CALIFORNIA
ENERGY COMMISSION

California Energy Commission
Clean Transportation Program

FINAL PROJECT REPORT

Fuel Conversion of Class 6 Sectran Security Armored Diesel Fueled Trucks to Renewable Natural Gas and Plug-In- Hybrid Electric Operated Vehicles for Reduced Emissions

Prepared for: California Energy Commission
Prepared by: North American Repower

Gavin Newsom, Governor
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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 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 Energy Commission's annual Clean Transportation Program Investment Plan Update. The Energy Commission issued PON-14-605 to fund medium and heavy-duty advanced vehicle technology demonstrations. In response to POM-14-605, the recipient submitted an application which was proposed for funding in the Energy Commission's notice of proposed awards March 24, 2015 and the agreement was executed as ARV-14-052 on July 1, 2015.

ABSTRACT

This report documents the demonstration, development, and deployment of alternative renewable fuels together with advanced technologies to help reduce emissions.

There are approximately 850,000 diesel trucks that are based and operate in California with only five percent of all registered trucks being a new truck sale. It is estimated that it will take approximately 20 years to completely renew in-use fleets to current emissions technology. Conversion of these older diesel fueled trucks to renewable natural gas and parallel hybrid electric vehicle will quickly reduce nitrogen oxides emissions.

North American Repower managed the conversion of six Sectran's armored Class 6 diesel fueled trucks to operate on renewable gas and parallel hybrid electric vehicle, and measure emissions before and after conversion on their real-world routes.

Conversion of in-use diesel engines to operate on renewable natural gas and plug-in hybrid electric vehicles can reduce emissions of nitrous oxide, non-methane hydrocarbons and particulate matter significantly. Compressed natural gas conversion alone can also reduce nitrogen oxides over diesel and slightly over plug-in hybrid electric vehicles in the high and medium speed operation. The renewable natural gas plug-in hybrid electric vehicle can produce lower emissions if plugged in every night to start routes fully charged.

Keywords: California Air Resources Board (CARB), compressed natural gas (CNG), Efficient Drivetrains Inc. (EDI), nitrogen oxides (NOx), North American Repower (NAR), plug-in hybrid electric vehicles (PHEV), renewable natural gas (RNG).

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Introduction

The durability of diesel truck technology does not lend itself to rapid turnover and investment in new equipment that meets stringent environmental standards. There are approximately 850,000 diesel trucks that are based in and operating in California that belong to large regional fleets. All of these trucks are subject to the California Air Resources Board's In-Use Truck and Bus Regulations, which require all trucks and bus fleets operating in California to be upgraded to meet more stringent emission standards. More recently, studies by California Air Resources Board, Environmental Protection Agency, and West Virginia University have demonstrated that the technologies employed with the objective to reduce heavy duty diesel emissions to meet these more stringent standards fail to meet these standards in real world use, especially in urban environments, substantially negatively impacting air quality in disadvantaged communities. These same studies demonstrated that only natural gas fueled heavy duty vehicles met current emissions under all driving conditions.

New truck sales generally account for only five percent of all registered trucks. It is estimated that it will take approximately 20 years to completely renew in-use fleets to current emissions technology, and as stated above, these new diesel technologies do not improve emissions in urban driving environments. Under this approach, high nitrogen oxides and particulate matter-emitting diesel trucks could remain on California roads for another two decades or longer. A more effective way to quickly reduce nitrous oxides and particulate matter emissions is to retrofit-upgrade existing diesel trucks to plug-in hybrid electric vehicles that can operate on electricity and renewable natural gas as this demonstration will do.

Project Purpose

This project was intended to support the Clean Transportation Program and the CEC to develop and deploy alternative and renewable fuels and advanced transportation technologies in disadvantaged communities to help attain the state's climate change objectives listed below:

- Demonstrate high-performance renewable natural gas plug-in hybrid electric armored trucks that utilize electricity as a primary fuel offer significant emissions reduction with no loss in vehicle performance in and around disadvantaged communities.
- Demonstrate the technical and economic feasibility of retro fitting upgrading existing medium and heavy-duty diesel trucks to near zero emissions and lay the ground for the commercialization of renewable natural gas plug-in hybrid electric trucks in other industries.
- Improve the efficiency, performance, and viability of alternative medium, and heavy-duty vehicle technologies.
- Retrofit medium and heavy duty on-road, and non-road vehicle fleets to alternative technologies or fuel use.

Disadvantaged Communities Served

This project demonstrated six Sectran renewable natural gas plug-in hybrid electric armored trucks on routes in disadvantaged communities in the Los Angeles basin. The trucks were based out of the Sectran facility located at 7633 Industry Ave., Pico Rivera, CA 90660.

According to Cal Enviro Screen 2.0, this location scores in the 91 to 95 percentile range, thus qualifying as a disadvantaged community.

Project Process

North American Repower executed a retrofit to six in-service class 6 trucks provided by Sectran. These trucks were manufactured in 1996, 1998 and 1999 which made them perfect candidates for our conversion. The actual service route includes a great deal of idling within disadvantaged communities. Since the traditional diesel would continue to run, this proves that the retrofit can be accomplished with significant reduction in both carbon dioxide, particulate matter, and nitrogen oxides.

The retrofit began with the conversion of the diesel fuel engine to operate on renewable natural gas. Then the vehicle was modified to operate on lithium ion battery power. After completion of the conversions they became renewable natural gas plug-in hybrid electric vehicles.

Project Results

North American Repower managed the conversion of six Sectran armored Class 6 diesel fueled trucks to operate on renewable natural gas and run parallel as a hybrid electric vehicle, measuring emissions before and after conversion on their real-world routes. As expected, renewable natural gas and plug-in hybrid electric vehicles had much lower nitrogen oxides and particulate emissions than the diesel vehicles in all operating conditions. The renewable natural gas and plug-in hybrid electric vehicles emitted much lower non-methane hydrocarbons in all driving conditions.

Conversion of in-use diesel engines to operate on hybrid renewable natural gas and plug-in hybrid electric vehicles can reduce emissions of nitrogen oxides, non-methane hydrocarbons, and particulate matter significantly. Furthermore, compressed natural gas conversion alone can significantly reduce nitrogen oxides over diesel and slightly over plug-in hybrid electric vehicles in the high and medium speed operation. The renewable natural gas and plug-in hybrid electric vehicles can produce lower emissions. However, it will require the vehicle to be plugged in and charged prior to use. When emissions are calculated on a per pound of payload basis, it can be shown that with current technology, renewable natural gas-powered heavy-duty vehicles produce the lowest emissions when compared to diesel or plug-in hybrid electric vehicles operation.

Sectran and the disadvantaged communities are unable to see any of these benefits from the conversion process. Although, the trucks were received prior to conversion as working diesels, after the conversion process the truck became non-functional due to an error in the plug-in hybrid electric vehicles electrical drive system. Purchasing the extended warranty from Efficient Drivetrains Inc. was cost prohibitive for Sectran so no warranty program was purchased and to date all six trucks remain non-operational.

Benefits to California

If commercially developed and adopted widely, the proposed technologies could dramatically reduce the emissions of particulate matter and nitrogen oxides from the largest source of these emissions on California's roads heavy-duty trucks. Data from the California Air Resources Board has shown that negative impact of emissions from heavy-duty trucks within California falls disparately on members of disadvantaged communities, many of whom live in close proximity to the state's highways and interstates. Currently, approximately 1.8 million heavy-duty trucks are registered and based in California. If all 1.8 million were to convert to renewable natural gas and plug-in hybrid electric vehicles, the state could dramatically reduce their exposure to particulate matter and nitrogen oxides emissions from heavy-duty trucks, thereby helping to improve their health and wellbeing of the citizens.

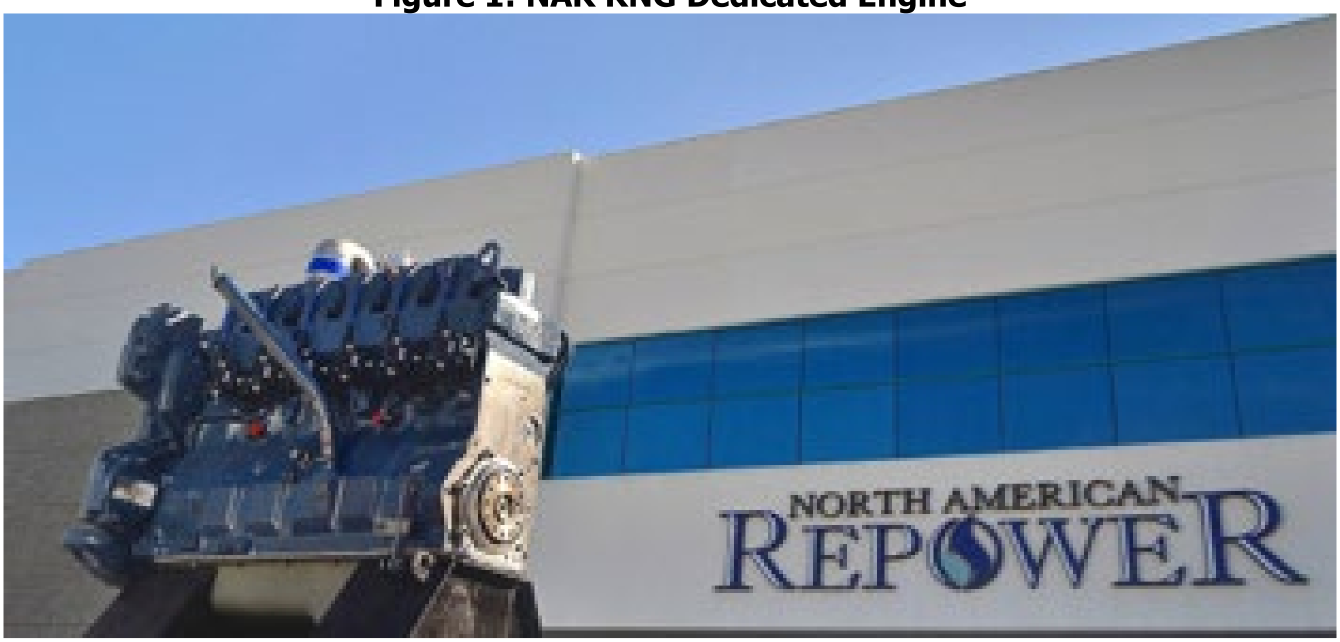
The technology demonstrated in the proposed project could allow highly fuel-efficient and low-greenhouse gas-emitting engines to be built and retrofitted into existing high-fuel-use vehicles through an already established market pathway: the diesel engine remanufacturing process. By introducing the technology demonstrated here into the remanufacturing process, California and the rest of the world could achieve rapid reductions in emissions of particulate matter, nitrogen oxides and carbon dioxide, move fleets to a lower carbon fuel source, create green jobs in California, and create the lowest-carbon-footprint fleets through reuse of high-carbon-cost materials rather than importing newly forged engines and vehicles.

