



California Energy Commission Clean Transportation Program

FINAL PROJECT REPORT

Range-Extended Medium-Duty Electric Pickup Truck

Prepared for: California Energy Commission Prepared by: Electric Vehicles International



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PREFACE

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

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

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

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued solicitation PON-09-004 to provide funding opportunities under the Clean Transportation Program for projects which develop the commercialization of advanced medium- and heavy-duty vehicle technologies. In response to PON-09-004, the recipient submitted application number 49, which was proposed for funding in the CEC's Notice of Proposed Awards on June 10, 2010. The agreement was executed as ARV-09-017 on August 16, 2010 in the amount of \$2.5 million. Electric Vehicles International contributed \$2.8 million in private matching funds.

ABSTRACT

Diesel-fueled medium-duty pickup trucks continue to be a major contributor to California's air quality challenges. Electric Vehicles International won a grant from the California Energy Commission in 2010 to engineer, develop, and build up to 10 range-extended electric vehicles based on the Ford F-450 chassis used for medium-duty pickup trucks. The project had three phases: 1) Create a medium-duty range-extended electric vehicle powertrain with a natural gas-fueled range-extending generator; 2) Integrate the powertrain into an industry standard medium-duty pickup; and 3) Deploy prototypes with project partners for real-world demonstration of performance, emissions reductions, and fuel and maintenance costs benefits. A range-extending generator charges the vehicle's battery pack and is not directly connected to the drivetrain. The battery pack and electric traction motor propel the vehicle. The rangeextended electric drive trucks had a range of 100 to 115 miles. The medium-duty rangeextended electric vehicles can help transform the state's large and dirty diesel-fueled mediumduty fleet into a clean, cost-effective model of sustainability, powered by state-of-the-art California technology. As compared to medium-duty diesel trucks, each range-extended electric vehicle 1) reduces CO2 emission by 57 percent, eliminating 38,850 pounds of CO2 each year, 2) saves 1,440 gallons of fuel each year, and 3) saves an average of \$4,320 in fuel costs and \$750 every year on engine maintenance. The medium-duty range-extended electric vehicles reduce toxic particulate and criteria air emissions, minimizing human exposure and associated health effects. The vehicles can also increase awareness and adoption of clean, electric drive solutions through the deployment of reliable prototypes.

Keywords: Electric Vehicle, Range-Extended Electric Vehicle, Medium-Duty Truck, Series Hybrid, Range Anxiety, Vehicle-To-Grid, Exportable Power.

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EXECUTIVE SUMMARY

Transportation is the largest source of greenhouse gas emissions in California and mediumduty pickup trucks are one of the largest sources of dirty diesel emissions, negatively impacting air quality in communities throughout California. Electric Vehicles International designed, developed, and deployed a range-extended electric vehicle powertrain and vehicle for medium-duty pickup truck applications in order to help transform California's dirty diesel medium-duty fleet and reduce greenhouse gas and criteria pollutants.

Through the *Range-Extended Medium-Duty Electric Pickup Truck* project, Electric Vehicles International designed and developed 10 zero-emission electric vehicle prototypes with the flexibility to use a gasoline generator for unlimited range, eliminating range anxiety and accelerating market transformation. The project used Electric Vehicles International's existing all-electric technology, which was already commercially available, for the primary technical design and development of the project vehicles.

The range-extended electric vehicle is a market-driven solution designed with the needs of large fleet operators in mind. Fleet operators and other pickup truck customers consistently complain that "range anxiety" and a perceived lack of freedom limit customer acceptance and the market viability of fully electric pickups. The range-extended electric vehicle pickup offers unlimited range and the same tough, reliable performance that fleet operators and pickup customers demand. This solves the primary barrier limiting a viable market for electric pickups. While this project has been designed specifically for medium-duty pickup truck operations, the technology is modular and flexible and can be quickly converted for use in refuse trucks, marine applications, and off-road heavy-duty applications.

Electric Vehicles International led the project team as the grant applicant and formed collaborations with component partners for the development and design portions of the project and end-use partners for testing and deployment. Other partners included UQM Technologies for the SmartTorq motor/generator, Pacific Gas & Electric, and the U.S. Department of Defense, who are demonstrating the vehicles, and Valence Technology for their lithium phosphate batteries that power the vehicles.

