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Demonstration of Heavy Hybrid Diesel Fleet Vehicles

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14. ABSTRACT
NAVFAC EXWC conducted demonstration validation testing on two heavy hybrid truck platforms. The first platform included a hybrid hydraulic refuse truck for curbside collection of recyclables. The second platform included a hybrid electric utility truck with an aerial lift system (i.e., bucket truck) for electric power line maintenance. The demonstration included a baseline evaluation at Aberdeen Proving Grounds, MD, followed by in-use operator testing at Bangor WA, and San Diego CA. The performance objectives included fuel economy, noise levels, brake wear, ease-of-use, maintainability, and drivability.

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Heavy Duty Vehicle, Hybrid Electric, Hybrid Hydraulic, Utility Truck, Refuse Truck, Fuel Efficiency, Noise Levels.

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EXECUTIVE SUMMARY

Environmental Security Technology Certification Program (ESTCP) Office awarded funds for a project to demonstrate heavy diesel hybrid trucks for non-tactical fleet applications. Naval Facilities Engineering Command (NAVFAC), Engineering and Expeditionary Warfare Center (EXWC) provided overall coordination for testing execution. Test objective was to evaluate cost and performance benefits of two primary types of heavy hybrid platforms for Department of Defense (DoD) Public Works applications.

The project team purchased four test trucks for the demonstration, including one pair of refuse trucks and one pair of utility trucks. Each test pair included a conventional truck baseline, and a hybrid truck of equivalent make, model year, and production run. Refuse trucks were built on a refuse truck chassis, with four individual troughs and side loaders for collection of separated recyclables. Utility trucks are based on a utility truck platform, and an aerial lift body to support utility line maintenance. The hybrid equipped utility truck is an electric configuration with battery storage, regenerative braking, launch assist, and engine-off power. Both the hydraulic and the electric hybrid systems are parallel configuration, where both the engine and the hybrid system can turn the drive axle (together or independently).

Test applications for each truck pair are common to the DoD. The refuse truck application is representative of pickup and delivery applications. The utility truck application is representative of stationary work applications requiring on-board power. Both applications show potential for broad integration across the DoD non-tactical vehicle fleet, and provide opportunities for fuel economy and noise reduction benefits.

Validation efforts included both track and site testing. Track testing provided baseline data using controlled drive cycles for reference evaluation of fuel economy and noise profiles. For site testing, host sites integrated the trucks into their routine operations for evaluation of drivability, maintainability, reliability, and ease-of-use. Track test procedures were designed as objective evaluation quantitative performance criteria and numerical results. Site testing relied heavily on feedback from the host operating and service teams with emphasis on qualitative performance.

The project team accomplished baseline testing at Aberdeen Proving Grounds. Aberdeen Test Center (ATC) provided all personnel and equipment for fuel economy testing on selected track facilities. Utility truck drive cycles included a one-hour test consisting of 12 minutes of mild driving and 48 minutes of stationary lifting, also known as the DoD Test Cycle. For the refuse trucks, ATC followed the Combined International Local Commuter Cycle (CILCC), a 30-minute drive cycle developed by industry that includes a combination of rural and suburban driving. ATC conducted a minimum of three valid test runs on each truck.

The project team also conducted noise testing at APGM track and road facilities. ATC provided truck operators and NAVFAC EXWC collected noise measurements on the sound level meters. EXWC used hand-held instruments to monitor A-weighted sound pressure levels. EXWC measured indoor noise following guidance with Federal Motor Carrier Safety Administration (FMCSA) 393.94. EXWC measured outdoor idling and acceleration noise as specified by International Standards Organization (ISO) Standard 362 guidelines. Microphone receptors for in-cabin measurements were six inches from the driver's left ear (vice the right ear)

for secure mounting and fastening of the microphones. For idle measurements, test personnel collected measurements at several locations around the perimeter of the truck, up to 10 feet from the truck body. Receptor locations for the drive-by acceleration testing were 25 feet from the centerline of the truck's direction of travel.

Fuel economy results were generally consistent for the track and the site testing. Hybrid refuse truck showed no fuel economy improvement for CILCC drive cycle tests, or for the on-site testing. Track testing indicated a 13 percent reduction in fuel economy, as the regenerative braking and launch assist are not designed for mild accelerations and coasting in the CILCC cycle. Site testing showed similar fuel economy for both refuse trucks. The system is intended for repeated stop/go deliveries at low average speed. The hybrid utility truck fuel economy demonstrated 75 percent higher fuel economy for the DoD Test Cycle, and a 15 percent improvement in fuel economy for the CILCC drive cycle. Site testing result showed an overall fuel economy improvement of 32 percent over the site testing period. Important to note is the site testing consisted of 10 to 20 percent lifting at most, as compared with 80 percent lifting for the DoD track test cycle.

Both the hybrid technologies were partially effective at reducing noise, depending on location and operational mode. Hybrid trucks reduced in-cabin noise levels by 40 percent during the acceleration events. Indoor noise was higher for deceleration or steady speed modes, apparently due to noise from the truck's regenerative braking systems. Both the hybrid trucks had higher outdoor noise levels than the baseline trucks for acceleration and deceleration modes. The hybrid utility truck, however, offered a significant noise reduction benefit in the engine-off power take-off (PTO) mode. During the stationary (idling mode) the hybrid utility trucks provided a 50 to 80 percent noise reduction.

NAVFAC deployed the truck pairs for site testing for a minimum of six months. NAVFAC Southwest launched the utility trucks into service in June 2011. The project team monitored utility trucks through March 2012. The hybrid utility truck saw 50 percent greater usage (i.e., operating hours) than the conventional, and over 80 percent higher mileage due to routine dispatches to MCAS Miramar, most remote of the San Diego dispatch service points. NAVFAC Northwest deployed the refuse trucks into solid waste collection operations in February 2012, nearly one year after receiving the trucks. Delays were due to a series of retrofits to make the side loaders compatible with Naval Base Kitsap (NBK) Bangor's waste collection containers. Initially, the hybrid refuse truck mileage was far higher than the conventional truck. In June 2012, NAVFAC Northwest adjusted the collection route, with both trucks operating under similar distances and operating cycles through August 2012.

Neither hybrid system required maintenance during the demonstration period. Also, there were no symptoms or issues that suggested the hybrid systems would become a future maintenance liability. All maintenance on the truck involved either the chassis or the application bodies. Both hybrid platforms showed less brake wear than the conventional counterparts. The hybrid hydraulic had 23 percent the wear of the conventional refuse truck brakes. The hybrid electric utility truck brakes had 63 percent less wear than the conventional truck brakes.

Economics depends on the severity of the duty cycle. We believe the best case scenario for the hybrid hydraulic systems are a recycling application. Project team received input on hybrid truck drivability during site testing. The hybrid hydraulic-equipped refuse truck received positive feedback, with the operator team noting the hybrid truck was comparable to the conventional truck. With the exception of the regenerative braking, the hybrid hydraulic truck was transparent to the drivers. NAVFAC Southwest found the hybrid electric utility truck acceptable for off-engine work in the quiet PTO mode, and noted the hybrids excellent startup. Concerns included lack of power for low speed acceleration and excessive shifting when driving on hilly roads. Drivability issues suggest further programming and optimization is necessary for the hybrid electric technology on this truck. This result suggests that fleet managers and procurement officials write the procurement specifications to ensure new trucks meet the performance requirements of the intended field application, and emphasize any special requirements for driving on hills and highways.

Both hybrid trucks met ease of use objective that indicates the level of training required. The hybrid launch assist (HLA) system on the refuse truck was transparent to the operator. There are no special operating procedures or controls that require driver attention. A one-hour training class and two to three hours of driving is sufficient orientation for the operators to adjust to the heavy braking characteristic when lifting the accelerator pedal. Additional driving procedures for the hybrid electric utility truck included attention to engine and transmission settings. Procedures were straightforward and the preliminary operator training was a sufficient orientation for the operators.

In terms of performance acceptance the hybrid refuse truck failed to meet the critical performance objectives for fuel economy. This result is not associated with the hybrid system itself, but due to the mild driving cycle typical of most non-tactical truck applications on DoD facilities. If placed in a severe duty cycle, further consideration is warranted, however it does not appear the DoD has a significant number of related applications. The hydraulic hybrid also fell short of the noise reduction objective for outdoor noise, instead increasing noise by 20 percent. The noise result is not final, and may be readily addressed by the manufacturer for next generation models through under-chassis shielding and dampening. The project team concludes that the design of the current generation hybrid hydraulic system is not compatible with most DoD duty cycles.

The hybrid utility truck successfully achieved four of the six the performance acceptance parameters, including fuel economy, noise, maintainability, and ease of use. The truck fell short of the drivability and brake wear objectives. The drivability characteristics were expressed as a considerable annoyance. The project team considers drivability as a work-in-progress that will improve with further engineering and software optimization. This was demonstrated in August 2011, when reprogramming helped address operator complaints by improving the shifting. Hybrid utility brake wear was 37 percent less, falling short of the 50 percent objective. As with drivability, brake wear can be improved with further optimization to meet the objective. Hybrid electric utility truck is considered acceptable by the project team, with the caveat that procurement officials give extra attention to ensure performance requirements of new purchases are carefully matched to the application, and that transportation officials require pre-acceptance truck inspections and test trials to ensure trucks meet minimum performance requirements.

Cost assessment for the hybrid trucks considers both capital and operating cost factors. In order to realize a payback for the hybrid cost premiums, the trucks must have high utilization and associated cost savings from reduced fuel use. Hybrid hydraulic refuse truck would not achieve simple payback for the mild drive cycle common to DoD applications. The target duty cycle application for a cost savings includes frequent and abrupt stops and starts. Hypothetically the system is capable of fuel savings improvements up to 30 percent under the abusive duty cycle. Without this fuel economy savings, the system has no chance of recovering the investment into this type of system for routine pickup/delivery applications.

A hypothetical scenario where the hybrid refuse truck would be cost effective includes six hours of daily use at low average speeds and multiple stops. The duty cycle assumes a 7,500 annual mileage, a $30,000 cost premium for the hybrid system, and $5 per gallon for petroleum diesel. This scenario would realize simple payback assuming a 20 percent efficiency improvement. Savings over a 12-year life cycle include avoided fuel payments ($23,333), reduced labor for fueling events ($3,967), avoided brake service events ($1,650), and fewer GHG impacts ($1,400). GHG savings is based upon results of an interagency working group for Executive Order 12866, and assumes a cap and trade market for heavy vehicle fleet emission reductions. Under this scenario, return on investment is approximately $4/mile for every mile above 90,000 miles.

Based on the validation test results, the hybrid electric utility truck will be cost effective for scenarios involving moderate driving (i.e., 7,000 miles per year) and high use of the PTO system (i.e., 3 hours daily). DoD applications meeting the criteria realize cost benefits from the technology's efficiency and quiet operation. Simple payback will occur over a 12-year life cycle assuming the above scenario. The estimated cost savings are as follows: avoided fuel payments ($31,071), avoided labor for fueling events ($4,661), avoided oil and brake service events ($4,070), enhanced productivity ($6,300), and GHG emission reductions ($1,554). The assumptions include a $37,000 premium for the hybrid truck, initial operation and maintenance training for $3,000, and a battery replacement for approximately $5,000. All benefits are direct with the exception of GHG emission reductions. The GHG benefits DoD by reducing the impacts related to global warming. An additional indirect benefit for DoD is improved National energy security and reduced petroleum dependence.

ACRONYMS AND ABBREVIATIONS

APGEN	Auxiliary Power Generator
APGM	Aberdeen Proving Ground Maryland
APTO	Advanced Power Technology Office
ATC	Aberdeen Test Center
BSVE	Base Support Vehicles and Equipment
CILCC	Combined International Local Commuter Cycle
CO_2	Carbon Dioxide
DOE	Department of Energy
EO	Executive Order
ePTO	Electric Power Take-Off
ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
FMCSA	Federal Motor Carrier Safety Administration
gph	gallons per hour
HEV	Hybrid Electric Vehicle
HEVEA	Hybrid Electric Vehicle Evaluation and Assessment
HLA	Hybrid Launch Assist
HTUF	High-Efficiency Truck User Forum
ICE	Internal Combustion Engine
IPT	Integrated Product Team
ISO	International Standards Organization
MPG	miles per gallon
MCAS	Marine Corps Air Station
NEC	Net Energy Change
NAVFAC	Naval Facilities Engineering Command
NAVFAC EXWC	Naval Facilities Engineering Command, Engineering and Expeditionary Warfare Center
NAVSTA	Naval Station
NBK	Naval Base Kitsap
PTO	Power Take-Off
SOC	State of Charge
TARDEC	Tank Automotive Research Development and Engineering Command Ultra
ULSD	Low Sulfur Diesel

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The Environmental Security Technology Certification Program's (ESTCP) sponsorship for testing under this project catalyzed interest among the services' and enabled leveraged funding for demonstration trucks. ESTCP also provided critical guidance and input on the demonstration plan and protocol for the validation effort.