CHAPTER 1:
Key Contributors

NAR

NAR[1] lead the effort in converting existing Navistar DT466 7.6-liter HD diesel engines[2] to RNG engines. NAR is a privately held clean-tech entity specializing in natural gas (NG) engine conversion, and consulting. Figure 1 below shows a photo of NAR's in-house research and development team and manufacturing facility, designs and manufactures products for the medium duty NG engine market, creating products in response to customer needs rather than selling customers on a product line. All NAR remanufacture engine providers are International Organization for Standardization[3] certified and recognized as leading experts in the remanufacture of each family of medium-duty engines that NAR converts. NAR systems are designed specifically for the medium-duty market, and components are chosen based upon known performance and quality. Each NAR system is unique to the engine type and application involves a complete redesign of the combustion chamber and fuel and air delivery process to optimize the engine for operation on NG/CNG/RNG. NAR extensively tested and validated its DT466 based conversion and has obtained CARB certification for this specific engine conversion to dedicated CNG/RNG.

Figure 1: NAR RNG Dedicated Engine



Source: NAR

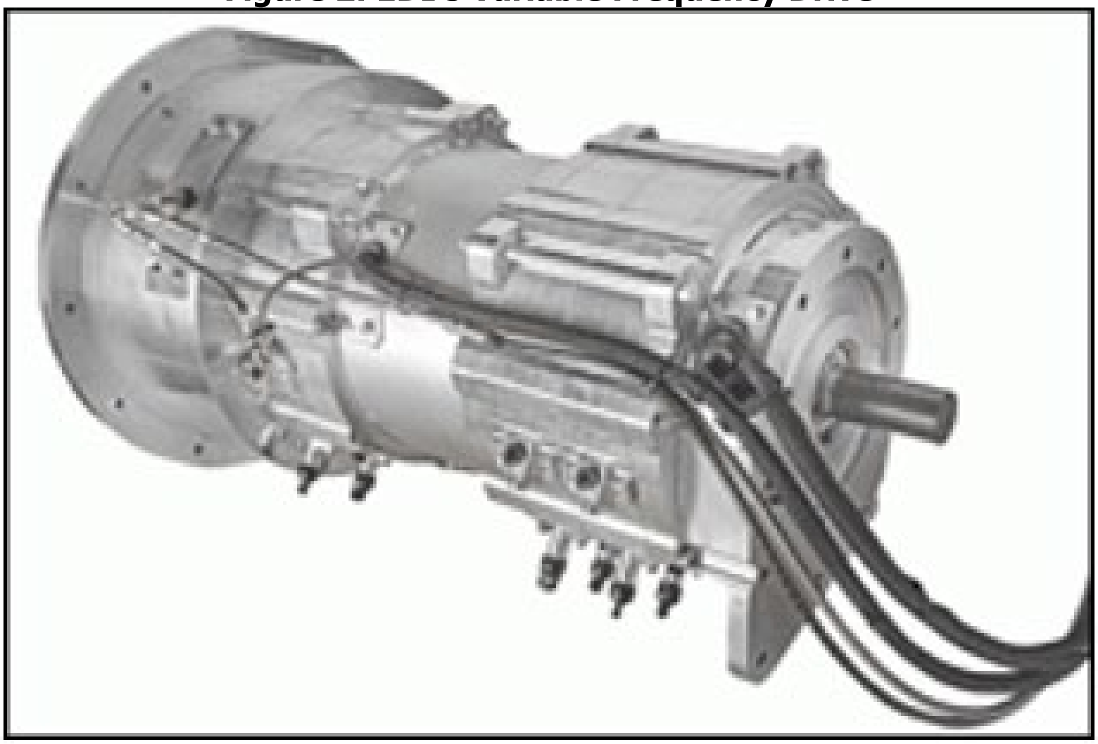
[1] NAR http://repowerednqv.com
[2] Navistar DT466 7.6-Liter HD Diesel Engines Description https://en.wikipedia.org/wiki/Navistar_DT_engine
[3] International Organization for Standardization https://www.iso.org/home.html

EDI

EDI performed detailed engineering and design for the integration of the EDI Drive with the RNG-powered Sectran armored trucks. They then performed integration, testing, and validation on the vehicles. EDI develops, manufactures, and markets a range of state-of-the-art proprietary drivetrain products and technologies that have direct application in PHEVs, hybrid electric vehicles (HEV)s, and battery electric vehicles worldwide. EDI's leading-edge hybrid-electric drivetrain systems and technologies provide significant cost and efficiency advantages for parallel and series hybrid drivetrain architectures across nearly all platform classes and configurations. In addition, the company has developed continuously variable transmissions (shown in Figure 2) that are the most efficient and largest capacity transmissions of their type in the industry today.

The company's hybrid-electric drivetrain systems and technologies provide significant cost and efficiency advantages by using both parallel and series drivetrain architectures, unique components, and proprietary control software and algorithms. The company's products have direct applications in PHEV vehicles, hybrids, and electric vehicles (EV), across nearly all platforms classes and configurations including light, medium, and heavy-duty market opportunities.

Figure 2: EDI's Variable Frequency Drive



Source: NAR

CarbonBLU LLC

CarbonBLU[4] helps fleets analyze and explore options for improvement and optimization without the costs associated with hiring technical staff. Its software empowers fleet managers

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[4] CarbonBLU http://www.carbonblu.com/

to purchase the right vehicle for the job, integrate alternative fuels, and advanced vehicle technology into fleet operations, and even improve energy use at their facilities. CarbonBLU will be providing third party emissions testing analysis.

Sectran Security

Based in Pico Rivera, California, Sectran provides fully insured and licensed armored transportation services to thousands of customers in retail, banking, and private industries throughout Southern California since 1982. With vaults in Los Angeles and San Diego counties. Sectran provides its customers with armored transportation, cash, coin, and check processing, change preparation, and currency management services. Sectran is representative of a large number of California-based fleets that own a significant number of pre-2010 diesel vehicles. Unlike national fleets, California based fleets can't move to "clean diesel" by shuffling existing fleet vehicles out to other states and purchasing newer trucks for California operation essentially exporting California's diesel pollution to other states rather than eliminating it. Instead, Sectran, and other similar fleets, must find economically viable alternatives to meet California's diesel fleet emission regulations. Conversion of existing fleet vehicles to operate on alternative fuels that reduce operating costs while reducing emissions enables these fleets to pay for modernization of their fleets through operating expense savings rather than new capital expenditures. Sectran is committed to obtaining accurate operational data from the project vehicles to enable an accurate determination of the economic viability of the RNG-PHEV solution. Sectran is also very interested in demonstrating its commitment to a cleaner environment in the communities where its trucks operate. Sectran hopes that this demonstration project will not only provide them and other California-based fleets with a viable green solution, but also that Sectran will become recognized as a leader in bringing the next generation of clean-vehicle solutions to California. Sectran looks forward to sharing its experience with this solution with other California fleets at industry events and through magazine articles and other publications.

CHAPTER 2: Objective and Approach

In collaboration with Sectran and EDI under the grant NAR converted six existing diesel-powered, Class 6 Sectran armored vehicles into near-zero-emission PHEV that run on electricity and RNG.

Sectran operated these modernized trucks within disadvantaged communities in the South Coast Air Quality Management District of Los Angeles[5]. The grants objective was to demonstrate that these converted near-zero-emission RNG-PHEV trucks would reduce emissions, improve fuel economy, and make a powerful business case for retrofit conversion of existing diesel fleets as a cost- competitive approach to dramatically reducing petroleum fuel consumption and harmful diesel and greenhouse gas (GHG) emissions.

The grants goal was to demonstrate high-performance RNG-PHEV armored trucks that utilize electricity as a primary fuel and offer significant emission reductions with no loss in vehicle performance. Objectives were to:

- Convert six diesel Class 6 Sectran armored trucks into RNG-PHEV.
- Eliminate the consumption of 30 gallons of diesel per day per truck.
- Demonstrate RNG as an ultra-low-carbon alternative transportation fuel in hybrid Class 5-8 work trucks that traditionally utilize standard diesel.
- Reduce GHG emissions per vehicle replaced by 124 metric tons of carbon dioxide (CO2) per year.
- Reduce NOx emissions per vehicle replaced by 0.99 to 2.15 tons per year.
- Virtually eliminate 50 kilograms (kg) of particulate matter (PM).
- Reduce Sectran annual fuel costs by $24,000 per truck.
- Document lower NOx emissions per mile than those diesels meeting current emissions standards.

