-8
Usage summary for the second quarter of 2015

Usage Summary	
Number of vehicles	90
Number of vehicle days	4,873
Total distance (mi)	74,619
Total driving time (hr)	3,604
Total job site time (hr)	6,424
Total idle time (hr)	4,230
Total drive fuel (gal)	11,365
Total engine charge fuel (gal)	269
Total idle fuel (gal)	1,869

Typically, the vehicles were operated during the early daytime hours and plugged in during the afternoon and night (see Figure 3-33). Most utilities appear to start their shifts around 5 to 6 a.m. and finish using the vehicles by 1 to 3 p.m. Most of the work outside that timeframe is due to emergencies or local restrictions.

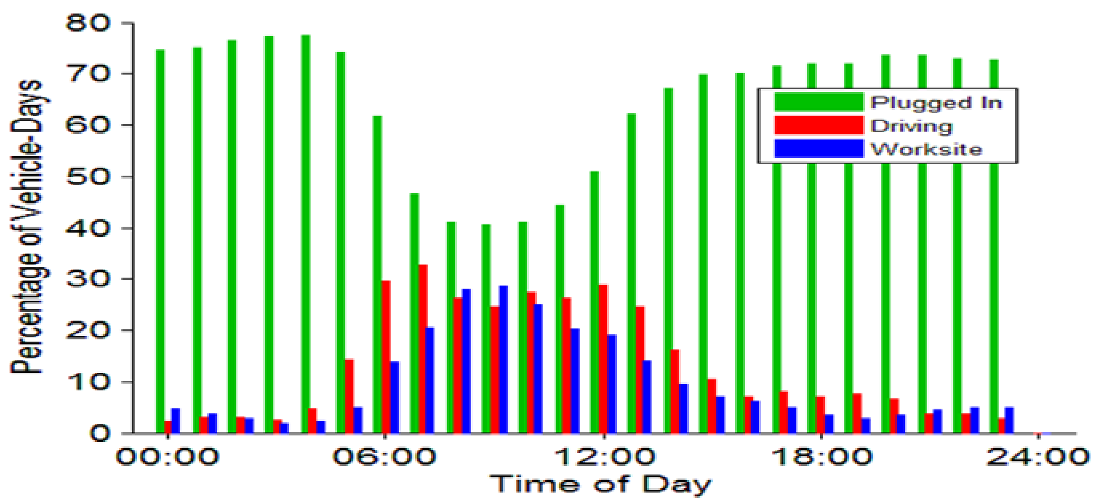


Figure 3-33
Modal time of day

As Figure 3-34 shows, more than 60% of plug-ins occurred between noon and 4 p.m., and the peak load on the grid occurs around 4 p.m. Much of the charging is completed by midnight. This shows the opportunity for smart charging—to delay charging until there is no peak demand for the electricity.

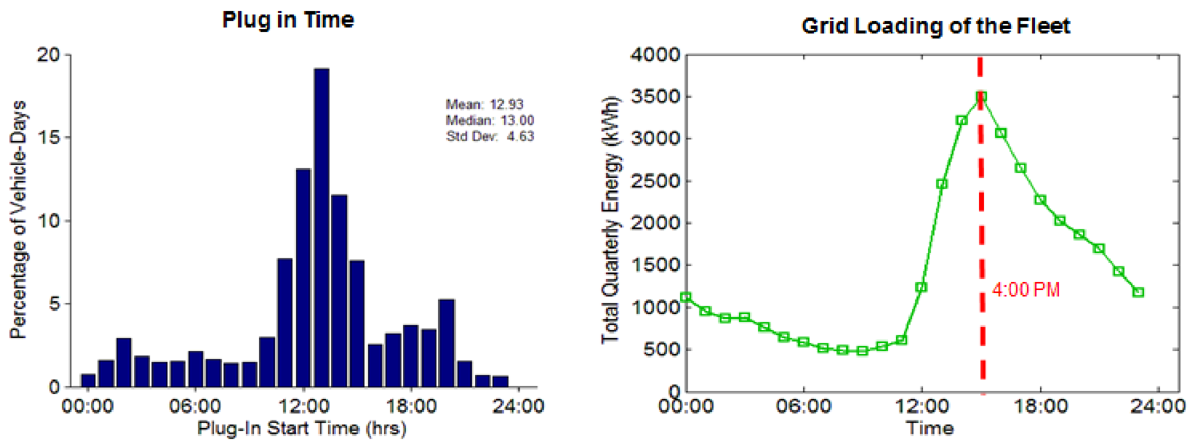


Figure 3-34
Plug-In Charging

Most vehicles average less than two hours of driving in a working day, and average daily job site usage ranges from one to six hours (see Figure 3-35).

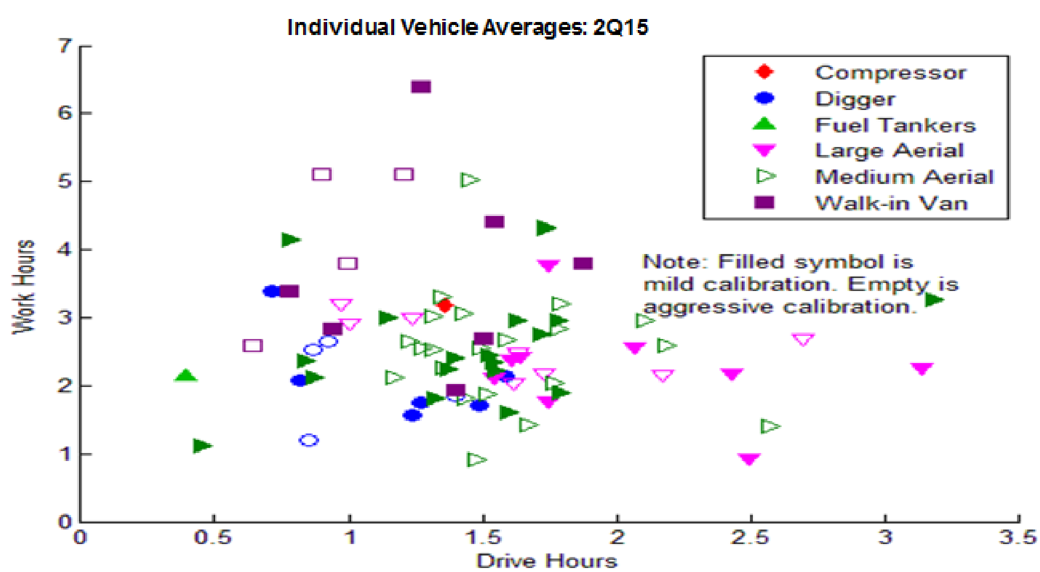


Figure 3-35
Vehicle usage

Most utility trucks are driven only a short portion of the working day—the fleet average was about 1.5 hours and 26 miles per day (see Figures 3-36 through 3-39). These trucks generally work in local communities and respond to problems within a short distance.

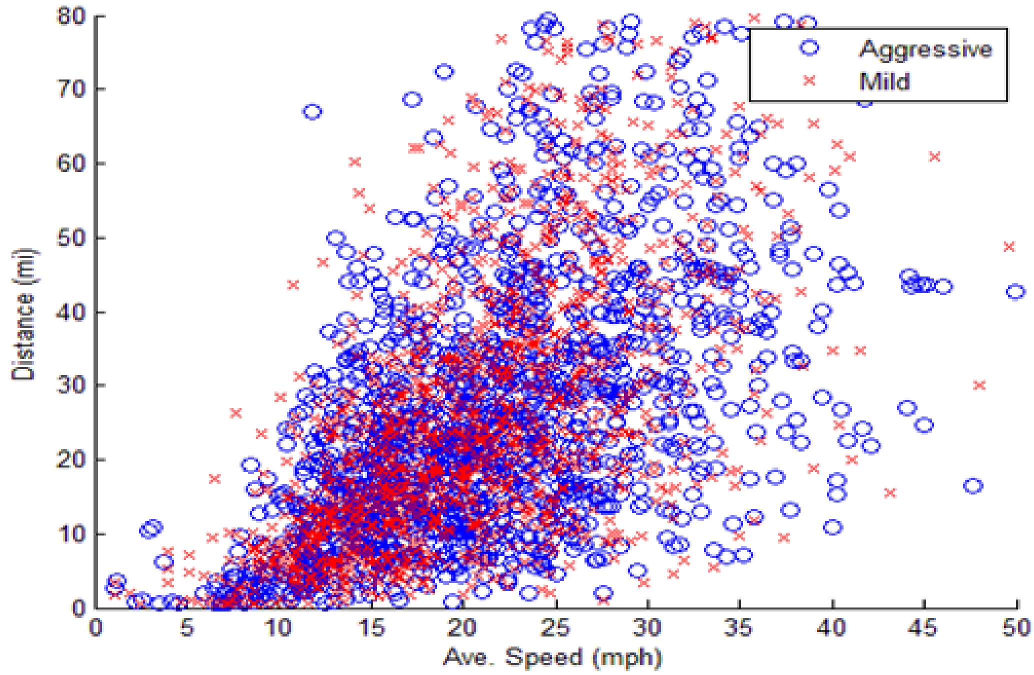


Figure 3-36
Driving—distance versus speed

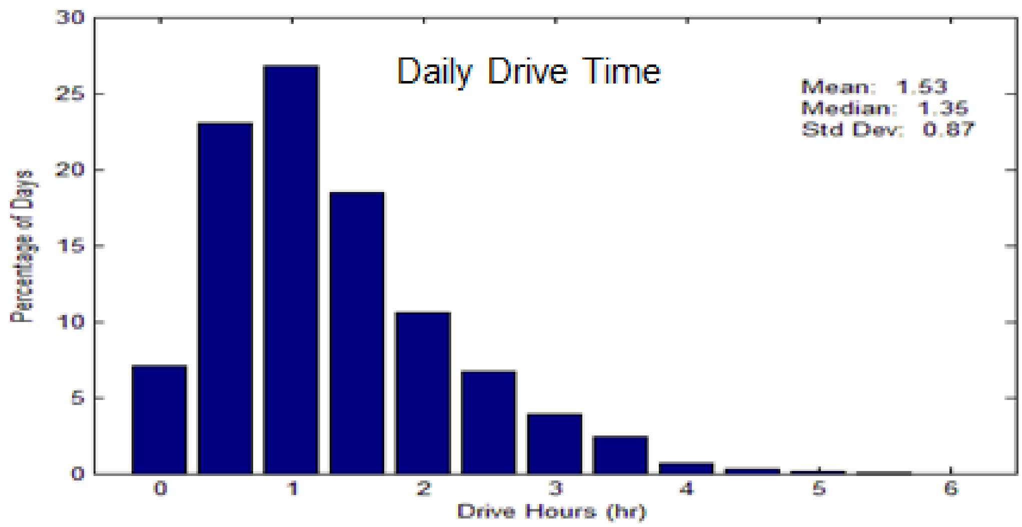


Figure 3-37
Driving—daily drive time

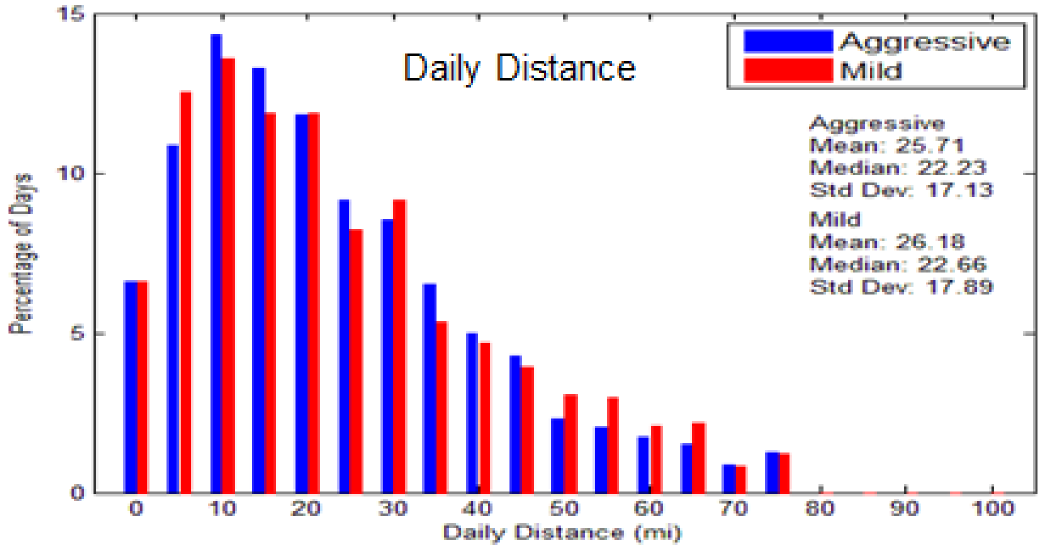


Figure 3-38
Driving—daily distance

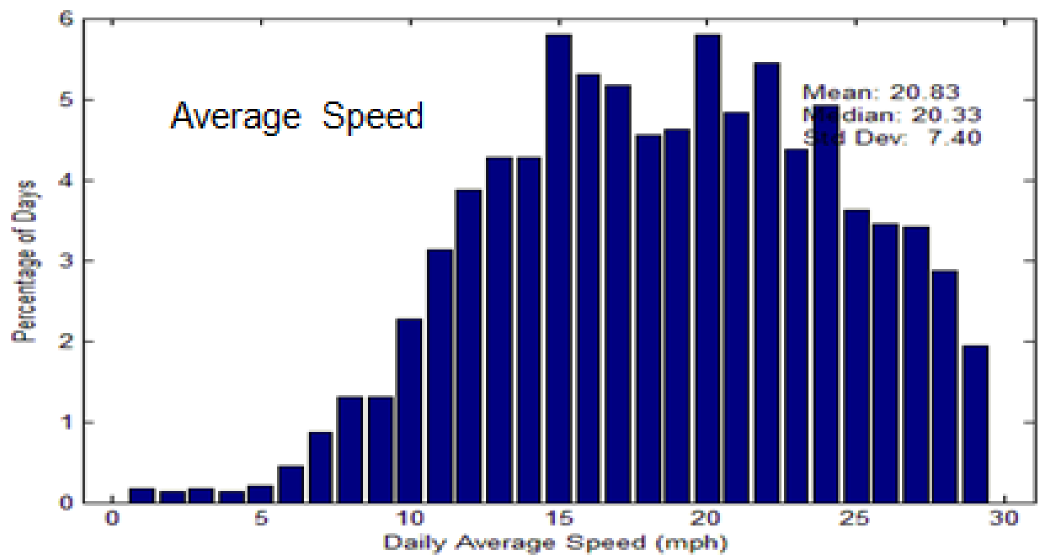


Figure 3-39
Driving—average speed

Across the fleet, mild versus aggressive calibration did not affect the basic usage metrics. Measurements such as speed, distance, and hours were quite similar regardless of calibration. Aggressive calibration improved the average fleet fuel economy by 8% compared to vehicles with mild calibration but used more than twice the battery power to achieve it. On average, aggressive calibration saved an additional 0.3 gallons of diesel fuel and used 4.8 kWh more electricity than mild calibration. Figures 3-40 through 3-42 and Table 3-9 illustrate the results.

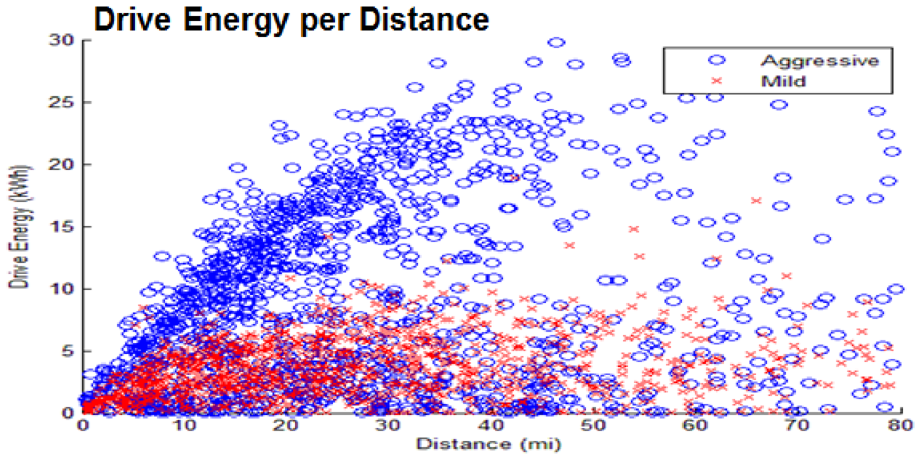


Figure 3-40
Torque calibration—energy versus distance

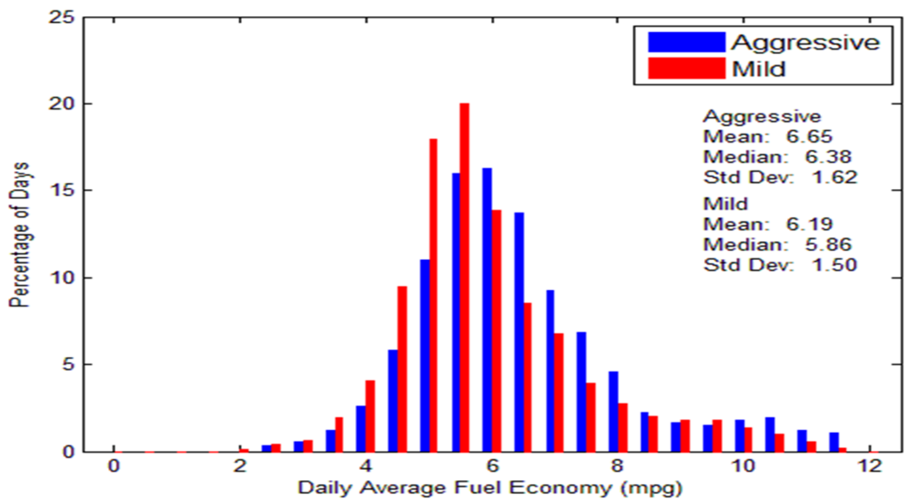


Figure 3-41
Torque calibration—daily fuel economy

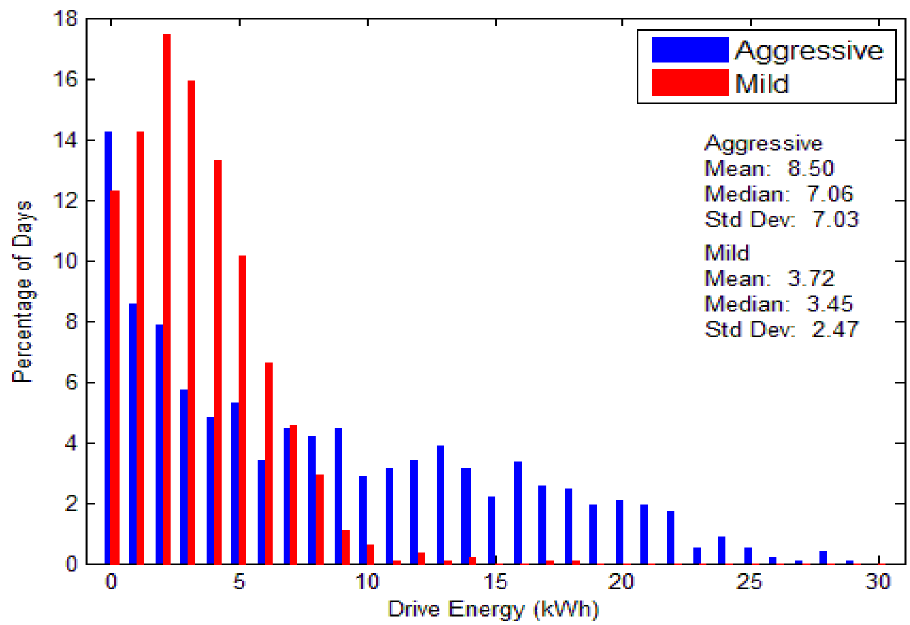


Figure 3-42
Torque calibration—drive energy

Table 3-9
Drive torque calibration comparison

Parameter	Mild Calibration	Aggressive Calibration
Drive fuel (gal)	4.1	3.8
Fuel economy (mpg)	6.2	6.7
Drive energy (kWh)	3.7	8.5
Drive energy/distance (kWh/100 mi)	20	50

Note: All values are daily averages.

The Odyne system focuses on providing engine-off support for stationary work applications. The average for the fleet was 2.8 hours of stationary work per day, with a broad distribution into the 5- and 6-hour range. The fleet also idled while stationary for an average of 1.7 hours per day without hybrid assist (a 0.7 gallons per vehicle-day opportunity), which may be an indicator of the need for follow-up training. On average, 5.5 kWh of energy were used in the stationary work mode (see Figures 3-43 through 3-46).