Recognition is due the Army's Tank Automotive Research Development and Engineering Center (TARDEC) and the Naval Facilities Engineering Command (NAVFAC) for funding purchasing the trucks, hosting the demonstrations, and providing data collection support during the demonstration effort. Also, NAVFAC Northwest and NAVFAC Southwest Base Support Vehicles and Equipment (BSVE), Solid Waste Management, and Coastal Utility Integrated Product Team (IPT) provided valuable feedback and insights on the truck operations and maintenance critical to the site validation testing.

Army's Aberdeen Test Center (ATC) provided logistics and testing support for track testing at Aberdeen Proving Grounds. This included development of the test procedures, delivery of the trucks to and from Aberdeen, equipping trucks with test instrumentation, coordinating with the manufacturers and Naval Facilities Engineering Command (NAVFAC), Engineering and Expeditionary Warfare Center (EXWC), and execution of the track testing.

Importantly CALSTART, through the High-Efficiency Truck User Forum (HTUF), established a working group for non-tactical fleets that facilitated a partnership with the manufacturers. This partnership enabled sharing of information to promote a successful demonstration. In addition, the organization also procured the hybrid utility truck, contributed logistical support, and managed the on-board data collection effort during the site testing effort.

Project success and accomplishment is owed to the suppliers of the truck chassis, hybrid systems, and body without which the project would not have been possible. The suppliers provided special on-site support and assistance for scheduling truck deliveries to the test sites and for equipping trucks with data collection instrumentation for all testing. Suppliers also provided extensive support for the track and site testing throughout the demonstration.

The Navy's Environmental Program provided fundamental project support. The Navy's Environmental Sustainable Development to Integration program provided initial leveraged funding for project development. NAVFAC EXWC provided guidance for conceptual project planning, test plan development, and technology integration objectives. In addition, NAVFAC EXWC's Environmental Technology team provided assistance with project logistics, scheduling, and test execution.

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1. Introduction

The Department of Defense (DoD) has a large fleet of diesel powered vehicles and equipment (e.g., utility service trucks, stake trucks, delivery vans, material handling equipment, etc.). Most of this equipment is operated under stressful, intermittent, and varying load conditions. For a conventional vehicle, these duty cycles make engine operations inefficient and increase fuel consumption and carbon dioxide (CO_2) emissions. Hybrid technologies reduce these problems by allowing for smaller engines that operate under steady RPM and load conditions, while recovering the energy normally wasted from braking. Fuel usage is reduced, air standards are met, and noise pollution and safety are improved.

From a tactical equipment perspective, hybridization lessens fuel delivery and operational logistics. Hybrid systems permit stealth operations (electric only operation) at low speeds and also supply mobile power for remote operations. Smaller engines have a reduced noise, heat, and emissions signature. Improved efficiency of hybrids relaxes the fuel delivery requirements to hazardous locations. This ultimately accelerates ability to mobilize and can improve the performance of each platform. Electric motors produce high torque at low engine speeds, and streamline auxiliary power use through the replacement of belt driven systems with electrical systems. DoD tactical equipment stakeholders are interested in the ability of recently fielded commercial hybrids for adaptation to a tactical environment.

Hybrid technology for light duty vehicles has already been successfully implemented. This proven technology has penetrated the commercial market. However, light and heavy hybrids are significantly different technologies. Early demonstration of commercial-ready medium and heavy duty hybrid platforms is limited to primarily commercial fleet entities, with a few developmental efforts within DoD. The threshold for acceptance has not yet been reached for medium and heavy-duty hybrids. How these systems perform in the military environment as they are demonstrated in hybrid vehicles may well determine design and performance characteristics of new generation models. Military and commercial fleet user involvement through demonstration will help justify and guide industry developmental efforts. The military must also determine, through direct experience, how heavy hybrids can best be integrated into the fleet to gain the greatest benefits.

DoD transportation planners are interested in determining the viability of commercial hybrid technologies for public works applications, and would like to see a validation study of hybrids in representative fleet applications. These planners include higher level agency personnel that manage non-tactical fleet operations for each of the four services (Naval Facilities Engineering Command Base Support Vehicles and Equipment (BSVE), Marine Corps Installation and Logistics Services Branch for Garrison Mobile Equipment, Army Assistant Chief of Staff for Installation Management, and Headquarters Air Force Vehicle Management Staff). While the vast majority of the efforts have been on light duty vehicles, these offices have an interest in heavy duty hybrids for their potential benefit.

DoD active duty forces and the service administrators are also very interested in improving energy efficiency. For example, the Naval Expeditionary Combat Command has expressed support for vehicle technologies that would improve efficiency and performance of construction support equipment. The Army aims to reduce its environmental “bootprint” in order to save lives as well as fuel. The high cost of fuels has not only stressed budgets military-wide, but has increased vulnerability and dependency for forward operating locations. This was seen during the early years of the Iraq war, where long convoy delivery operations from Kuwait to the battlefield were plagued by improvised explosive device attacks. The military's adoption of heavier armored vehicles as an interim answer reduced fatalities, but also has diminished already low fuel efficiency, and exacerbated the supply dependency. Defense Science Board's February 2008 Task Force Report on the Military Energy Strategy observes the military's unnecessarily high and growing battlespace energy consumption is compromising operational capability and jeopardizing mission success.

1.1. Background

NAVFAC EXWC demonstrated two commercial hybrid power train technologies as potential solution to mitigate impacts of heavy trucks on the environment and on energy security. Systems included an aerial lift truck and refuse hauler. The project team conducted baseline testing and subsequently placed the test vehicles at supportive sites with an operational requirement for these vehicles. Monitored parameters included fuel economy, noise levels, unscheduled maintenance issues, vehicle availability, vehicle reliability, and any impacts to day-to-day operations, as well as impacts to overall mission readiness. The team conducted the validation assessments to determine how the hybrid vehicles could meet operational performance goals, including accelerations, stops and auxiliary system functioning (e.g., equivalent lifting, loading, and cargo handling capacity).

Heavy duty hybrid vehicles feature a supplemental power system for the diesel internal combustion engine (ICE). The supplemental system is typically either electric or hydraulic. With an electric hybrid, braking (kinetic) energy is captured by using the propulsion system to apply a load to the drive axle during braking, and then converted into electrical energy via a generator. The vehicle stores that energy in on-board batteries for driving the wheels at another time. Hydraulic hybrids are similar in approach, except they store braking energy with high pressure accumulators that assist with vehicle propulsion when needed. These systems avoid the requirement for large battery systems and complex electrical controls.

1.2. Objective of the Demonstration

DoD's fleet of diesel powered vehicles and equipment generates greenhouse gases, criteria pollutants, soot, and noise. These emissions are hazardous to the environment and the equipment operators. Rising fuel prices and logistics of delivering the fuel to forward deployed bases increase cost and risk of heavy equipment operations. This project evaluated the benefits and readiness of existing early-commercial hybrid platforms, and also helped establish a military link to the hybrid vehicle manufacturing industry. The project also provided data on which platforms would benefit most from the hybrid technology

1.3. Regulatory Drivers

Public and scientific environmental awareness and concern surrounding the combustion of fossil fuels and resulting greenhouse gases, criteria gas pollutants, and particulate matter is forcing regulatory agencies to impose more stringent standards and regulations for energy efficiency. Future tightened air quality standards and controls on CO_2 emissions and other greenhouse gases are emerging both at the state as federal levels. Executive Order (EO) 13423 mandates that governmental agencies reduce fuel consumption in federal vehicles by 2 percent per year through FY 2015. This EO also requires a 3 percent reduction in greenhouse gas emissions through the FY 2015. This requirement challenges the agencies to operate more efficiently. Also, unprecedented since the Energy Policy Act (EPAct 1992), the National Defense Authorization Act of 2008 expanded the definition of an “alternative fueled vehicle” to include more fuel efficient engines and powertrains. This includes qualifying hybrid vehicles, fuel cell vehicles, and any other vehicle demonstrated to achieve a significant reduction in petroleum use.

1.4. Stakeholder/End-User Issues

This demonstration engaged two primary user communities to achieve acceptance of hybrid technology. Managers of non-tactical and deployed equipment, respectively, have provided input on the testing activities acceptance criteria, and are reviewing results for determining next steps in the acceptance process. Acceptance for non-tactical public works applications is a critical first step. After achieving this acceptance, the project managers for tactical equipment will determine whether the vehicle can pull heavier loads under more demanding conditions common to military environments.

Acceptance for tactical users requires buy-in from the program equipment managers. Two primary deployed equipment types include both on-road tactical and aviation support equipment. For the Army, the Tank Automotive Research, Development and Engineering Command (TARDEC) National Automotive Center (NAC) is a major organization responsible for specifying, procuring, and testing ground tactical equipment. The other services also purchase common platforms through contracts specified by TARDEC’s NAC. Other activities that purchase and specify equipment include the Air Force Advanced Power Technology Office (APTO), NAVFAC EXWC, Naval Air Systems Command, United States Coast Guard, and United States Marine Corps.

The U.S. Army has engaged in partnerships to accelerate the commercialization of heavy hybrid technology. The High Efficiency Truck User Forum (HTUF) is a national joint venture program between CALSTART and the U.S. Army. CALSTART in partnership with TARDEC’s NAC, manages the HTUF program, with project support from the Hewlett Foundation and the Department of Energy (DOE).

HTUF works to speed the commercialization of hybrid drivelines that could be used in both military and commercial vehicles. The program consists of over 80 participating fleets that represent over one million trucks and buses. HTUF has successfully fielded early production hybrid trucks, cutting up to two years from product development. HTUF has helped establish initial markets and has managed incentive programs in the state of California.

HTUF is broken into working groups that execute the commercialization activities. CALSTART facilitates the working group efforts. Each working group has the goal of identifying a common truck type, size, and duty cycle across user group fleets. Once they identify an objective truck platform, the working groups determine if that platform could work as a hybrid truck. If so, the group outlines a basic performance specification and a business case with the intent of working with truck and system makers to build and sell that platform.

HTUF working groups establish a framework for early user demonstrations. The partnership encourages initial purchase and user commitments. The model for the demonstrations is limited to early field testing of prototype and pre-production platforms.

To date, four working groups have initiated early user demonstrations: including the utility, refuse, parcel delivery and bus working groups. The class 8 line-haul truck working group is next-in-line for field deployments. HTUF has also recently conducted demonstrations with the commercial construction equipment working groups.

Non-tactical users require support and acceptance from the fleet managers, at both the regional and overall levels. While requirements are far less than for deployable applications, users still require that the vehicles maintain comparable performance and maintainability. This demonstration accomplished a critical first step by establishing DoD non-tactical fleet acceptance through six-months of site testing and controlled track testing. Testing addressed operational performance criteria parameters that are common across the user community.

Another objective of the Environmental Security Technology Certification Program (ESTCP) project supports commercial development. The project established a link with existing commercial and military hybrid activities. APTO and TARDEC have taken a major role in development of hybrid equipment for military applications. TARDEC's partnership with CALSTART and HTUF is spurring the commercial industry to develop diesel hybrid systems. The APTO has also demonstrated prototype and early user systems on equipment that can be used in deployable military platforms. Tactical fleet managers have not accepted hybrid systems. Although the early hybrid platforms are emerging, their performance must be sufficiently tested by military users.

2. Technology

Emerging heavy hybrid electric vehicle (HEV) technologies feature a supplemental power system that substantially improves efficiency. Similar to light duty hybrids, heavy systems recover the energy normally wasted during braking operations. Hybrid systems supplement the conventional engine during peak power demands (accelerations, hill climbing, lifting, drilling, excavating, etc.). Use of regenerative braking also reduces maintenance required on braking systems. The following sections will go into detail about heavy hybrid technology.

2.1. Technology Description

Heavy duty hybrid vehicles feature a supplemental power system for the diesel ICE. The supplemental system is typically either electric or hydraulic. With an electric hybrid, braking (kinetic) energy is captured by using the propulsion system to apply a load to the drive axle during braking, and converted into electrical energy via a generator, as shown in Figure 2-1. The vehicle stores that energy in on-board batteries for driving the wheels at another time. Hydraulic hybrids are similar in approach, except that they store braking energy with high pressure accumulators that assist with vehicle propulsion when needed, as shown by the diagram in Figure 2-2. These systems avoid the requirement for large battery systems and complex electrical controls.