Electric Vehicles International succeeded in designing, developing, and deploying clean, rangeextended electric vehicle powertrain technology for use at medium-duty pickup truck applications. Electric Vehicles International deployed an attractive, unlimited range mediumduty pickup truck and is helping clean one of California's highest emitters of pollutants. The project met its key goals, including:

- Transforming California's current dirty diesel medium-duty fleet by offering a clean, cost-effective, and flexible electric alternative.
- Achieving significant reductions in greenhouse gas and criteria pollutant emissions.
- Assisting the state in achieving its progressive environmental goals, including the implementation of AB 32 milestone for 2020.

• Creating green jobs in an economically distressed area of California.

The environmental and market benefits of the zero-emission range-extended electric pickup trucks include:

- Reducing 57 percent of CO2 emissions per vehicle.
- Eliminating 38,850 pounds of CO2 each year per vehicle deployed.
- Saving 1,440 gallons of fuel each year per vehicle, avoiding 144 barrels of oil per vehicle every year.
- Reducing fuel consumption for fleet operators and medium-duty pickup truck owners by 1,400 gallons for each vehicle, averaging \$4,320 in fuel savings every year.
- Saving \$750 every year on gasoline engine maintenance per vehicle.
- Lowering net cost to purchase and operate medium-duty pickup trucks.
- Reducing return on investment to less than five years with incentives, creating an attractive and immediately viable market.
- Reducing toxic particulate and criteria air pollutants, which minimizes exposure and associated health effects, including cancer, asthma, and heart disease.
- Increasing the awareness and adoption of clean, electric truck solutions through the deployment of reliable prototypes.
- Generating green jobs in Stockton, California.

In conjunction with the medium-duty range-extended electric vehicle project, Electric Vehicles International designed and developed exportable power and vehicle to grid capabilities to supply power to homes and businesses during power outages or in emergency response situations and help reduce the strain on the electrical grid during peak hours.

The *Range-Extended EV Medium-Duty Pickup Truck* project successfully demonstrated the capability of medium-duty range-extended electric vehicles. To further improve efficiency and reduce costs, Electric Vehicles International recommends developing an alternative vehicle platform that has a smaller, more accessible engine for the second-generation medium-duty range-extended electric vehicle.

CHAPTER 1: Introduction

Project Scope

In 2010, Electric Vehicles International (EVI) won a grant from the CEC to design, develop, and deploy a Range-Extended Electric Vehicle (REEV) powertrain for medium-duty pickup truck applications. EVI proposed building 10 vehicles. The CEC provided \$2.5 million in funding and EVI and its partners committed \$2.8 million.

Taking advantage of the benefits of clean electric energy, the flexibility and scalability of EVI's powertrain technology, and EVI's strong partnerships at all phases of production and deployment, the REEV Medium-Duty Pickup Truck project will help transform California's truck fleet to attain the state's climate change goals while creating significant health and economic benefits.

The scope of this project is to:

- Create a medium-duty range-extended electric vehicle (EV) powertrain; EVI will use its medium-duty EV powertrain platform and add a gasoline range-extending generator;
- Integrate the powertrain into an industry standard pickup (Ford F450); and
- Deploy prototypes with EVI partners for real-world demonstration of performance, emissions reductions, and fuel and maintenance costs benefits.

The project was broken into 3 phases:

- **Phase 1**: Design and test a single Engineering Validation Test (EVT) vehicle to prove concepts, algorithms and integration to the chosen original equipment manufacturer (OEM) chassis. This phase includes test rides and feedback from the end user partners.
- **Phase 2**: Design and test two Development Validation Test (DVT) vehicles. These vehicles carry on the lessons learned and design successes garnered from the EVT vehicle into a production representative vehicle. This phase includes the testing of vehicles for 6 months by the end user partners.
- **Phase 3**: Build seven Production Validation Test (PVT) vehicles to prove the production capability of the system and to provide more vehicles for expanded on-road testing by the end user partners.

Transportation is the largest source of greenhouse gas (GHG) emissions in California. It is also the fastest-growing source of GHG emissions in the U.S., accounting for 47 percent of the net increase in total national emissions since 19901. Medium-duty trucks are responsible for 27 percent of national transportation GHG sources. Figure 1 shows the share of national transportation GHG emissions caused by medium-duty vehicles.



Figure 1: Transportation Greenhouse Gas Emissions

Source: U.S. Environmental Protection Agency (U.S. EPA) (https://www.epa.gov/vehicles-and-engines)

The EVI REEV pickup is designed to fit the specific needs of medium-duty pickup truck applications, one of the highest emitting sectors in California. By deploying an attractive, unlimited range medium-duty pickup truck, this project is helping to clean one California's highest emitters of pollutants.