Sectran armor trucks make frequent stops on highly congested urban routes. At each stop for security and driver comfort the engines are kept running, but risk violating California's strict diesel idling regulations, which prohibit idling diesel truck engines for more than five minutes. With the modernized trucks, Sectran would be able to eliminate diesel engine idling while maintaining security and driver comfort by operating in all-electric mode during stop-and-go operations on urban routes and in hybrid-mode during highway operations. Building upon a 2014, CEC funded prototype and expanding into new markets, the proposed RNG-PHEV truck would enable Sectran to replace existing diesel trucks that consume 30 gallons of diesel fuel per day and emit large quantities of GHGs, NOx, and PM in highly impacted urban environments. The clean, near-zero-emission RNG-PHEV trucks run on both electricity and RNG which has a low and in some cases negative carbon intensity. This can occur if the RNG is made from low carbon intensity feedstocks, as determined under the California Low Carbon

[5] South Coast Air Quality Management District of Los Angeles http://www.aqmd.gov/

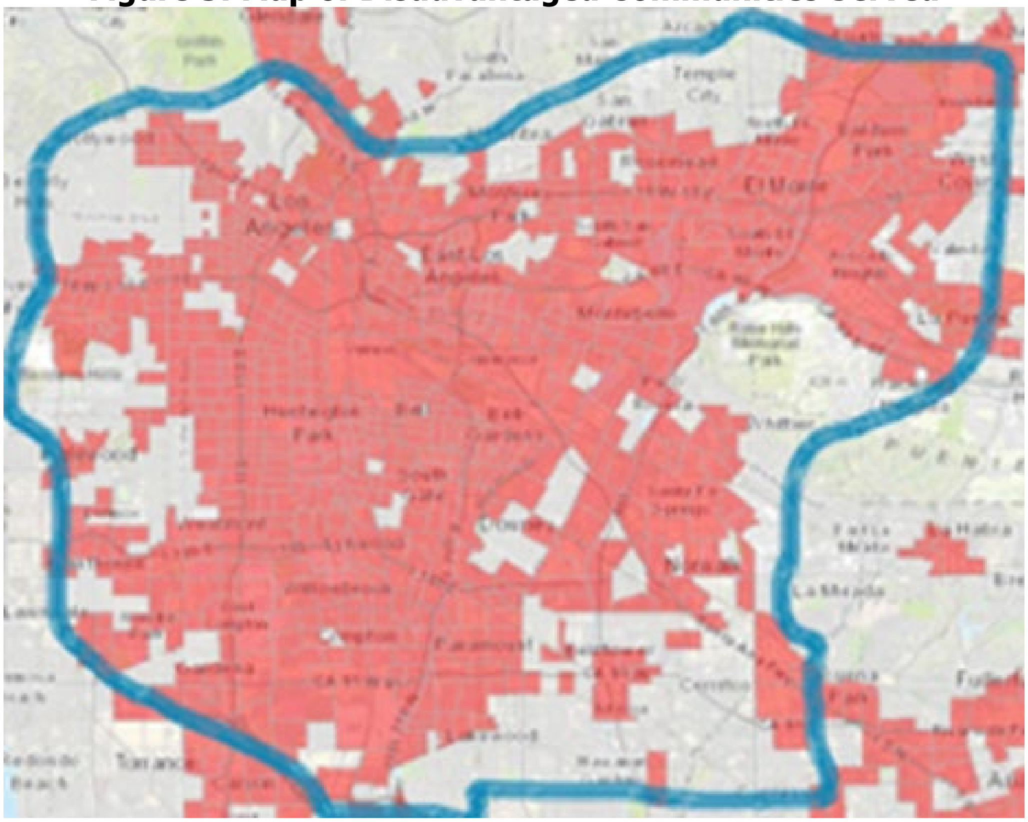
Fuels program[6], such as dairy waste, swine waste and food waste. Retrofit conversion of their existing trucks will enable Sectran to produce the first net-negative-carbon commercial fleet at a far lower cost and smaller carbon footprint than through purchasing new armored trucks which have a replacement cost of more than $145,000. When operational, the modernized RNG-PHEV trucks enabled Sectran to reduce annual diesel consumption by 31,200 gallons, reduce annual fuel costs by $144,144, reduce harmful PM emissions by 99.9 percent, and reduce GHG emissions by 742.5 metric tons of CO2. Furthermore, the project team also anticipated the converted trucks would have the potential to attain or surpass the voluntary CARB goal of 0.02gallon/horsepower-hour of verified NOx emissions, while demonstrating required levels of performance, drivability, durability, and cost effectiveness in comparison with current on-road diesel engines. If commercialized, this approach could enable fleets that have made significant capital investments in the cargo "boxes" attached to the chassis of their vehicles to extend the useful life of the "boxes," while reducing emissions, improving fuel economy, and complying with increasingly stringent CARB and Environmental Protection Agency emissions and air quality regulations.

Disadvantaged Communities Served

This project demonstrated six Sectran renewable natural gas plug-in hybrid electric armored trucks on routes in disadvantaged communities in the Los Angeles basin. The trucks were based out of the Sectran facility located at 7633 Industry Ave., Pico Rivera, CA 90660. According to Cal Enviro Screen 2.0, this location scores in the 91 to 95 percentile range, thus qualifying as a disadvantaged community. The proposed demonstration period routes although kept confidential for driver safety and cargo security all fall within the blue line in Figure 3 and all trucks were to operate almost entirely (95 percent) within disadvantaged communities (red-shaded areas) within the blue. The goal was to demonstrate high-performance renewable natural gas plug-in hybrid electric armored trucks that utilize electricity as a primary fuel.

[6] CEC California Low Carbon Fuels Program https://www.energy.ca.gov/programs-and-topics/programs/low-carbon-fuel-production-program

Figure 3: Map of Disadvantaged Communities Served



Source: NAR

CHAPTER 3: RNG and PHEV System Design

For the grant's purpose, NAR and EDI combined their designs in providing Sectran with an RNG/PHEV vehicle solution. NAR expertise would be focused on the engine conversion from diesel to RNG, vehicle body safety upgrades, Interior upgrades for safety and aesthetics, as well as the design and installation of the fuel system to include tanks and covers ensuring an effective and professional final product for their business. EDI provided the electric solution with their intelligent PHEV powertrain and battery pack.

RNG System

NAR, an RNG engine solution provider, provided the conversion of the current diesel engine repowered to RNG, which is ideally suited for integration with this scaled up solution. NAR's natural gas (NG) engine management and conversion technology is uniquely able to adapt to disruptive and innovative engine technology. NAR's engine management system is based on torque-demand optimization and is readily adaptable to unique engine demands. This engine documented the highest efficiency of any NG engine ever built and was a conversion from diesel.

NAR's system has the flexibility and advanced controls needed to provide the required functionality, because of this flexibility and its unique approach to efficiency optimization, the NAR system enabled the EDI drive system to operate in an optimized fashion.

PHEV System

EDI manufactures an intelligent PHEV powertrain (the EDI Drive) and battery pack with 40 miles of all-electric range to support integration with an existing Environmental Protection Agency and CARB certified 6.0-liter Class 6 CNG engine from Greenkraft[7]. The intelligent EDI Drive is a compact, lightweight, high efficiency 4-mode, series-parallel, PHEV drivetrain that has been tested and proven in light, medium, and heavy-duty vehicles using both diesel and gasoline. The EDI-Drive system intelligently and automatically adapts its functions so it can operate as either a EV for trips around the neighborhood, as a series hybrid, optimum for stop-and-go city traffic conditions, or as an efficient parallel hybrid that is ideal for the highway. It also features an EV plus mode for hill climbing and added acceleration. To best understand the benefits of the EDI Drive, it is first necessary to understand the two most common conventional HEV systems. In parallel hybrid systems, both the electric motor and the internal combustion engine (ICE) can provide propulsion power simultaneously.

Typically, the ICE provides power to drive the vehicle, while the electric motor engages as needed, providing additional torque for acceleration, and climbing. In most series hybrid systems, the ICE turns a generator, which either charges the battery or provides propulsion power.

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[7] Greenkraft http://greenkraftinc.com/

The intelligent EDI Drive is a disruptive advanced series-parallel hybrid system that automatically incorporates the functionality of two electric motors and two dry clutches and lacks a conventional transmission. Designed to operate at maximum efficiency under a wide variety of driving conditions and cargo load points, the EDI Drive can operate in four modes as either a conventional HEV or as a PHEV capable of charging directly from the electric grid. In the EDI Drive, an ICE is connected to clutch #1. Clutch #2 is sandwiched between electric motor (EM)1 and EM2. During launch, driving, braking, and stop scenarios, sophisticated software controls clutch engagement and disengagement. Depending on the operation mode, the ICE and two electric motors can individually or jointly transfer power to the output shaft, intelligently switching among operating modes as required in order to maximize electric range and minimize fuel usage and emissions. The four modes operate as follows:

- **Zero-Emissions EV Mode**: the battery provides power to drive EM2.
- **Zero-Emissions EV+Mode**: the battery provides power to drive both electric motors, providing additional torque for acceleration and climbing.
- **Parallel Mode**: ICE engine provides power to drive the vehicle; EM1 and EM2 add power or provide battery maintenance. Most efficient for continuous high-speed driving.
- **Series Mode**: EM2 provides power to drive wheels; ICE and EM1 generate electricity to maintain battery pack at a 50 percent charge. EM1 can also add power. Most efficient for city or very low-speed driving.