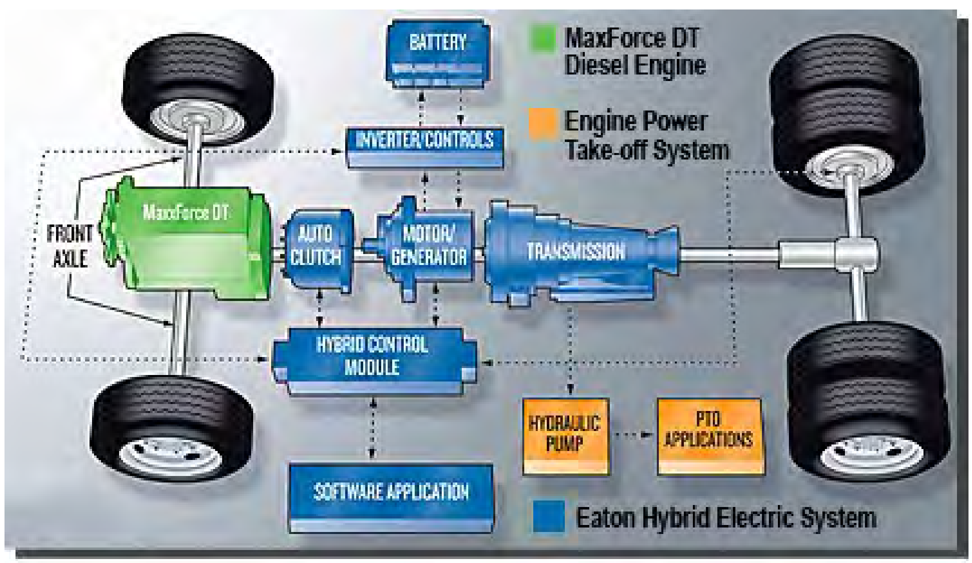


Figure 2-1. Diagram of Hybrid Electric System (Courtesy of Eaton Corp.)

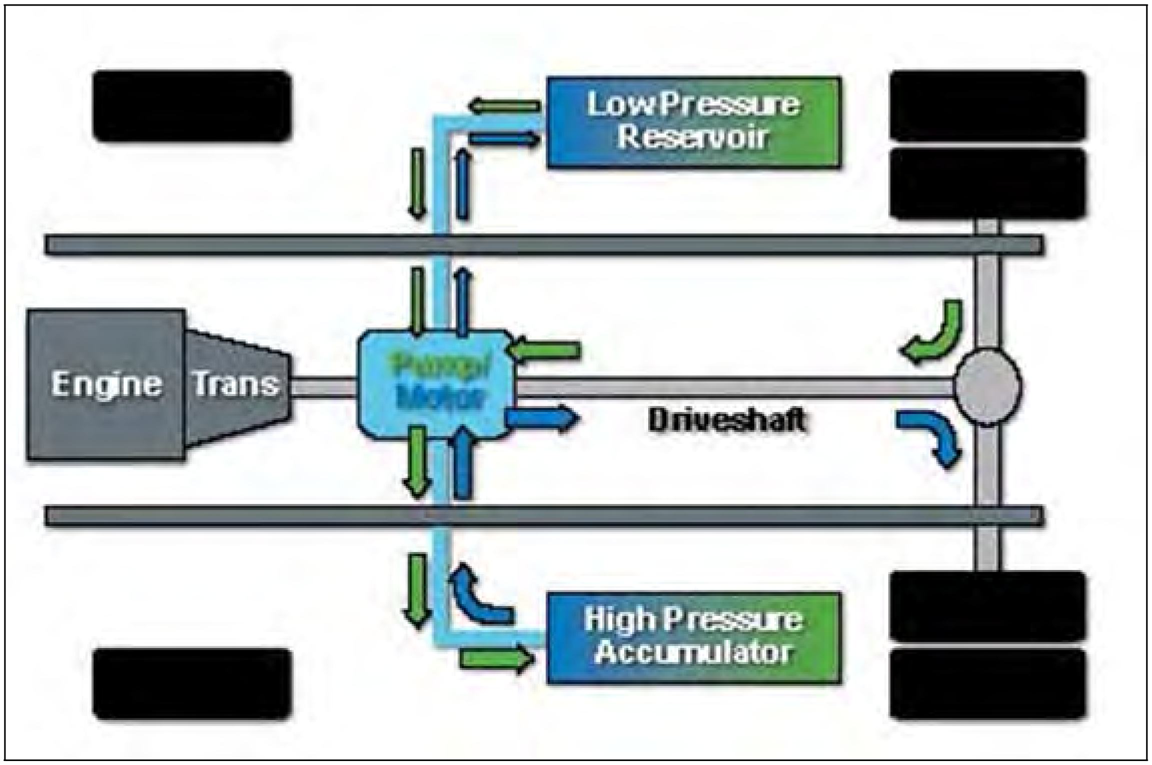


Figure 2-2. Diagram of Hydraulic Hybrid System. The high pressure accumulator stores energy as a battery would in a HEV (Courtesy of Eaton Corp.)

Industry has focused their developmental efforts on heavy diesel hybrid technology for the past decade. HTUF is the instrument by which industry is fielding the technology to fleets. The first substantial introduction of the technology to the field occurred in 2006. Manufacturers deployed 24 trucks to the commercial utility fleets. HTUF working groups have since introduced new hybrid platforms across a range of applications.

Applications for hybrid technology include those with heavy start/stop duty cycles and those requiring power take-off (PTO) for a work application. Start/stop applications include transit, shuttles, refuse haulers, and pickup/delivery. Common PTO applications include utility trucks such as pole and line maintenance trucks, auger trucks, air compressor trucks, and electric generator trucks.

2.2. Technology Development

Most industry efforts are being orchestrated by CALSTART, a non-profit organization working with the public and private sectors to develop advanced transportation technologies. CALSTART's HTUF is a national user-driven program that assists the commercialization of heavy-duty hybrid technologies. HTUF has launched six active user groups working toward preproduction manufacturing and deployment. Each group is fielding platforms that benefit from hybridization: utility, delivery, refuse, line-haul, construction, and transit. This project has complemented the HTUF program by providing additional performance data on specific use patterns for DoD. As an example, low speed and intermittent use are common for non-tactical installation vehicles, as opposed to repetitive daily use. This type of use helps identify performance, durability, and reliability considerations for vehicles that sit idle for several days or weeks between uses.

The Army's NAC is chartered as the Army's focal point for dual-use automotive technologies and their application to military ground vehicles. Under this charter, the NAC initiated and continues to support efforts of the HTUF working groups. The Forum is a key activity to building commercial support for potential dual use hybrid technologies. The Forum fielded prototype hybrid medium and heavy duty trucks into commercial fleets as an initial validation effort. As a second step, the early commercial vehicles and equipment are going to DoD installations for validation. The results of this ESTCP demonstration are being used by TARDEC to aid in transitioning this technology to the non-tactical military fleet. Experience gained from this demonstration of commercial vehicle fleets ties back to TARDEC's broader military hybrid activities through another initiative, the Hybrid Electric Vehicle Evaluation and Assessment (HEVEA) program.

TARDEC and the ATC established the HEVEA program to evaluate the benefits of hybrid electric propulsion systems on tactical vehicles. Tools developed through the program include test procedures that consider the hybrid electric system. Hybrid fuel efficiency benefits are heavily dependent on terrain and braking frequency. Traditional track testing procedures do not account for differences in the hybrid system. HEVEA program includes accepted track courses and also considers energy gains and losses from the battery pack to more accurately model fuel economy improvements.

The Air Force's APTO is participating in a number of demonstrations of advanced technology vehicles. For example, under the Hawaii Center for Advanced Transportation Technologies program, an ongoing partnership with State of Hawaii and Hickam Air Force Base (AFB) involves demonstrating a bus, step van and MB-4 tug, all fuel cell hybrid electrics powered by hydrogen, and also a plug-in hybrid step van. In addition, APTO has participated in the design, development, and demonstration of a hybrid refueler and tow tractor.

2.3. Advantages and Limitations of the Technology

Diesel hybrids will provide direct benefits to the vehicle owner and operators. For DoD, hybrids will benefit not only domestic public works vehicle applications, but also deployed vehicle operations. Table 2-1 shows the approximate replacement potential in the fleet. Hybrids provide better vehicle performance, reduced engine size and footprint, reduced environmental impact, and improved range for remote operations. Hybrid systems will enable manufacturers to optimize diesel engines for lower and steadier loads. This dramatically decreases emissions, fuel use, and noise in high load situations. Electrification further improves efficiency, response-time, and precision of traditional belt-driven systems. Heavy vehicle platform benefits include smaller engines, smaller after-exhaust particulate filters, and electrification of auxiliary equipment, which could further reduce operating costs and enhance performance.

CALSTART conducted dynamometer testing to evaluate the benefits of preproduction hybrid electric utility trucks. Test subjects included three utility trucks equipped with aerial lift platforms, and of the same chassis model: two conventional and one hybrid electric power train. Dynamometer testing included four mission cycles that range from mild (Cycle A) to severe duty (Cycle D). Cycles

A and B simulate a greater driving distance (i.e., 70 miles) and moderate use of the aerial lift. Cycles C and D simulate shorter driving distances (i.e., 48 and 36 miles, respectively) and greater use of the hydraulic lift or auxiliary power (i.e., 3 hours). Figure 2-3 summarizes test results. As shown by the bar graph, hybrid system benefits (i.e., emission and fuel economy) increase with intensity of the duty cycle (i.e., less driving and heavy use of the aerial lift).

Table 2-1. DoD Equipment Platforms and Hybrid Replacement Potential

Vehicle Type Description	*Approximate Quantity	Commercial Hybrid Replacement Availability
Commercial Highway Vehicle Types		
Bus, School	3,516	Parallel Drive System
Ambulance	564	
Truck, Aerial Lift	389	Hybrid Drive System
Truck, Multi-Stop	118	Hydraulic Drive System
Truck, Line-Haul Tractor	2,173	In-Progress; Hybrid Electric System
Truck, Crash Fire Rescue	215	
Truck, Earth Auger/Digger Derrick	154	Hybrid Electric System
Truck, Refuse	54	Hybrid Launch Assist
Truck, Dump	921	
Truck, Refrigerator	147	
Truck, High Reach, Various	327	
Crane, Wheeled, Truck Mounted	250	
Truck, Firefighting	387	
Nonroad Equipment Types		
Crane, All Terrain	403	
Crane, Rough Terrain Container	646	
Excavator, Hydraulic	1,835	In-Progress
Forklift, (4000-22000 lbs capacity)	5,340	
Loader, Front End	441	
Lift, Platform	803	
Scraper, Earthmoving	944	
Loader, Scoop	1,271	
Tactical Highway Vehicles Types		
Medium Tactical Vehicle Rep. (MTVR)	9,069	
Line Haul Tractor	5,013	In-Progress; Hybrid Electric System
Dump Truck	776	
Naval Construction Force Truck	1,500	
Engineer Tractor	2,942	
Heavy Equipment Transporter (HET)	1,961	
Palletized Load System (PLS)	3,096	
Heavy Exp. Mobility Tactical Truck (HEMTT)	12,869	Hybrid Electric System
TOTAL:	**58,124**	

*Data is preliminary and was collected in 2008 at the project's proposal phase. CALSTART is conducting an in-depth study to further characterize the most likely platform candidates among DoD's non-tactical vehicles.

Mission Cycle ID	HC (g/mi) %	CO (g/mi) %	NOx (g/mi) %	PM (g/mi) %	Fuel (mpg) % (increase)	Miles Driven	Hours of Operation (hydraulic + electric)
A	58	50	34	25	68	70	1.5
B	73	94	34	34	80	70	4.5
C	78	73	61	37	139	48	3
D	80	74	58	32	150	38	3

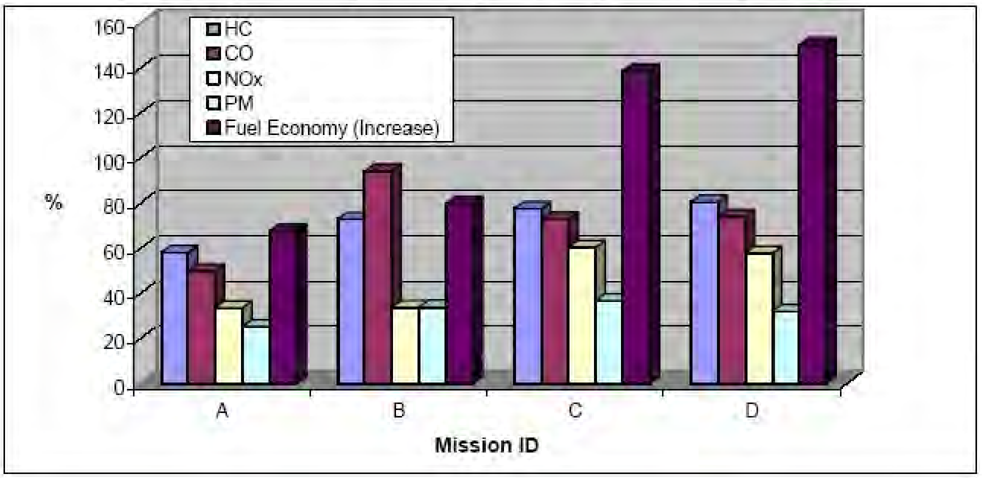


Figure 2-3. Industry Emission and Fuel Economy Test Results. Bars Represent Percent Fuel Economy Improvement and Percent Emission Reductions for Each of Four Missions for the Hybridized Aerial Lift Truck as Compared with the Conventional Version [1].

Heavy diesel hybrid technology is at a very early stage. Further developments will better integrate and optimize the overall drive train. Plug-in capable vehicles are emerging and will allow greater range on electric only operation, smaller size diesel engines, and improved petroleum efficiency. With these improvements, and careful selection of the truck application, a fuel economy gain of 40 percent could be assumed for that platform over the baseline conventional diesel vehicle.