Fleet managers demand the most efficient and cost-effective vehicles, and are beginning to place a premium on environmentally friendly products and initiatives. In completing this project and deploying range-extended EV technology into a market that has long been criticized for its dirty emissions, this project provides consumers with a clean, viable, cost-effective alternative to highly inefficient diesel technology. The resulting REEV maintained the same operator experience and functionality as its diesel counterparts, while reducing GHG emissions and eliminating mobile diesel particulate pollution.

Project Approach

The range-extended EV is a market-driven solution that was designed with the needs of large fleet operators in mind. To successfully transform the market and accelerate modernization of the legacy diesel fleet, EVI addressed key concerns traditionally raised by fleet operators, such as price and range. The range-extended EV pickups offer unlimited range and the same tough, reliable performance that fleet operators and pickup customers demand.

The project used EVI's existing all-electric technology, which was already commercially available, for the primary technical design and development of the project vehicles. EVI added a range-extender for continuous use to overcome the perceived range anxiety by large fleet operators. Figure 2 shows the range-extended EV in production.

Figure 2: Range-Extended EV in Production



Source: EVI

EVI led the project team and formed collaborations with component partners for the development and design portions of the project. Other partners included UQM Technologies for the SmartTorq motor/generator, and Valence Technology for their lithium phosphate batteries. Pacific Gas & Electric (PG&E) and the U.S. Department of Defense (U.S. DOD) conducted field trials of the vehicles.

In designing, developing, and deploying the REEV for market, EVI used its Product Lifecycle Management process. This process encompasses all project activities, including project initiation, engineering, design, testing, and mass production. A full description of the process is included in the Project Implementation section below.

The REEV Architecture

The EVI REEV is a plug-in series hybrid. The internal combustion engine (ICE) is not mechanically linked to the drive wheels. The ICE powers the electric generator, which provides electrical power to the high voltage direct current (DC) bus. The control inverter converts a DC power source to an appropriate alternating current (AC) power source and vice versa.

The drive to the wheels is provided solely by the electric traction motor, which is powered from the main high voltage bus via a second motor control inverter. This inverter is bidirectional; the inverter can draw power from the high voltage bus to drive the wheels of the vehicle, but importantly it also returns energy back onto the DC bus through regenerative braking.

A high voltage traction battery provides an energy store. This energy store means that the vehicle can operate without having to run the onboard generating system; the vehicle can run in an 'all electric' mode. The capacity of the battery pack determines the 'all electric' range of the vehicle. One of the missions of the EVT phase is to define the traction energy usage of the vehicle, i.e. the watt-hours required per mile required to operate the vehicle. Figures 3 and 4 are schematics of the REEV powertrain. Figure 5 shows a completed vehicle.



Figure 3: Schematic of the REEV Powertrain



Figure 4: Schematic of the REEV Powertrain Installed in Chassis

Figure 5: Photos of a Completed EVI REEV Medium Duty Work Truck







CHAPTER 2: Project Implementation and Results

Project Implementation

EVI designed its project implementation plan to maximize efficiency in manufacturing and deployment. As the project manager and operator for the *Range-Extended EV Medium-Duty Pickup Truck* project, EVI successfully implemented and completed the responsibilities outlined in the project Scope of Work, including:

- Managed project
- Researched and developed the range-extended EV powertrain
- Tested the durability of the powertrain
- Integrated the powertrain into the vehicle
- Tested the durability of the vehicle
- Procured and inspected incoming materials
- Ensured quality management
- Manufactured the demonstration vehicles
- Collected data in the demonstration period
- Reported progress to the CEC
- Provided field service throughout the warranty period

To ensure the effective and efficient implementation of the project responsibilities, EVI implemented its robust Product Lifecycle Management process. Based on best-practice automotive procedures, this process comprised seven main steps, each with specific entrance and exit criteria to ensure that the product has successfully fulfilled each step.

- Design, Development, and Internal Testing
 - Task 1: Business Case and Administration
 - Task 2: Engineering Validation Testing
 - Task 3: Design Validation Testing
 - Task 4: Pilot Validation Testing
- Demonstration Testing
 - Task 5: Demonstration Testing

- Post-Funding Activities
 - Task 6: Mass Production
 - Task 7: End of Life

During the initial four tasks, EVI successful designed and developed 10 medium-duty extended-range electric vehicles. The Engineering Validation Testing phase (Task 2) produced one prototype vehicle that helped identify design issues and enabled EVI's engineering team to solve them as early in the design cycle as possible. This included reconfiguring the batteries and the Battery Management System from U-charge batteries. The U-charge BATTERY Management System was reconfigured to a new Powercell battery to better meet the driving demands of the range-extended vehicle. It also included changes to the electric motor and generator to better meet the torque profiles and the drive profiles in 1st and 2nd gears.