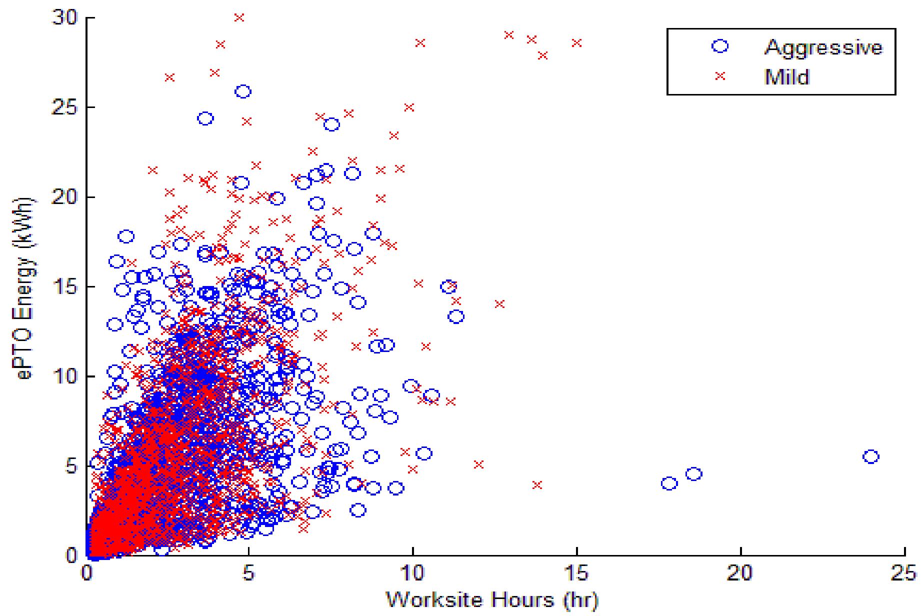


Figure 3-43
Stationary—energy versus time

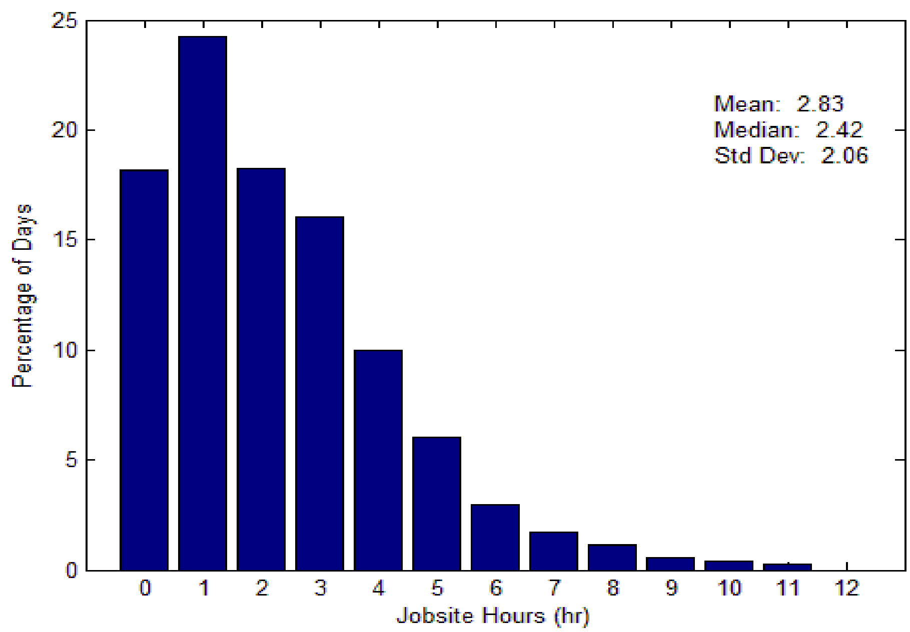


Figure 3-44
Stationary—job site time

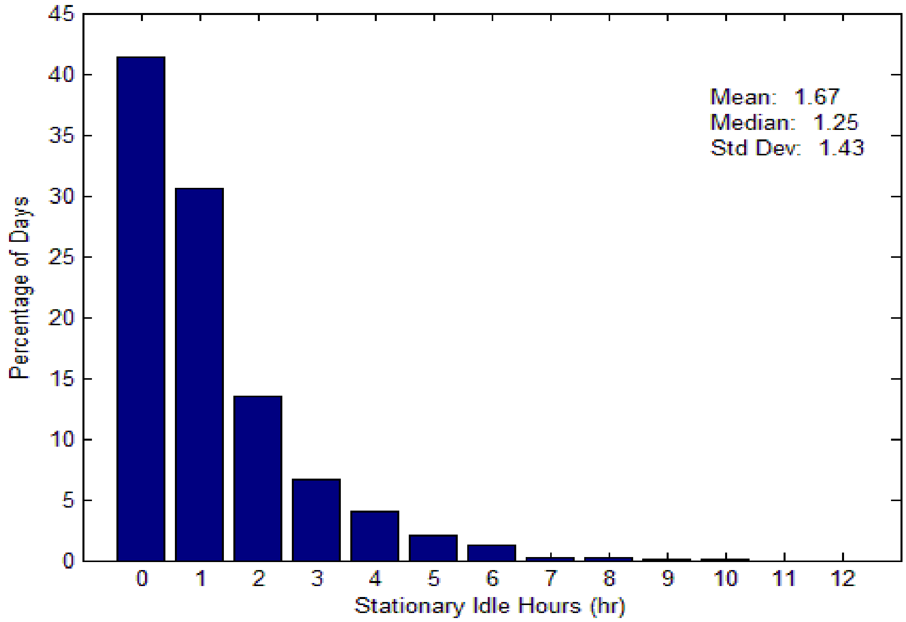


Figure 3-45
Stationary—idle time

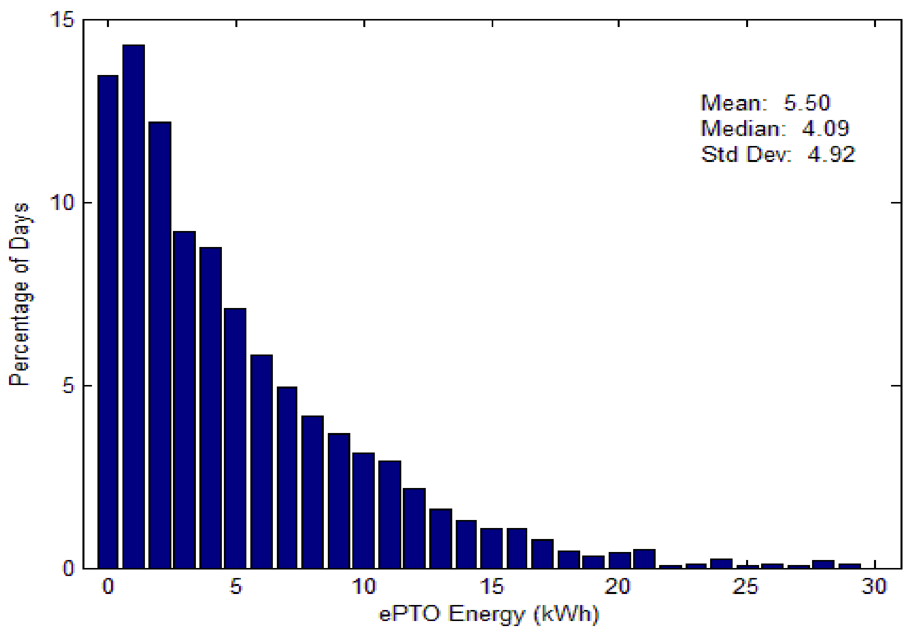


Figure 3-46
Stationary—power take-off energy

A typical vehicle is used for single-shift operation (with extended days) that starts between 5 a.m. and 8 a.m. Driving and stationary work are interspersed throughout the day. The majority of plug-ins occur between noon and 4 p.m. but can extend beyond midnight. Figures 3-47 through 3-50 show the results for a typical vehicle.

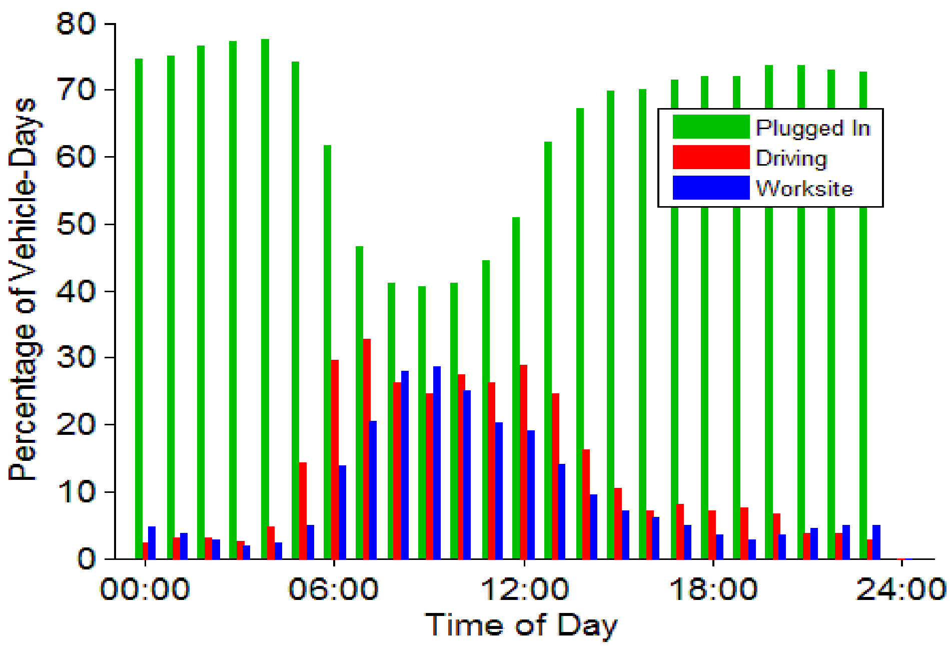


Figure 3-47
Typical—mode distribution

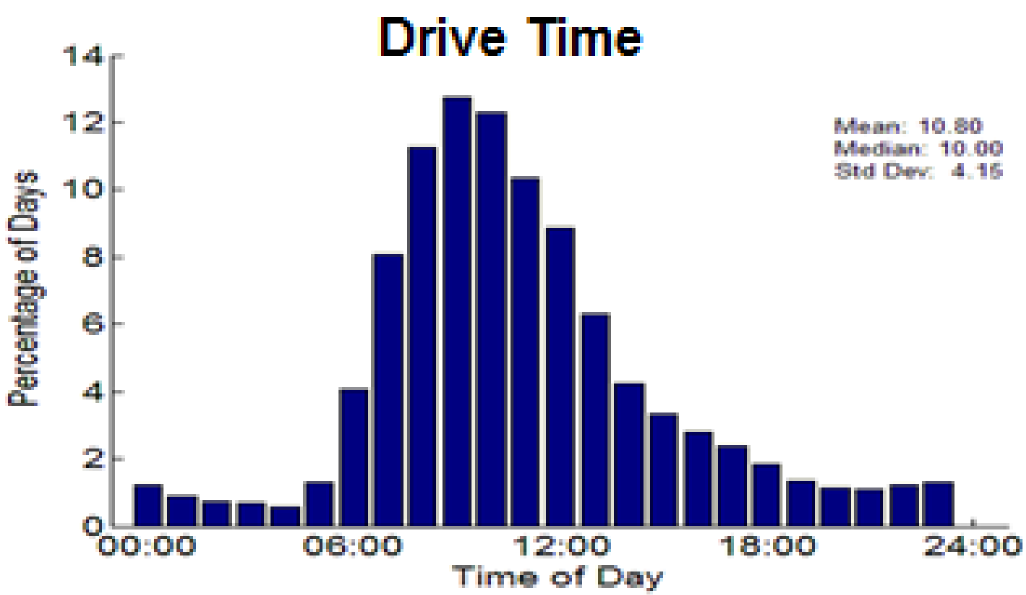


Figure 3-48
Typical—drive time

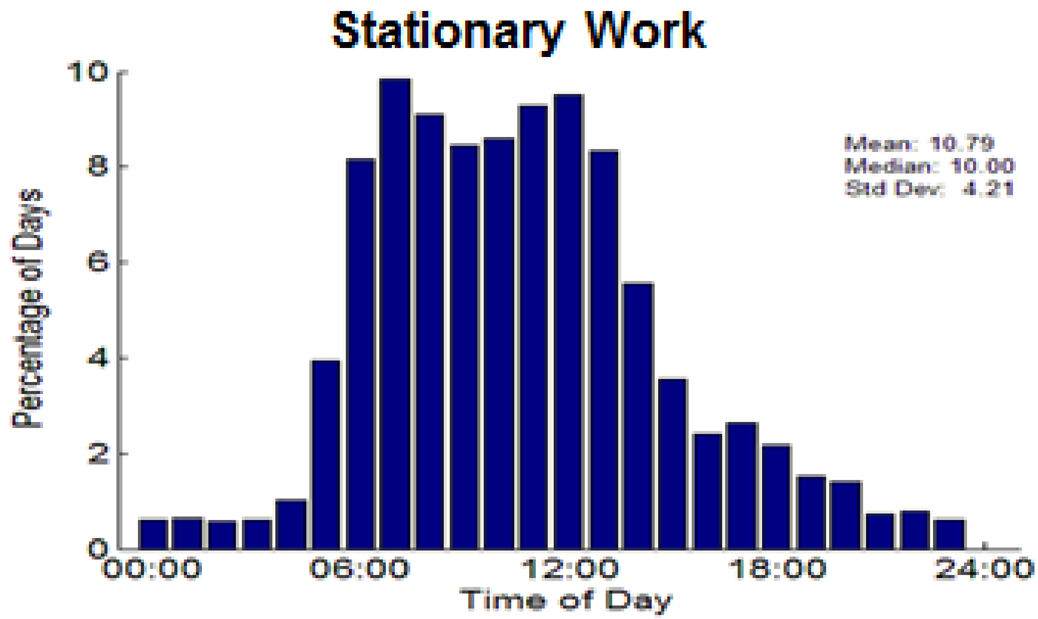


Figure 3-49
Typical—stationary time

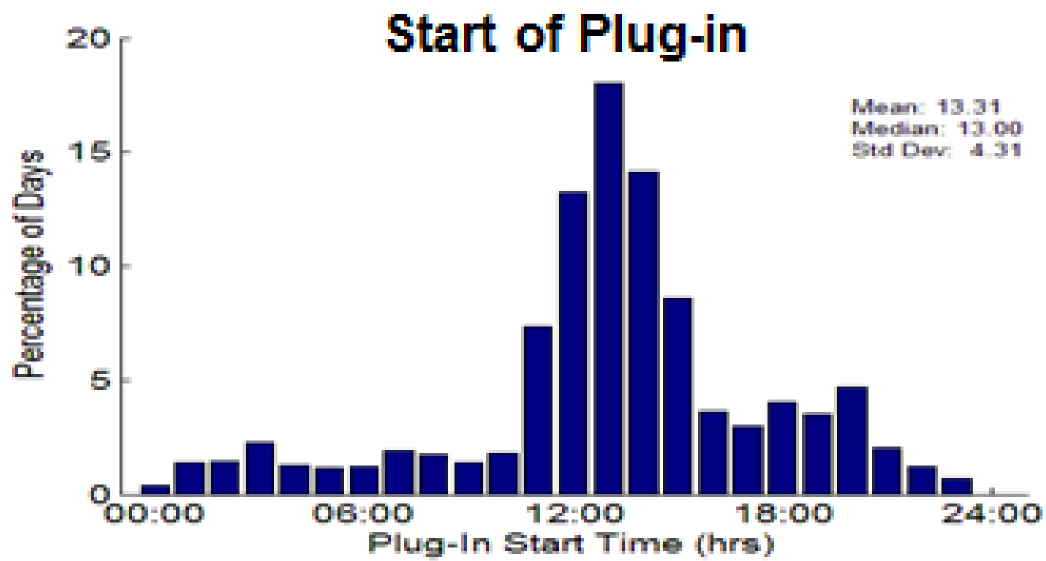


Figure 3-50
Typical—start of charge plug-in

A typical day consists of a drive time of one to three hours, an average distance of 26 miles, and an average speed of 21 mph. The vehicle is involved in stationary work for up to six hours and idle time of up to two hours. The average time plugged in is 15.7 hours. Figures 3-51 through 3-54 show the data for a typical day.

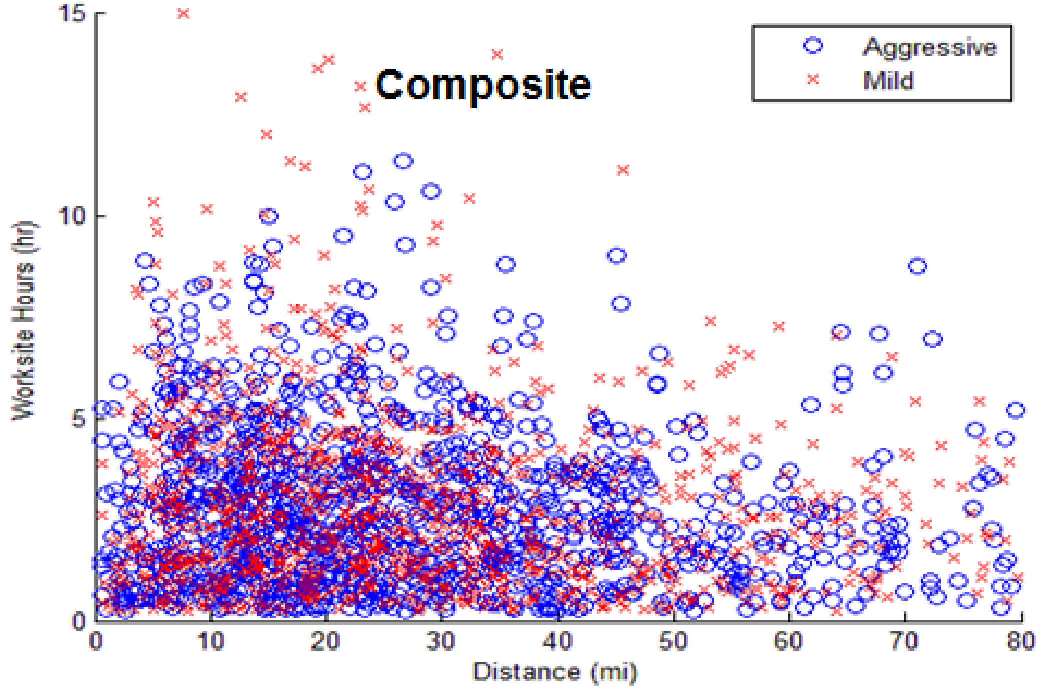


Figure 3-51
Typical day—job site versus distance

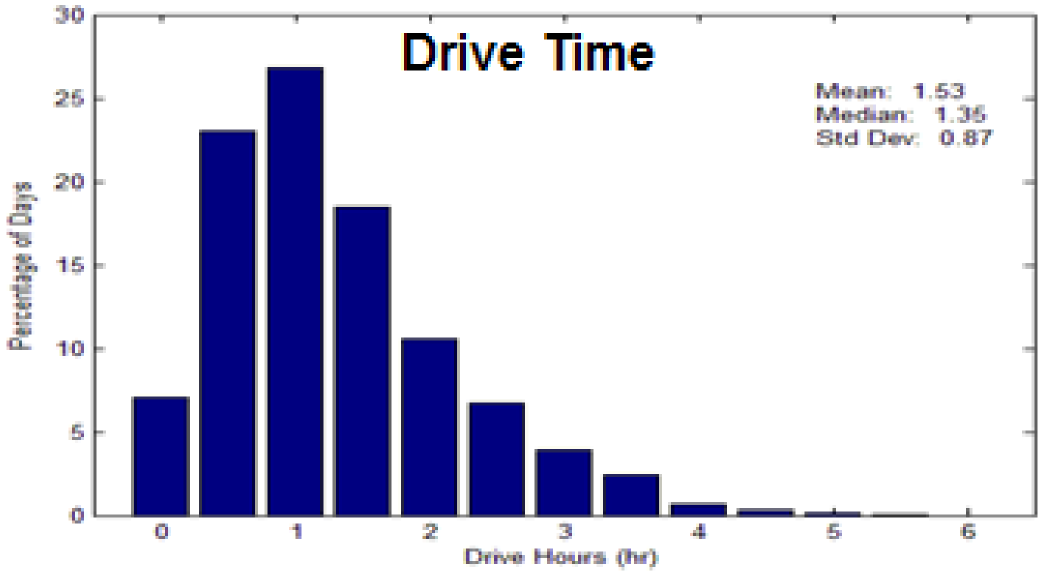


Figure 3-52
Typical day—drive time

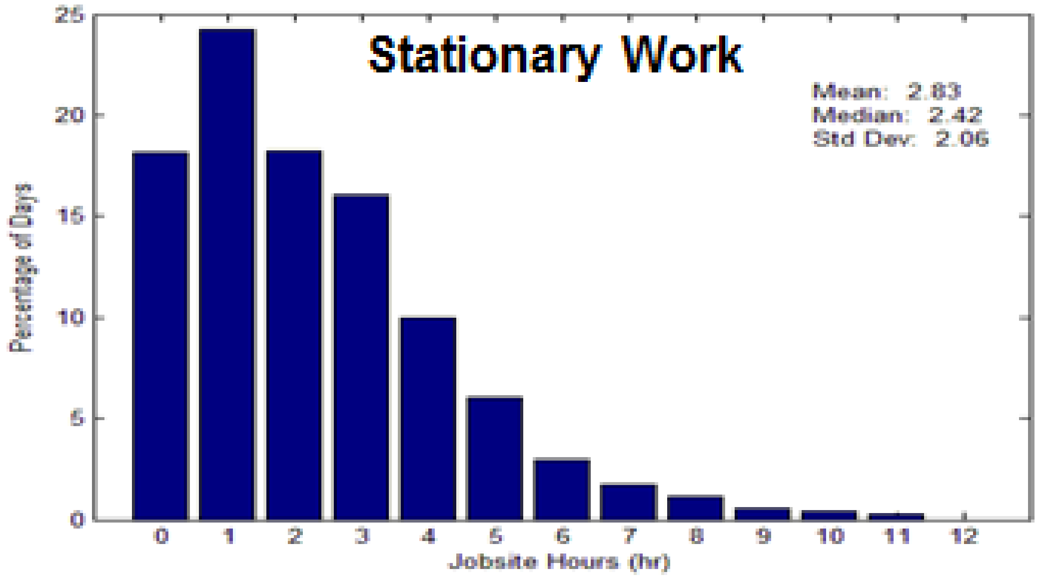


Figure 3-53
Typical day—stationary time

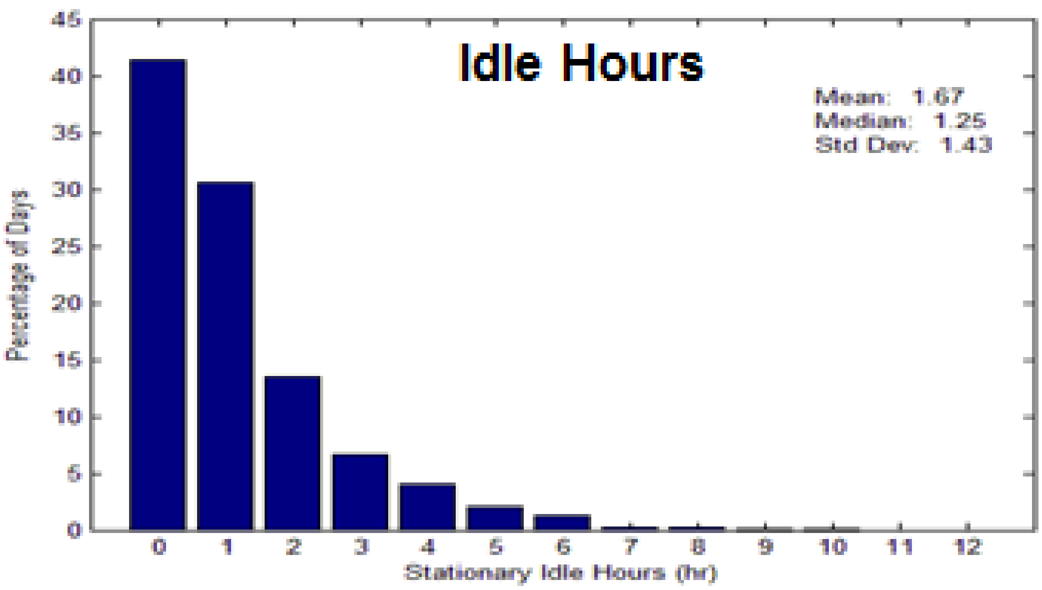


Figure 3-54
Typical day—idle time

3.8 Odyne Survey Results

The project team developed a survey and solicited feedback from both Odyne and VIA vehicle operators. The objective of the survey was to assess drivers' opinions of the vehicles with respect to performance, ease of use and charging, most-used features, overall impressions, and so on. The survey was completed online and took about 20 minutes to complete. It covered Odyne Class 6, 7, and 8 vehicles.

The majority of respondents (84%) had more than years of commercial driving experience (see Figure 3-55).

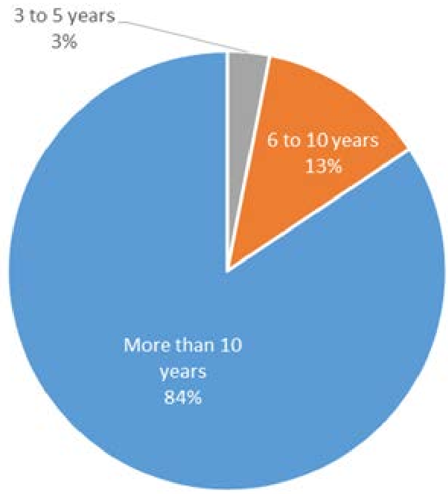


Figure 3-55
Years of experience driving a commercial work truck (n = 32)

The overall satisfaction rating, on a scale of 0 to 10, was 8.2. The highest ratings were for ease of use and charging, and the lowest were for intuitiveness of controls and ease of hydraulics use (see Figure 3-56).

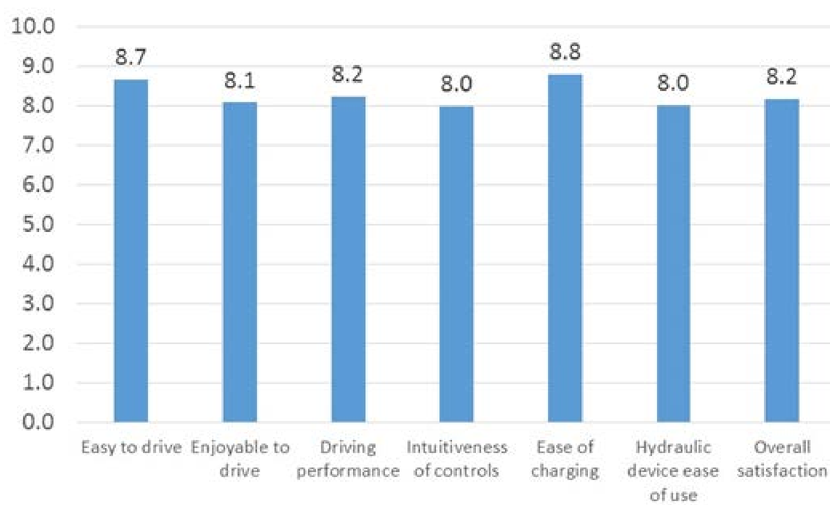


Figure 3-56
Satisfaction ratings (n = 33)

The majority of respondents (62%) preferred the PHEV over their regular work trucks, and drivers clearly preferred the noise level of the PHEV's hydraulic device (see Figure 3-57).