While existing costs for heavy hybrids prohibits widespread adoption, further industry developments will substantially reduce cost. Hybrid system costs will drop due to scales of economy, improved production processes, and optimized component designs. Larger numbers of light hybrids and introduction of light hydraulic hybrids will lead to synergistic cost reductions for heavy duty systems. Smaller engines and auxiliaries will reduce per vehicle cost. Assuming the cost of heavy hybrid systems falls by 50 percent to $30,000 per vehicle, hybrid economics will be viable for several domestic DoD applications. This is consistent with a recent study by the National Academies for projected costs for 2015 to 2020[2].

Today's (2013) fuel prices would be much higher if there had been no global economic downturn. Rising prices through 2008 are due to general conditions of ever-rising demand and limited supply. The lack of new discoveries of light, sweet crude oil has required that petroleum companies resort to alternative sources (i.e., tar sands, oil shale, and bitumen) to keep up with demand. These alternative sources are more costly to recover and process. Price issues are likely to return as the economy improves. Based on these trends, a cost for fuel of between $4.00 and $6.00 per gallon over the next five to 10 years is very probable.

Additional considerations for a hybrid ROI include lower operating costs. Diesel engines on hybrid trucks run fewer hours at lower, steadier loads. For example, utility truck engines may only operate for one-hour per day instead of the eight hours for combined driving and idling required for a conventional truck. This reduction in use will contribute to reduced engine wear. It is predicted that regenerative braking will increase brake life by a factor of four. Hybrid trucks will also require fewer trips to the fuel station. All of these factors are expected to reduce operating cost.

For remote tactical users, diesel hybrid platforms provide several important benefits. One of the greatest benefits may be stealthier operation. Hybrids have lower overall heat, noise, and exhaust signatures. Improved efficiency of hybrids moderates the fuel delivery logistics in deployment situations. Fuel delivery on the battlefield substantially increases vulnerability and can cost several hundred dollars per gallon delivered, depending on the location and conditions. Assuming a conservative delivery cost of $100 per gallon for remote military operations, the hybrid technology pays for itself after just 25,000 miles of use (i.e., assuming 40 percent fuel economy improvement, baseline fuel efficiency of 12 miles per gallon, and an incremental cost of $80K).

Beyond simple payback from a more efficient power train, hybrid technologies offer far-reaching benefits. The technology will improve energy security and sustainability for DoD’s vehicle fleet and the nation as a whole. Hybridization is a transitional technology that will lead to downsized powertrains that will minimize dependency on fossil fuels. This lessens the impacts of petroleum supply constraints and resultant price shocks on DoD’s vehicle fleets. From a national perspective, studies indicate an investment into hybrid and other advanced efficiency technologies would reduce nationwide annual fuel use by 11 billion gallons by 2030, and reduce global warming emissions by 140 million metric tons.[3] This is the equivalent of removing 21 million cars from the nation’s roads. Furthermore, the investment would ultimately create jobs and achieve a savings beyond the initial investment.

3. Performance Objectives

This project evaluated the benefits and readiness of existing early-commercial hybrid platforms, and established a military link to the hybrid vehicle manufacturing industry. The project further identified platforms that would benefit most from the hybrid technology. Table 3-1 and Table 3-2 below describe in detail both the quantitative and qualitative performance objectives.

Table 3-1. Performance Objectives – Refuse Trucks

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Fuel Economy - Track Testing - Site Testing	• Controlled Drive Cycle Fuel Economy Test • Fuel Transaction Logs, On-Board Computer Data	• >20% Increase Fuel Economy	• Objective Met? No • Track: 13% Decrease • Site: No Significant difference
Noise Levels - In-Cabin Noise Levels - External Engine Noise	• FMCSA Part 393.94 • Exterior: 10 Ft Away, 25 Ft from Centerline	• >20% Peak (dBA) Noise Reduction for Accelerations	• Objective Met? Yes, partially. • In-Cabin: 39% Decrease • Exterior: 20% Increase
Brake Wear	• Measure Brake Lining Thickness Initially and at Six Months	• >50% Reduction in Brake Wear	• Objective Met? Yes. • Conv.: 8.13 inches. • Hybrid: 1.86 inches • 77 percent reduction.

Maintainability	• Interviews with Fleet Manager
	• Maintenance Logs
	  o Downtime for Troubleshooting or Repairs
	  o Time In Shop
	  o Parts Failures
	• Inspection Records
		• No Major System Failures
		• ≤2 Minor Parts Failures
		• ≤1 Week Downtime for Unanticipated Service
		• ≤1 Additional hour of Service
		• No Service or Maintenance Oriented Complaints from the Fleet Manager
			• Met objective
			• No hybrid system or parts failures
			• Extensive downtime to resolve trough loader operational issues
			• No additional hybrid related service required during the testing period
			• No hybrid related service complaints

Qualitative Performance Objectives			
Drivability	• Accelerator Pedal Position • Driver Survey • Telematics Data	• No Excessive Accelerator Position • Comparable Approval Ratings by Users • Comparable Operation of Utility and Refuse Lift Systems • Sufficient Power Under Heavy Loads and Low Speed Conditions	• Met objective • Operator team reported overall excellent power and drivability performance • HLA equipped unit provided additional power over and above baseline truck. • Operators noted issue with strong regenerative braking on HLA equipped truck
Ease of use	• Survey and feedback data from operators and fleet managers on usability of trucks and training / adjustment time	• ≤2 Hours operator training required • ≤10 hours Driver Adaptation Time	• Met objective • One Hour Driver Training Orientation plus Adaptation was Sufficient.

Table 3-2. Performance Objectives – Utility Trucks

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Fuel Economy - Track Testing - Site Testing	• Controlled Test Cycle Fuel Economy Test • Fuel Transaction Logs, On-Board Computer Data	• >20% Increase Fuel Economy	• Objective Met? Yes. • Track: 75% and 15% increase for DoD Cycle, CILCC Cycles. • Site: 32% increase
Noise Levels - In-Cabin Noise Levels - External Engine Noise	• FMCSA Part 393.94 • Exterior: 10 Ft Away, 25 Ft from Centerline	• >20% Peak (dBA) Noise Reduction for Low Speeds, Static	• Objective Met? Yes (PTO operation). • In-Cabin testing achieved 39%-49% decrease. • Outdoor testing achieved a 77%-83% decrease for PTO Operation; 12%-55% increase for drive-by tests
Brake Wear	• Measure Brake Lining Thickness Initially and at Six Months	• >50% Reduction in Brake Wear	• Objective Met? No. • Conv.: 5.62 inches. • Hybrid: 3.58 inches • 36 percent reduction.

Maintainability	• Interviews with Fleet Manager
	• Maintenance Logs
	  o Downtime for Troubleshooting or Repairs
	  o Time In Shop
	  o Parts Failures
	• Inspection Records
		• No Major System Failures
		• ≤2 Minor Parts Failures
		• ≤1 Week Downtime for Unanticipated Service
		• ≤1 Additional hour of Service
		• No Service or Maintenance Oriented Complaints from the Fleet Manager
			• Met Objective
			• No major System Failures
			• No Minor Parts Failures
			• Zero Days Downtime due to Hybrid System
			• No hybrid Related Service Required

Qualitative Performance Objectives			
Drivability	• Accelerator Pedal Position • Driver Survey • Telematics Data	• No Excessive Accelerator Position • Comparable Approval Ratings by Users • Comparable Operation of Utility and Refuse Lift Systems • Sufficient Power Under Heavy Loads and Low Speed Conditions	• Did not meet Objective • operators reported lack of power for accelerations, excessive shifting on hilly terrain
Ease of use	• Survey and feedback data from operators and fleet managers on usability of trucks and training / adjustment time	• ≤2 Hours operator training required • ≤10 hours Driver Adaptation Time	• Met Objective • Initial 1-hour orientation during kick-off sufficient; operator adaptation time for hybrid truck was approximately 4 to 6 hours.

Performance objectives are based on user defined requirements and environmental benefits either sought or claimed by the hybrid truck industry. The following sections include an explanation, description, success criteria, and results for each objective.

Fuel Economy. This objective is the fundamental benefit sought by the industry and the fleet users, and is critical to the success of hybrid industry. Fuel economy gains will help the fleet owners justify upfront investments in the hybrid technology. If the technology fails to meet this objective, the customers will not see a return on the hybrids' initial cost premium.

Metric for the vehicles can be expressed in different ways depending on the type of use or duty cycle. For refuse trucks, or vehicles whose work mode is predominantly driving, units are miles per gallon (mpg). For the utility trucks, or vehicles whose primary application involves engine off work, units are in terms of gallons per hour (gph).

Success criteria include a 20 percent improvement in fuel economy (minimum) over the conventional trucks. This is the benefit sought as an initial objective, depending on the duty cycle. Units for the metric depend on the application as noted above.

The hybrid utility truck achieved the success for the fuel economy objective for the intended use pattern (i.e., 80 percent lifting, 20 percent driving) demonstrated on the track. It also achieved the objective for the site testing.

The project team attributes this to a mild drive cycle that does not take advantage of the hybrid's regenerative braking and launch assist features. The hybrid refuse truck fell short of the fuel economy objective for both the track and site testing.

Noise Levels. This includes both in-cabin and exterior engine noise affecting the driver and persons in the immediate area, respectively. This includes nuisance noise with potential to disturb nearby residents or personnel and disruptive noise that interferes with communications among the work crew. Either type of noise limits productivity and reduces quality of work or life for base personnel (i.e., employees or residents).

Performance for the refuse and utility trucks are evaluated for different operating modes. Refuse truck noise is associated with acceleration, deceleration, and lifting operation. For this reason, noise associated with accelerations and decelerations is most critical. Utility truck nose is associated with PTO, work operations. Noise associated with this mode is a concern for both the operators and the surrounding public. As such, utility trucks are rated for noise reduction in the PTO work, or idling mode.

Noise measurement is in terms of A-weighted decibels. The A-weighted scale is selected to best characterize noise levels perceived by humans. A-weighting helps compensate and adjust levels based on frequency variation. Humans perceive noise as being louder or more offensive at the higher frequencies. This is also the range that results in damage to the audible mechanism.

This project established a 20 percent reduction as an initial objective for the technology. The 20 percent criterion is based on the assumption that the hybrid system provides a moderate reduction in engine load and resultant peak noise levels. This assumes that the noise will decrease further with additional engineering and development.

The hybrid refuse truck fell short of the objective noise reduction criterion. Hydraulic hybrid system reduced in-cabin noise, and increased outdoor noise. Outdoor noise is a common complaint. Outdoor noise reduction is therefore the primary performance objective for this demonstration. Overall peak noise levels increased by 20 percent for the hybrid truck.

The hybrid electric utility truck achieved an 80 percent reduction for the primary mode of interest, including the PTO mode for work operations. This addresses both interference with crew communications, and annoyance noise impacts to the surrounding public. As such, the hybrid truck is considered to have successfully met this objective.

Brake Wear. Use and replacement of brakes is a significant maintenance expense on severe duty trucks. Brake wear is an indicator of avoided brake use relative to baseline truck operation. The metric (i.e., 50 percent reduction in brake wear) reflects truck manufacturer claims that hybrid system can extend replacement cycle double to quadruple the baseline.

The refuse truck met performance acceptance objective for brake wear. When engaged, the hydraulic launch assist unit offsets brake use. Under actual use conditions, the hybrid launch assist (HLA) disengages at speeds in excess of 20 mph and will incur related brake wear. Despite higher speed use during site testing, the truck still met the 50 percent objective. If matched with the appropriate application, the HLA would result in significant greater reduction in brake wear. Normalized over 100,000 miles of operation, brake wear on the conventional truck was 8.13 inches, as compared with 1.86 inches on the hybrid truck. This is a 77 percent reduction in wear for the hybrid truck.

Normalized brake wear on the hybrid utility truck was 3.58 inches per 100,000 miles, as compared with 5.62 inches for the conventional truck. This is a 36 percent wear rate reduction for the hybrid truck, short of the 50 percent performance objective. Differences in driving habits or duty cycle are a potential source of bias. Manufacturer adjustments to the regenerative braking system could reduce the wear rate.

Maintainability. Preventative maintenance for new technologies must be comparable to the existing platforms. Technologies that require a high level of effort to maintain suggests greater downtime, higher operating costs, and user frustration, which ultimately leads to failure.

The project team used feedback from the service team and maintenance records to evaluate whether the trucks met the maintainability criteria. To meet the criteria, the trucks must not have incurred any substantial maintenance or downtime. This includes less than two minor service events, no major component failures, less than one-week of downtime (for hybrid related failures), and no related complaints from the fleet manager or service team.

Both hybrid systems met the maintainability performance acceptance criteria. Refuse trucks performed well throughout the demonstration period, without drive-train or hybrid related maintenance. All work performed on utility trucks was related to the chassis or body, and independent of the hybrid system. The hybrid electric system displayed no service issues throughout the demonstration that would impose additional burden on the operator or service teams.

Drivability. This factor is critical to the success of the new technology. In broad terms, this is how well the truck performs (i.e., whether driving or operating) relative to the baseline truck.