EVI modified the information display gauges on the electric drive train over and above the normal lamps in the stock Ford instrument cluster. Figure 6 shows sample screen data from the display.



Figure 6: Hybrid Drivetrain Information Display Unit

Source: EVI

Control Integration

The vast majority of medium duty trucks today have sophisticated multiprocessor control systems. These systems generally use Controller Area Network buses for communications. Ford does not use the standard SAE J1939 data layers for its Controller Area Network protocols, instead using its own set of message definitions over its Medium Speed and High Speed buses. The diagram in Figure 7 shows a schematic representation of the integration of the REEV vehicle control system including both the stock Ford controllers and the controllers added for the REEV architecture.

Figure 7: Schematic Diagram Showing Integration of EVI REEV Components with Ford 450 Components



Source: EVI

Design Validation Testing Phase

EVI utilized the lessons learned from the Engineering Validation Testing phase to develop and deploy two vehicles to PG&E during the Design Validation Testing phase (Task 3). See Figure 8 for photo of the range-extended EV in the DVT phase. Following the Design Validation Testing phase, EVI used the lessons learned from the two-vehicle deployment to PG&E to design and develop the remaining vehicles for both PG&E and the U.S. Department of Defense during the Pilot Validation Testing stage (Task 4). In addition to range-extension, PG&E requested the next generation vehicles include exportable power capabilities to supply power to homes and businesses during power outages or in emergency response scenarios. The U.S. DOD requested that EVI develop vehicle-to-grid capabilities for their vehicles in order to give electricity back to the grid when needed, particularly during peak demand periods and power outages.



Figure 8: Range-Extended EV in the DVT Phase

Source: EVI

EVI is continuing to collect data and validation from both PG&E and the U.S. DOD for Task 5. In addition, EVI plans to develop a more efficient and less expensive second- generation medium-duty range-extended vehicle that will help carry out the post-funding activities of both Task 6 and 7.

Project Results

EVI successfully designed and developed 10 range-extended electric drive, medium-duty pickup trucks that are helping to reduce greenhouse gas emissions. The *Range-Extended EV Medium-Duty Pickup Truck* project helped advanced state-of-the-art technology to transform California's large and dirty conventional diesel fleet into a clean, cost-effective model of sustainability. Through the REEV project, EVI is contributing to the efforts to attain the Governor's climate policies and goals, including reaching 1.5 million ZEVs by 2025, reducing petroleum consumption by 50 percent by 2030, and meeting the emission reduction goals of AB 32, the Global Warming Solutions Act.

EVI developed a REEV medium-duty pickup truck that maintains the same operator experience and functionality as its diesel counterparts while reducing GHG emissions and eliminating diesel particulate pollution. The REEV has SmartTorq acceleration, power take-off transmission, fully functional highway speed performance, a range of up to 45 miles per charge in fully electric zero emission mode, and unlimited range in gasoline mode. These vehicles are charged using plug-in AC power. The motor/generator turns on only when the vehicle is running below a certain threshold of charge. This approach optimizes the lithium phosphate battery chemistry, which safely charges batteries at high charge rates without affecting performance.

In addition, EVI included additional capabilities on the range-extended electric vehicles to meet the needs of the end-users, including exportable power and vehicle-to-grid options. The REEV utility truck with exportable power has the capacity to export power to the grid for up to 100 kW peak and 70 kW continuously, adjusting to the demand by the grid using an onboard customized inverters. Exportable power capability provides a unique opportunity to supply power to homes and businesses during power outages or in emergency response situations.

The range-extended electric vehicles with the vehicle-to-grid capability has the ability to perform with AC and DC charge; the DC charge is capable to charge and discharge batteries at a 50 kW rate. These vehicles are helping take the strain off the electric grid during peak hours by utilizing the vehicles' batteries, as well as acting as mobile distributed energy resources to optimize existing generator efficiencies and provide spot power to locations for the U.S. DOD. Figures 9 and 10 show the range-extended EV at the U.S. DOD launch event.