CHAPTER 4: Hybrid System Manufacturing Process

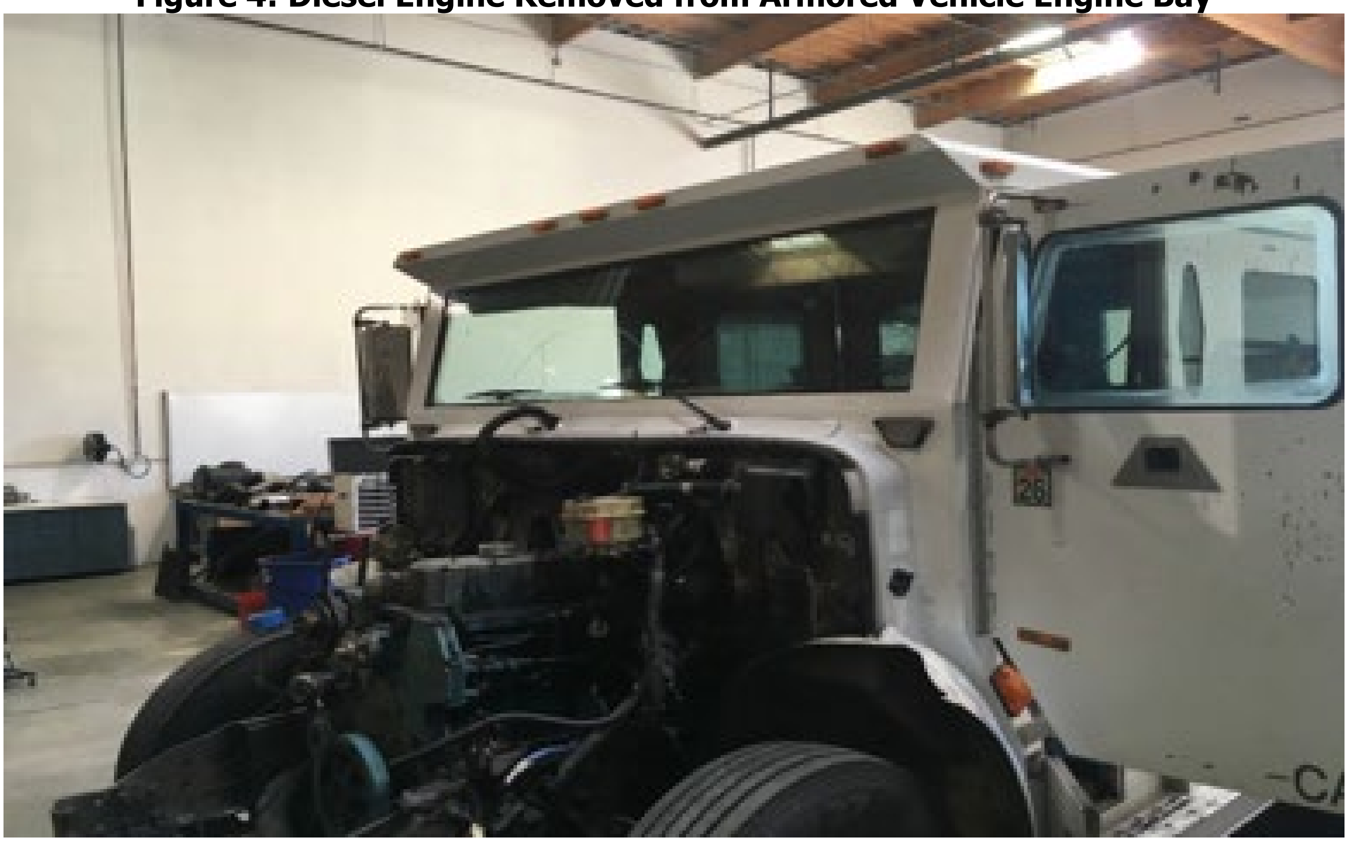
Conversion of the existing diesel powered Sectran vehicles was a shared effort performed by both NAR and EDI. Where NAR was responsible for the RNG conversion process, and EDI's responsibility was the PHEV conversion of the vehicle.

RNG Conversion Process

Engine Conversion

The hybrid manufacturing process started at NAR with the RNG conversion process which is broken down into six phases: engine, vehicle body, fuel tanks, fuel system, interior and electrical system. The requirements of each phase can vary depending on the condition of each truck when it is delivered to NAR's facility. Once the truck is received at the NAR facility, a thorough inspection is performed and documented. With each conversion the process first starts with the engine conversion. NAR removed the current International DT466 diesel powered engines. It then prepped the engine bay, rerouted the air conditioning (AC) refrigerant lines and relocated the existing sirens so they would not impact the installation of the repowered DT466 RNG. It then installed the RNG engine and accessories with the cooling system. Next, NAR installed the electronic control module, electrical harnesses, brackets, ignition system that are unique and proprietary to NAR's solution. This process can be seen in Figures 4 below and Figure 5 on the next page.

Figure 4: Diesel Engine Removed from Armored Vehicle Engine Bay



Source: NAR

Figure 5: Repowered RNG Engine Installed in Engine Bay

Source: NAR

Body Work

The second phase consisted of body work to the truck, where we removed the cargo bay body panels and inspect them. We then added structural steel to the interior roof and side walls of the cargo box (Figure 7) which was required to support the rooftop RNG tanks that we would be installing. We then painted the welded structure, re-installed the cargo body panels, gun ports, tie down racks, and had bare metal parts powder coated or painted for aesthetic purposes and to help protect against rust. We then removed the diesel fuel tanks, fabricated a fuel tank cover (Figure 6). We then fabricated and installed a side bumper extension, as well as installed rubber bumpers as needed. We installed all new weather strips, prepped, and painted all welds and modified metal that require it. We then polished the hood, mirrors, and prepped and painted the wheels if their condition required it. Figures 8(page 14), 9(page 15), and 10 (page 15) show the finished modifications of these vehicles that were needed to proceed with the drivetrain installation process.

Figure 6: Fabricated Fuel Tank Cover

Source: NAR

Figure 7: Structural Steel Added for Additional Weight Support

Source: NAR

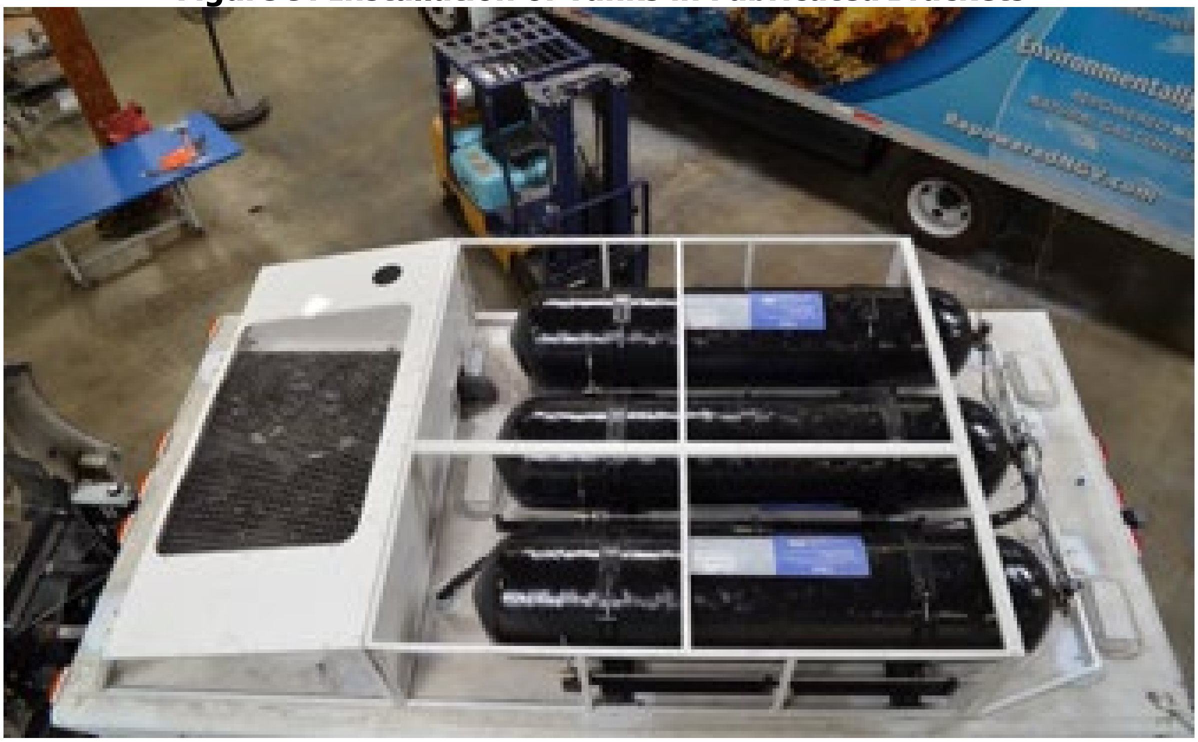
Figure 8: Cargo Bay Finished and Ready for PHEV Alterations.

Source: NAR

Fuel Tank

The third phase in the RNG conversion process was installing the fuel tanks which would reside on the exterior roof of the vehicles. We first had to design and fabricate the tank brackets, tank structure and the cover for tanks. Next, we sent the tank cover panels out for powder coating, once completed we then installed the tank structure and the cover.

Figure 9: Installation of Tanks in Fabricated Brackets



Source: NAR

Figure 10: Tank Cover Located on the Roof of the Vehicle

Source: NAR

CNG Fuel System

The fourth phase is the installation of the RNG fuel system. We first had to fabricate an opening for the fill panel, which can be seen in Figure 11, into the body of the truck. We then installed the NAR fill panel, which can be seen in Figure 12, and high-pressure conduit lines from the tank to the fill panel.

Figure 11: Installed Fill Panel

Source: NAR

Figure 12: Installed Fill Panel and High-Pressure Lines

Source: NAR

Interior of Vehicle

In our fifth phase we moved to the interior of the truck, removing steering wheel, repair or replaced any broken windows or glass, cleaned dash. In Figure 13, you can see that we removed the seats and install rubber diamond-plate flooring, clean the seats, and re-install in vehicle. We fabricated and installed a bracket for the shift selector, fabricating and installing the touch screen panel, fuse panel and the instrument panel.

Figure 13: Interior of Cab

Source: NAR

Electrical

The final phase of the build is the electrical. In this phase we designed and manufactured the new instrument panel wiring harness. We manufactured and installed the engine electrical harness. Next step was to design, manufacture, and install the hybrid adapter electrical harness which allows the electric drive to communicate with the RNG engine. We modified the interior electrical harness and then we designed, manufactured, and installed the body electrical harness. To finish up the electrical phase we installed the camera system, global positioning system displays and installed new 12-volt batteries. These modifications can be seen in Figures 14-16 on the following pages. At this point after all assembly and final inspections are completed, we prepared the truck for on road testing prior to delivering to EDI for the PHEV installation.