Characteristics captured under drivability include acceleration, hill-climbing ability, cornering, lifting, controlling, starting, stopping, and ride quality.

This parameter is evaluated through response to the driver's application of the accelerator pedal, brake pedals, and lift controls. Given the subjective nature of the data, the project has established baseline trucks to increase objectivity.

To have acceptable drivability, trucks must offer sufficient power to accelerate under heavy loads and low speed conditions. Routine operation should not require excessive accelerator position to achieve the desired results. To succeed, trucks must receive comparable approval ratings by users for both driving and for work modes of the utility and refuse lift systems.

The refuse trucks fully achieved the drivability criteria. Both the hybrid and the conventional truck performed well throughout the test period. HLA system provided additional power and improved acceleration over the baseline conventional truck. Operator team noted the truck's strong regenerative brakes were not compatible with the mild duty cycle. Driving at low-speeds and coasting required operators' extended accelerator use to maintain normal speeds.

Hybrid utility truck fell short of the drivability performance objective. Operators complained of the hybrid truck's lack of power for low speed acceleration, and sub-optimal or excessive shifting when driving on hilly terrain. Drivers expressed no related complaints on the conventional truck. Given the success criteria for "comparable approval ratings by users", the hybrid truck fell short of the drivability rating.

Ease of Use. This acceptance factor is qualitative and measures complexity and/or operator's time to adapt to the new operating procedure. Ideally the operations will be comparable to the existing technology, transparent to the user, and requires no additional training. Technologies with complex operating procedures require additional training, reduce flexibility to switch operators, and have potential to reduce productive time in the field depending on complexity.

Selected ease-of-use threshold level is two hours of training, and 10 hours of adjustment time. It is the intent of the project team that this criterion correspond to the training investment required to learn and adapt to operating controls for new truck models. As such, the hybrid technology should be transparent in terms of time to become acquainted.

Both hybrid systems met the ease of use performance criteria. With the exception of the regenerative braking, the HLA system on the hybrid refuse truck was transparent to the operator. There were no special procedures or controls requiring operator attention. For the hybrid utility truck, operating procedures were straightforward. Initial training for the hybrid electric truck was sufficient for the operators. Neither the driving nor the work modes for the hybrid system entailed complex operating procedures

4. Sites/Platform Description

4.1. Test Platforms/Facilities

The Naval Base Kitsap (NBK) Recycling Team collects solid waste media with conventional diesel trucks. Trucks serve facilities throughout the Bangor, Bremerton, Keyport, and Indian Island installations. Conventional diesel engines are powerful, but the older engines are relatively high pollution, emitting NOx and particulate matter in quantities that are several times the level of 2007 and newer engines. The trucks are of two types, the first similar to a residential refuse hauler with a grasping arm side loader, and the second a roll-on/roll-off large container hauler that collects 20, 30, and 40 cubic foot containers. The recycle team is interested in new upgraded trucks to improve operational efficiency. One desired feature is, instead of a single integral on-board collection container, to have four separate trough compartments that allow curbside separation. This will reduce labor time required for separating glass, plastic, paper, and metal by 50 percent or more. Second, the team has an objective to test trucks with an auxiliary hybrid power system that improves efficiency of heavy start-stop cycles.

NAVFAC Southwest utility truck fleet consists of conventional diesel trucks. Trucks have aerial lift platforms that have “buckets” that hold one or two personnel conducting the line maintenance. Two trucks are due for replacement and the team is very interested in potential benefits of the hybrid platform. The team will purchase two replacement units, one conventional diesel truck and one diesel hybrid electric truck. Both will be new utility trucks with 50 foot aerial lifts of the same model year. Standard trucks have a two-person or 600 pound capacity with a 1,000 pound capacity material lift. An articulating boom holds the aerial lift. The diesel engine PTO supplies the hydraulic system for operation of the lift and hydraulic tools. The open center hydraulic system rotates and tilts the boom base to position the platform for positioning the lifts. Trucks have an utility truck chassis, push-button operated automatic transmission, and 225 horsepower diesel engine.

4.2. Present Operations

At NBK, The refuse trucks average 14,000 to 18,000 miles per year. They operate on a regular five day work schedule and support additional collection runs on the weekend as needed. Haulers see multi-stop operations that may benefit from launch assist and regenerative braking systems. The diesel engines not only provide power to move the truck, but also power a hydraulic pump that operates the collection arm and lifts the bin for emptying contents at the recycle center. Engine “revving” occurs at stops to increase pressure necessary to operate the hydraulic collect arm and container lift mechanism. As the truck becomes loaded with the recycling materials, the accelerations increasingly burden the engine, consuming larger amounts of fuel, and generating more heat and braking wear during vehicle stopping. The 33,000 gross vehicle weight rating trucks collect curbside materials in a single bin and deliver them to the on-base recycle center.

NAVFAC Southwest utility team operates aerial lift trucks for maintenance of electric power lines throughout the metropolitan San Diego Area. Trucks operate five to six days per week, with 35 to 50 hours of field time. Although trucks operate all day, most of the time they remain stopped. Daily driving averages only 35 miles. The engine is typically in an idle mode, powering the hydraulic system while the crews perform maintenance. The hydraulic systems power the lift platform, resulting in continuous diesel engine exhaust emissions and noise. Due to the nature of the typical duty cycle, engine idling operations are the driving factor responsible for a larger proportion of fuel consumption and emissions.

4.3. Site-Related Permits and Regulations

With the exception of slightly different operating and maintenance considerations for the auxiliary power system, hybrid vehicles are virtually transparent to existing operations. No environmental permits are required to proceed with the demonstration.

From an infrastructure perspective, hybrids may require a few additional tools, diagnostic equipment, and procedures. Training for the technicians and operators will address these changes and provide a smooth transition to the technology. Hybrids can be readily integrated into the existing operations with only slight modifications. No new infrastructure, beyond authorized service support from the manufacturer is needed. Both trucks already have existing hydraulic systems and require no special considerations. Battery packs are advanced and require additional attention due to their different type (i.e., lithium ion), and higher voltage than the electric systems on conventional trucks. The demonstration does not require any environmental permits.

5. Test Design

5.1. Conceptual Experimental Design

Test Vehicles

The project team carefully selected test vehicles to ensure a valid comparison. The hybrid and non-hybrid trucks were both new, of the same manufacturer model year, and included the same options. This prevents non-hybrid related performance variations due to engine or exhaust technology, aerodynamics, tires, or vehicle wear. Table 5-1 lists features of the vehicles, engines, and auxiliary systems. Section 5.2 describes the hybrid systems in further detail.

Table 5-1. Test Vehicle Specifications

Utility Trucks	
Chassis	128 in wheelbase
Diesel Engine	7.6L, 225 hp,
Transmission	6-Speed Automated Manual
Utility System	Articulating, Telescoping Aerial Lift
Platform Reach / Capacity	49.5 ft Vertical / 39 ft Lateral / 600 lbs
Platform Movement	Continuous Rotation and Tilt
Upper Boom Articulation	-25 to 75 degrees
Articulating Arm	5.25 to 92.5 degrees
Tools Support	Two Hydraulic Circuits at Platform
Stability Support	A-Frame Outriggers, Motion Alarm, Interlocks
Refuse Trucks	
Chassis	Refuse, 37600 GVW, 191 in wheelbase
Engine	320 hp, 1150 ft-lbs
Equipment	Remote Power Take-off Idle Shutdown Enable Timer (5 minutes) Max Speed in Top Gear (65 mph)
Transmission	Rugged Duty Service, 6-Speed, Auto
Refuse System	Curbside Recycler
Capacity	Four Separate Bins: 28.45 CY Total
Fuel Tank	70 Gallon

The project sites approved orders for the test vehicles in FY10. NAVFAC EXWC placed purchase orders for the conventional utility truck and the two refuse trucks with funds provided by the respective test sites. CALSTART purchased the hybrid utility truck under TARDEC's hybrid demonstration program, under the sponsorship of the HTUF program. Purchase prices for the conventional and hybrid utility trucks, including delivery, excluding the cost of optional data acquisition instrumentation for this project, were $150,015 and $214,382. Prices for the conventional and HLA refuse trucks, including delivery and Defense Logistics Agency contracting fees, were $240,720 and $292,564, respectively.

Test Locations

Aberdeen Proving Ground Maryland (APGM)

ATC conducted track testing at Aberdeen Proving Ground MD. ATC oversees a range of testing operations for automotive, engineering, and ground equipment. A diverse, multipurpose proving ground, APGM encompasses 56,707 acres of engineered and dedicated land and water. The facility includes 40 miles of test track to support vehicle testing.

ATC has several tracks with both paved and off-road tracks with engineered slopes, hills, and surfaces for vehicle testing. The project team selected and tested the trucks on a three-mile straight track in the Perryman Test Area. This track is flat and paved, and is representative of the generally flat paved roads on the industrial and administrative areas of military installations. Figure 5-1 provides a view of the three mile straightaway used for the testing.

Figure 5-1. View of the Three-Mile Straightaway at APGM's the Perryman Test Area (Photo by Chris Shires, US Army ATC)

Naval Base Kitsap

Consolidated in 2004, NBK consists of the three separate installations: Bangor, Bremerton, and Keyport. Bangor covers 7,201 acres, and is the largest of the three while Keyport and Bremerton are much smaller at 340 and 419 acres, respectively. Terrain at Bangor ranges from flat to moderate rolling hills, while Bremerton and Keyport are primarily flat. NAVFAC Northwest's Integrated Waste Management Team oversees NBK's waste collection program. Trucks collect mixed curbside recyclables, but are aspiring for curbside separation to enhance efficiency and reduce operating labor.

San Diego Naval Complex

NAVFAC Southwest Coastal Utilities IPT is based in San Diego, California. The IPT serves naval installations throughout the metropolitan San Diego area. Beyond work at Naval Station (NAVSTA) San Diego, work sites include Coronado, Imperial Beach, North Island, and Point Loma. These facilities range from 5 to 22 miles apart. Roads at each installation are generally paved and flat. The IPT dispatches trucks daily to the installations in order to accomplish a variety of power line maintenance tasks.

Schedule

ATC conducted track testing schedule soon after delivery of the new truck pairs. Track testing schedule and execution was according to the test plan, occurring from October 2010 through January 2011. Site testing at NBK Bangor experienced severe delays, commencing February 2012, or 10 months behind the objective test schedule. Delays at NBK Bangor were due to side loader compatibility issues with the tote containers. Considering both locations, site testing extended the overall schedule by approximately 14 months considering the data assessment. Figures 5-2a and 5-2b provide the actual schedules of test activities for the refuse and utility trucks, respectively.

Test Schedule for Recycling Trucks	Duration	Start	Finish
Truck Purchase Orders	129 days	Mon 12/14/09	Thu 6/10/10
Truck Delivery to APG	54 days	Mon 8/30/10	Thu 11/11/10
Pre-Track Test Meeting	3 days	Mon 10/25/10	Wed 10/27/10
Baseline Truck Inspections	37 days	Tue 9/28/10	Wed 11/17/10
Conduct Track Testing	39 days	Mon 10/25/10	Fri 12/17/10
Review & Assess Track Data	50 days	Mon 12/20/10	Fri 2/25/11
Send Trucks to Host Sites	5 days	Mon 12/27/10	Fri 12/31/10
Site Inspection & Training Events	4 days	Mon 2/7/11	Mon 2/28/11
Install/Test Dataloggers	30 days	Fri 3/4/11	Fri 4/15/11
Resolve Side Loader Issues	252 days	Mon 2/14/11	Tue 1/31/12
Site Operational Testing	174 days	Wed 2/1/12	Mon 10/1/12
Initial Review Discussion	1 day	Tue 4/3/12	Tue 4/3/12
Mid-Term Site Review Discussion	1 day	Tue 6/19/12	Tue 6/19/12
Final-Term Site Review Discussion	1 day	Mon 11/19/12	Mon 11/19/12
Data Assessment & Analysis	261 days	Tue 5/1/12	Tue 4/30/13