Figure 9: EVI REEV at the U.S. DOD Launch Event



Figure 10: EVI REEV at the U.S. DOD Launch Event

CHAPTER 3: Advancements and Project Success

Advancements in Science

EVI designed, developed and deployed the innovative REEV powertrain to help transform California's medium-duty diesel truck sector. Funding for the project advanced the science and technology for range-extended electric vehicles, as well as for vehicle to grid and exportable power capabilities for medium- duty electric vehicles. Technology advancements helped improve efficiency, reduce weight, increase safety and reliability, and reduce costs. These advancements include:

- Tailoring the battery technology to meet the requirements of the vehicle to improve efficiency, reduce weight, and increase the charge and discharge rate of units;
- Updating the Battery Management System strategy to read the battery data more precisely, including the state of charge, discharge, cell spreads and balance strategies;
- Improving the electric motor and generator to meet on-road demand of the rangeextended electric vehicles;
- Updating the onboard electric vehicle charger to a IP67 rated product in order to meet the duty cycle for the medium-duty range-extended EVs; and
- Reduce the high voltage connectors, update automotive grade fuses, connectors and plaster grounds to help further increase the safety and reliability of the vehicles

In conjunction with the medium-duty range-extended electric vehicle project, EVI designed and developed exportable power and vehicle to grid capabilities to supply power to homes and businesses during power outages or in emergency response situations and help reduce the strain on the electrical grid during peak hours.

Project Success - Goals and Objectives

EVI successfully designed, developed, and deployed clean, state-of-the-art range-extended EV powertrain technology for use at medium-duty pickup truck applications. EVI deployed an attractive, unlimited range medium-duty pickup truck and is helping clean one of California's highest emitters of pollutants.

The project met its key goals, including:

- Transforming California's current dirty diesel medium-duty fleet by offering a clean, cost-effective, and flexible electric alternative
- Achieving significant reductions in greenhouse gas and criteria emissions
- Assisting the state in achieving its progressive environmental goals, including the implementation of AB 32 milestone for 2020, and

• Creating green jobs in an economically distressed area of California.

The zero-emission electric vehicle prototypes with the flexibility to use a gasoline generator for unlimited range, eliminating range anxiety and accelerating market transformation are:

- Reducing 57 percent of CO2 emissions per vehicle;
- Eliminating 38,850 pounds of CO2 annually per vehicle deployed;
- Saving 1,440 gallons of fuel each year per vehicle, avoiding 144 barrels of oil per vehicle every year;
- Reducing fuel consumption for fleet operators and medium-duty pickup truck owners by 1,400 gallons for each vehicle, averaging \$4,320 in fuel savings every year;
- Saving \$750 every year on gasoline engine maintenance per vehicle;
- Lowering net cost to purchase and operate medium-duty pickup trucks;
- Reducing return on investment to less than five years with incentives, creating an attractive and immediately viable market;
- Reducing of gasoline toxic particulate pollution, other air toxics, and criteria air pollutants, which minimizes exposure and associated health effects, including cancer, asthma, and heart disease;
- Increasing in awareness and adoption of clean, electric truck solutions through the deployment of reliable prototypes; and
- Generating green jobs in Stockton, California, with the potential of 40 more jobs with continued production.

CHAPTER 4: Observations and Conclusions

Observations and Conclusions

The REEV Medium-Duty Pickup Truck project successfully demonstrated the viability of medium-duty range-extended electric vehicles. EVI designed and developed additional capabilities on the range-extended electric vehicles to meet the needs of the end-users, including exportable power and vehicle-to-grid options. The exportable power and vehicle-to-grid capabilities enable both PG&E and U.S. DOD to supply power to homes and businesses during power outages or in emergency response situations and help reduce the strain on the electrical grid during peak hours.

Funding for the project helped advance the technology for extended-range electric vehicles, as well as for vehicle to grid and exportable power capabilities for medium-duty electric vehicles. To further improve efficiency and reduce costs, EVI recommends developing an alternative vehicle platform that has a smaller, more accessible engine for the second-generation medium- duty range-extended electric vehicle. This project used Ford F-450 and F-550 platforms with V8 and V10 engines for the medium-duty range-extended electric vehicles. After completing the project, EVI determined that a smaller size engine – V4 or V6 – will be sufficient for the applications of the vehicles and will help improve efficiency, reduce weight, and reduce costs.

In addition, EVI plans to acquire its own ICE engine technology, which will also help improve efficiency on hybrid mode and will be more cost effective.