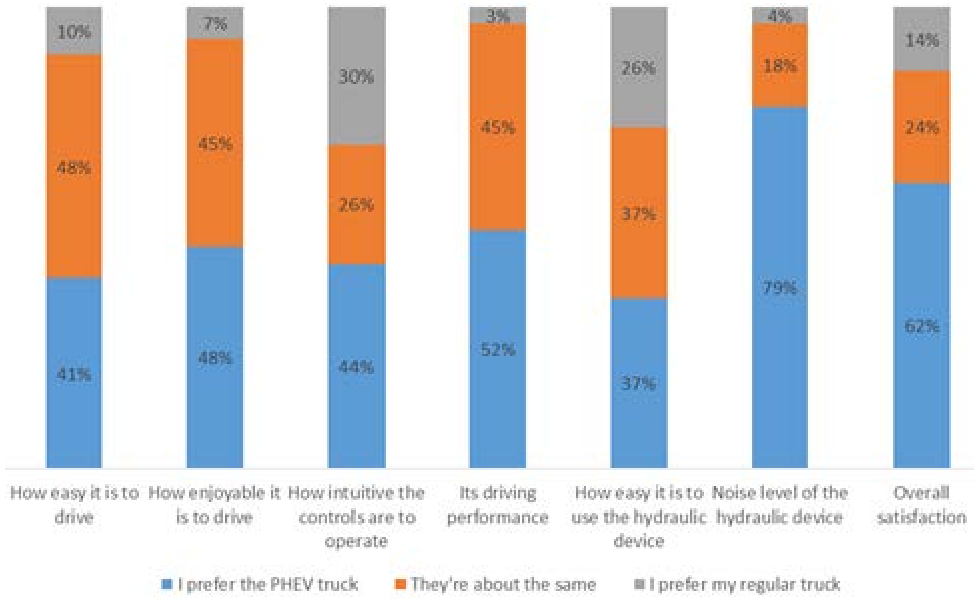


Figure 3-57
Overall satisfaction (n = 27–29)

The majority of drivers would choose the PHEV as their main work truck (see Figure 3-58).

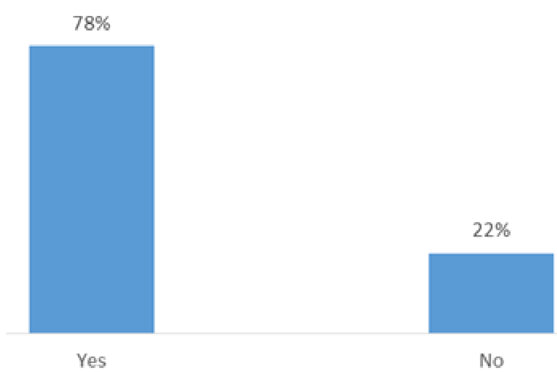


Figure 3-58
Would choose the plug-in hybrid vehicle as main work truck (n = 32)

Preferred features include quietness, acceleration, drive quality, and bucket operation (see Figure 3-59).

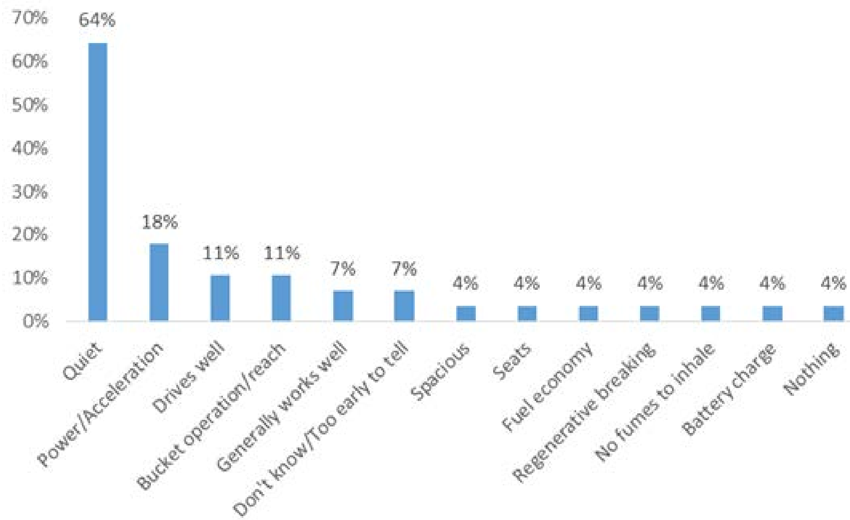


Figure 3-59
Preferred features (n = 28)

The most-desired improvements included the cab design/ amenities, storage space, charging issues, controls operation, and body design/layout (see Figure 3-60).

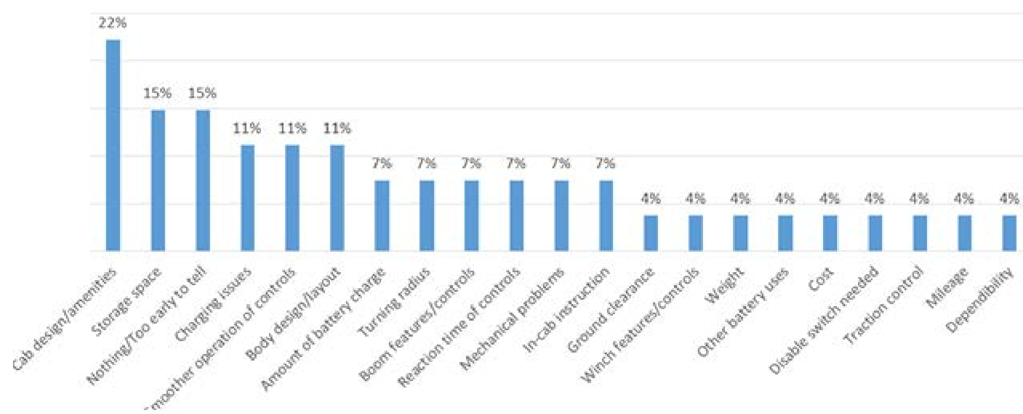


Figure 3-60
Desired improvements (n = 27)

When asked their opinions about the reasons for employers investigating the use of PHEV trucks, drivers most frequently cited improved fuel economy, reduced emissions, and reduced job site noise (see Figure 3-61).

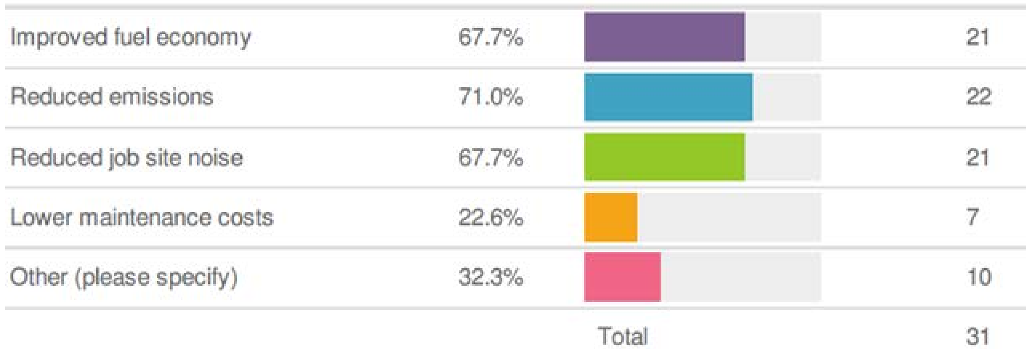


Figure 3-61
Reasons for investigating the use of plug-in hybrid vehicles (n = 31)

3.9 Opportunities for the Future

3.9.1 Design Refinements

Several opportunities were identified, including the following:

- Packaging and cost
  - Improve battery space and upfit conflicts (smaller battery, 14 kWh, single-battery systems)
  - Reduce complexity; consolidate components and reduce the "little bits"
  - Use field data to optimize component and system requirements (14 kWh systems, smaller motors, inverters, and so on)
- Performance
  - Improve driving battery use; optimize power used per mile
  - Use multi-mode calibrations to optimize driving versus stationary days
- Other opportunities
  - Expand applications for Odyne engine-off heating and air conditioning
  - Further refine full-day test cycles
  - Investigate hybrid NOx effects (potential project with National Renewable Energy Laboratory)

3.9.2 Business Opportunities

Several business opportunities were also identified, as follows:

- Ongoing sales—2015 sales have exceeded the business plan
  - A total of 75 units; new and repeat customers
  - Strong growth in walk-in segment
  - Orders have been closed for 2015 and begun for 2016
  - Inland Power (Butler, Wisconsin) remains the primary manufacturing location, with Valley Power (Ontario, California) available for expansion and additional locations under investigation
- New active projects
  - CEC and CALSTART: Established production at Valley Power Systems (Ontario, California); two of four vehicles delivered
  - CEC and EPRI: Develop retrofit capabilities at Valley Power (two of five trucks in process)
  - SCAQMD 14222: Develop retrofit system (in design; one SCE vehicle planned)
- Potential future projects
  - Further integration of engine-off fuel and emissions saving opportunities (alternative architecture yielding notably smaller and lower-cost solutions; improved heating and air conditioning integration, improved controls, smart auto-off systems)
  - Optimization of duty cycles (maximizing driving versus stationary energy trade-off; user interfaces, telematics, smart, learning systems)
  - Investigation and improvement of hybrid NOx effects

4
VIA DEVELOPMENT, PERFORMANCE, AND MANUFACTURING

4.1 System Design

4.1.1 Overall System Design

The VIA design is a series PHEV system. The electric motor provides all the propulsion power directly to the wheels. The gasoline engine provides torque to a generator that provides power to the battery pack and traction motor. The vehicles have up to 47 miles of all-electric range before the engine turns on and provides load-follower torque to the driveshaft while running in charge-sustaining mode. The general assembly process is that VIA purchases completed 2014 trucks from Chevrolet, eliminates the transmissions, and replaces them with generators. A motor and gearbox are attached to the propshaft for traction torque, and two inverters are used to control the generator and the motor.

The VIA Class 1 PHEV pickup truck design is as follows:

- Series hybrid system with single-speed gearbox
- 4.3-L gasoline V6 engine
- High-energy lithium-ion batters (23 kWh, A123)
- Blended regenerative braking
- Onboard charger (14.5 kW)
- Charging level 1 (120 Vac) and level 2 (240 Vac)
- Reduces payload by about 950 lb
- Vehicle can be driven without being charged
- Extended cab
- Export power (14.4 kW, 120/240 Vac, 60 Hz)

The expected performance of the pickup truck is as follows:

- All-electric range up to 47 miles
- Range between refills up to 400 miles
- Charge time less than 6 hours with level 2 (240 Vac) charging

- Charge time less than 100 minutes with level 2 (240 Vac) charging and 14.5 kW
- FMVSS compliant
- Limited warranty 8 years/150,000 miles

Figure 4-1 shows the pickup configuration.

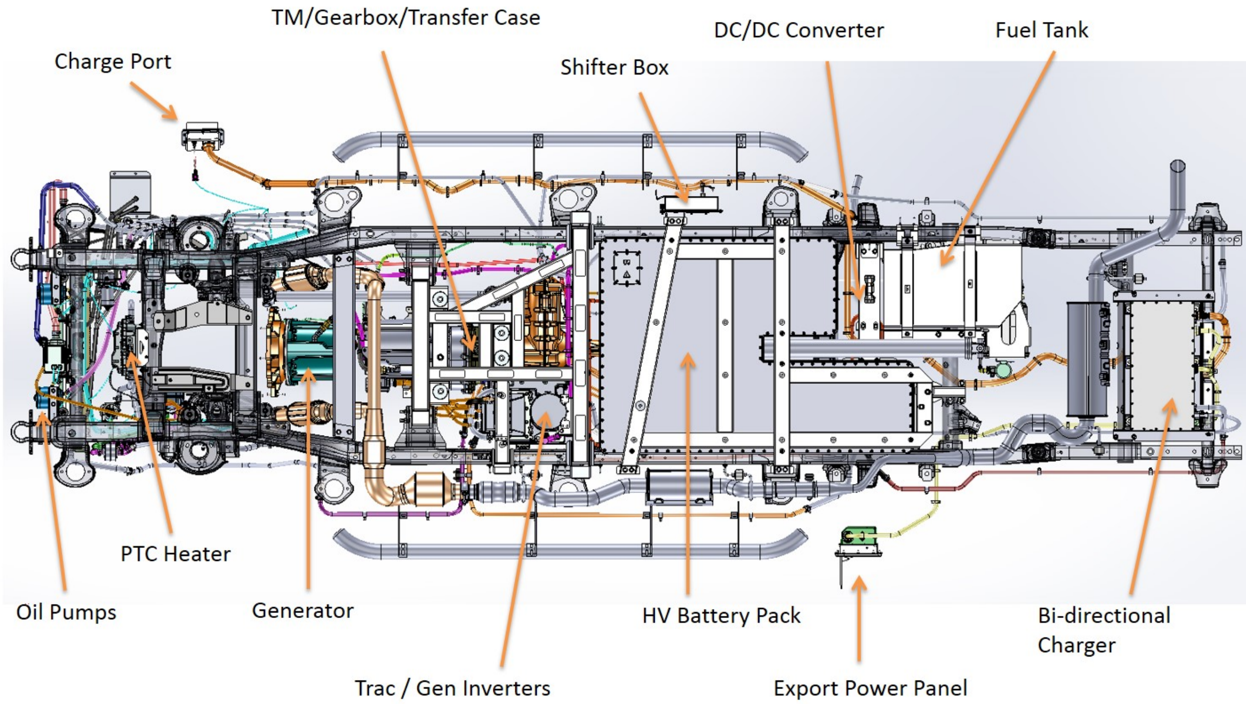


Figure 4-1
Pickup configuration

The VIA Class 2 van design is as follows:

- Series hybrid system with single-speed gearbox
- 4.8-L gasoline V8 engine
- Rear-wheel drive, 135-in. wheel base
- High-energy lithium-ion batters (23 kWh, A123)
- Blended regenerative braking
- Onboard charger (14.5 kW)
- Charging level 1 (120 Vac) and level 2 (240 Vac)
- Reduces payload by about 865 lb
- Vehicle can be driven without being charged
- Cargo van or 12-seat arrangement
- Export power (14.4 kW, 120/240 Vac, 60 Hz)

The expected performance of the van is the following:

- All-electric range up to 48 miles
- Range between refills up to 400 miles
- Charge time less than 6 hours with level 2 (240 Vac) charging
- Charge time less than 100 minutes with level 2 (240 Vac) charging and 14.5 kW
- Federal Motor Vehicle Safety Standards (FMVSS) compliant
- Limited warranty, 8 years/150,000 miles

Figure 4-2 shows the van configuration.

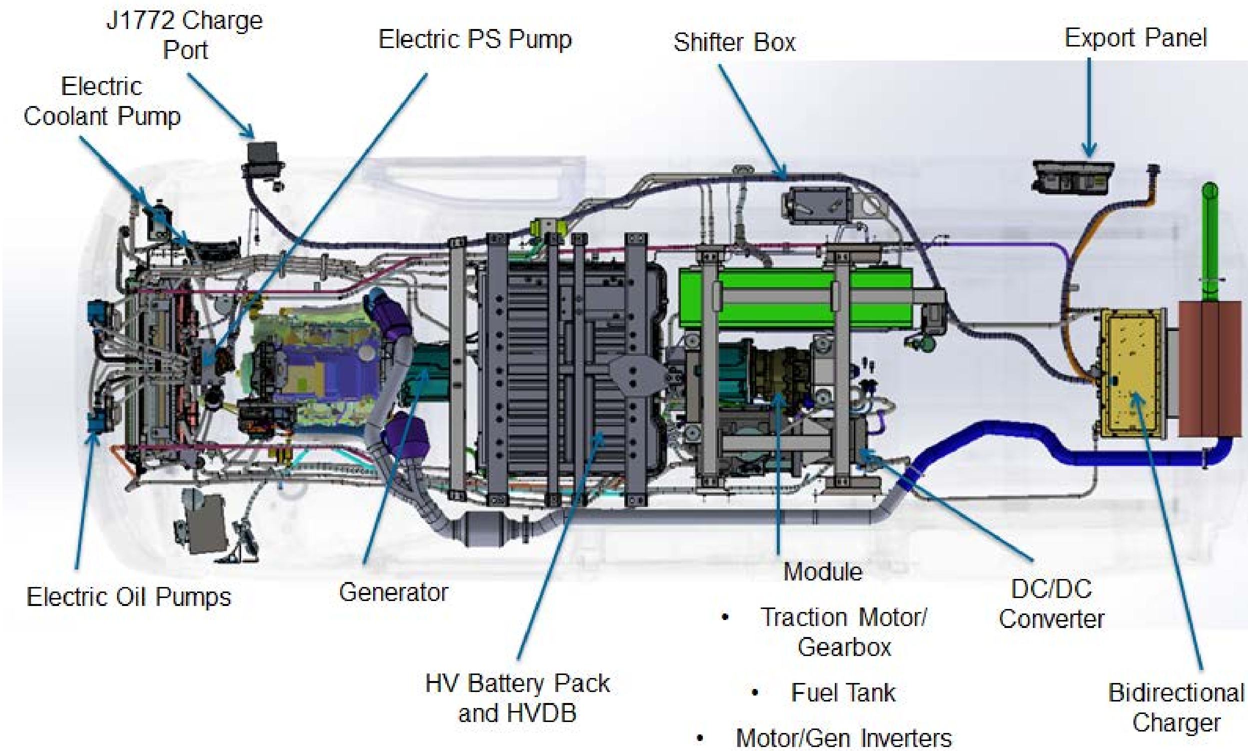


Figure 4-2
Van configuration

4.1.2 Battery Pack

The battery pack is cooled and heated depending on the environment of the battery. The pack is installed under the vehicle. The 23-kWh battery contains A123 lithium-ion prismatic cells configured in both series and parallel configurations (see Figure 4-3).

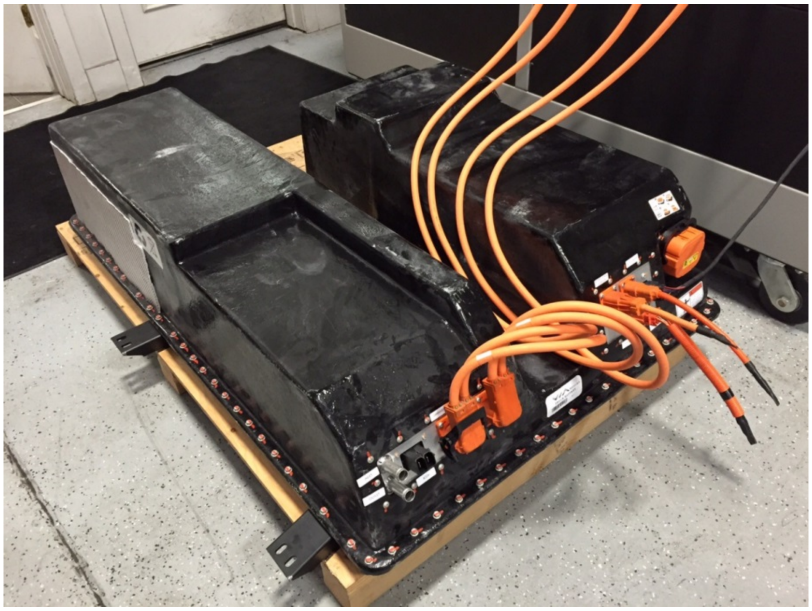


Figure 4-3
Pickup truck battery pack configuration

A high-power charger was included in the design. The 14.5-kW charger allows for a 90-minute charge. The charging connector and interface are compliant with the “Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler.” The same electronics are also used for the 14.4-kW export power unit. A smart charging system was developed in conjunction with the charging system. This system is described in Section 4.2.

4.1.3 Export Power

Each VIA vehicle is equipped with export power. Export power provides the capability of plugging in electrical equipment at the job site. VIA provides 14.4 kW of power with either 240 Vac or 120 Vac. The export panel is equipped with a ground fault circuit interrupt (GFCI), a key to enable the power output, and switches to enable the power. The two 240 V receptacles are different from one another to accommodate two different available plugs. A power splitter cord is included to split the voltage into two or more 120 V receptacles. The export power output is inverted from the 350 V battery pack. When the battery is low on charge, the engine turns on and generates power to the battery to be used as export power. The export power panels are shown in Figures 4-4 and 4-5, and the power splitter cable is shown in Figure 4-6.

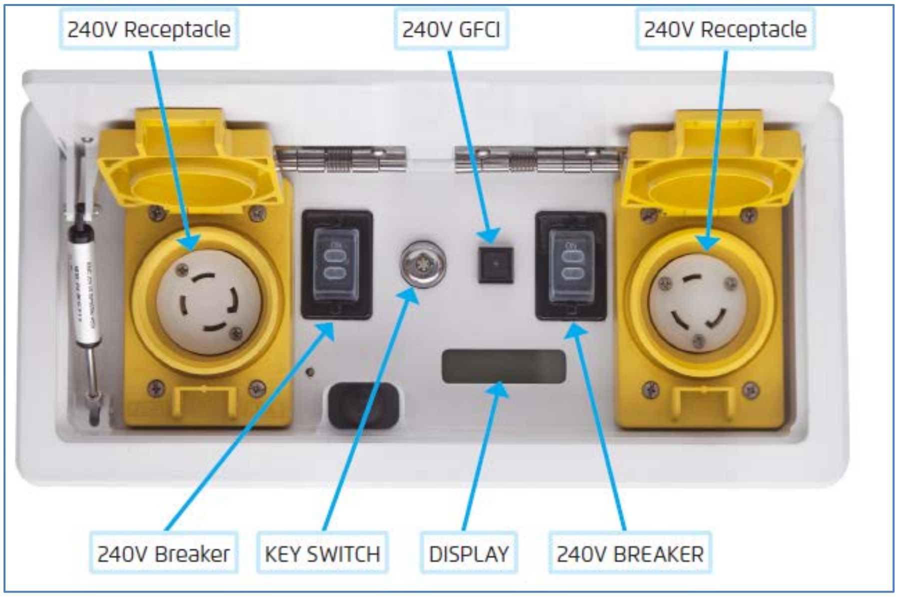


Figure 4-4
Export power panel for the van

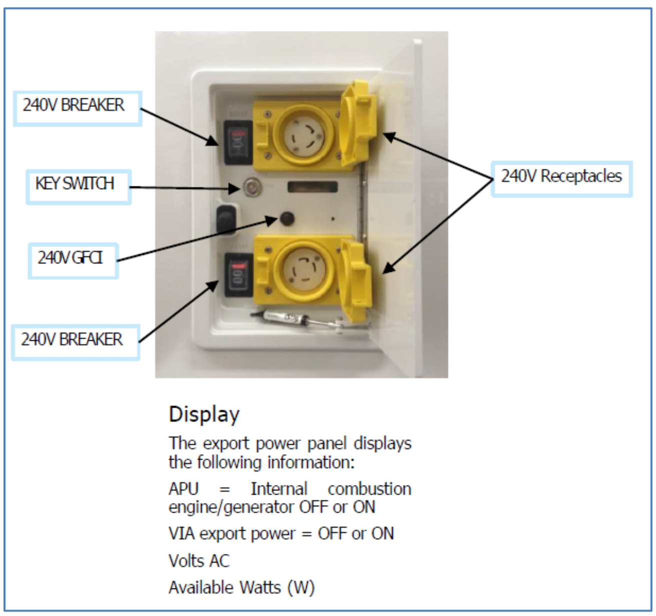


Figure 4-5
Export power panel for the pickup truck

Figure 4-6
Power splitter cable

4.1.4 Dashboard Display

The dashboard display has been modified to allow the hybrid displays. A power gage, a generator gage, and an energy gage, as well as a few new telltales, have been incorporated into the dashboard for driver reference. Figure 4-7 shows the van display, and Figure 4-8 shows the pickup truck display.