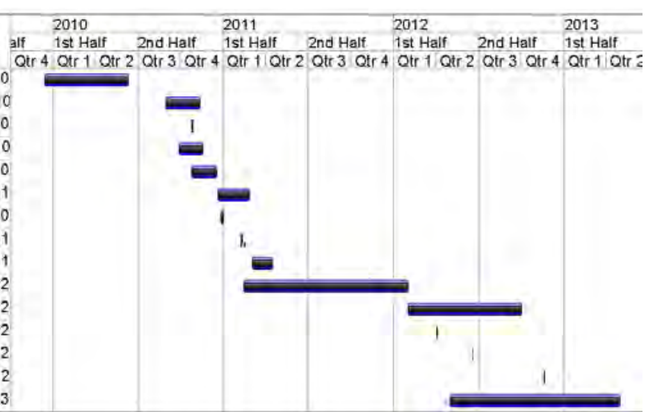
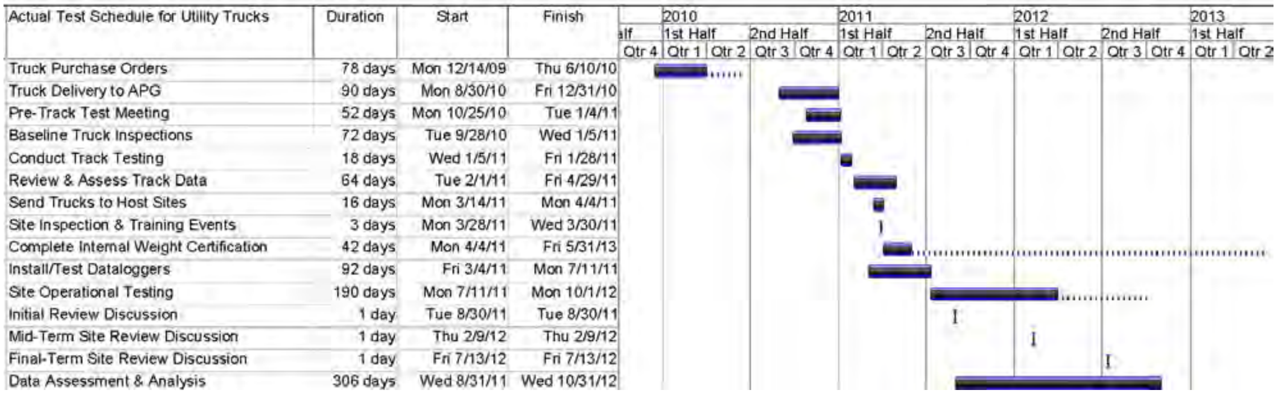


Figure 5-2a. Test Schedule for Refuse Truck Pair



Actual Test Schedule for Utility Trucks	Duration	Start	Finish
Truck Purchase Orders	78 days	Mon 12/14/09	Thu 6/10/10
Truck Delivery to APG	90 days	Mon 8/30/10	Fri 12/31/10
Pre-Track Test Meeting	52 days	Mon 10/25/10	Tue 1/4/11
Baseline Truck Inspections	72 days	Tue 9/28/10	Wed 1/5/11
Conduct Track Testing	18 days	Wed 1/5/11	Fri 1/28/11
Review & Assess Track Data	64 days	Tue 2/1/11	Fri 4/29/11
Send Trucks to Host Sites	16 days	Mon 3/14/11	Mon 4/4/11
Site Inspection & Training Events	3 days	Mon 3/28/11	Wed 3/30/11
Complete Internal Weight Certification	42 days	Mon 4/4/11	Fri 5/31/13
Install/Test Dataloggers	92 days	Fri 3/4/11	Mon 7/11/11
Site Operational Testing	190 days	Mon 7/11/11	Mon 10/1/12
Initial Review Discussion	1 day	Tue 8/30/11	Tue 8/30/11
Mid-Term Site Review Discussion	1 day	Thu 2/9/12	Thu 2/9/12
Final-Term Site Review Discussion	1 day	Fri 7/13/12	Fri 7/13/12
Data Assessment & Analysis	306 days	Wed 8/31/11	Wed 10/31/12

Figure 5-2b. Test Schedule for Utility Truck Pair

5.2. Technology Description

One truck from each test pair includes a hybrid power system. One refuse truck is equipped with a hybrid electric system, and one utility truck is equipped with a hybrid hydraulic system. Sections below review important details of each hybrid system.

Hybrid Electric System

The parallel hybrid electric system provides launch assist, regenerative braking, engine-off electric power, and engine-off hydraulic system operation. The parallel system is coupled with a diesel engine, electric motor, and battery pack for energy storage. The motor can supply 25 kilowatts of off-board power. Figure 5-3 provides a layout of system components. The hybrid electric system supplements engine power during acceleration, recaptures energy during braking, and supplies power for engine-off work operations.

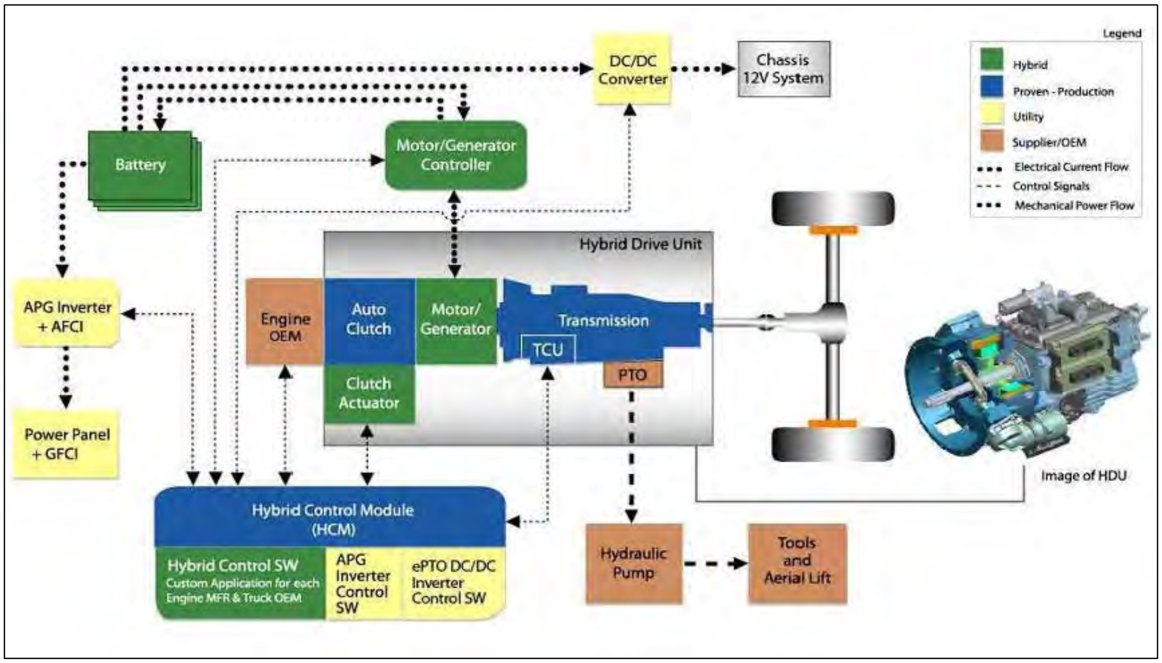


Figure 5-3. Schematic of the Hybrid Electric Drive System (Courtesy of Eaton Corp.)

Primary components of the hybrid drive system are described below:

- **Integrated Motor Generator:** In-line with the engine, the motor generator transfers power to or from the engine. It allows the engine and transmission to operate independently. A clutch actuator determines whether the transmission will engage. If driving conditions require engine power, as with acceleration or uphill driving, the generator draws energy from the battery pack to supplement the ICE. When excess power is available due to braking, the engine generator charges the battery pack.

- **Battery Pack and Auxiliary Power Generator (APGEN)**: The 340 volt lithium ion battery pack provides energy storage for the hybrid electric system. The batteries either supply or receive power, depending mode of operation. Batteries provide supplemental power during accelerations. Batteries charge during the regenerative braking mode. The APGEN acts as the interface for supplying auxiliary electricity for work operations.

- **Hybrid Control Module:** This module manages energy flow in the hybrid drive unit. It monitors status of the engine, transmission, battery pack, motor generator. Issued commands depend on the current driving conditions and power requirements. The module governs power output from both the conventional engine and the battery pack. It is integrated together with the APGEN's inverter software and electric P (ePTO) software that controls battery pack charging operations and auxiliary power operations. The control module software program varies based on manufacturer, vehicle type, application, and operational design parameters.

The parallel hybrid drive system is coupled with a six-speed transmission to support the different operating modes. Figure 5-4 shows the placement of hybrid electric components on the vehicle. The system is capable of operating in both an automated or manual shift mode. Table 5-2 provides specifications for the hybrid electric drive system.

Figure 5-4. Parallel Hybrid Electric Component Locations (Courtesy of Eaton Corp.)

Table 5-2. Parallel Electric Drive System Specifications

Feature	Specification
Weight (hybrid drive unit, clutch, batteries, hardware)	980 lbs. [444.52 kg]
Transmission	Automated Manual with 6 forward speeds, 1 reverse
Operating Modes	APGEN – Auxiliary Power Generator ePTO – Electric Power Take-Off R – Reverse N – Neutral D – Drive - Automatic Gear Selection Manual – Manual Gear Selection
Battery System:	Nominal 340 Volts Direct Current / Lithium Ion
Electric Motor:	44 kW peak, 60 hp/308 lb-ft. torque [420 Nm]; 26 kW continuous, 35 hp/186 lb-ft. torque [252 Nm]
Oil Capacity:	19.5 pints [9.23 liters].
Torque	Capacity: 660 lb-ft. torque [895 Nm]

The aerial lift trucks were not equipped with the auxiliary power option. In addition to the mechanical PTO that supplies hydraulic systems on conventional trucks, this option provides users with electric power from the hybrid electric battery pack via the ePTO. The hybrid-supported APGEN enables quiet engine-off field operations that improve overall efficiency. Specifications for the generator are listed in Table 5-3.

Table 5-3. Auxiliary Power Generator Specifications

Feature	Specification
Dimensions	20” x 12” x 12”
Circuits	3 Isolated Ground Fault Interrupted Circuits
Output Voltage	120 V +/- 2%
Output Power	5KW (6KW Peak)
Total Harmonic Distortion	< 5%
Operating temperature	– 40 deg C to + 55 deg C
Storage temperature	– 40 deg C to +85C
Standards	Society of Automotive Engineers J1455 and manufacturer-specific

Hybrid Hydraulic System

Hybrid refuse trucks included the parallel hydraulic system. The hydraulic system supplements the conventional power-train, without any other major chassis or engine modifications. Table 5-4 lists specifications for the hybrid hydraulic system. The HLA equipped Model 320 uses the same engine and transmission as the conventional truck. Figure 5-5 shows locations of the HLA components on the chassis. The HLA is a relatively simple system that is suited for vehicles with stop-and-go duty cycles, as it is power dense but stores less energy than other hybrid platforms. The system was recently released and emerged in 2010 commercially as for refuse hauler applications. Other applications of interest include pickup and delivery trucks and shuttles.

Table 5-4. Hydraulic Launch Assist System Specifications

Feature	Specification
Weight of HLA System	1250 lb
Max Pressure	5000 psi
Total Oil Volume	21 gal
Torque	2550 ft-lb max
Active Speed Range	Up to 25 mph
Transfer Case Ratio	2.55:1
Oil Cooler	7.5 kW Oil to Air

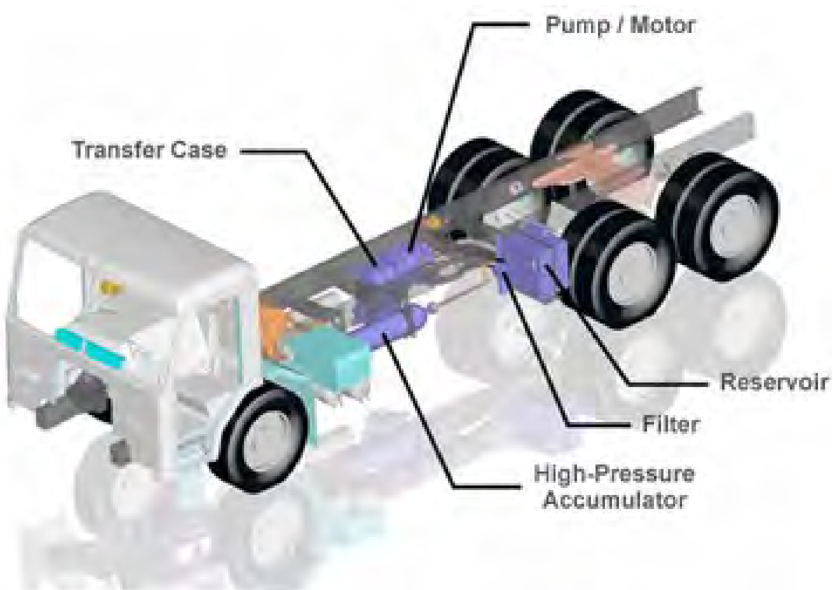


Figure 5-5. Hydraulic Hybrid Component Chassis Locations (Courtesy of Eaton Corp.)

The parallel hydraulic system has two basic functions: regenerative braking and launch assist. The system assists and works with the existing transmission. The supplemental power unit acts as either a pump or a motor, depending on whether it is in the regenerative braking mode or launch assist mode:

- **Regenerative Braking:** During braking, the regenerative system drives a hydraulic pump to pressurize nitrogen gas in a high-pressure accumulator. The regenerative system captures about 70% of the kinetic energy normally lost to braking.

- **Launch Assist:** During acceleration, the system releases pressure from the gas accumulator to drive the "motor" and supplement engine power. The system provides propulsion energy by transmitting torque to the driveshaft via the transfer case.

- **Operating Modes:** Two operating modes allow the HLA system to optimize for performance or fuel economy. Economy mode draws energy from the accumulator alone for acceleration. Performance mode draws energy from both the accumulator and the engine.