There is significant market potential for medium-duty range-extended electric vehicles. Following the successful completion of EVI's second-generation vehicle with improved efficiency and reduced costs, EVI anticipates significant market demand and vehicle sales. Based on the current market sales of diesel vehicles as determined by EVI's partner PG&E, the potential market is approximately 15,000 vehicles annually nationwide with over 2,500 vehicles in California per year. EVI's first-year production demand with incentives and pent up demand is expected to be around 500 units; by the year 2022, EVI's sales projections expect a market penetration of 3,500 units (See Figure 11).



Figure 11: Estimated Production Demand

Source: EVI

EVI designed and developed 10 range-extended electric vehicle prototypes with the flexibility to use a gasoline generator for unlimited range, eliminating range anxiety and accelerating market transformation. The medium-duty range-extended EV prototypes are helping transform the state's large dirty diesel medium-and heavy-duty fleet into a clean, cost-effective model of sustainability, powered by state-of-the-art California technology. As compared to medium-duty diesel trucks, each range-extended EV is reducing CO2 emission by 57 percent, eliminating 38,850 pounds of CO2 each year, saving 1,440 gallons of fuel each year, and saving an average of \$4,320 in fuel costs and \$750 every year on engine maintenance. The medium-duty REEVs reduce toxic particulate pollution and criteria air pollutants, which minimizes exposure and associated health effects. In addition, the vehicles are increasing awareness and adoption of clean, EV solutions through scaling and fully commercializing successful prototypes.

GLOSSARY

AB 32 - The Global Warming Solutions Act of 2006 (AB32) - The Legislature passed and Governor Schwarzenegger signed AB 32, which set the 2020 greenhouse gas emissions reduction goal into law. It directed ARB to develop discrete early actions to reduce greenhouse gases while also preparing a scoping plan to identify how best to reach the 2020 limit on greenhouse gas emissions.

ALTERNATING CURRENT (AC) - Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

CARBON DIOXIDE (CO2) - A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO2 emissions is fossil fuel combustion. CO2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO2 have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels.

COMPRESSED NATURAL GAS (CNG) - Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

DEVELOPMENT VALIDATION TEST (DVT) - The second phase of Electric Vehicle International's project to develop range-extended electric vehicles in which additional trucks were built and field-tested.

DIRECT CURRENT (DC) - A charge of electricity that flows in one direction and is the type of power that comes from a battery.

ELECTRIC VEHICLES (EV) - A broad category that includes all vehicles that are fully powered by Electricity or an Electric Motor.

ENGINEERING VALIDATION TEST (EVT) - Design and engineering phase of Electric Vehicle International's project to develop range-extended electric vehicles.

GREENHOUSE GAS (GHG) - Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). (EPA)

INTERNAL COMBUSTION ENGINE (ICE) - An engine in which fuel is burned inside the engine. A car's gasoline engine or rotary engine is an example of a, internal combustion engine. It differs from engines having an external furnace, such as a steam engine. PLUG-IN ELECTRIC VEHICLE (PEV) - A general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two different types of PEVs to choose from - pure battery electric and plug-in hybrid vehicles.

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

PACIFIC GAS AND ELECTRIC COMPANY (PG&E) - The acronym for Pacific Gas and Electric Company an electric and natural gas utility serving the central and northern California region.

PRODUCTION VALIDATION TEST (PVT) – The third phase of Electric Vehicle International's project to develop range-extended electric vehicles in which production and manufacturing processes were refined and the vehicles subjected to more lengthy field trials.

RANGE-EXTENDED ELECTRIC VEHICLE (REEV) – A range extender electric vehicle is a battery electric vehicle with a series hybrid drivetrain, where an internal combustion engine may drive an electric generator, which delivers electricity to the battery, the electric vehicle (EV) traction electric motor/generator, or in principle, both. The battery delivers electricity to the EV traction electric motor/generator propelling the vehicle, or it receives electricity from the EV traction electric motor/generator during regenerative braking. The key function of the range extender is to increase the vehicle's range.1

UNITED STATES DEPARTMENT OF DEFENSE (U.S. DOD) - The United States Department of Defense is an executive branch department of the federal government charged with coordinating and supervising all agencies and functions of the government directly related to national security and the United States Armed Forces.

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

¹ Albert Boretti. *Electric Vehicles with Small Batteries and High Efficiency On-Board Electricity Production*. Energy Storage, Vol. 1, Issue 4. August 2019.