Figure 4-7
Van dashboard display

Figure 4-8
Pickup truck dashboard display

4.1.5 Shift Control

The shift control (park, reverse, neutral, drive, manual [PRNDM]) on the VIA vehicles (see Figure 4-9) is used just as in conventional vehicles. In the drive and reverse modes, if the SOC is high enough, the vehicle will drive in electric or charge-depleting mode. When the SOC is low, the engine will turn on and generate power to the battery and output motor in a charge-sustaining manner. If the SOC is less than 90%, shifting to the manual (M) position will cause the engine to turn on and maintain the SOC at this level. This can be used to save the stored energy in the battery to be used later for driving in all-electric mode or for exporting power. The manual mode (M position) can also be used to improve vehicle performance under extreme cold conditions or steep grade with lower SOC.

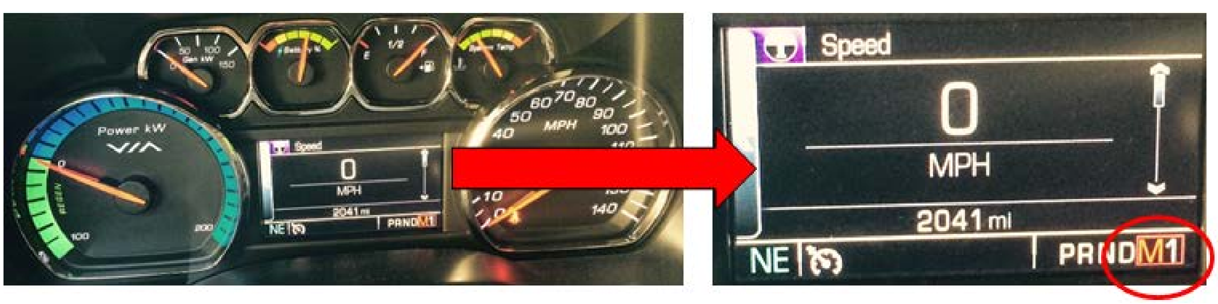


Figure 4-9
Shift control

4.2 Electric Vehicle Operating Modes

The extended-range electric truck has two modes for driving: battery electric and extended-range electric. In both modes, the vehicle is propelled by the electric traction motor. The traction motor uses electrical energy either from the high-voltage battery or from engine operation to drive the wheels. The level of performance is the same in either mode.

4.2.1 Battery Electric Mode

If the high-voltage battery is fully charged, the vehicle will operate using the high-voltage battery for an initial period (as far as 47 miles). The engine will not start until the battery reaches a low-level SOC. During this time, vehicle operation is quiet, no fuel is used, and no tailpipe emissions are produced. Figure 4-10 illustrates the battery electric mode.

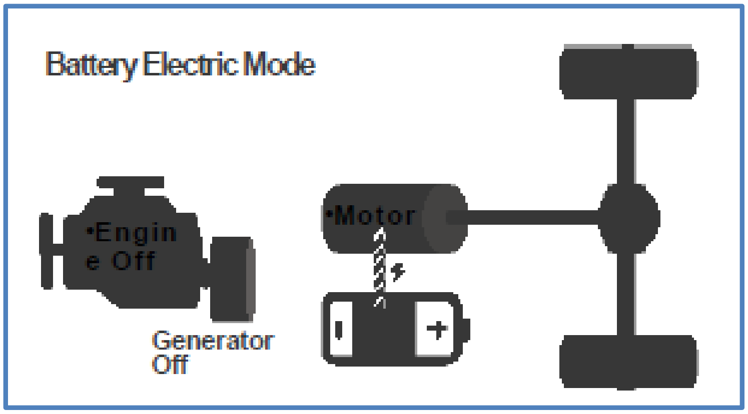


Figure 4-10
Battery electric mode

4.2.2 Extended-Range Electric Mode

When the battery charge falls to a low level, approximately 20% SOC, the vehicle switches to extended-range electric mode, and the gasoline-powered internal combustion engine starts automatically. The sound of the engine can be heard during operation. The engine is connected to a generator that produces electricity to propel the vehicle. The engine/generator combination is known as an *auxiliary power unit* (*APU*). Figure 4-11 illustrates the extended-range electric mode.

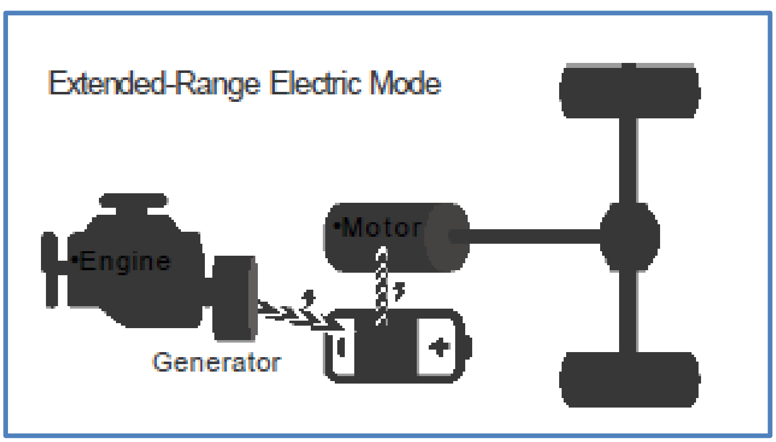


Figure 4-11
Extended-range electric mode

4.2.3 Regenerative Braking Mode

Regenerative braking enables the traction motor to operate as a generator when coasting or braking. This provides energy to recharge the high-voltage battery. Both the hydraulic brakes and the drive motor provide braking. The braking system is computer controlled and blends the regenerative braking with the conventional hydraulic disc brakes to meet any requirements for deceleration. As with all hydraulic-assist vehicles, the brake pedal may be harder to push and the stopping distance may be longer in the event of a controller problem. Figure 4-12 illustrates the regenerative braking mode.

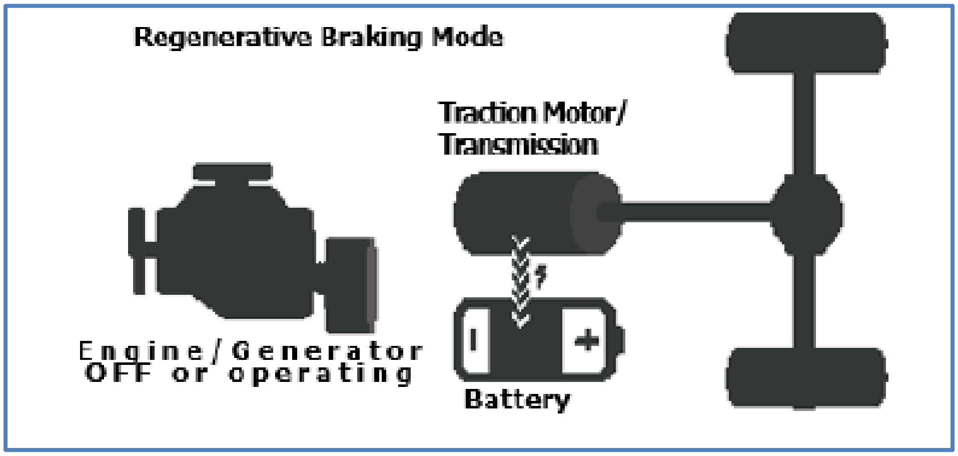


Figure 4-12
Regenerative braking mode

4.3 Performance

4.3.1 Mass and Gross Vehicle Weight Rating

Both the van and pickup truck added mass to the conventional vehicle (see Figures 4-13 and 4-14). When the engineering tests were run, they were run at a higher GVWR than the conventional vehicle. This was done to provide a higher payload for these work trucks. The vehicles were crashed at the higher GVWR, as well, to allow the higher payload. Currently, the pickup loses about 950 lb of payload due to hybridization; future testing may improve that by about 400 lb. The van loses about 865 lb due to hybridization.

1500 4WD Crew Cab Truck 6'6" Box	VIA			Stock
	Front	Rear	Total	Total
Curb Weight (lbs)	3820	2920	6740	5359
		Current	Projected*	
GVWR (lbs)		7500	7900	7100
Payload (lbs)		760	1160	1710
Payload Difference (lbs)		950	550	

Notes:
* Re-running FMVSS135 at 7900 lbs.

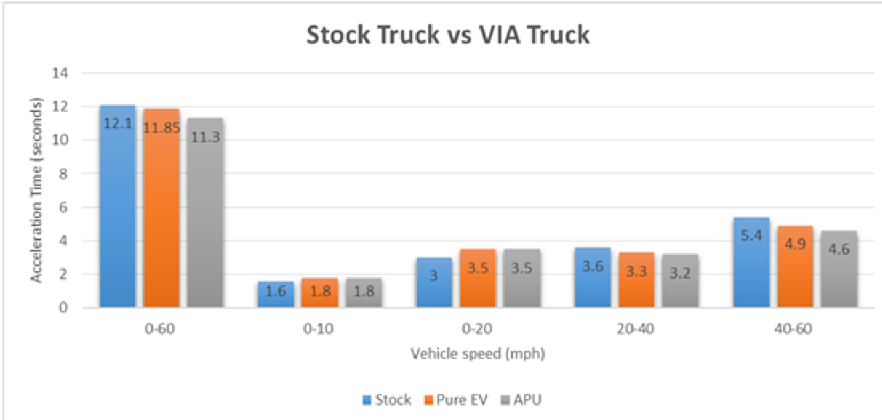
Figure 4-13
Pickup truck mass analysis (1500 four-wheel-drive crew cab, 6.5 ft box)

Passenger VAN 3/4 ton	VIA			Stock
	Front	Rear	Total	Total
Curb Weight (lbs)	3900	3610	7510	5873
		GVWR (lbs)	9350	8600
		Payload (lbs)	1840	2705
		Payload Difference (lbs)	865	

Figure 4-14
Passenger van mass analysis (3/4-ton van)

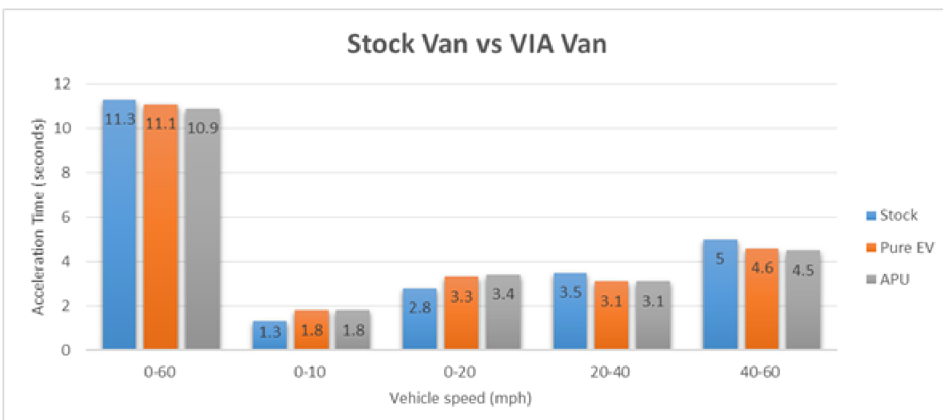
4.3.2 Acceleration

The van and pickup truck acceleration times are similar to that of conventional vehicles (see Figures 4-15 and 4-16).



TRUCK: 2014 Silverado 1500 4WD , 1WT CREW			
Vehicle characteristics	Stock	VIA (Pure EV)	VIA (APU)
0-60 mph	12.1 seconds	11.85 seconds	11.3 seconds
0-10 mph	1.6 seconds	1.8 seconds	1.8 seconds
0-20 mph	3.0 seconds	3.5 seconds	3.5 seconds
20-40 mph	3.6 seconds	3.3 seconds	3.2 seconds
40-60 mph	5.4 seconds	4.9 seconds	4.6 seconds

Figure 4-15
Truck acceleration times (stock truck compared to VIA truck)



VAN: 2014 Cargo			
Vehicle characteristics	GM (stock)	VIA (Pure EV)	VIA (APU)
0-60 mph	11.3 seconds	11.1 seconds	10.9 seconds
0-10 mph	1.3 seconds	1.8 seconds	1.8 seconds
0-20 mph	2.8 seconds	3.3 seconds	3.4 seconds
20-40 mph	3.5 seconds	3.1 seconds	3.1 seconds
40-60 mph	5.0 seconds	4.6 seconds	4.5 seconds

Figure 4-16
Van acceleration times (stock van compared to VIA van)

4.3.3 Towing

VIA conducted tests for towing heavy boats (4780 lb), as shown in Figure 4-17. The truck maintained 60 mph on a Provo Canyon climb.

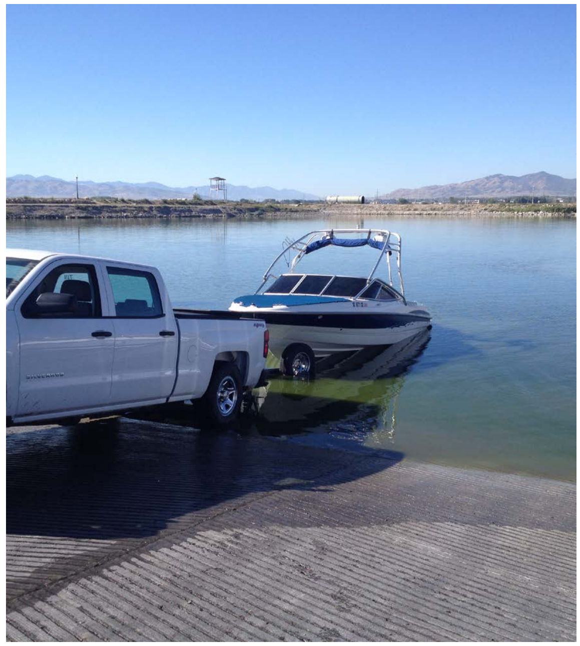


Figure 4-17
Towing

4.3.4 Fuel Economy and Emissions

The fuel economy of the VIA vehicles is significant if the vehicle is charged often. The electric range is about 48 mpg for the van and 47 mpg for the pickup truck, using the assumptions shown in Figure 4-18.

TRUCK (Crew Cab 4x4) Weight 6670 Lbs / tires 255 @ 35 psi		VIA Vtrux	Conv Vehicle	% Improvement
Battery Electric Range (Charge Depleting)	City Drive	47.6 miles ave.		
	Highway Drive	47.5 miles ave.		
Fuel Economy (Charge Sustaining)	City Drive	19.6 mpg ave.	13.6 mpg (20% idle)	44%
	Highway Drive	22.2 mpg ave.	22 mpg (0% idle)	1%
Combined Fuel Economy (70% City/30% Hwy)	Combined Average	102 mpg Equiv.	16.1 mpg	534%

VAN (Cargo) Weight 6655 Lbs / tires 245 @ 70 psi F 80 psi R		VIA Vtrux	Conv Vehicle	% Improvement
Battery Electric Range (Charge Depleting)	City Drive	48.1 miles ave.		
	Highway Drive	48.2 miles ave.		
Fuel Economy (Charge Sustaining)	City Drive	16.6 mpg Ave.	9 mpg (20% idle)	84%
	Highway Drive	21.4 mpg Ave.	16 mpg (0% idle)	33%
Combined Fuel Economy (70% City/30% Hwy)	Combined Average	96 mpg Equiv.	11.1 mpg	765%

VIA Current Assumption: Test was run at 45 mph city and 55 mph highway without cabin conditioning. Real world results should reflect higher highway speeds and cabin conditioning. Anticipated results given these two factors are 40 miles battery electric range and probable 20% reduction in combined fuel economy from the reported test results.

Figure 4-18
Fuel economy comparison

If the driving is limited to the electric range, the fuel economy is infinite. After the engine turns on, the fuel economy reduces as vehicle is driven with gasoline until it approaches the charged sustained fuel economy of a hybrid (see Figure 4-19). The fuel economy can be improved by charging more frequently during the day.

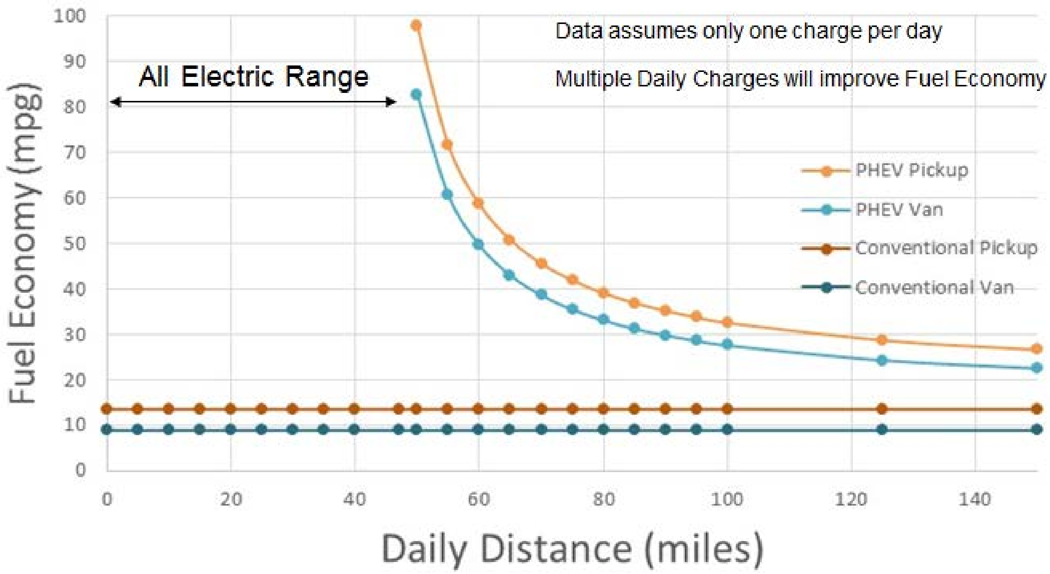


Figure 4-19
Fuel economy as a function of distance

Both the van and the pickup truck have received executive orders from CARB for vehicle sale. The EPA has also approved both vehicles for sale.

VIA worked with each agency to establish the requirements, and then VIA conducted and successfully passed the required tests, which included tailpipe emissions and evaporative emissions. Unlike the Chevrolet Volt, the VIA vehicles do not have a sealed fuel tank containing the evaporative emissions. Therefore, CARB and the EPA wanted to ensure that the purge canister would be purged regularly to avoid releasing excess hydrocarbons into the atmosphere. VIA resolved this issue by turning the engine on for 15 minutes at least every five days, and the agencies allowed it. This is an annoyance to the customer, but it resolved the certification issue. VIA is currently researching other solutions to avoid this annoyance.

The emissions results are presented in Table 4-1, assuming 60 miles per day and an all-electric range of 40 miles.

Table 4-1
VIA emissions

Electric Miles per Charge	Charges per Day	Electric Vehicle Drive Percentage (Charge Depleting)	Charge-Sustain Mode	Emissions Improvement (Compared to Conventional Vehicle)
40	1	66%	34%	66%
40	1.5	100%	0%	100%

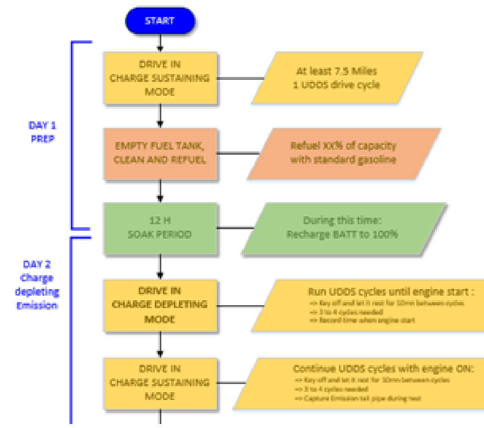
15,000 miles annual driving = 60 miles per day; electric vehicle range on single charge = 40 miles

4.3.5 Vehicle Certification

VIA is compliant with both CARB and EPA. Both the van and the pickup truck are fully certified with the EPA. Currently, VIA has executive orders from CARB indicating that the vehicles are certified with exception. The exception is that all the onboard diagnostic monitors are not being set as frequently as they should be. VIA is working on these exceptions and plans to meet the full certifications dates shown in Figure 4-20. Figure 4-20 also provides a summary of the compliance procedures.

COMPLIANT WITH REGULATORY AGENCIES:

- California Air Resource Board – CARB
- Environmental Protection Agency - EPA



SUMMARY TEST PROCEDURES:

- Emissions
  - Charge depleting
  - Charge sustaining
- Evaporative
  - 2-day Diurnal test (shed)
  - Purge mode
- On-Board Diagnostic
  - Monitor setting
  - Fault detection

VEHICLE SCHEDULE FOR FULL CERTIFICATION:

- VAN
  - OBD Fault Detection - OCT 2015
- TRUCK
  - OBD Monitor Setting - OCT 2015
  - OBD Fault Detection - DEC 2015

Figure 4-20
VIA vehicle certification overview

In charge-sustaining mode, the emissions requirements make the controls stay within a tolerance of ±1% around the affected SOC, which causes unconventional engine speed changes (see Figure 4-24). With respect to vehicle certification requirements, a recommendation was identified to relax the SOC constraint when the engine is on. The current requirement is that when the engine is on (APU is active), the SOC of the high-voltage battery should be sustained to the APU start value with an accuracy of ±1%, so that there is no use of electrical energy to pass the engine emissions test during certification. The recommended requirement is that when the engine is on (APU is active), the SOC of the high-voltage batter should be maintained at least to the APU start value -1% but can be increased by Y% using the engine. This would result in fewer engine power transients and greater fuel economy, while still using no electrical energy to pass the engine emissions test during certification.

The blue trace in Figure 4-21 shows the relationship between the road speed and motor speed. It is quite linear. The red trace shows the relationship between the generator/engine speed and the road speed. It is quite variable and unpredictable. This unpredictability is the cause of engine noise issues. The VIA vehicles are limited to 75 mph due to efficiency considerations.

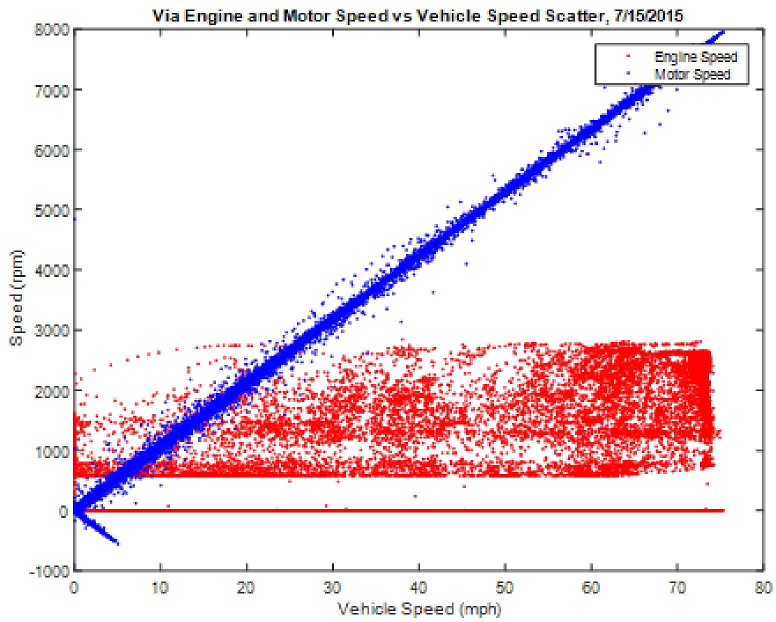


Figure 4-21
VIA engine and motor speed versus vehicle speed scatter

4.3.6 Crash and Safety

Safety was an important design feature. The vehicle was tested with a higher GVWR than the conventional General Motors vehicle. The higher GVWR provided nearly the same payload as the base production vehicle. The added battery, motor/generator, and other high-power components added about 1300 lb to the chassis mass. All crash tests were passed successfully. Both the van and the pickup truck were required to be crashed and certified for safety in all respects (see Figure 4-22). The vehicles also had to be turned over (see Figure 4-23).

Figure 4-22
Van frontal crash

Figure 4-23
Van rollover test

4.4 VIA Engineering Process

VIA's engineering process was complete with DVP plans, DFMEA, risk assessments, and BOM. The BOM for the pickup truck has more than 746 lines, which includes all new parts and 77 unique subassemblies. The BOM for the van has a similar number. Design reviews were held periodically during the engineering process (see Tables 4-2 and 4-3).