Figure 14: Modified Electrical Wiring Harness

Source: NAR

Figure 15: Newly Installed Instrument Cluster Dash

Source: NAR

Figure 16: Newly installed Instrument Gauge

Source: NAR

PHEV Conversion Process

Since the purpose of this project was to convert existing diesel trucks to CNG-PHEV, a custom PHEV drivetrain had to be designed that would fit in the existing trucks without having to do important modifications that could compromise the existing chassis or body. A significant amount of time was spent by EDI to design the PowerDrive™ 6000[8] PHEV and select its components. In July 2016, the project team met at EDI to review the proposed renewable NG plug-in hybrid electric armored truck data design and integration of the PowerDrive™ 6000 PHEV drivetrain. Upon the completion of the review meeting, EDI worked on the mechanical integration of the PowerDrive™ 6000 PHEV drivetrain into the truck. The first steps included removing the conventional powertrain components not needed in the new PHEV design (such as the transmission) and taking accurate measurements of the transmission tunnel to adjust the preliminary design. In parallel, EDI assembled the different modules to be installed in the truck: PowerDrive™, high voltage battery, high voltage module, low voltage module, electrified accessories, and cooling system. Once all the modules were completed and the vehicle was prepared for assembly, EDI installed all the modules. The last tasks included the PowerDrive™ 6000 PHEV drivetrain commissioning and calibration. This completed installation can be seen in Figure 17 on the next page.

[8] PowerDrive 6000 Drivetrain https://electriccarsreport.com/2016/11/edi-powerdrive-6000-phev-system-hits-1m-miles/

This proved to be a challenging process creating significant delays by EDI to complete the first truck, the continued project delays were caused by lack of resources and delivery delays of their batteries and drive train from China as well as other parts that were critical to the build. The estimated delay was approx. One year from May 2016 to May 2017. It was such a lengthy delay that NAR was not able to make up the time which forced a delay in the entire project extending past the grant deadline.

Figure 17: EDI's Variable Frequency Drive Installed

Source: NAR

EDI Commissioning and Integration Test Plan

Upon completing the assembly of a vehicle, EDI performed a commissioning procedure to ensure all components and subsystems were installed and operating correctly. Once this passed, a second procedure evaluates the overall performance of the systems in the vehicle and culminates with a 500-mile test drive in a variety of conditions to ensure proper vehicle operation. The vehicle then went through a final visual inspection for safety items and is readied for delivery to the customer.

Visual Inspection

Prior to commissioning, a visual inspection was performed on all systems. All mechanical mounting features are inspected to confirm proper installation and torque striping.

Mechanical wiring was inspected for proper installation, securing, strain relief, and termination. Pull tests were performed on a random set of wires to confirm proper crimping. All hoses and cooling system components were inspected for leaks. A pressure check was done on the AC system to ensure pressure integrity. All fluid reservoirs were inspected to ensure each is filled within acceptable levels. A safety inspection was also performed to ensure proper labeling and marking of high voltage components and rotating machinery.

Commissioning

The commissioning process involves individually testing each of the components and subsystems installed on the vehicle. It began with a checkout of the low voltage systems such as 12-volt key-on, parking brake operation, PRNDL operation[9], cooling pumps, heaters, fans, throttle and brake position sensors, clutch operation, and HVIL integrity[10]. The next step was to evaluation the communication system on the vehicle. The EDI hybrid system communicates on a CAN bus[11] separate from the vehicle CAN bus, but also connects the two and translates messages as needed. The checkout process goes through each component and confirms proper communication on all CAN buses. This would include communication to main drive inverters, aux inverters, direct current converters, chargers, engine controllers, HVAC controllers, and CAN based sensors and actuators. The most up-to-date vehicle specifications of the remodeled PHEV armored truck can be seen in Figure 18 below.

Figure 18: PHEV Vehicle Specification

EFFICIENT DRIVETRAINS   Vehicle Specifications (PHEV)   NORTH AMERICAN REPOWER

Curb Weight/GVWR	14, 500/25,500 lbs	High Voltage Electrical	
Wheel Base	355.6 cm	Plug In Charger	
Trans / Electric Drive	EDI PD6000	Electrified A/C	
Flywheel Housing	Was SAE #2 or #3 adapter used?	Electrified Power Steering	
Brakes	Bosch Hydraulic Split Brake System, Regenerative Braking Through PD6000		
Low Voltage Electrical	2X 12V batteries 1100 CCA		
Alternator	115 A		
Engine	International DT466 I6 CNG C215		
Throttle	Electronic		
Fuel Tanks	CNG Type 3, Roof Mount (56.7 DGE)		
Battery Capacity			
Electric Only Range	25 Miles		
Total Range			

Source: EDI

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[9] PRNDL Power Switch https://patents.google.com/patent/US5861800A/en
[10] High Voltage Interlock Loop https://static.nhtsa.gov/odi/tsbs/2014/SB-10052449-4313.pdf
[11] Controlled Area Network https://www.csselectronics.com/screen/page/simple-intro-to-can-bus/language/en

CHAPTER 5: Data Collection, Test Results, Voice of Customer

Data Collection

There were several approaches taken to ensure we had the most accurate data utilizing multiple collection processes. The collection and analysis were performed by both EDI and CarbonBLU, a third-party service provider.

Data Collection Specifics are as Follows:

Evaluate Baseline Scenario: CarbonBLU used the SEMTECH-DS[12] to perform PEMS testing[13] on an existing Sectran diesel truck to set a baseline and then conduct PEMS testing on a newly converted renewable NG plug-in hybrid electric truck for comparison. Testing occurred over a single daily duty cycle for each truck. CarbonBLU's Emission results were based upon a specific driving route in which the emissions tests duplicated speeds, loads and idle times. CarbonBLU results were all run on the same route. Fuel economy and fuel cost savings data were derived from actual data on six different trucks collected by EDI that were operated on different Sectran specific routes.

Monitor Usage with Testing and Validation Drivers: NAR in conjunction with EDI installed CAN-BUS data loggers on all Sectran trucks for ongoing measurement of drive cycle performance variability and fuel consumption during the formal six-month data collection and analysis period. Data loggers tracked a series of data points defined in the test plan developed during the design phase. Measured units included: electric energy consumption, drive cycles, fuel consumption, kilowatt per/mile, and miles per gallon (MPG).

Calculate Benefits: Tangible benefits were recorded, and we calculated the fuel consumption rates vs. diesel, average and cumulative emissions vs. diesel, cost of operation vs. diesel, operational up time vs. diesel, maintenance costs vs. diesel, and driver satisfaction/experience vs. diesel. Much of this data was gathered weekly, analyzed, and summarized on a weekly and monthly basis, projected to annual results.

User Satisfaction and Acceptance: Surveys were used to collect input from drivers and O&M personnel, and to gain input on their experience with the new renewable NG plug-in hybrid electric trucks on a monthly basis. The team designed and distributed a survey, "Voice of the Customer", filled out by various positions within Sectran to better understand their experience and to better evaluate their satisfaction or dis-satisfaction in an effort to determine how best to serve the customer. Their input was critical to understand improvements that will be required for future technical and functionality improvements.

[12] SEMTECH https://www.semtech.com
[13] Portable Emissions Measuring Systems https://automotivetesting.com/pems

Test Results

CarbonBLU's Evaluation of Baseline:

The results show that conversion of the armored truck from an older, conventional diesel to a RNG (spark-ignited) PHEV with a 20-mile, EV-only range resulted in significant emissions reductions. Benefits were maximized in the best-case scenario where drivers consistently recharge the PHEV at night to take advantage of the available battery storage. If they did not do so, the EV range of the vehicle was reduced and less of the driving occurred with zero tailpipe emissions. Although the payload of the PHEV was significantly reduced by the added weight of the batteries, this is not seen as enough of a reduction to interfere with the utility of the vehicles since they are used by Sectran and required a limited load and only one person in the cargo bay area. However, the curb weights of the vehicles are substantially increased by the EV system which reduces efficiency when compared to a diesel or RNG only vehicle.

Although the CO2 inventory slightly increases with the PHEV, the other pollutants are all greatly diminished. Most noteworthy among those is the particulate inventory, which was reduced by almost two orders of magnitude (from 1.5 gallons per day, down to 0.036 gallons per day). As mentioned above, and can be viewed in Table 1 below, these results are not *as* dramatic if the PEHV is not fully charged overnight. However, even in the worst-case where the batteries were not charged at all, the PHEV still provides very significant reductions in pollutants and in fuel consumption. Also, Nonmethane Hydrocarbons (NMHC) can be seen in Table 1, fourth down from the top.

Table 1: Modeled Daily Mass Emissions: Sectran Duty-Cycle (PHEV Charged Overnight)

	PHEV Plugged-In O-night Typical Total Daily Emissions	
	Diesel	PHEV*
CO2 (kg/day)	111	51
CO (kg/day)	0.368	0.441
NOx (kg/day)	0.982	0.290
NMHC (kg/day)	0.0829	0.0195
PM (g/day)	1.474	0.036

* Assumes 20-mile EV-only range to begin day and does not account for local energy grid emissions.

Source: NAR staff

As shown in Table 2 on the next page, the PHEV vehicle had significantly lower CO2 emissions than the baseline vehicle for all tests. Meaning it consumed less fuel per unit time in all modes of operation. As expected, the diesel vehicle had much higher NOx and particulate emissions than the RNG PHEV vehicle. The diesel vehicle had the inherently low CO2 emissions that are typical of most diesels. The CO2 from the CNG PHEV vehicle was much higher than from the diesel, but still typical for a spark-ignited engine with no exhaust after-treatment. A simple passive oxidative catalyst would eliminate this amount of CO2.