5.3. Track Test Protocol

The Army's ATC accomplished outdoor track testing at Aberdeen Proving Grounds, MD facilities. Certified test personnel ran the vehicles at selected track using specific drive cycles to measure fuel economy, noise levels, and other performance data. ATC conducted the test runs separately on individual trucks. In order to minimize external bias factors, testing occurred on the same track and within climate control parameters stated in Section 5.3.4. ATC evaluated challenges following each speed trace in the track testing effort. Industry generally typically conducts this testing on a chassis dynamometer in the interest of maintaining test controls environment and to meet regulatory requirements. This project did not include dynamometer testing as track testing better represents actual use conditions.

ATC also collected data on the state of charge (SOC) and net energy change (NEC) for the HEV. SOC indicates the degree to which the battery is fully charged. For example, a battery pack with a 100 percent SOC is fully charged. A battery pack with 50 percent SOC contains one-half of a complete charge. Measuring the SOC before and after the drive cycle enables calculation of the NEC, which can be expressed in terms of kilowatt hours. ATC factored NEC of the hybrid electric system into the final fuel economy results. Hybrid hydraulic system stores a small amount of energy. NEC did not factor into the results for the hybrid hydraulic truck.

Test Preparation

Upon truck delivery to ATC, the team conducted activities to setup for the track testing. Preparation included pre-test coordination, a truck inspection, and installation of test equipment on-board the trucks as follows.

- Pre-Test Coordination Meeting: The project team convened on-site before the testing to review test procedures, track condition, test controls, and demonstration objectives. The team discussed validation drive cycle procedures, number of runs, test acceptance criteria, and post test evaluation and assessment. This ensured the testing data acceptance prior to shipment of the vehicles to the site testing destinations.

- Vehicle and Fuel Checks: ATC technicians conducted truck inspections prior to the testing. Inspections verified that fluid levels and tire pressure conformed to manufacturer specifications, and confirmed no trouble codes or diagnostic problems were present. ATC test personnel also tested available ultra-low sulfur diesel (ULSD) to ensure conformance with test fuel specifications. CALSTART did not use the Telematics system to support collection of backup data as originally planned under the demonstration. ATC provided instrumentation for the track testing, with additional data acquisition equipment from the chassis manufacturer. ATC verified that sensors monitoring the hybrid and engine system parameters were functional.

- Test Equipment Configuration: ATC test personnel verified that the weather station was functional and the selected track in good condition prior to initiating each test run. ATC personnel calibrated and installed on-board instrumentation for fuel economy and noise testing. NAVFAC EXWC configured the instrumentation for the noise data collection. The test personnel ensured all instrumentation was functioning properly. The industrial noise team will install the noise monitor inside the cabin. The noise team will also setup noise monitors on the track in order to collect outdoor noise generated during truck accelerations or work operations. ATC placed cones and signs at select points along the test track. Cones and signs guided test driver speed, stops, and engine-off operations for the utility trucks.

Track Facility

The track facility included provisions similar to those required by the EPA's Smartway Test Protocol.[iv] These provisions helped increase repeatability of the test results.

- Track Shape and Surface: Proposed facility is the three-mile paved straight track at Perryman Test Center. Track surface included paved asphalt. Surfaces were also well maintained to avoid losses due to uneven pavement, and representative of most installations.

- Track Weather Station: ATC setup equipment to measure and record weather conditions at the truck starting point on the test track. Figure 5-6 provides a photo of the weather station used at the track. The weather tower monitored wind speed and direction, ambient temperature, relative humidity, and barometric pressure. Positioning of ambient condition sensors generally followed guidelines outlined in the Federal Standard for Siting Meteorological Sensors at Airports, FCM-S4-1987.

Figure 5-6. Photo of Weather Tower at the Perryman Straightaway (Courtesy of Chris Shires, US Army ATC)

- Track Speed/Time Measurement Equipment: The track will have equipment to measure vehicle speed and distance, to support on-board odometer and speedometer verification. The track will also have distance markers positioned to match target speed and distance parameters of the selected drive cycle, including braking points.

Test Methods

Drive Cycles

Industry groups have established drive cycles corresponding to vehicle application categories. Applications represented range from local delivery trucks to line haul trucks. Cycle intensity ranges from moderate (i.e., no stops and constant speed) to severe (i.e., multiple stops, lower average speeds).

Drive cycles for this project consider the nature of DoD driving and differences from commercial truck use. The general assumption for this project is DoD's non-tactical vehicles drive less and at lower speeds than commercial trucks in similar applications. DoD trucks operate within the confines of a base, adhere to lower posted speed limits, and serve areas with smaller geographical footprint than commercial trucks. In contrast, non-DoD fleets generally serve larger areas. They might support an entire city, suburb, or region. In summary, DoD trucks generally drive fewer miles at lower speeds than corresponding commercial trucks.

Refuse Cycle Analysis

A majority of commercial waste truck collection is from residences. As such, the commercial refuse cycle adapted by industry emulates residential pickup and collection. The cycle, shown in Figure 5-7 is routinely conducted on a dynamometer. It is severe duty, and includes 50 stops simulating material pickups, and trips to and from the landfill or waste collection facility. The cycle has three segments: 1) Collection; 2) Landfill visit; 3) Duplicate collection. It assumes stops every 200 feet. Duration of the cycle is 30 minutes.

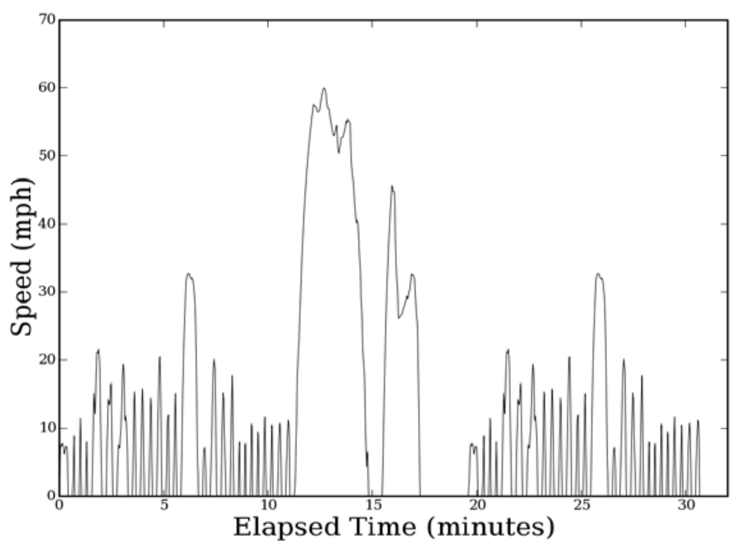


Figure 5-7. Residential Refuse Drive Cycle (ATC Report No. 10546)

A larger volume of DoD refuse collection is from industrial or administrative facilities than residential areas. Collection points will be further apart and waste volumes larger than the residential cycle. The National Renewable Energy Laboratory cycle is therefore more severe than typical DoD driving. Most of DoD's cycle would be a composite of driving characteristics for several installations. Route speeds would range from 15 to 45 mph. For visits to the landfill, trucks may travel to a remote section of the base, or may travel off-base at higher speeds similar to the landfill trip in the commercial refuse cycle.

Payload is an important consideration for the refuse truck fuel economy. Collected refuse material will comprise as much as 40 percent of a fully loaded truck, rated at 37,600 pounds. The empty truck is estimated at 21,900 pounds when empty. Payload depends on route, as some routes include greater collection of the lighter materials (metal and plastic). Office paper is the larger and denser commodity. On average, the truck will be holding an estimated 4,000 to 6,000 pounds of collected material, or one half of the fully loaded truck.

Utility Cycle Analysis

Commercial utility trucks travel across a broad range of roadway types to their service points. Driving plays a minor role in the trucks' daily activity. Vehicles spend much of their time at service points in an idle mode. During field service mode, the truck engines idle to supply hydraulic pressure to aerial lifts and hydraulic tool circuits.

DoD utility trucks operate in much the same way as the commercial trucks. Most of the trucks' operating time is in an engine idle mode. For example, NAVFAC Southwest's Utility Team drives 35 miles per day on average, approximately 20 to 30 percent of the 8-10 hours of daily operating time. The 70 to 80 percent balance of operating time consists of field work with hydraulic lift and tools circuit operation. The only substantial difference for DoD trucks might be fewer daily operating hours if the commercial trucks operate longer than a single shift.

For the utility trucks, payload is less significant to fuel economy than for the refuse trucks. Average payload is an estimated 1,500 pounds, including personnel, safety gear, and equipment.

Selected Drive Cycles

Selected drive cycles for this project modified portions of the Combined International Local Commuter Cycle (CILCC). The CILCC is a composite of city, suburban, and highway driving. It generates a "median" fuel economy result for the spectrum of duty cycles ranging from the mild Commuter Cycle to the severe New York City Garbage Truck Cycle. The CILCC offers an achievable speed-time trace and is feasible for track testing. The US DOE sponsored CILCC development in support of the Advanced Heavy Hybrid Propulsion Systems Program. The working team that developed the cycle included chassis and hybrid manufacturers directly involved in hybrid vehicle development, and the National Renewable Energy Laboratory.[v]

Refuse truck cycle is a modified version of the first 30 minutes of the CILCC. The first two local sub-cycles of the CILCC replicate the traffic and large volume collection stops, while the final 55 mph drive distance represents the trip to the collection center. For this test cycle, the first two sub-cycles incorporate eight (8) more stops than the CILCC. This modification simulates an abbreviated representation of the actual duty cycle. Assumptions for one day of actual use include 60 miles total, 24 suburban and highway miles, 200 stops per day. This scenario assumes the trucks collect three full loads of recyclables over a one-day period. Under actual use, the truck travel 4 miles to and from the collection center. Fuel economy results for this cycle will be more conservative than for the severe residential cycle that includes more than double the number of stops and one-half the average speed. Figure 5-8 illustrates the cycle speed versus time plot for the selected cycle.

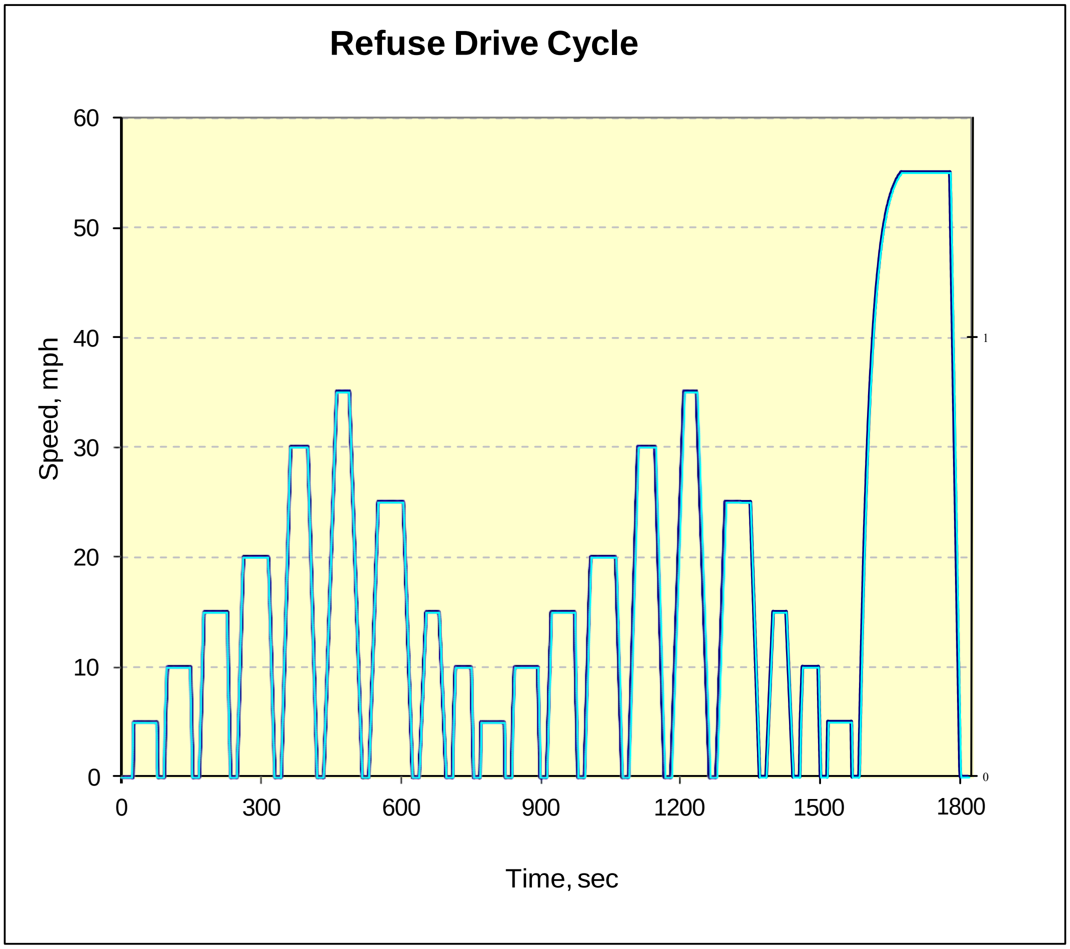


Figure 5-8. DoD Drive Cycle for Refuse Trucks

The utility truck cycle models a 6-minute trip to the job site, 45 minutes of field work using the aerial lift, followed by a return 6-minute trip to the utility team's central shop. The field work portion of the cycle includes 45 minutes of hydraulic lift testing. Figure 5-9 shows the vehicle speed and the aerial lift height versus time plot. Driving constitutes 20 percent of the truck use during application, and field work accounts for the 80 percent balance. The truck uses an estimated 2.5 gph while driving the CILCC cycle and one (1) gallon per hour for hydraulic work applications assuming continuous idling.