Table 4-2
VIA van design reviews

Design Review	Title
VV1	System requirements and design
VV2	Prototype vehicle complete
VV3	Production validation complete
VV4	Production release review
VV5	First end-user production vehicle

Table 4-3
VIA pickup truck design reviews

Design Review	Title
VP1	System requirements and design
VP2	Prototype vehicle complete
VP3	Production validation complete
VP4	Production release review
VP5	All end-user production vehicles

VIA created a hot/cold room around a chassis dynamometer at their Orem facility to accommodate engineering development. This site provided cold and hot environments for development, while allowing the vehicle to be driven on the chassis dynamometer.

4.5 VIA Manufacturing Accomplishments

The VIA manufacturing facility for these vehicles is located in Orem, Utah (see Figure 4-24). The vehicles were built on six hoists (see Figure 4-25) with technicians underneath assembling the parts (see Figure 4-26). The battery packs were assembled on a production line at VIA in Orem, Utah.

Figure 4-24
VIA engineering and manufacturing facility in Orem, Utah

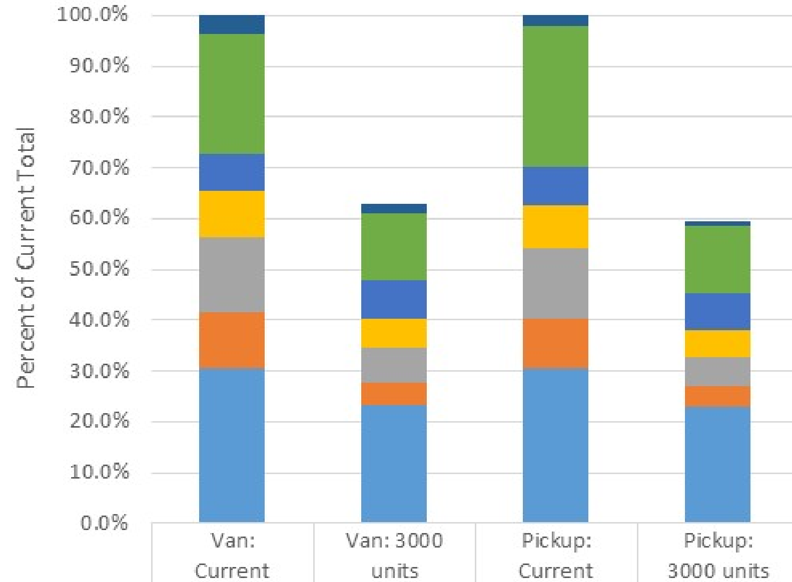
Figure 4-25
Vehicles being manufactured

Figure 4-26
Technicians assembling vehicles

Future VIA production will include an assembly plant in San Luis Potosi, about 100 miles from the General Motors truck assembly plant in Silao, Mexico. This will allow shorter shipping times and a direct path from one plant to another.

4.6 VIA Cost Analysis

VIA performed a cost analysis of their PHEV system. The results are shown in Figure 4-27. The data indicate that the total component costs can be reduced by about 38% to 40% by increasing the volume to 3000 units. The reductions come by providing higher-volume tooling and higher unit volumes; changing suppliers; and redesigning some components such as the fuel tank. The most costly component is the battery pack, which can be reduced by about 24% with the incremental volume.



	Van: Current	Van: 3000 units	Pickup: Current	Pickup: 3000 units
Export Power	3.6%	1.9%	2.2%	0.9%
Other Components	23.5%	13.3%	27.8%	13.3%
Motor/Generator	7.5%	7.5%	7.5%	7.2%
Charger	9.2%	5.6%	8.5%	5.4%
Controller	14.6%	7.0%	13.8%	5.4%
Power Electronics	11.1%	4.3%	9.8%	4.2%
Batteries	30.5%	23.3%	30.5%	23.0%

Figure 4-27
VIA cost analysis

4.7 VIA Data Analysis

Data were collected using the data acquisition system described in Section 5.1. The results are described in this section.

All 177 VIA vehicles are equipped with a data acquisition system that collects data at a rate of up to 1 Hz. Data are collected during the day and sent to the server daily. SCAQMD has provided funding to continue gathering data for the next 12 months. Data collected include the following:

- Motor current and voltage
- Battery current and voltage
- Charger current and voltage
- Motor and engine torque and speed
- Export power current and voltage
- Odometer
- Vehicle speed
- Accelerator and brake pedal position
- Fuel used
- Charger time
- Software and calibration level

Data for the month period include 82,520 miles driven, more than 3985 drive events, and 1658 charging events. The data reflect primarily the VIA vans; the pickup trucks were recently added. Table 4-4 presents the usage summary.

Table 4-4
VIA data collection

January 1, 2015 to August 31, 2015	Vans	Trucks	Total
Fleet size	51	100	151
Number of events	1,461.0	4,306.0	5,767.0
Total time (hours)	3,994.6	12,225.4	16,220.0
Total miles	24,172.3	58,347.7	82,520.0
Electric miles	9,568.7	18,440.5	28,009.2
Approximate fuel gallons displaced (20 mpg)	478.4	922.0	1,400.4
Percentage of miles electric	39.6%	31.6%	33.9%
Fuel miles	14,603.6	39,907.2	54,510.8
Total energy (fuel plus electric; kWh)	33,980.8	59,224.0	93,204.8
Electric energy (kWh)	1,734.0	3,546.0	5,280.0
Fuel energy (kWh)	35,714.7	62,724.3	98,439.0
Fuel gallons used	1,059.8	1,861.3	2,921.1
Number of drive events	983	3,002	3,985
Number of charge events	444	1,214	1,658
Number of operate events	34	45	79
Net drive (hours)	2,467	3,941	6,408
Net operate time (hours)	42	16	58
Net charge time (hours)	1,485	2,156	3,641
Number of drive days	197	116	313
Number of charge days	158	102	260
Number of operate days	28	32	60
Average miles per drive event	16.5	13.6	14.3
Average length (hours) per charge event	3.3	1.8	2.2
Average length (hours) per operate event	1.2	0.3	0.7
Average miles driven per drive day (whole fleet)	122.7	503.0	263.6
Average hours charge per charge day (whole fleet)	9.4	21.1	14.0
Average hours operation per operate day (whole fleet)	1.5	0.5	1.0

The peak driving time for the VIA vans and pickup trucks is midday, and charging occurs primarily during the day (see Figures 4-28 and 4-29). The export power has not been used significantly during stationary operation.

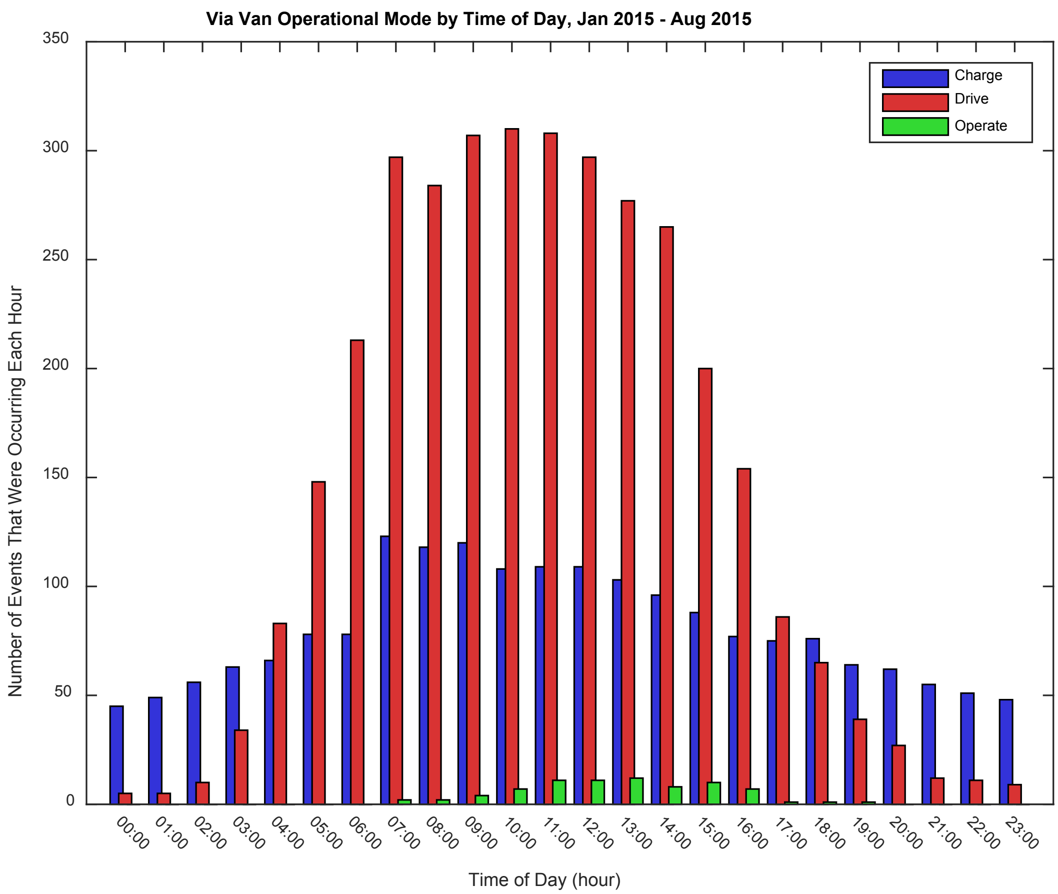


Figure 4-28
VIA vans—operational modes by time of day

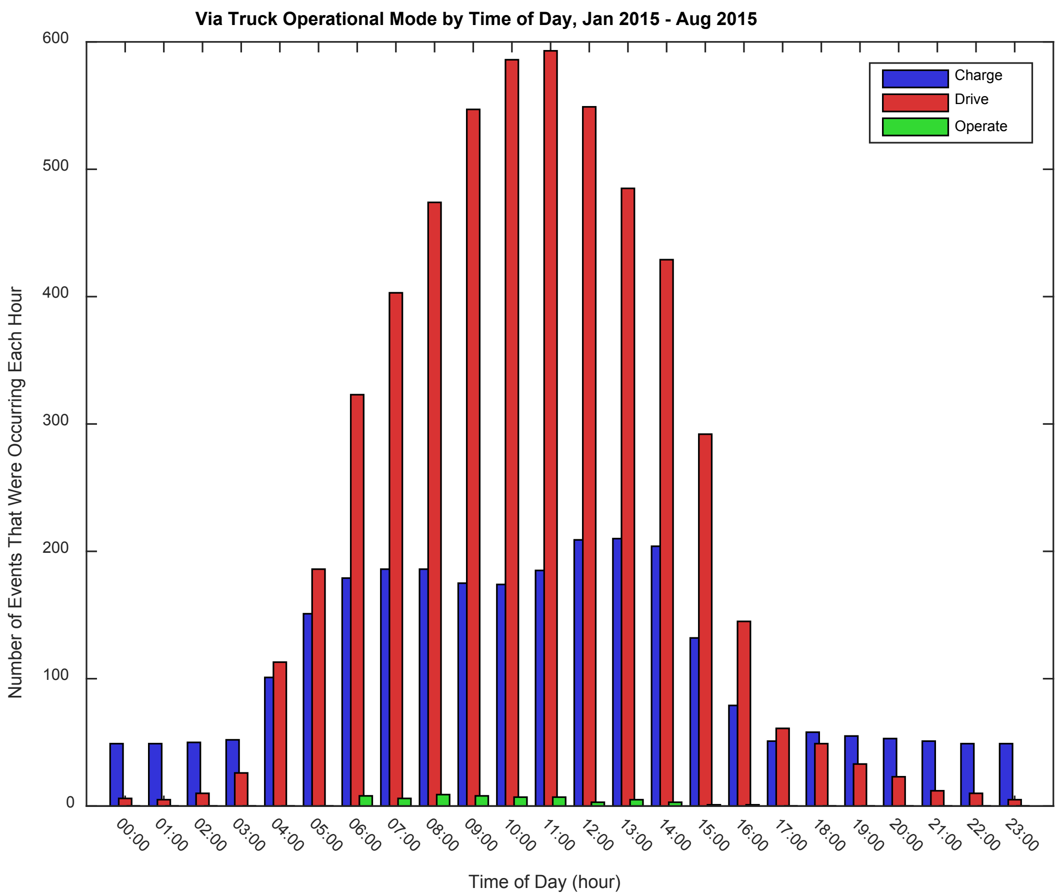


Figure 4-29
VIA pickup trucks—operational modes by time of day

Most charging was done using level 2 (240 V). There were many short-term (< 5 hours) charges and some overnight charges (see Figure 4-30).

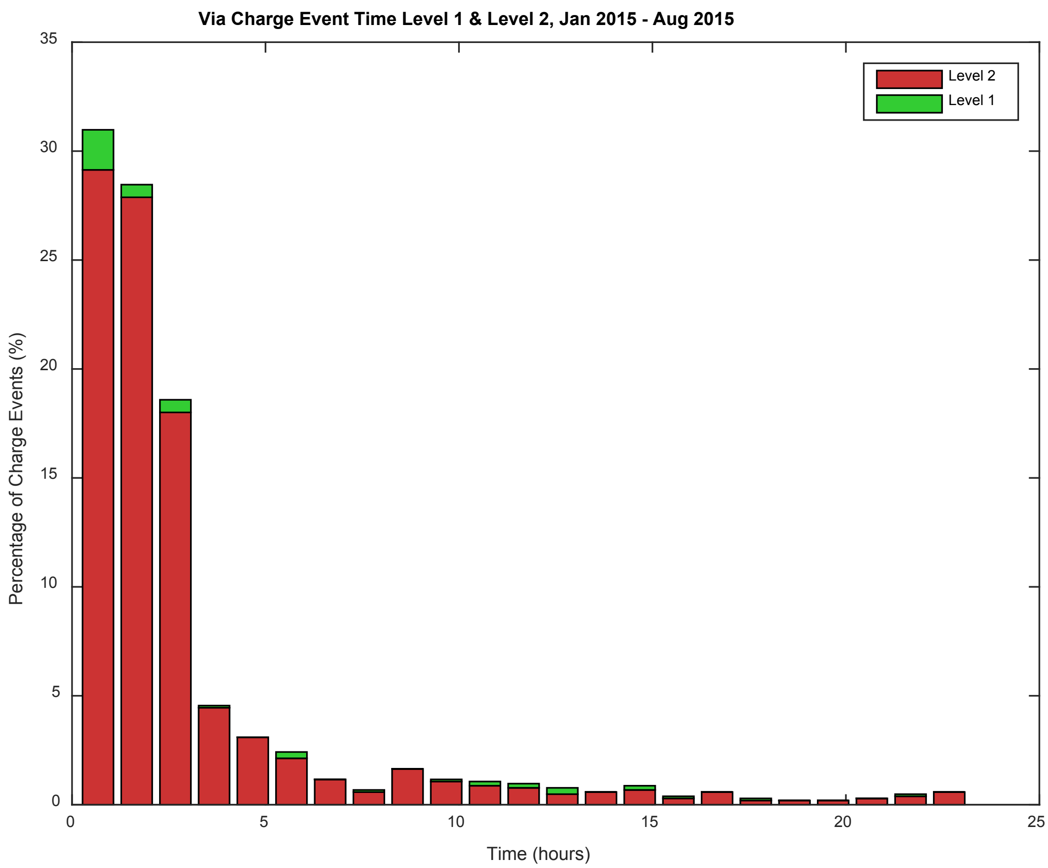


Figure 4-30
VIA charge times

More electric power was used on short-distance trips, and more fuel was used on longer-distance trips (see Figures 4-31 and 4-32).

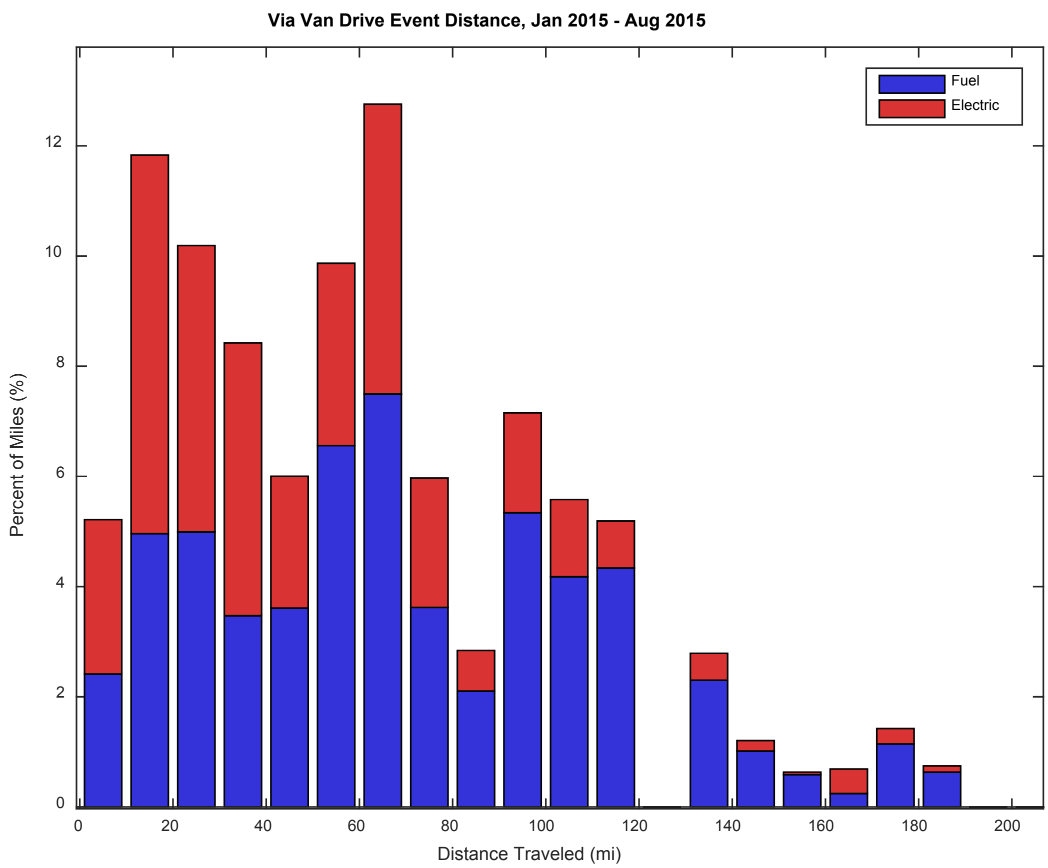


Figure 4-31
VIA vans—energy type by distance

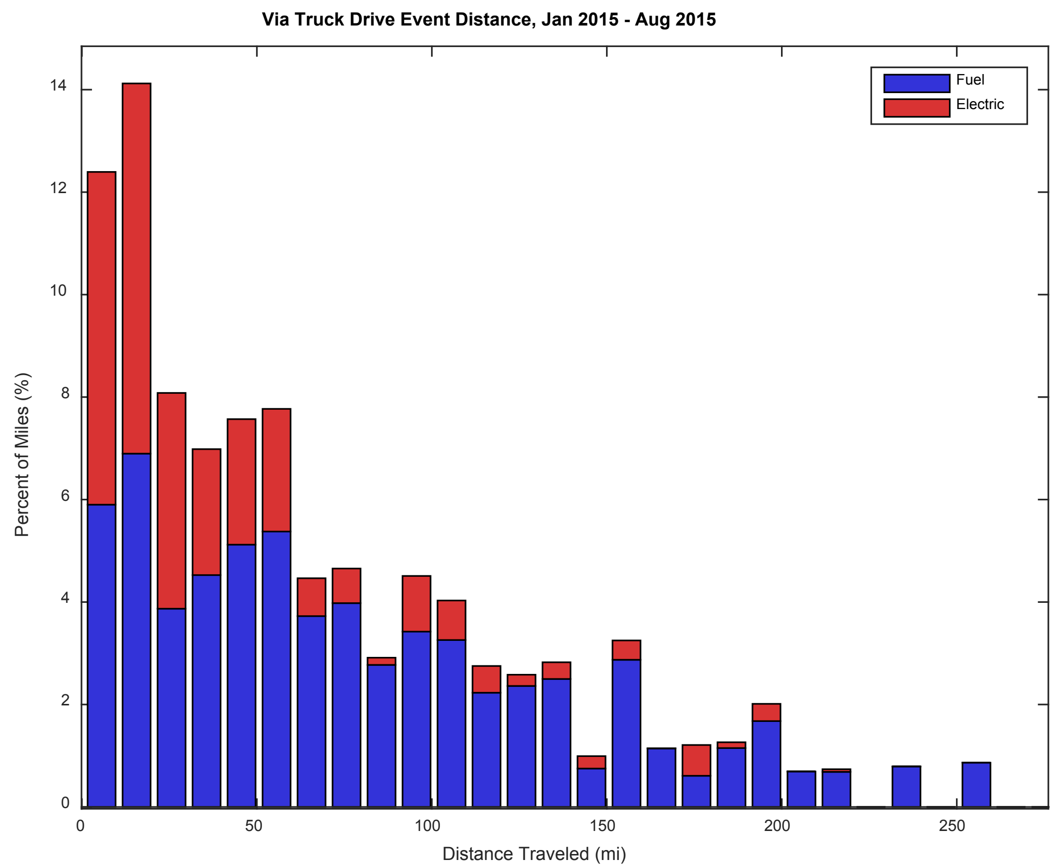


Figure 4-32
VIA pickup trucks—energy type by distance

About 15% to 20% of the VIA vehicles began their drives with more than 90% SOC. Many vehicles began below 30% or in need of a charge (see Figure 4-33).

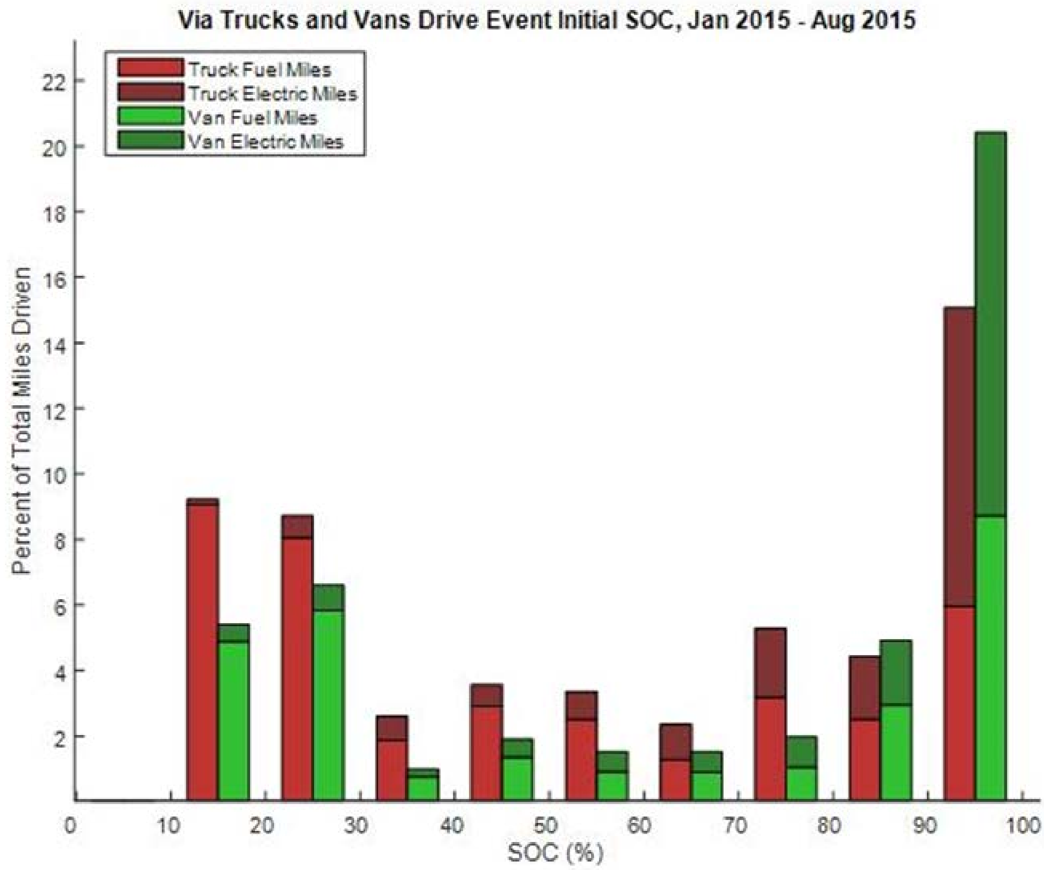


Figure 4-33
VIA initial state of charge of drive events

Figure 4-34 shows the delta SOC used during a drive event. The data show that 12% to 18% of the drive events used less than 10% of SOC, whereas 16% of the drive events used more than 70% SOC.