Table 2: Average Emissions Test Results for Each Vehicle and Test Type

	Test-Averages: Time-Specific Emissions Rates							
	Diesel				PHEV			
	High-Spd	Med-Spd	Low-Spd	Idle	High-Spd	Med-Spd	Low-Spd	Idle
CO2 (g/min)	681	469	220	94	597	354	0	0
CO (g/min)	0.888	0.837	0.777	0.701	3.27	3.50	0	0
NOx (g/min)	5.05	3.75	2.34	0.99	1.95	2.76	0	0
NMHC (g/min)	0.195	0.200	0.201	0.161	0.211	0.142	0	0
PM (mg/min)	9.34	6.32	1.99	1.15	0.424	0.198	0	0

Source: NAR staff

Table 3 below summarizes CarbonBlu's calculation results for total daily emissions on a typical Sectran day from the test vehicles. This scenario assumes that the PHEV was not plugged-in overnight. The modeled cold-start emissions are shown on the left, the warm-operation emissions in the middle, and these two are added to give the total emissions inventory for each pollutant on the right. Notice that the emissions totals are in kg per day for the gases and grams per day for the particulate.

Discussing the CO2 results for the diesel vehicle, during cold-start on a typical day it would emit about four kg of CO2 (top-left corner of left table). After warming up, the vehicle would spend the next seven hours or so running non-stop, which would result in the production of about 107 kg more of CO2 (top-left corner of middle table). These two results add to the total CO2 inventory for the diesel vehicle of 111 kg of CO2 (top-left corner of right table).

Table 3: Total Mass Emissions per Day – PHEV not Charged Overnight

	Typical Cold-Start Daily Emissions			PHEV Not Plugged-In Typical Warm Daily Emissions			PHEV Not Plugged-In O-night Typical Total Daily Emissions	
	Diesel	PHEV		Diesel	PHEV		Diesel	PHEV
CO2 (kg/day)	4	5		107	73		111	78
CO (kg/day)	0.039	0.082		0.329	0.566		0.368	0.648
NOx (kg/day)	0.050	0.030	+	0.932	0.410	=	0.982	0.440
NMHC (kg/day)	0.0055	0.0020		0.0774	0.0275		0.0829	0.0295
PM (g/day)	0.118	0.007		1.356	0.046		1.474	0.052

Source: NAR Staff

EDI Test Results

EDI's data in Figures 19-24, on the following pages, shows the fuel economy for the Diesel engines in each of these Class 6 armored trucks was about 4.0 MPG. The RNG–PHEV Class 6 armored trucks would get anywhere from 5.0 to 9.2 MPG. Truck number 828–F19 which had the most miles of 15,327 saved approximately 3,832 gallons of diesel fuel.

These RNG–PHEV Class 6 trucks are about 53–71 percent less expensive to operate than diesel engine on these types of routes. It is very important to note that this savings would be improved up to 65-80 percent by simply plugging them in to the electrical grid and charging the trucks daily.

Third party testing with CarbonBLU has confirmed that RNG operation resulted in much lower NOx emissions during cold start and normal steady state temperature operation with the most significant reduction during the high-speed testing from 5.05 gallons per minute to 1.62 gallons per minute. The RNG trucks also emitted less NOx at medium speed, low speed, and idle conditions. The total daily NOx emissions with RNG is 0.356 kg per day vs diesel at 0.982 kg per day for a significant reduction with RNG.

The RNG and PHEV vehicles emitted more CO2 in all conditions with the plugged in PHEV at .441 kg per day vs 0.368 kg per day which is only 0.073 kg per day delta increase. A simple passive oxidative catalyst would eliminate this level of CO2 emissions.

The PHEV vehicles plugged in and not plugged in emit less CO2 emissions with 0.51 kg per day and 0.78 kg per day respectively vs diesel which was emitting 111 kg per day.

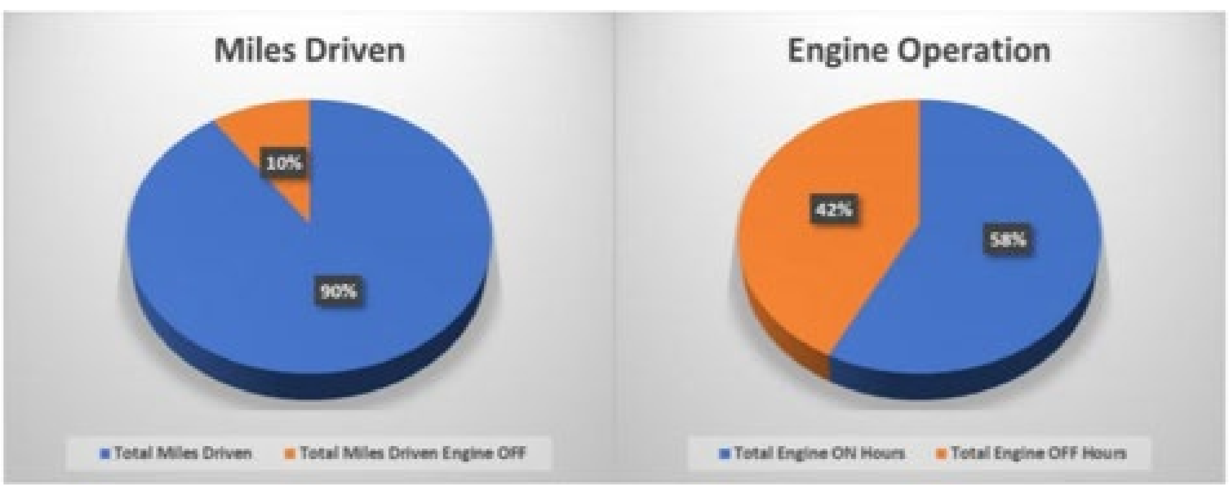
Total mass emissions of NMHC and PM are less on the RNG and PHEV converted trucks.

The RNG Trucks emitted the lower levels of NMHC than the diesel or the PHEV that was not fully charged. RNG NMHC was 0.0265 kg per day as opposed to diesels 0.0829 kg per day. PHEV plugged in was the lowest of all at 0.0195 kg per day.

Particulate matter was significantly lower in all conditions with RNG and PHEV not charged and plugged-in, than the diesel engine which emits 1.474 kg per day vs 0.161 kg per day, and 0.052 kg per day, and 0.036 kg per day.

In conclusion, converting older medium duty trucks with no after treatment to operate on RNG and PHEV (fully charged PHEV) would contribute significantly to the reduction in CO2, NOx, NMHC, and PM.

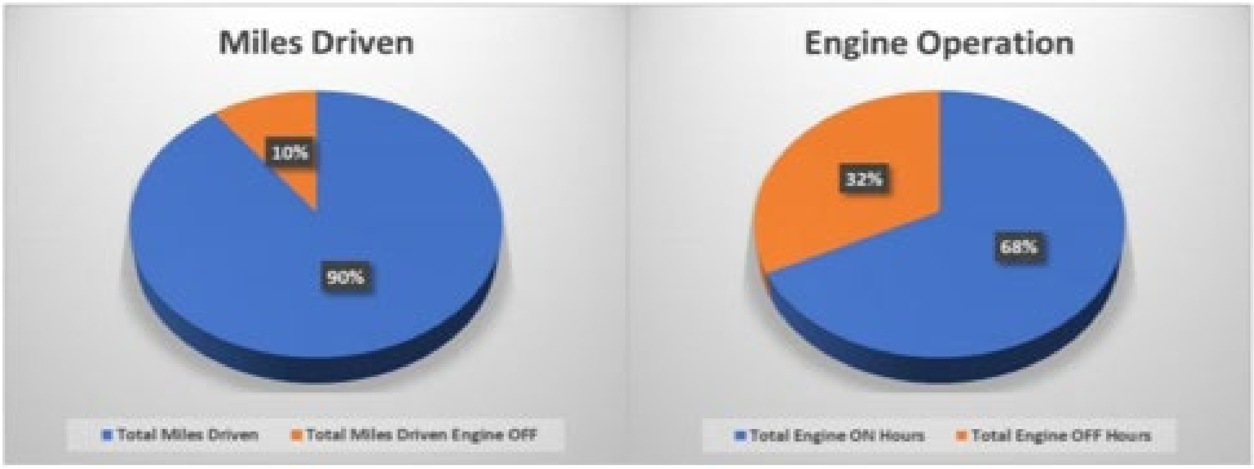
Figure 19: Truck 828 Miles Driven Engine off and Operation Key on Engine off



Truck 828 – F04 drove 10% of the total miles driven with the engine off and for 42% of the time when the truck was key on, the engine was off, eliminating over 585 hours of engine operation and associated wear and tear.

Source: EDI

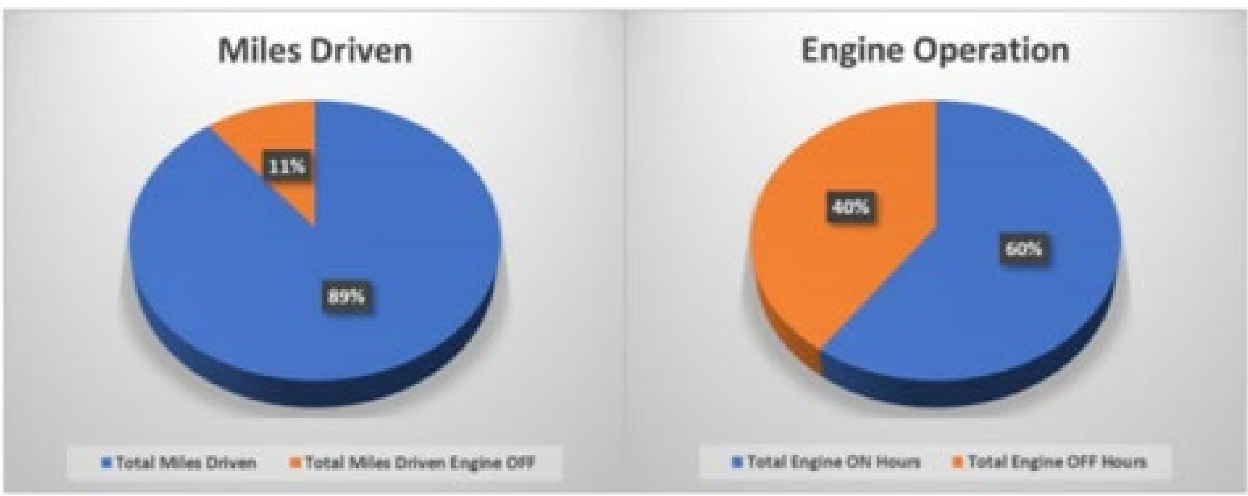
Figure 20: Truck 829- Miles Driven Engine off and Operation Key on Engine off



Truck 829 – F05 drove 10% of the total miles driven with the engine off and for 32% of the time when the truck was key on, the engine was off, eliminating over 295 hours of engine operation and associated wear and tear.