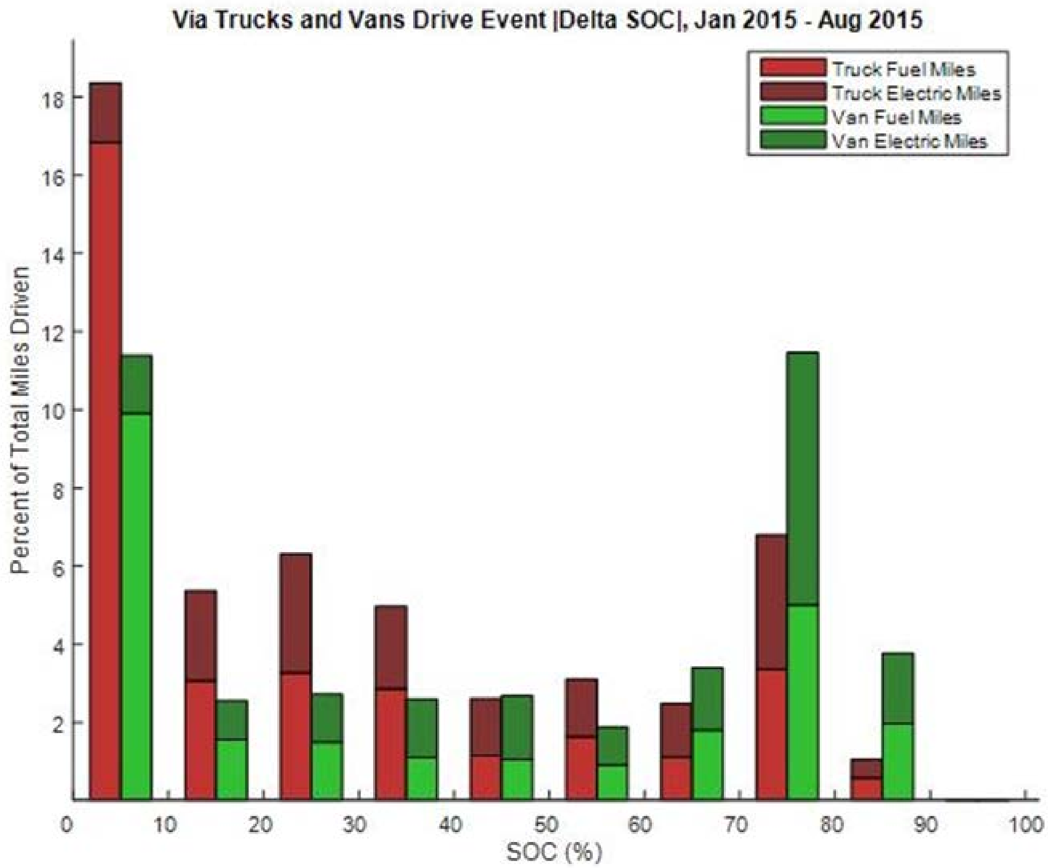


Figure 4-34
VIA delta state of charge of drive events

Figure 4-35 shows the SOC at the end of the drive events. About 38% of the drive events ended with 10% to 30% SOC.

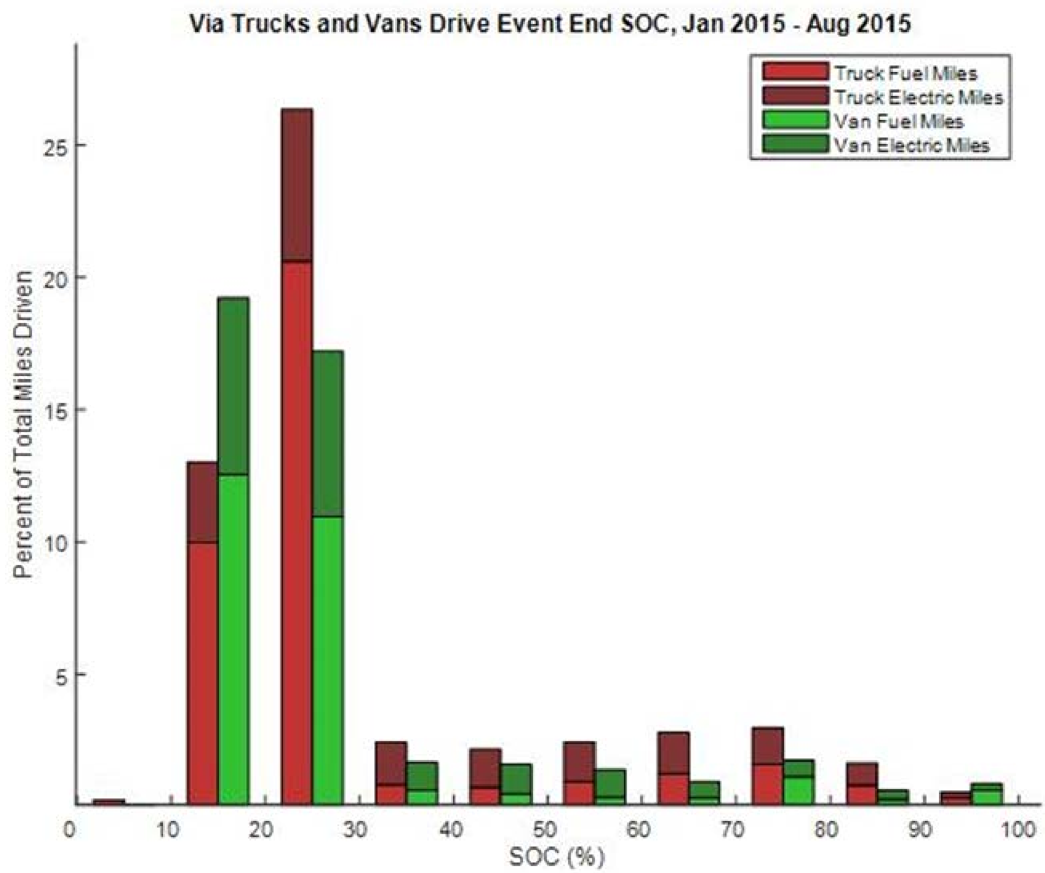


Figure 4-35
VIA final state of charge of drive events

4.8 VIA Survey Results

The project team developed a survey and solicited feedback from both Odyne and VIA vehicle operators. The objective of the survey was to assess drivers' opinions of the vehicles with respect to performance, ease of use and charging, most-used features, overall impressions, and so on. The survey was completed online and took about 20 minutes to complete.

The VIA respondents had a mix of driving experience (see Figure 4-36).

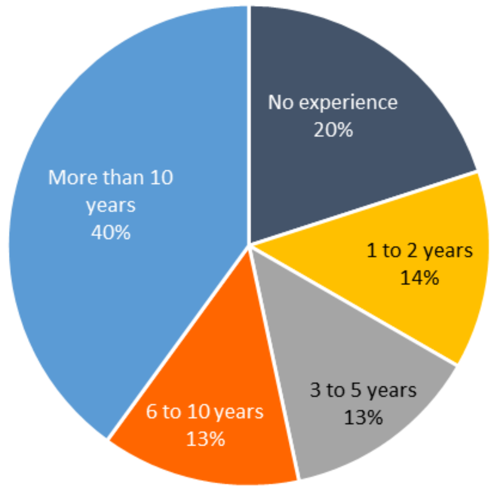


Figure 4-36
Years of experience driving a commercial work truck (n = 15)

The overall satisfaction rating, on a scale of 0 to 10, was 6.9. The highest ratings were for ease of use and charging, and the lowest were for driving enjoyment in hybrid mode and driving performance in both all-electric and hybrid modes (see Figure 4-37).

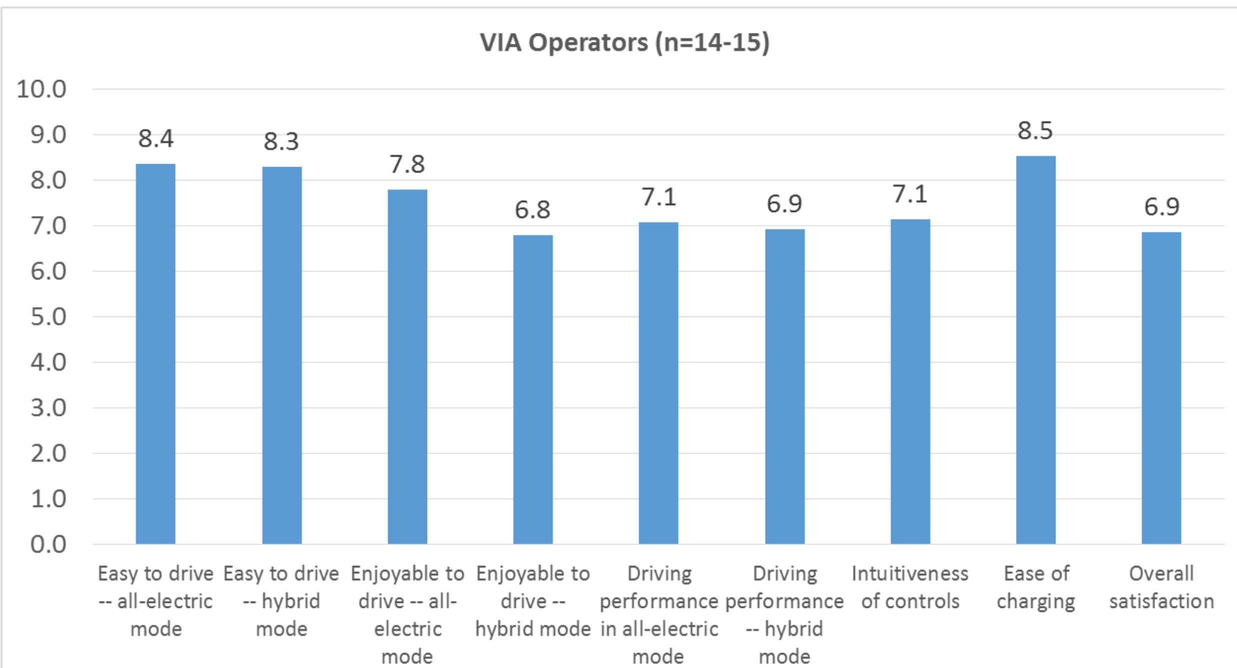


Figure 4-37
Satisfaction ratings (n = 14–15)

A slight majority of van drivers would choose the PHEV as their main work vehicle, although the results are fairly close (see Figure 4-38). Pickup trucks are not included due to lateness.

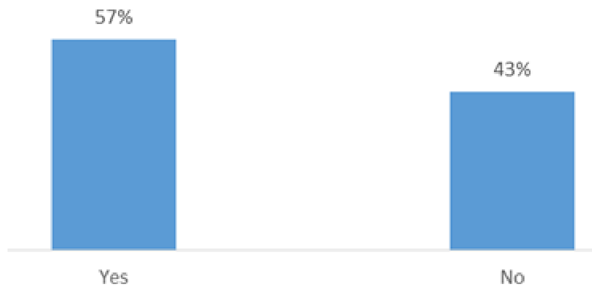


Figure 4-38
Would choose the plug-in hybrid vehicle as main work vehicle (n = 14)

Preferred features include all-electric mode, drive quality, and acceleration (see Figure 4-39).

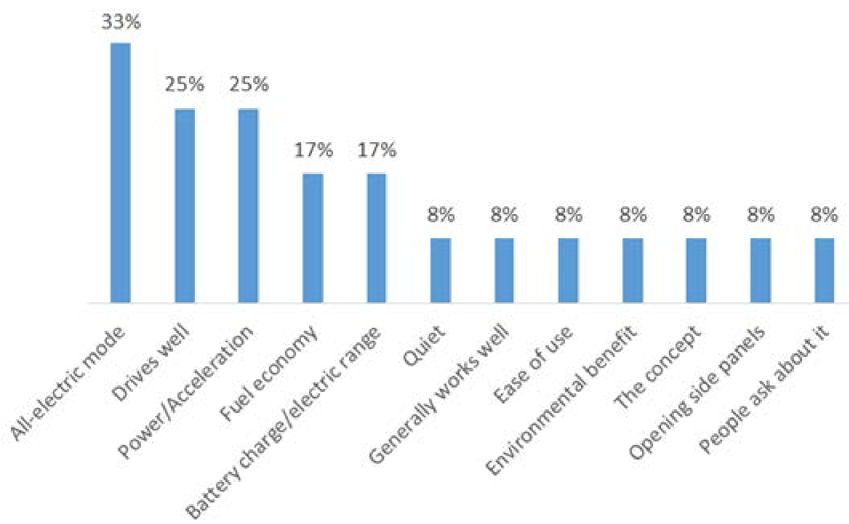


Figure 4-39
Preferred features (n = 12)

The largest performance-related concern was starting on an incline. The next most-desired improvements included noise, throttle response and consistency, electric range, and ride quality (see Figure 4-40).

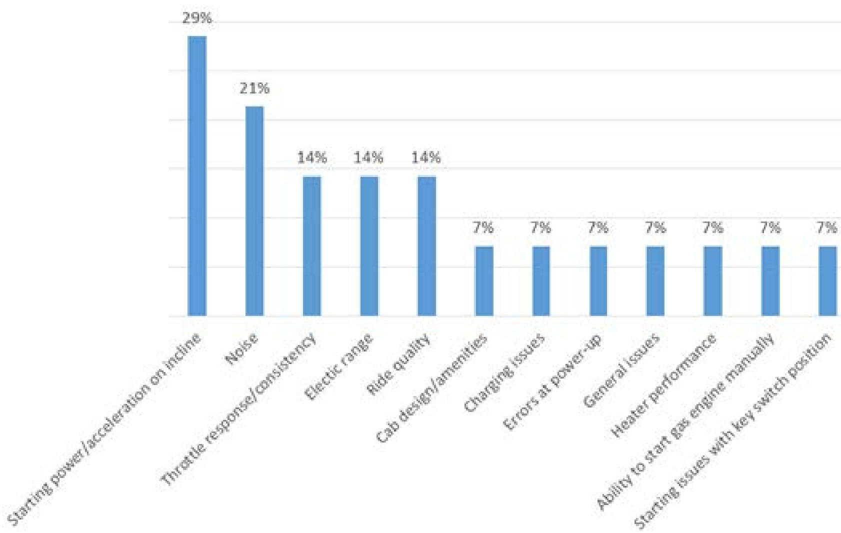


Figure 4-40
Desired improvement (n = 14)

When asked their opinions about the reasons for employers investigating the use of PHEV trucks, drivers most frequently cited improved fuel economy, reduced emissions, and reduced job site noise (see Figure 4-41).

Improved fuel economy	100.0%	12
Reduced emissions	83.3%	10
Reduced job site noise	50.0%	6
Lower maintenance costs	16.7%	2
Other (please specify)	8.3%	1
	Total	12

Figure 4-41
Reasons for investigating the use of plug-in hybrid vehicles (n = 12)

4.9 VIA Program Delays

4.9.1 Battery Supplier

VIA chose A123 as the battery supplier for both the van and the pickup truck. The development of the battery pack was nearly complete when A123 went into bankruptcy and was taken over by a Chinese entity. After that, the cost of the batteries from the new A123 supplier increased significantly, and VIA decided to try a different battery supplier, Valence. A new battery pack was developed, but VIA found that the batteries, controls, and pack design were inferior. VIA went back to working with A123 for costing and delivery. Finally, VIA abandoned the Valence battery pack and designed a new pack with the A123 battery modules. The van and the pickup both have similar A123 battery modules that are heated and cooled with a proprietary battery climate control module. This extra development caused a delay in the program.

4.9.2 Chevrolet Redevelopment of the Pickup Truck

Late in the development of the pickup truck, Chevrolet brought out the next generation of the Silverado in 2014. VIA was almost ready to deliver the 2013 pickup trucks with the hybrid system when Chevrolet announced the next generation pickup model. VIA had to wait to obtain drawings and reengineer the new pickup truck. This also caused a delay and excess development costs for VIA.

4.10 Opportunities for the Future

4.10.1 Design Refinements

Potential future design refinements include the following:

- Cost reduction
  - Volume negotiations for production ramp-up with suppliers
  - Hard tool specific components to reduce costs
  - Simplify and refine design based on field results and experience
- Improve charge-sustaining fuel economy
  - Refine software to improve fuel economy
  - Use data to work with CARB for change of strategy and limitations
- Improve performance
  - Modify designs to reduce weight using extensive finite element analysis and field results
  - Reduce weight to improve payload
- Proliferate extended-range electric vehicle architecture into similar models (such as extended cab, 2500, and so on)
- Increase sales to further reduce cost

4.10.2 Business Opportunities

Business opportunities for the future include the following:

- Vehicle to grid (V2G). VIA is the only manufacturer of an EPA/CARB-certified van that is V2G enabled with Underwriters Laboratories–approved components. VIA plans to expand this technology to the pickup truck platform as requested by several utilities and the U.S. Department of Defense. The current demonstration project at Los Angeles Air Force Base has 13 V2G vans.
- Vehicle to home or business (V2H). VIA trucks and vans are currently capable of V2H operation through its export power system. This application is perfect for emergency power backup applications.
- Consortium initiative. VIA is working with the utility industry and others on an aggregated purchase of trucks and vans. Group purchasing will allow for lower cost and payback (return on investment)
- High voucher incentive programs. VIA will continue to work to get incentive programs for their vehicles, including good incentive programs such as those offered in Chicago, Illinois ($US45,000 per vehicle), New York, and California.

4.11 VIA Current Status

VIA will continue to manufacture vehicles at its facilities in Orem, Utah, and Mexico. The jobs created by this project are intended to be permanent. VIA continues to sell trucks and vans to commercial customers across the United States and Canada regularly. There are currently 50 vehicles in production. VIA is working with several large commercial fleets on a 1000-vehicle aggregated order for 2016. Sales are planned for a controlled growth, allowing for a smooth ramp up. VIA’s current projections anticipate sustainability with positive cash flow and net profits before the end of 2016.

5
COMMON SYSTEMS FOR THE VEHICLES

5.1 Data Acquisition System

The data acquisition system used on both the VIA vehicles and the Odyne trucks is shown in Figure 5-1. The system is relatively inexpensive and simply includes two GoPoint Technology modules, each connected to different CAN buses and an iPhone for storage and transmittal. The GoPoint modules collect up to 64 CAN messages per second, and the data are sent via Bluetooth to an iPhone in the vehicle, which stores the data. Once a day or whenever the phone gets a good signal, the data are broadcast to a server that holds the program data. This capability is also available to charge the onboard software using telemetry.

The GoPoint modules were purchased and the software contained within was developed by EPRI. The GoPoint modules and iPhones are programmable from an external source by telematics. The system is connected to the onboard diagnostic 2 (OBDII) bus and the J1939 bus that passively listens to the vehicle CAN bus traffic. Selected CAN bus parameters were decoded and wirelessly sent to an iPhone for data storage and upload to a central data server. The operation of the data collection system is described in the following subsections.

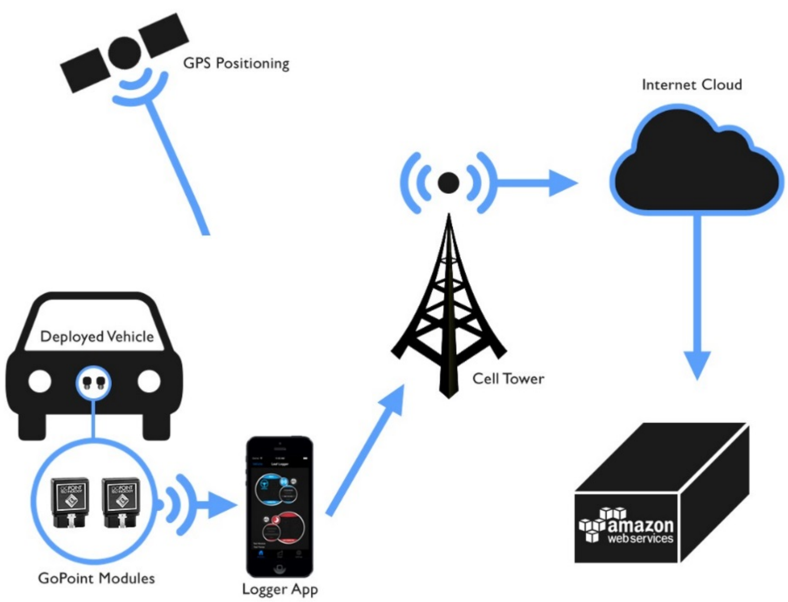


Figure 5-1
Data acquisition system used on both Odyne and VIA vehicles

5.1.1 Controller-Area Network Bus Interface

The CAN bus hardware interface consists of two GoPoint J1939 OBDII modules. Figure 5-2 shows a photograph of one of the modules. These commercially available modules have been reflashed with EPRI-specific firmware to act as a Bluetooth wireless data gateway to the iPhone hardware and application to collect the CAN bus data streams. Internally, the GoPoint modules have preset CAN bus filters to specifically decode the parameters of interest, such as SOC, speed, and others. The preset filters are stored in the iPhone application and are transmitted to the modules at the start of the data collection session. These various parameters are vehicle-specific from the individual vehicle database container (DBC) parameter files. Database container files contain the data and field names used by the Microsoft Visual FoxPro database.

Figure 5-2
Controller-area network bus hardware interface module

The modules have an enhancement of detecting bus traffic and waking up from a low-power sleep mode of operation to conserve energy taken from the vehicle. The modules will also power down to sleep mode two seconds after CAN bus traffic ceases. Because the CAN bus operations of the EV and OBDII buses operate independently, the modules will wake and sleep independently, depending on the bus function. For example, the OBDII bus is inactive during a vehicle charge session, but the EV CAN bus remains active until the vehicle is fully charged. Therefore, the OBDII-connected module would be asleep during the charging session.

The CAN modules are capable of acquiring data at the rate of hundreds of parameters per second. The data acquired per bus will easily exceed one-second data collection per parameter. The ultimate data rate limits are the CAN bus data parameter specifications imposed by the specific vehicle.

5.1.2 iPhone and Application

The iPhone and application receive data from the two Bluetooth CAN modules, store the data, and upload the data to the central server at a predetermined time. The phone is physically located in the vehicle and externally powered from the vehicle system battery. Like the CAN modules, the phone will enter the low-power sleep mode when both modules have informed the phone that both modules are in sleep mode. When Bluetooth traffic from either or both of the CAN modules is detected, the phone will wake and acquire the data streams. Data collected by the phone from the vehicle is uploaded via cellular connection to the EPRI servers at 2:00 a.m. local time. If no cellular connectivity is found, the phone will store up to 30 days of data internally. Data are validated from the server before being deleted from the phone memory to ensure that data are successfully uploaded.

5.1.3 Controller-Area Network Bus Server

The hardware server and associated server software permit secure data aggregation reporting from each vehicle. Several key features include secure password login, encrypted data, and implementation of a data segment based on each company in the program. Only vehicles in a specific utility data set are visible to that utility. No other utilities may view any other vehicle data. Only those EPRI individuals responsible for the data may view the entire data set. A rich graphic and report generator allow data to be presented in a graphic or table view, and data can be exported in a simple, comma-separated values (.csv) file format for further data analysis. Figure 5-3 shows an example of the utility data.

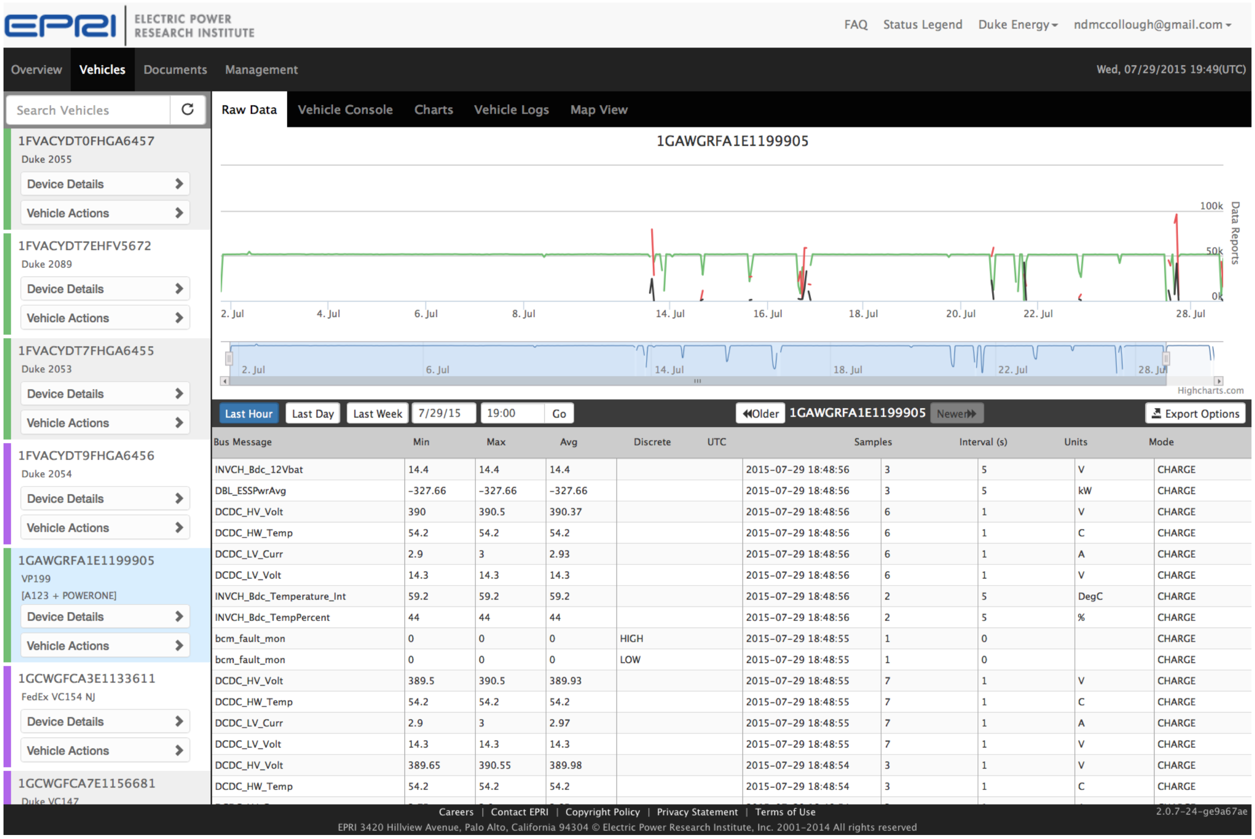


Figure 5-3
Server screenshot of utility segments

Figure 5-4 shows the vehicles assigned to each participant. The data are largely stored in an unstructured database on the server. Reports and graphics are generated on demand from the server. The graphical data can allow an instant visualization of vehicle performance. Figure 5-4 shows a typical recorded state-of-charge graph during drive and charge events over a date range. Other graphs are available and data can be exported to a .csv file. Other enhancements include automatic application updating, additional graphics and reporting, cloud data services, and live vehicle map views.

Two data acquisition systems were used on the Odyne trucks. One was primarily used for data analysis, and the other was used for system diagnostics and analysis.

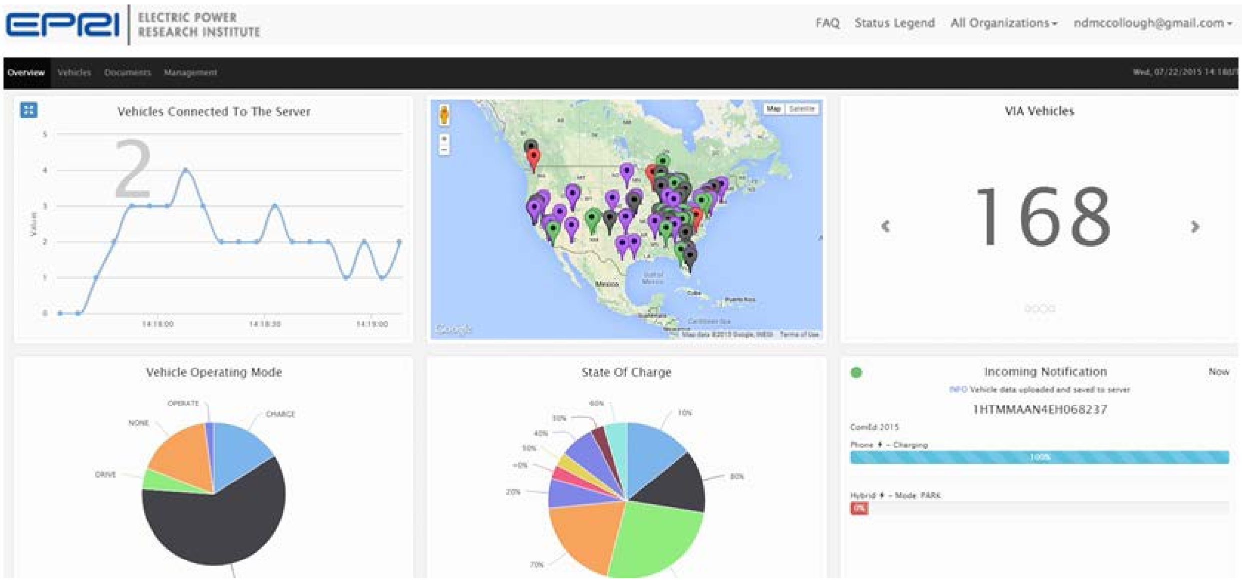


Figure 5-4
Website visualization

5.2 Smart Charging System

Pathway Technologies, Inc., developed a smart charging system for the Odyne and VIA vehicles. The smart charger module is called a *multi-protocol router* (*MPR*). The system contains two MPRs—one is packaged on the vehicle near the charger and the other mounts and connects to the EVSE.

The smart charging system allows the vehicle to communicate with the utility grid and allows the grid to charge at a specified time of day. The system is capable of using multiple protocols to accomplish the smart charging. The protocol used for this development uses the pilot signal of the J1772 connector to communicate with the utility grid.

5.2.1 System Requirements

SAE J2847/1 and J2931/1 defined the interface architecture between the PHEV and the smart grid (see Figure 5-5).

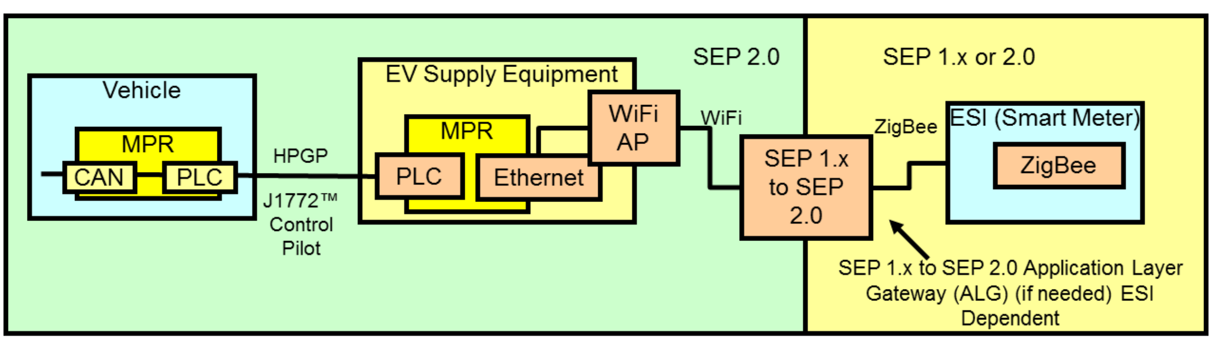


Figure 5-5
Conceptual layout of interface between plug-in hybrid electric vehicle and smart grid based on SAE J2847/1 and SAE J2931/1

The term *MPR* refers to the EPRI-embedded Linux computer that was specially developed to serve as the interface between the PHEV and the smart grid according to automotive and industrial requirements. The scenario shown in Figure 5-5 assumes that utility messages are being sourced from a utility smart meter. Figure 5-6 shows the other two scenarios involving a local electric service identifier (ESI) providing the utility commands and a Smart Energy Profile 2.0 (SEP2) server that resides on the Internet (see Figure 5-7).

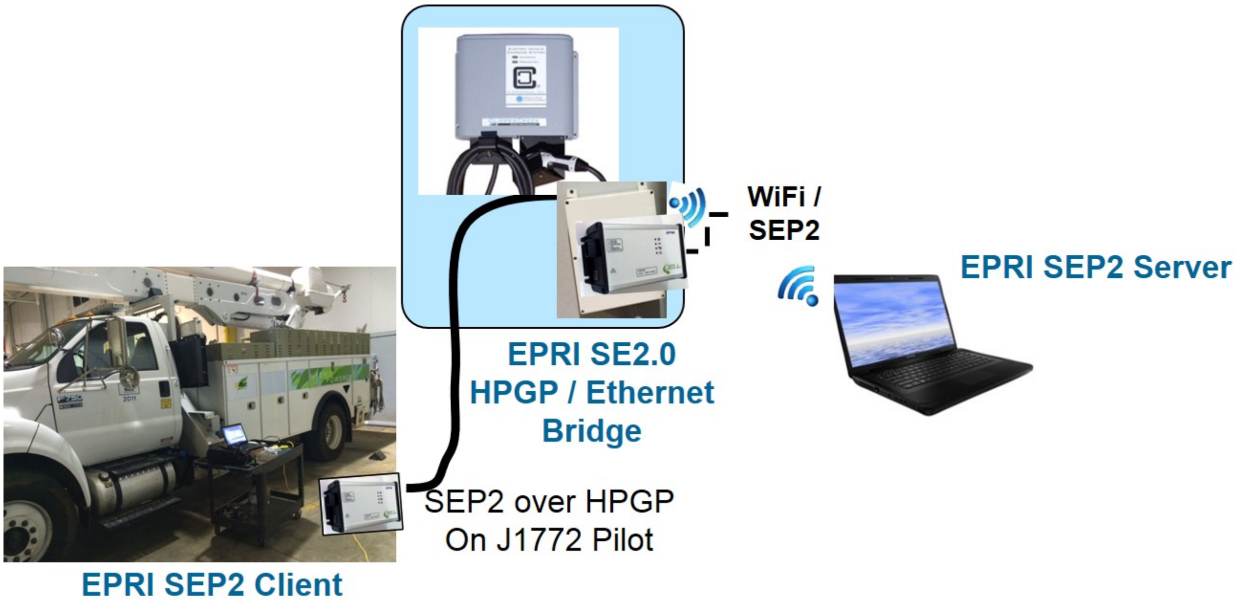


Figure 5-6
Variety of scenarios for interface between plug-in electric vehicle and smart grid

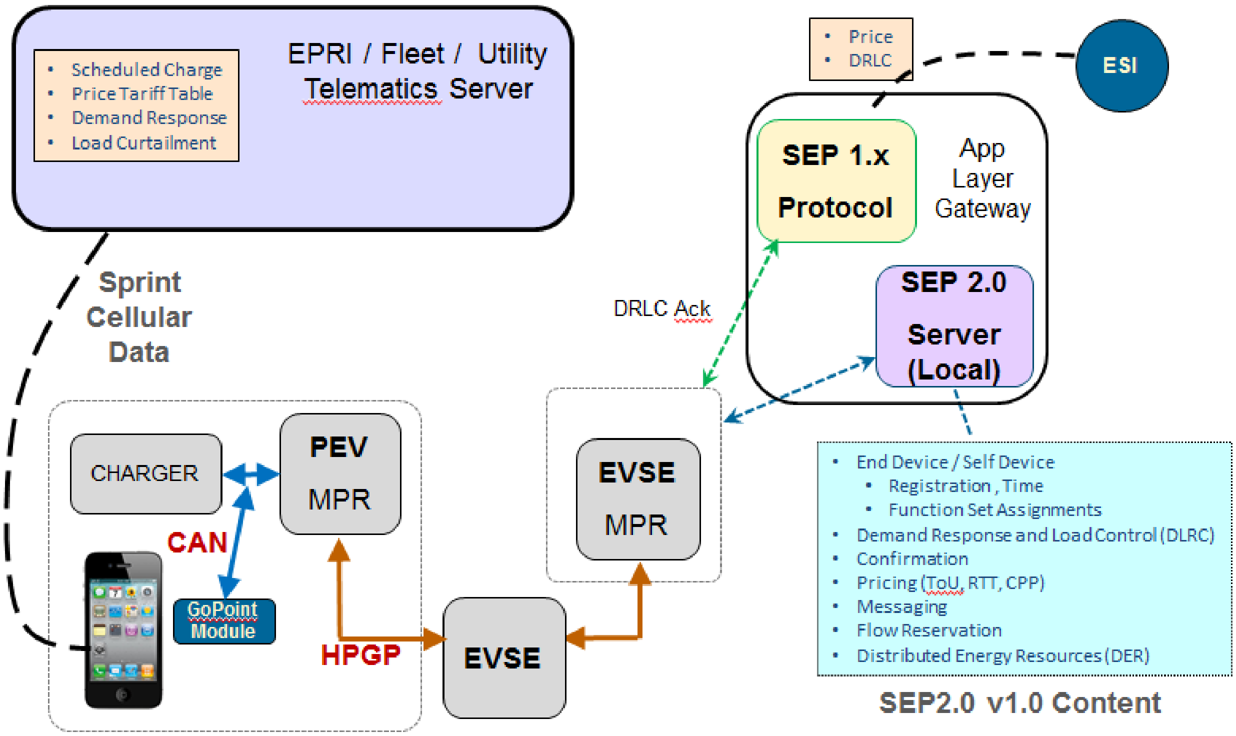


Figure 5-7
Complete system functional diagram

Figure 5-8 shows the configuration of a single PHEV with smart meter and Smart Energy 1.x plus a local SE 2.0 server.

Figure 5-8
Single plug-in vehicle communication architecture

5.2.2 Requirements for the Smart Grid Interface

The requirements for the MPR are to encapsulate the variability in communication protocols and physical layers on the smart grid side and still present a uniform, CAN-based interface on the vehicle. EPRI designed the MPR in such a manner that the same hardware can be used to implement a SEP2 client on the vehicle and a link-layer bridge at the EVSE. The smart grid interface devices were required to connect either with the advanced metering infrastructure (AMI) network and the ZigBee interface or with the SEP2 server across the Internet.

The functional requirements are detailed in the SEP2.0 specification, version 1.0, which was released in May 2013. This open standards–based specification enables the implementation of the following:

- Device registration with the network
- Authorization and authentication of the end device (the PHEV)
- Association (through a programmable logic controller [PLC])
- Service discovery through xmDNS 1.2
- Security according to Transport Layer Security (TLS), version 1.2, 128-bit encryption
- Time synchronization
- Customer message broadcast
- Pricing, including real-time, critical peak, and time-of-use rates
- Demand response and load curtailment
- Flow reservation to assist scheduled charging and effective distribution load management
- Distributed energy resource (DER) function set that enables bidirectional power flow–capable PHEV to provide reverse power flow in response to utility conditions

These features and functions were required to be implemented on both the server side (residing locally or on the Internet) and the client side (residing on the PHEV)

5.2.3 Multi-Protocol Router Hardware Development and Characterization

The EPRI MPR concept originated from extensive discussions with member utilities during 2007–2008, when it was evident that the utility industry, by its very nature, has smart grid deployments that create diverse information pathways that are nonstandard and driven by the vendors. Furthermore, the physical link (wired or wireless) was also present in many scenarios. On the vehicle side, the single interface based on HomePlug Green PHY (HPGP) was agreed upon within SAE to be the standard interface. It therefore became necessary to create a general-purpose device based on popular hardware and software platforms—an ARM9 processor that is commonly used on a wide variety of smartphones and tablets and embedded Linux that is open source, freely available, and widely supported. The MPR deployed for this project was the third generation device. Figure 5-9 shows the three generations of MPRs.

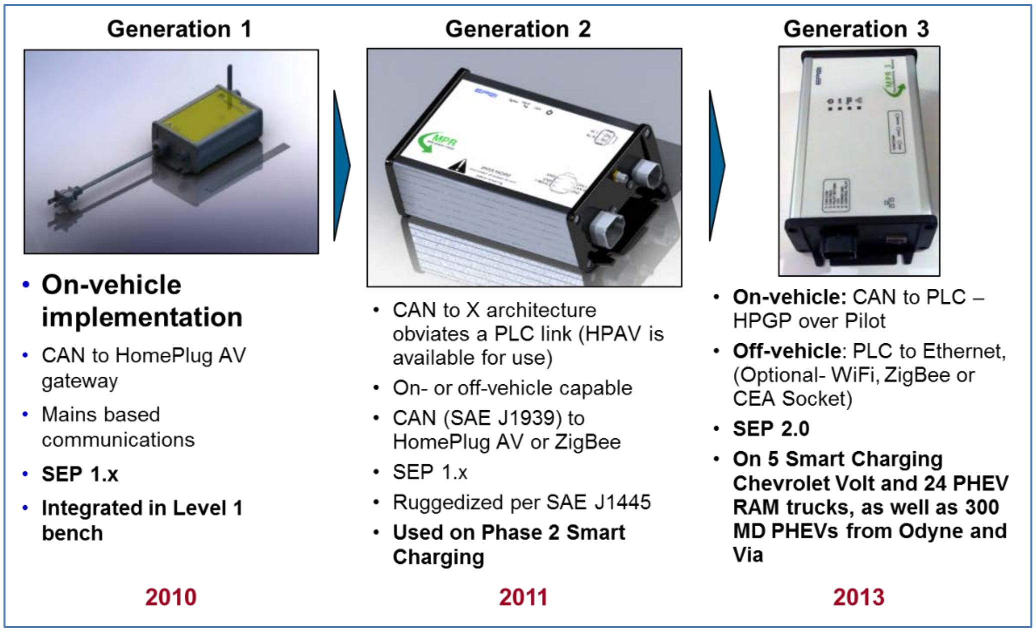


Figure 5-9
Three generations of multi-protocol routers; generation 3 was deployed for the plug-in hybrid electric vehicle program

For the MPR to be an automotive-grade device, it was put in a water-tight enclosure (IP65 rated), and all the parts were chosen with industrial temperature range. Figure 5-10 shows the generation 3 MPR hardware feature set, and Figure 5-11 shows the software architecture layout.

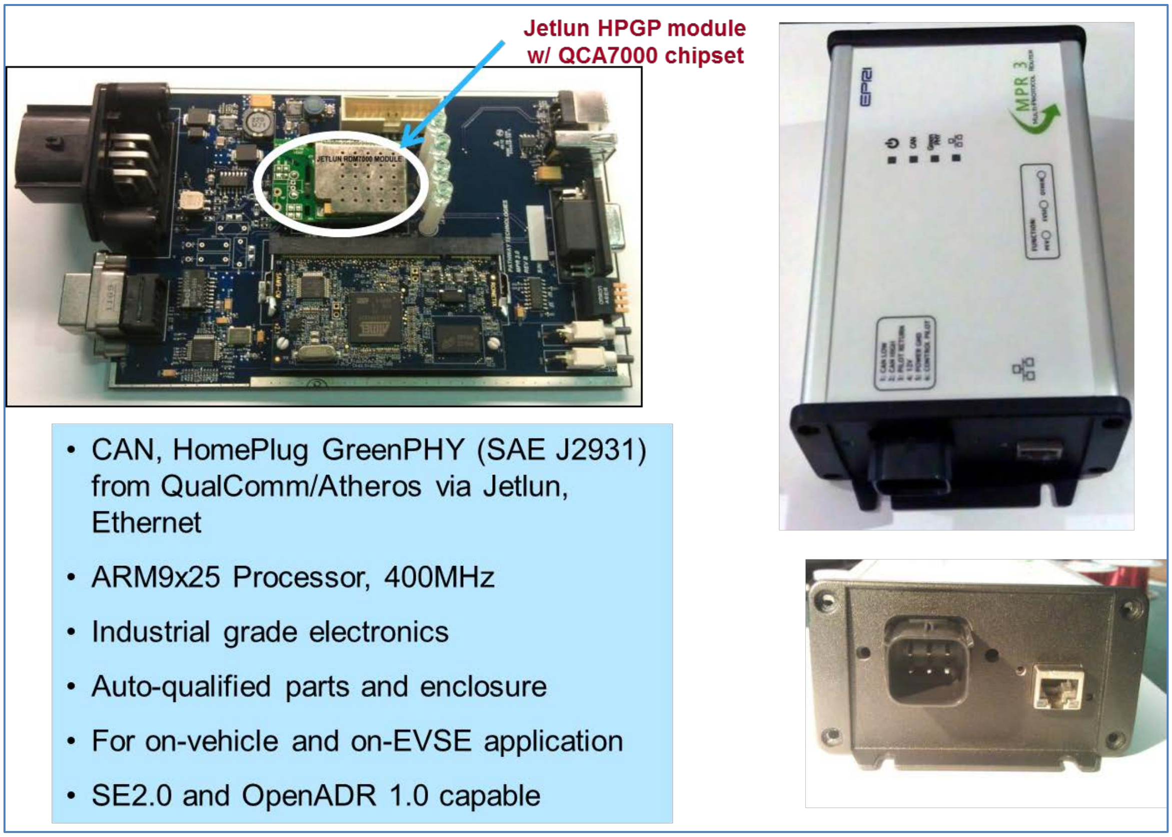


Figure 5-10
Generation 3 multi-protocol router details and feature set

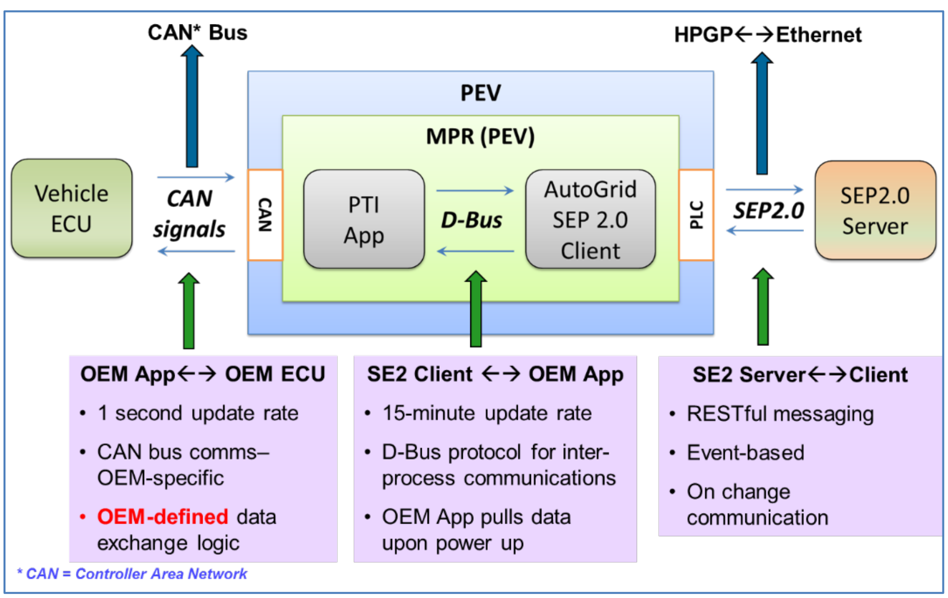


Figure 5-11
Generation 3 multi-protocol router architecture layout for initial build

The specifics of the on-vehicle integration were implemented by EPRI. The first iteration of the SEP2 integration involved AutoGrid Systems (who subsequently certified the SEP2 client that is currently deployed in field trial). EPRI and AutoGrid jointly defined a data interchange protocol between two asynchronous, concurrent processes running at utility (SEP2 client) and automotive (OEM application) periodicity.