Source: EDI

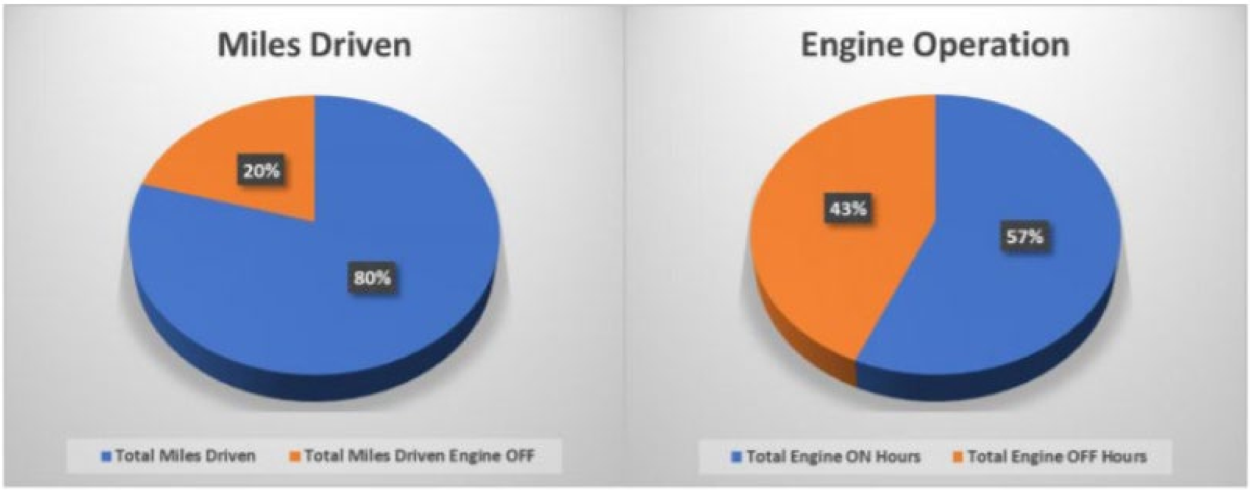
Figure 21: Truck 830- Miles Driven Engine off and Operation Key on Engine off



Truck 830 – F08 drove 11% of the total miles driven with the engine off and for 40% of the time when the truck was key on, the engine was off, eliminating over 21 hours of engine operation and associated wear and tear.

Source: EDI

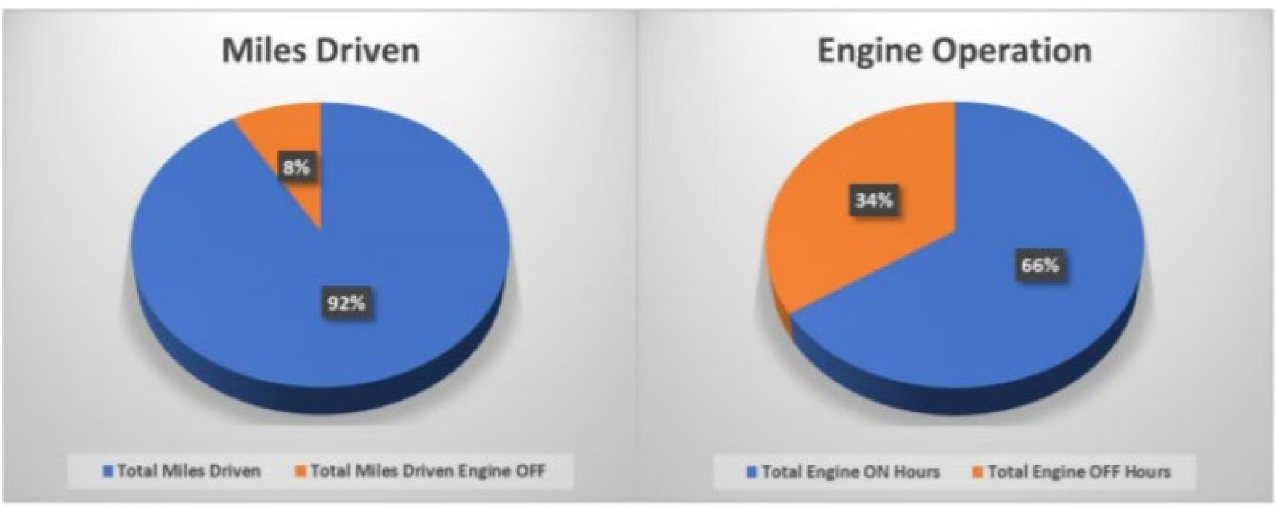
Figure 22: Truck 831- Miles Driven Engine off and Operation Key on Engine off



Truck 831 – F07 drove 20% of the total miles driven with the engine off and for 43% of the time when the truck was key on, the engine was off, eliminating over 50 hours of engine operation and associated wear and tear.

Source: EDI

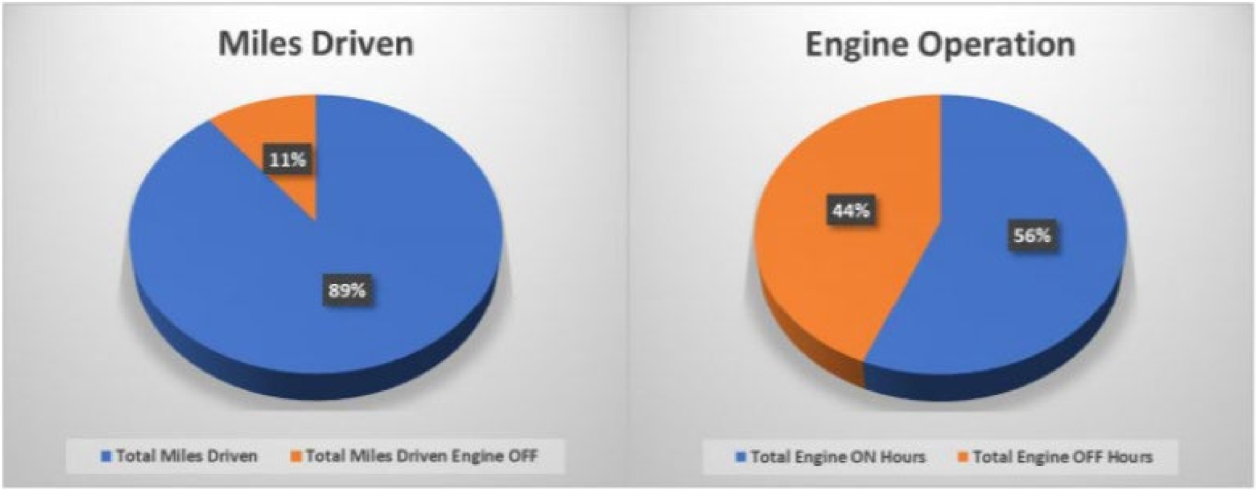
Figure 23: Truck 832- Miles Driven Engine off and Operation Key on Engine off



Truck 832 – F09 drove 8% of the total miles driven with the engine off and for 34% of the time when the truck was key on, the engine was off, eliminating over 125 hours of engine operation and associated wear and tear.

Source: EDI

Figure 24: Truck 834- Miles Driven Engine off and Operation Key on Engine off



Truck 834 – F06 drove 11% of the total miles driven with the engine off and for 44% of the time when the truck was key on, the engine was off, eliminating over 157 hours of engine operation and associated wear and tear.

Source: EDI

Fuels Economy Data

Tables 4-9 show an analysis of the fuel economy data for trucks 828-834.

Table 4: EDI Data and Analysis of Fuel Economy Truck 828

Truck 828	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
828-F04 Average MPG in Hybrid Mode	6.2 MPG
828-F04 Average MPG	6.9 MPG
Diesel Fuel Displaced	3832 Gallons of diesel

Source: EDI

Table 5: EDI Data and Analysis of Fuel Economy Truck 829

Truck 829	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
829-F05 Average MPG in Hybrid Mode	4.9 MPG
829-F05 Average MPG	5.5 MPG
Diesel Fuel Displaced	2540 Gallons of diesel

Source: EDI

Table 6: EDI Data and Analysis of Fuel Economy Truck 830

Truck 830	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
830-F08 Average MPG in Hybrid Mode	6.2 MPG
830-F08 Average MPG	7.0 MPG
Diesel Fuel Displaced	167 Gallons of diesel

Source: EDI

Table 7: EDI Data and Analysis of Fuel Economy Truck 831

Truck 831	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
832-F09 Average MPG in Hybrid Mode	7.3 MPG
832-F09 Average MPG	9.2 MPG
Diesel Fuel Displaced	391 Gallons of diesel

Source: EDI

Table 8: EDI Data and Analysis of Fuel Economy Truck 832

Truck 832	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
831-F07 Average MPG in Hybrid Mode	5.3 MPG
831-F07 Average MPG	5.8 MPG
Diesel Fuel Displaced	937 Gallons of diesel

Source: EDI

Table 9: EDI Data and Analysis of Fuel Economy Truck 834

Truck 834	Environmental Benefits
Conventional Diesel Average MPG	4.0 MPG
834-F06 Average MPG in Hybrid Mode	6.1 MPG
834-F06 Average MPG	6.9 MPG
Diesel Fuel Displaced	847 Gallons of diesel

Source: EDI

User Satisfaction

Voice of the Customer Questionnaire

We feel that the customers input is critical to understand the success or failure of the proposed project and the effects on their business. On February 15, 2018 Sectran was sent the "Voice of the Customer" questionnaire where they were given the opportunity to determine ratings from 1-5 and noting both pros and cons of the project from their prospective.