Figure 5-12 illustrates a reference design for a medium-duty PHEV to smart grid interface using an MPR. This design connects a PEV with AMI or HAN. It is an open, extensible architecture that uses off-the-shelf components and a ruggedized enclosure for on-vehicle implementation in accordance with SAE J1445. It uses a standard SE 2.0 application layer for data messages. The physical connections consist of J1939 (CAN), RS-232, and USB on the vehicle side and ZigBee, WiFi, Ethernet, HomePlug, or GreenPHY on the meter side.

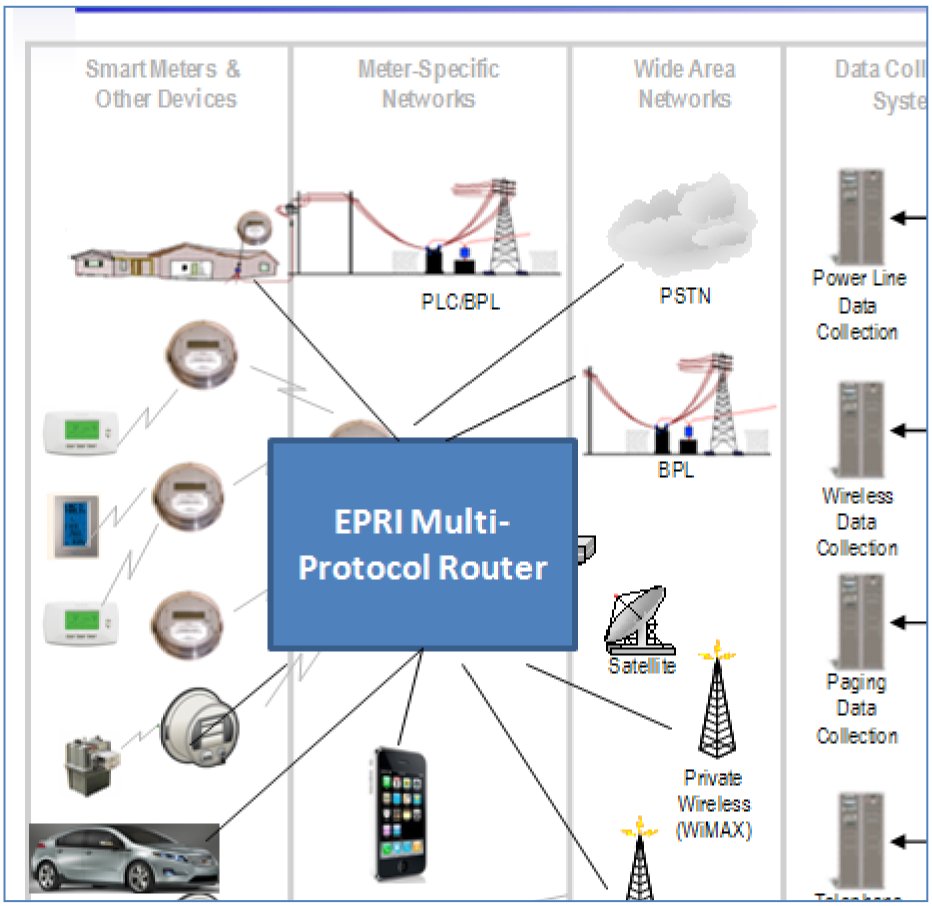


Figure 5-12
Reference design

Figure 5-13 illustrates the physical characteristics of the multi-protocol router.

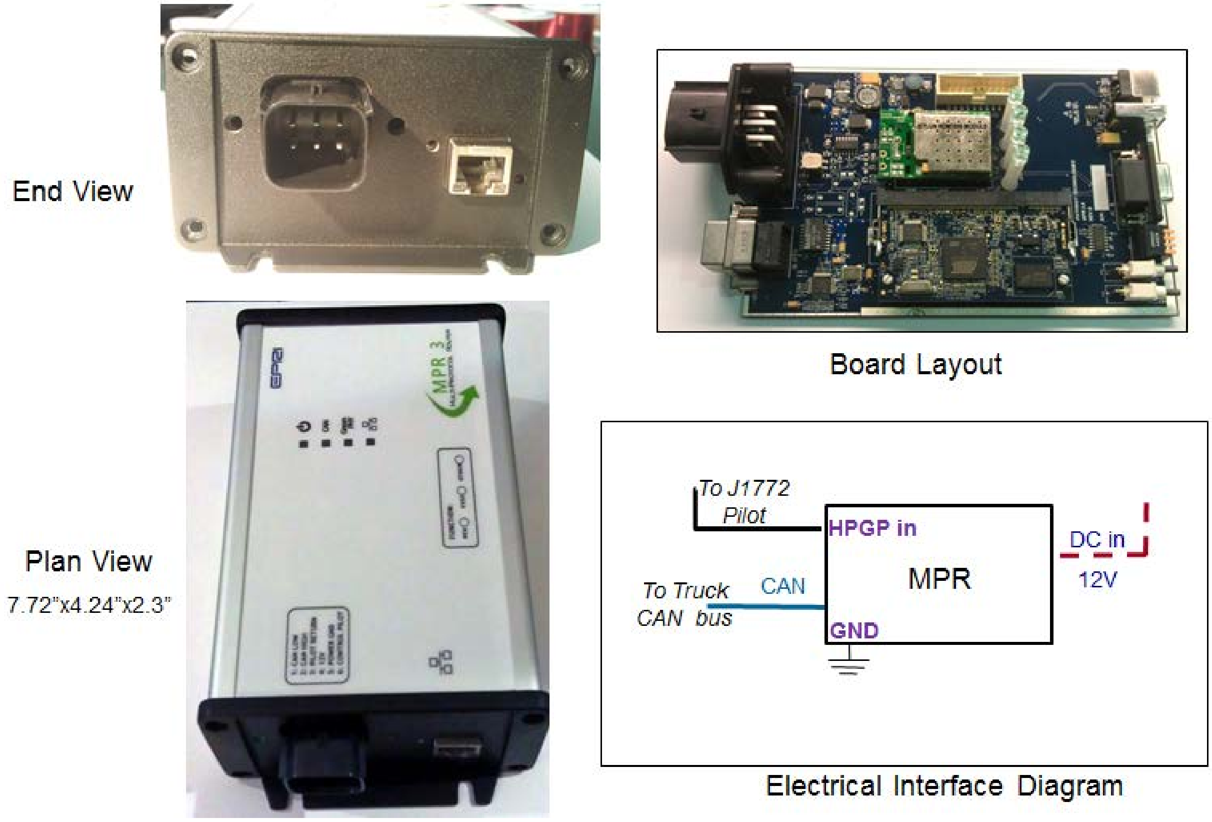


Figure 5-13
Physical characteristics of the multi-protocol router

5.2.4 Electric Vehicle Supply Interface Development

The PHEVs were deployed with passive EVSEs that were SAE J1772 compliant but did not have the SAE J2931 capability or any physical layer communication interface with a home area network (HAN). EPRI therefore worked with Pathway to develop an SAE J2931/1–capable interface using the MPR and a WiFi access point to enable the EVSE to transmit PLC signals over the J1772 pilot to the vehicle and to receive SEP2 signals from the utility smart grid over WiFi from a HAN or AMI device, through an application layer gateway. A communication box was created to house the on-EVSE MPR, the WiFi bridge, and power supply, with a pigtail to connect to the EVSE to couple the PLC carrier signal to the pulse-width-modulator pilot of the J1772 connector. Mounting provisions were created to ensure that the communication box can be mounted close to the EVSE on a pedestal. Figure 5-14 shows the internal layout of the EVSE communication box.

Figure 5-14
Electric vehicle supply equipment communication box layout and contents

5.2.5 Field Deployment

Most vehicles were equipped with smart charging systems distributed throughout the United States. The MPR for the Odyne systems was mounted in front of a shield in the rear of the left battery pack. On the VIA van and pickup truck, the MPR was located above the onboard charger near the rear of the vehicle. The system was developed and demonstrated at the Knoxville Utilities Board in Knoxville, Tennessee. The method of testing varied, depending on the scenario. Figures 5-15 and 5-16 illustrate the accomplished system hardware and software.

Figure 5-15
Smart charging setup and layout at the Knoxville Utility Board

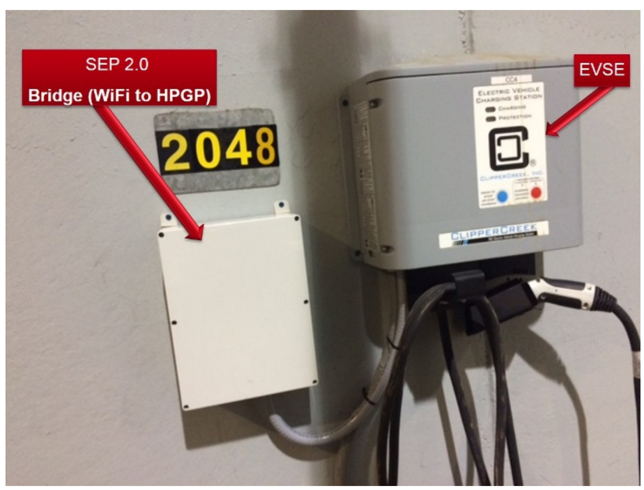


Figure 5-16
Communication box connected to electric vehicle supply equipment

5.2.6 Lessons Learned

Several lessons were learned from this experiment, as follows:

- Whereas successful implementation of smart charging using the very first available hardware samples and prototype software was achieved, much remains to be done to ensure that the system survives in mass production and a wide variety of ambient conditions.
- Specifically, MPRs were found to be operating well outside their industrial temperature range; therefore, their vehicle packaging and ventilation will be critically important. Totally enclosed MPR boards, when again enclosed in an oven-like tool box with no air circulation, tended to become extremely hot and malfunctioned.
- Guaranteeing association between PHEV and EVSE or end-use measurement device (EUMD) is an issue with power spectral density differentiation through signal-level attenuation characterization (SLAC) unique to HPGP (and the reason for choosing HPGP) and must be made robust.
- Conducted noise immunity of an electromagnetic compatibility (EMC) signal. When exposed to a certain frequency band, the external noise source (such as a police band radio) had the ability to completely jam the HPGP signal due to its low amplitude requirement. The peak-to-peak voltage was raised to partially offset this issue. Further study should be done to identify other approaches to alleviating this condition.
- Different utilities are different. Therefore, creating an open standards–based interface on the PEV side gives the PEV manufacturer some certainty as to the technical direction for a smart grid interface. Encapsulating utility-side variability in communications and connectivity through the use of MPR-like devices will be critical to making any mass-market smart grid integration technology's success.
- Since the advent of MPR, many new commercial gateway products have introduced features originally designed in the MPR. This has made it possible for the utilities to approach the "bring your own device" model by giving customers an incentive to procure a home gateway device that enables smart grid communications.

A
ODYNE SYSTEM SPECIFICATIONS

	Odyne Systems Truck
Hybrid Configuration	Parallel through the PTO
AER (up to miles)	0
EAER (up to miles)	7.2
Chassis Manufacturer	Ford, International, Freightliner, Kenworth
Chassis Size	Class 6, 7, or 8
Chassis Configuration	RWD
Battery Energy (kWh)	28.4
Battery Manufacturer	Johnson Controls
Battery Thermal	Liquid-Cooled
Motor Power (kW) Peak	71 @ 2200 rpm
Motor Power (kW) Cont.	42 @ 3000 rpm
Motor Torque (Nm)	315 @ 2000 rpm
Motor Manufacturer	Remy
Engine Displacement (l)	6.7, 8.9, 9.0, 9.3, 12.8
Engine Type	Diesel
Engine Manufacturer	Cummins, Navistar, Detroit Diesel
Transmission Manufacturer	Allison
Export Power (kW)	6 or 12 60 Hz 120/240 Vac
Charger Power (kW)	3.0
Power Steering	Standard
HVAC	Electric A/C
Heating	Hydronic
Brakes	Standard
Warranty	3 years/ 36,000 miles
Manufacturing Location	Butler, WI

Figure A-1
Odyne system specifications

B
VIA SYSTEM SPECIFICATIONS

VIA Motors

	Van	Pickup Truck
Hybrid Configuration	Series	Series
AER (up to miles)	35	45
Chassis Manufacturer	Chevrolet	Chevrolet
Chassis Type	Express	Silverado
Chassis Size	3/4 ton	1/2 ton
Chassis Configuration	RWD	4X4, RWD
Battery Energy (kWh)	23	23
Battery Manufacturer	A123	A123
Battery Thermal	Liquid-Cooled	Liquid-Cooled
Motor Power (kW) Peak	190	190
Motor Power (kW) Cont.	115	115
Motor Torque (Nm) Peak	410	410
Generator Power (kW) Peak	190	190
Generator Power (kW) Cont.	115	115
Corner Speed (rpm)	4000	4000
Motor Manufacturer	Remy	Remy
Engine Displacement (l)	4.8	4.3
Engine Configuration	V8	V6
Engine Power (HP)	285 @ 5400 rpm	285 @ 5300 rpm
Engine Torque (Nm)	295 @ 4600 rpm	305 @ 3900 rpm
Engine Type	Gasoline	Gasoline
Engine Manufacturer	General Motors	General Motors
Export Power (kW)	2.4 @ 60 Hz 120 Vac & 7.2 @ 60Hz 240Vac	2.4 @ 60 Hz 120 Vac & 7.2 @ 60Hz 240Vac
Charger Power (kW)	14.5	14.5
Power Steering	Electric Hydro-Boost	Electric
HVAC	Electric A/C	Electric A/C
Brakes	Electric Hydraulic Assist	Electric Vacuum Assist
Warranty	8 years/ 150,000 miles	8 years/ 150,000 miles
Manufacturing Location	Orem, UT	Orem, UT

Figure B-1
VIA system specifications

C
ODYNE DRIVE CYCLES

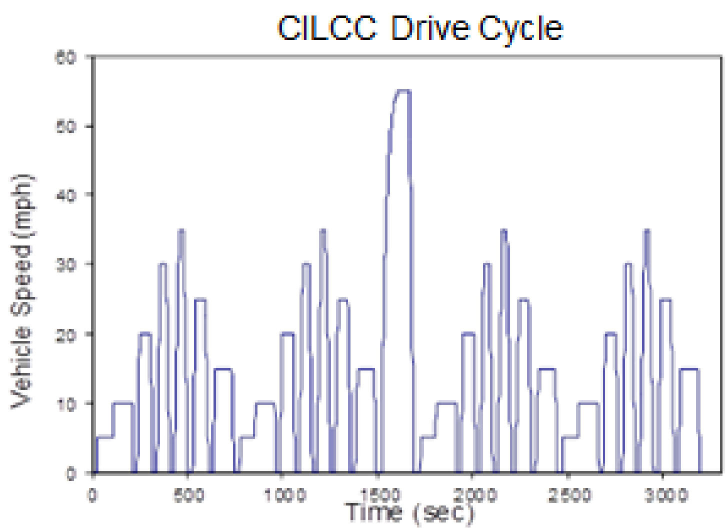


Figure C-1
Odyne combined international local and commuter cycle drive cycle

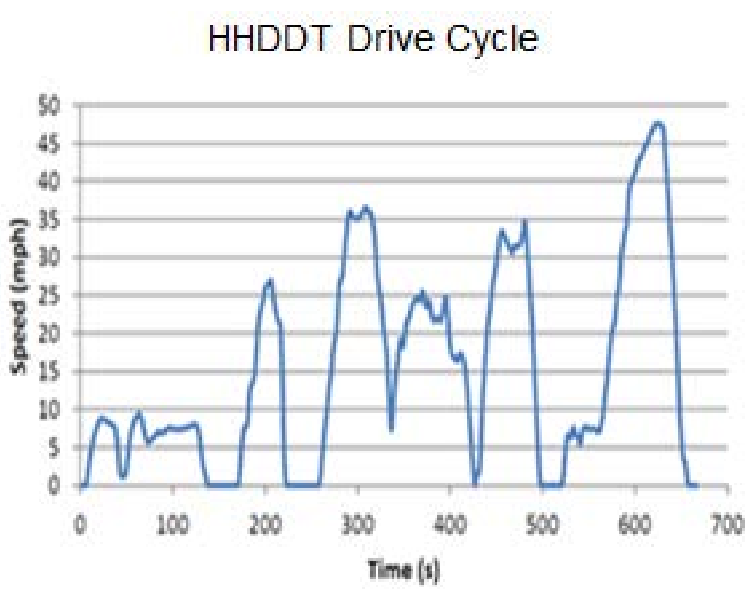


Figure C-2
Odyne heavy-heavy duty diesel truck emissions test drive cycle

Odyne Drive Cycles

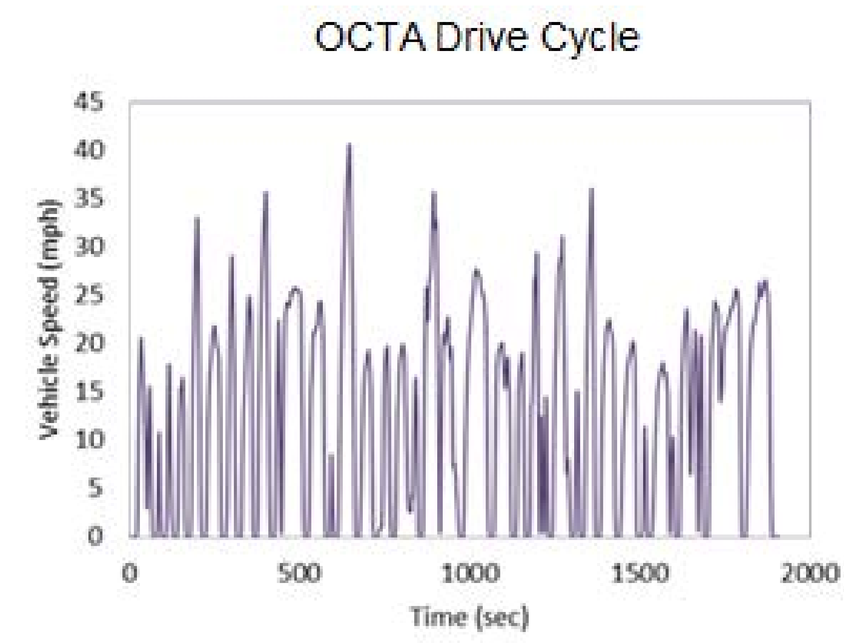


Figure C-3
Odyne Orange County Transportation Authority drive cycle

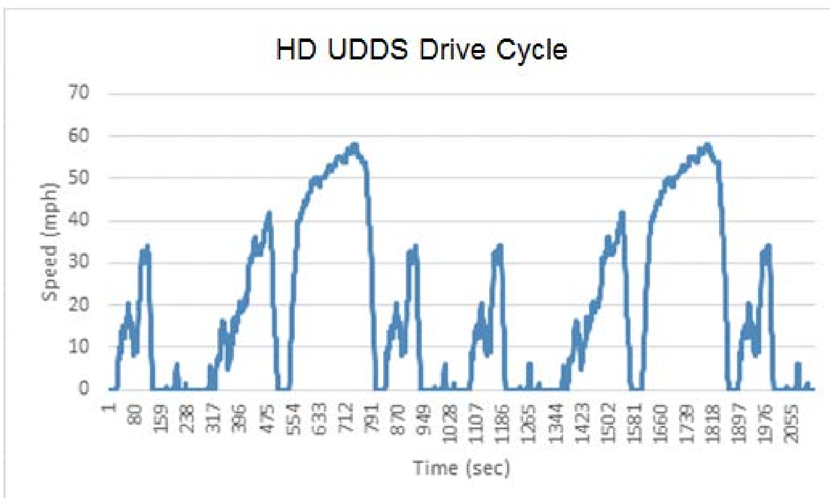


Figure C-4
Odyne heavy-duty urban dynamometer driving schedule drive cycles

D

VIA PERFORMANCE TEST PROTOCOL

CD/CS TEST PROTOCOL
Charge Depleting: pre-conditions: battery charged (solid green) no canister purge, no DTCs, 1/4 tank of fuel run condition: from 100% to ICE started
Charge Sustaining: pre-conditions: 1/2 fuel tank, SOC 20% cold start, no DTC run condition: Drive 60 Miles Measure fuel consumption by weighting fuel tank before and after the drive.

Drives Test protocol	**Internal Testing** min and max of 3 vehicles, driven at the same time	**3rd Party Testing** 1 vehicle on 4 corner dyno
City drive	**Identified city route,** Speed max 45 MPH, Ambient temp 18C to 28C, No AC or Heat, windows up Data log CAN1 & CAN2	**UDDS cycles**, Ambient temperature 25C, Data log CAN1 & CAN2
Highway Drive	**Identified Highway route,** Speed 55 MPH using CC, Ambient temp 18C to 28C No AC or Heat, windows up Data log CAN1 & CAN2	**USO6 & HWFET cycles**, Ambient temperature 25C Data log CAN1 & CAN2

Figure D-1
VIA vehicle performance test protocol

E
EARLY PROGRAM HISTORY

E.1 Eaton Corporation and Azure Dynamics, Inc. (November 2009)

The program originally had 378 PHEV Ford F-550 bucket trucks and PHEV Ford F-450 trucks. The F-550 trucks were to be hybridized by Eaton in Galesburg, Michigan, and bodies were to be produced by Altec, Inc. Azure Dynamics, Inc. was being contracted to bring the PHEV F-450 to production. Many of the original participants stayed through the program to the end, but some also lost interest as the truck program evolved with different products and designs.

The Eaton system had been used on several earlier demonstration trucks and was to be reengineered to a better production design for this program. Eaton designed and prototyped a design and, at the end, excluded a discharge capacitor, which caused a redesign and hindered the schedule significantly. Upon this discovery in March 2011, Eaton decided not to participate in the program any longer. The program immediately began a search for new partners.

E.2 Odyne and Azure (June 2011)

In spring 2011, two other engineering and manufacturing companies were selected, and development began. Odyne was to develop the Class 6 to 8 trucks for the participants, and Azure Dynamics changed their offering to include a Ford F-550 bucket truck and the F-450. This change took some time to conclude. In March 2012, before the new program was kicked off, Azure declared bankruptcy, leaving just Odyne with the large vehicles, and requiring the program team to find other PHEV sources.

E.3 Odyne, VIA, and Quantum Technologies, Inc. (May 2012)

After searching for other sources of PHEVs, the project team located several others and selected VIA Motors and Quantum Technologies. VIA would produce a series PHEV, and Quantum would produce a parallel PHEV, both achieving about the same 35–40 miles of all-electric range. Odyne would remain in the program and produce the Class 6 to 8 trucks.

All three development efforts began, but by November 2012, Quantum was experiencing difficulties and indicated that they could not meet the anticipated schedule. Quantum withdrew, leaving Odyne and VIA for the remainder of the program. VIA grew their production volume by the volume that Quantum had.

F
ABBREVIATIONS AND ACRONYMS

AMI	advanced metering infrastructure
APU	auxiliary power unit
BOM	bills of materials
CA	cab-to-axle (dimension)
CAN	controller-area network
CARB	California Air Resources Board
CEC	California Energy Commission
CILCC	Combined International Local and Commuter Cycle
DBC	database container
DER	distributed energy resource
DFMEA	design failure modes and effects analysis
DOE	Department of Energy
DVP	development, validation, and production
EMC	electromagnetic compatibility
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESI	electric service identifier
EV	electric vehicle
EUMD	end-use measurement device
EVSE	electric vehicle supply equipment
FSM	final stage manufacturers
GVWR	gross vehicle weight rating
HAN	home area network
HDUDDS	Heavy-Duty Urban Dynamometer Driving Schedule
HHDDT	Heavy-Heavy Duty Diesel Truck
HPGP	HomePlug Green PHY

HVIL	high-voltage interlock loop
J1939	"SAE J1939 Recommended Practice—Serial Control and Communications Heavy Duty Vehicle Network"
J1772	"Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler"
MPR	multi-protocol router
OBDII	onboard diagnostic 2 (bus)
OCTA	Orange County Transportation Authority
OEM	original equipment manufacturer
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PTO	power take-off
PWM	pulse-width modulated
SAE	SAE International (originally established as the Society of Automotive Engineers)
SCAQMD	South Coast Air Quality Management District
SLAC	signal-level attenuation characterization
SOC	state of charge
TLS	Transport Layer Security