After receiving the completed questionnaire from the Sectran fleet manager, on May 15, 2018, it was noted that Sectran had the following concerns:

- Heat and engine exhaust emissions entering the driver compartments through cracks throughout the body and driver compartment.
- EDI electrical connections and the ability of the connections to be watertight. When it rains and the electrical components become wet from their daily drive this causes the trucks to shut down.
- Engine abuse or wear at start up from PHEV operation. At engine start up from PHEV mode the engine is engaged at a rotations per minute of 2200, this can cause possible longevity problems to the engine's internal components.
- The new EDI AC compressors did not work properly with the vehicles original AC system. Due to older AC components in poor condition, lack of maintenance and years of abuse and soot build up within the vehicle's original AC systems evaporator and condenser units, the new EDI AC Compressor units had little effect to combat the heat of the Electrical batteries and engine exhaust.
- The vehicles complete AC system was not updated. The added heat from the batteries in the cargo bay created an unsafe condition for the men that need to ride in there. The original vehicles AC evaporators and AC condenser were later replaced, which helped, but the issue, to some degree, remained.
- Poor electrical connections and failure of components throughout the EDI hybrid system, resulted in complete immobilization of the vehicle during periods of operation.
- The overall weight of the EDI hybrid system and the effect on the vehicle chassis and suspension.
- High capital cost to install a battery charging system to recharge the EDI hybrid system at night when the vehicles were not in operation.

Overall, Sectran was pleased with the RNG operation and engine performance, but had problems with the hybrid operation, electrical components, electrical connections and lack of cooling from the vehicles AC systems to combat the higher engine exhaust temp and heat generated from the vehicles electrical batteries.

Sectran was pleased overall with the service and support received from both NAR and EDI throughout the build and operation period of the grant. They stated that they also noticed a considerable amount of fuel cost savings running the RHG/PHEV vehicle over the traditional diesel fueled vehicles and the environmental impact and benefit that these hybrid vehicles provide while being in service.

However, according to Sectran the hybrid electrical system did not prove to be reliable for everyday use and, due to high electrical system warranty costs, they did not choose to purchase an extended vehicle warranty option from EDI.

Unfortunately, the hybrid trucks experienced many electrical issues related to poor electrical connections and components. The electrical hybrid drive installation quality, mounting selection and materials also posed a problem, contributing to the vehicle being down for extended periods of time

Throughout the process of the grant trial period Sectran expressed interest in a NAR engine only solution and related RNG fuel system solution without the electrical hybrid system. Because of the high capital costs of the EDI hybrid electrical system, service, and repair related issues, Sectran would not recommend nor purchase additional RNG/PHEV hybrid vehicle such as these.

CHAPTER 6: Conclusion

In conclusion, converting older medium duty trucks with no after treatment to operate on RNG and PHEV (fully charged PHEV) would contribute significantly to the reduction in CO2, NOx, NMHC, and PM as shown above in the testing data if the resulting trucks can be made reliable. Most significantly, as these vehicles operate nearly 100 percent in urban environs, these reductions could bring welcome relief to many disadvantaged communities in California.

Had Sectran installed the designated charging units at their facility, we would have seen better results. It is our understanding they only had one charging unit installed. The cost may have been prohibitive for a small company, such as Sectran, to upgrade their facility for higher electrical output to enable the daily charging requirements of six hybrid vehicles.

In addition to emission reductions there is also significant fuel savings based on the fact the trucks no longer use diesel. Whereby the conventional diesel average MPG is 4.00, with the average MPG for hybrid mode is 6.3. The economic benefits according to EDI's data analysis, for conventional diesel trucks is $0.92 per mile. With the CNG/PHEV economics benefits being $0.33 per mile and if charged every day the operating costs would then drop to $0.24 per mile.

There were also additional costs incurred in converting the older trucks combining the current electric drive components with much older electric components found on the diesel vehicle which proved to be problematic.

Unfortunately, the cost to purchase and maintain the vehicles proved not to be cost effective. For Sectran the six CNG/PHEV hybrid vehicles have been down since August 2018, due to unknown electrical hybrid issues. Their incredibly generous donation to the grant has cost them much more $145,000 cost per vehicle, but the loss of business they have incurred with the trucks being down which is a cost that cannot be measured. Simply put, the CNG/PHEV solution is cost prohibitive given the current costs of the PHEV System and the extended warranty. As a company you would see a fuels savings, as well as the trucks providing a reduction in CO2, NOx, NMHC, and PM, but the costs to purchase and maintain the system would not be cost effective, and the PHEV has proven to be an unreliable solution.

EDI's PHEV solution for heavy duty vehicles proved to not be ready for commercial role out. EDI's recent purchase by Cummins[14] should enable its product to be developed to a much higher level of reliability. However, the current heavy duty EV technology is deeply hampered by the added weight from batteries and the inadequacy of the cooling systems for these batteries. As documented by this demonstration project, operation of heavy-duty vehicles on RNG is the lowest emissions solution available, even when the vehicles are handicapped with the additional curb weight of a non-contributory EV system.

[14] Cummins Website https://www.cummins.com/

Unfortunately, the Volkswagen mitigation funding made available to California fleets from the diesel emissions settlement came at a time when diesel fuel prices are down and PHEV/RNG solutions are still coming to market. The newer heavy-duty diesel vehicles purchased to replace older diesels are not capable of bringing emissions relief to urban locations, and will remain in operation for another 10-25 years, and only add to California's carbon footprint as newly created vehicles. Although NAR's RNG conversion technology is market ready and CARB certified, market conditions and the availability of CNG in local stations is a limiting factor allowing for success as a viable option for commercialization as we had hoped at the start of this grant as part of the project purpose.

GLOSSARY

AIR CONDITIONING (AC)—is an air conditioning system that is specifically designed to provide climate control for the interior of an automobile. Before the introduction of air conditioning in automobiles, the only standard method of cooling the interior was to open the windows. Auto air conditioning creates a much more comfortable environment for the passengers of a vehicle.[15]

CALIFORNIA AIR RESOURCES BOARD (CARB)— The state's lead air quality agency consisting of an 11-member board appointed by the Governor, and just over thousand employees. CARB is responsible for attainment and maintenance of the state and federal air quality standards, California climate change programs, and is fully responsible for motor vehicle pollution control. It oversees county and regional air pollution management programs.

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

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

CARBON DIOXIDE (CO2)—A colorless, odorless, nonpoisonous 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).

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.

EFFICIENT DRIVETRAINS Inc. (EDI)— EDI develops a range of state-of-the-art proprietary drivetrain products and technologies that have direct application in PHEVs, HEVs, and BEVs worldwide.[16]

ELECTRIC MOTOR (EM)—An electric motor is an electrical machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding to generate force in the form of torque applied on the motor's shaft. Electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters, or electrical generators. An electric generator is

[15] Air Conditioning Defined https://www.wisegeek.com/what-is-auto-air-conditioning.htm
[16] Efficient Drivetrains Facebook Site https://www.facebook.com/efficientdrivetrains

mechanically identical to an electric motor, but operates with a reversed flow of power, converting mechanical energy into electrical energy.[17]

ELECTRIC VEHICLE (EV)—A broad category that includes all vehicles that are fully powered by electricity or an electric motor.

GRAM (g)—A metric unit of mass equal to $^1/_{1000}$ kilogram and nearly equal to the mass of one cubic centimeter of water at its maximum density.[18]

GREENHOUSE GAS (GHG)—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O3), per fluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

HYBRID ELECTRIC VEHICLE (HEV)—A vehicle that combines an internal combustion engine with a battery and electric motor. This combination offers the range and refueling capabilities of a conventional vehicle, while providing improved fuel economy and lower emissions.

INTERNAL COMBUSTION ENGINE (ICE)—The ignition and combustion of the fuel occurs within the engine itself. The engine then partially converts the energy from the combustion to work.

KILOGRAM (kg)—The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density.

MILES PER GALLON (MPG)—A measure of vehicle fuel efficiency. Miles per gallon or MPG represents "Fleet Miles per Gallon." For each subgroup or "table cell," MPG is computed as the ratio of the total number of miles traveled by all vehicles in the subgroup to the total number of gallons consumed. MPGs are assigned to each vehicle using the EPA certification files and adjusted for on-road driving.

NATURAL GAS (NG)—Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane, and other gases.

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx)—A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.

NONMETHANE HYDROCARBONS (NMHC)—are important reactive gases in the atmosphere since they provide a sink for hydroxyl radicals and play key roles in the production and destruction of ozone in the troposphere.[19]

PARTICULATE MATTER (PM)—Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines.

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[17] Electric Motor Definition https://en.wikipedia.org/wiki/Electric_motor
[18] Gram https://www.merriam-webster.com/dictionary/gram
[19] Nonmethane Hydrocarbons https://www.sciencedirect.com/topics/earth-and-planetary-sciences/nonmethane-hydrocarbon

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).

RENEWABLE NATURAL GAS (RNG)—Or biomethane, is a pipeline-quality gas that is fully interchangeable with conventional gas and thus can be used in natural gas vehicles. RNG is essentially biogas (the gaseous product of the decomposition of organic matter) that has been processed to purity standards. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).[20]

SECTRAN SECURITY (Sectran)—Sectran Security has provided fully insured and licensed armored transportation services to thousands of customers in retail, banking, and private industries throughout Southern California since 1982.[21]

[20] U.S. Department of Energy (https://afdc.energy.gov/fuels/natural_gas_renewable.html)
[21] Sectran Security https://www.sectransecurity.com/