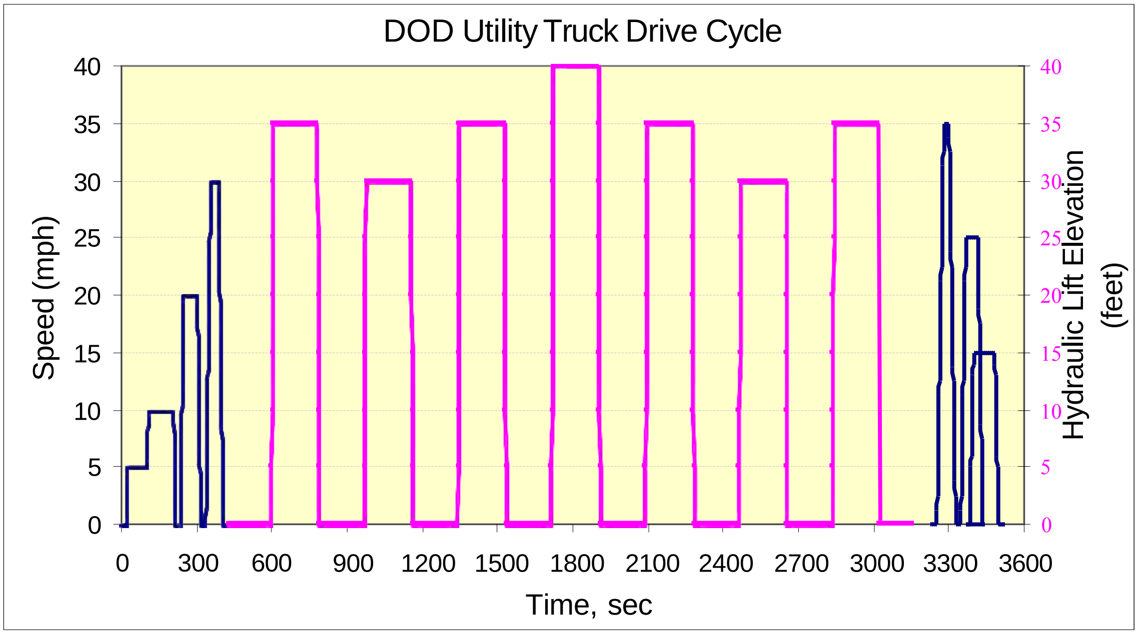


Figure 5-9. DoD Test Cycle for Utility Trucks

Table 5-5 below compares the commercial and DoD selected test cycles. An important difference of DoD's utility cycle is integration of hydraulic lift operations along with the drive cycle.

Table 5-5. Comparison of Commercial and Selected DoD Drive Cycles

	Commercial Cycle	**DoD Cycle**
Utility Cycle		
Drive Cycle Name	CILCC	DoD Utility Cycle
Total Elapsed Time	53.2 minutes	60.0 minutes
Driving Time	53.2 minutes	12.5 minutes
Hydraulic Load Test Time	0 minutes	47.5 minutes
Distance	12.3 miles	2.5 miles
Max Speed	55 mph	35 mph
Average Speed	14 mph	14.8 mph
No of Stops	25 stops	5 stops

Fuel Economy

ATC installed a fuel metering system in order to record fuel flow throughout the testing. Refer to Figure 5-10 for photo of the temporary metering system as configured on the refuse trucks. The metering method improves logistics of testing as compared with a portable fuel tank that must be removed, weighed, and reinstalled after each completed test run. ATC decided on this approach due to successful use of the meters for prior track testing at APGM. Rated accuracy of the meter is 0.5 percent. The fuel meter enables continuous measurement of the fuel flow. In addition to a high resolution flow sensor, the metering system consisted of a level controller, separate pumps, and a heat exchanger for stabilizing temperature of the return fuel from the engine.

Figure 5-10. Temporary Metering System Used to Capture Fuel Consumption (Photo by Chris Shires, US Army ATC)

For the HEVs, ATC personnel also factored in the energy changes to the battery pack. Battery voltage and hydraulic system pressures were recorded throughout the testing. Energy gains or losses were subtracted or added to the diesel fuel consumption, respectively in order to calculate the vehicle's resultant fuel economy.

Noise Testing

NAVFAC EXWC personnel observed industry test methods for the sound level measurements. Measurements characterized noise inside the driver's cabin and outside the truck, in order to assess noise reduction benefits for the driver and the public. Meter locations were based on industry test methods on the intended receptors. NAVFAC EXWC test personnel placed monitors according to the locations in Table 5-6. Sound level meters conformed to minimum requirements described in American National Standards Institute S1.4-1983 and International Electro-technical Commission Standard 61671-1.

Table 5-6. Industry Guidelines for Noise Sampling Locations

Noise Location and Type	Receptor	Microphone Locations	Reference Method
Indoor Engine Noise	Driver	Truck Cabin, 6-inches from Driver's Right Ear	FMCSA 393.94
Outdoor Acceleration	Bystanders	25-Feet from the Centerline of Travel, Both Driver and Passenger Sides of Truck	ISO 362-1:2007
Outdoor Engine and Lift System	Utility Workers, Bystanders	10 feet from the Driver and Passenger Sides of the Truck; 25 feet from the Truck Centerline.	ISO 362-1:2007

In-cabin noise measurement methods are based on Federal compliance standards applicable to trucks and buses. Federal Motor Carrier Safety Administration (FMCSA) Part 393.94 specifies meter locations. Guidelines call for a vertical microphone inside the cabin that is six (6) inches from the driver's right ear, and at the same height. During actual testing, personnel mounted microphones on the driver's left side due to available mounting surfaces. Refer to Figure 5-11 for photo of in-cabin microphone placement. ATC personnel closed the windows, doors, and vents for the duration of in-cabin noise testing.

Figure 5-11. Microphone Placement for In-Cabin Noise Testing (Photo by Chris Shires, US Army ATC)

Outdoor acceleration/deceleration measurements observed International Standards Organization (ISO) 362 guidelines for placement of the meters. ATC accomplished metering in an open space location clear of structures, land features, and vegetation (i.e., berms or trees) for 50 meters or 164 feet extending horizontally in all directions around the truck. NAVFAC EXWC adjusted tripod stands so that microphone receptors were at a height of 5 feet from ground level. ATC personnel conducted three trials for each mode, as suggested by Table 5-7. NAVFAC EXWC positioned the meters 25 feet from the centerline of travel as shown by Figure 5-12.

Table 5-7. Noise Test Matrix for Drive-by Testing

Mode	Speed (mph)	Trial 1	Trial 2	Trial 3
Constant Speed	10 mph			
	20 mph			
	25 mph			
Acceleration	0-10 mph			
	0-20 mph			
	0-25 mph			
Deceleration	10-0 mph			
	20-0 mph			
	25-0 mph			

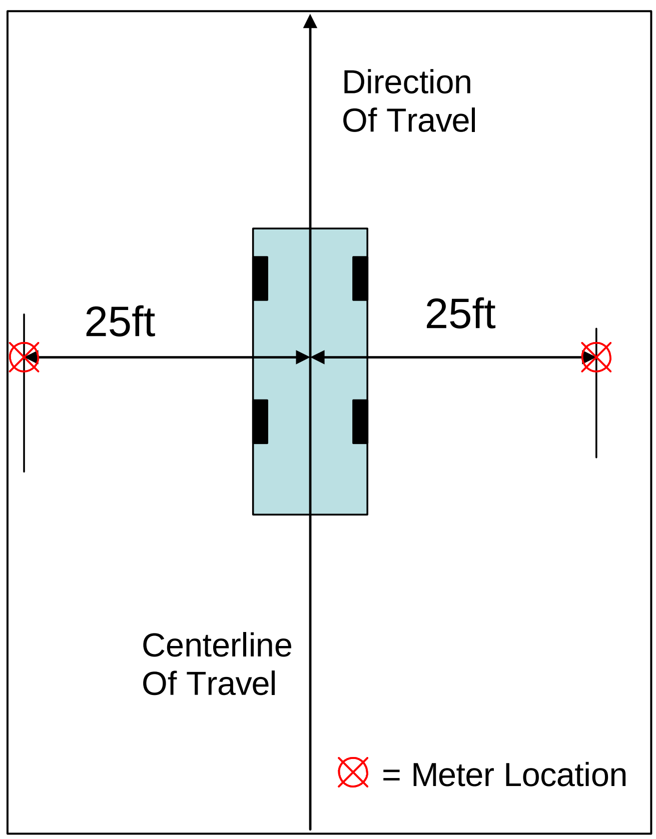


Figure 5-12. Meter Placement for Drive-by Noise Testing

Outdoor noise testing will also assessed work noise reduction for hybrid utility trucks. For the utility trucks this includes measuring conventional engine idling required for hydraulic lift operations. The noise from engine idle, which masks both background sounds and calls from personnel in the platform, will be 10 feet from the left and right sides of the truck. Personnel collected data for five minutes at locations specified in Figure 5-13.

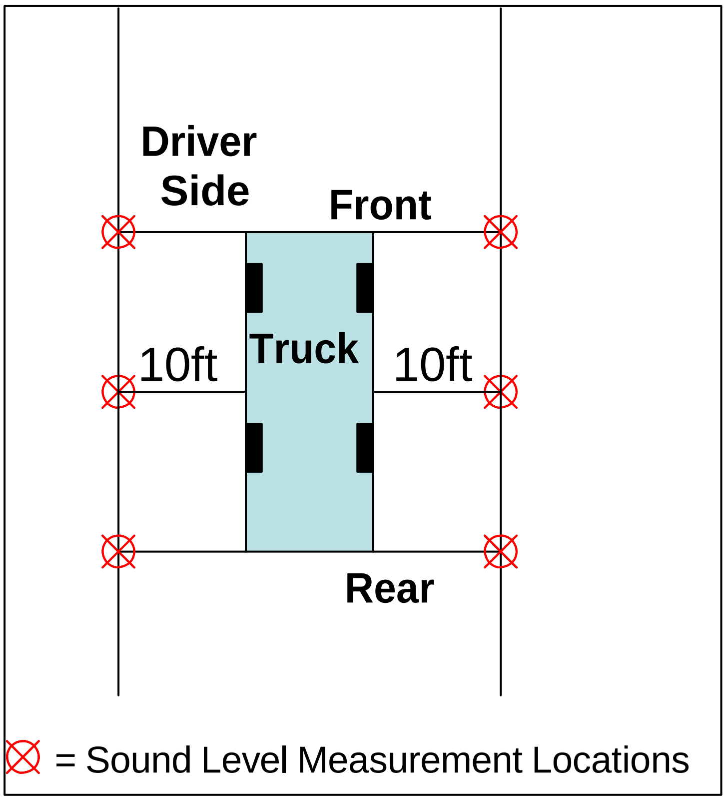


Figure 5-13 Meter Placement for Utility Truck Idle Measurements

Sound level measurements did not characterize lift event noise for the refuse trucks. The original plan was to characterize noise generation during the raising and lowering of the truck's side loader during refuse collection operations. These measurements were deemed unnecessary upon discovering the hybrid system during idle mode.

Test Controls

Track tests included several provisions to collect comparable data and remove interfering factors. Skilled operators adhered to controlled cycle parameters on measured courses to eliminate bias due to individual operator driving habits. ATC discarded test runs that fell more than five (5) percent outside the speed variation allowances. To avoid climate factors, ATC limited testing to times when average wind speeds were 12 mph or less and where peak wind speeds were 15 mph or less. ATC filled test vehicles with the same pre-certified test fuel (No. 2 ULSD). Test personnel also checked vehicle specifications to ensure the vehicle tire pressures and fluid levels conformed to manufacturer specifications prior to track testing. All test vehicles also ran for a minimum of 30 minutes prior to official track testing trials to ensure they reached operating temperature. Additional track test control provisions are contained in the track test protocol below.

Track Test Procedure

Personnel shall deliver all test vehicles by driving them directly to Aberdeen Proving Grounds, MD from the final manufacturer assembly locations**.** This initial operation will identify potential problems and serve as initial break-in prior to drive cycle testing. After truck delivery, the project team shall conduct initial inspections to prepare the trucks for drive cycle testing. Figure 5-14 provides an overview of the drive cycle test procedures. The following numbered paragraphs provide additional detail.

1) **Setup Track:** Configure in-cabin monitor with speed vs. time points for each drive cycle. Setup cones on the test track to indicate consistent start and stop points for each trial run in the drive cycle. Collect photos of the setup and auxiliary equipment including weather station, instrumentation trailer, truck scale, and outdoor sound pressure level meters. Place sound meters on both sides of the track, at locations equidistant from the vehicle path, as discussed in prior section.

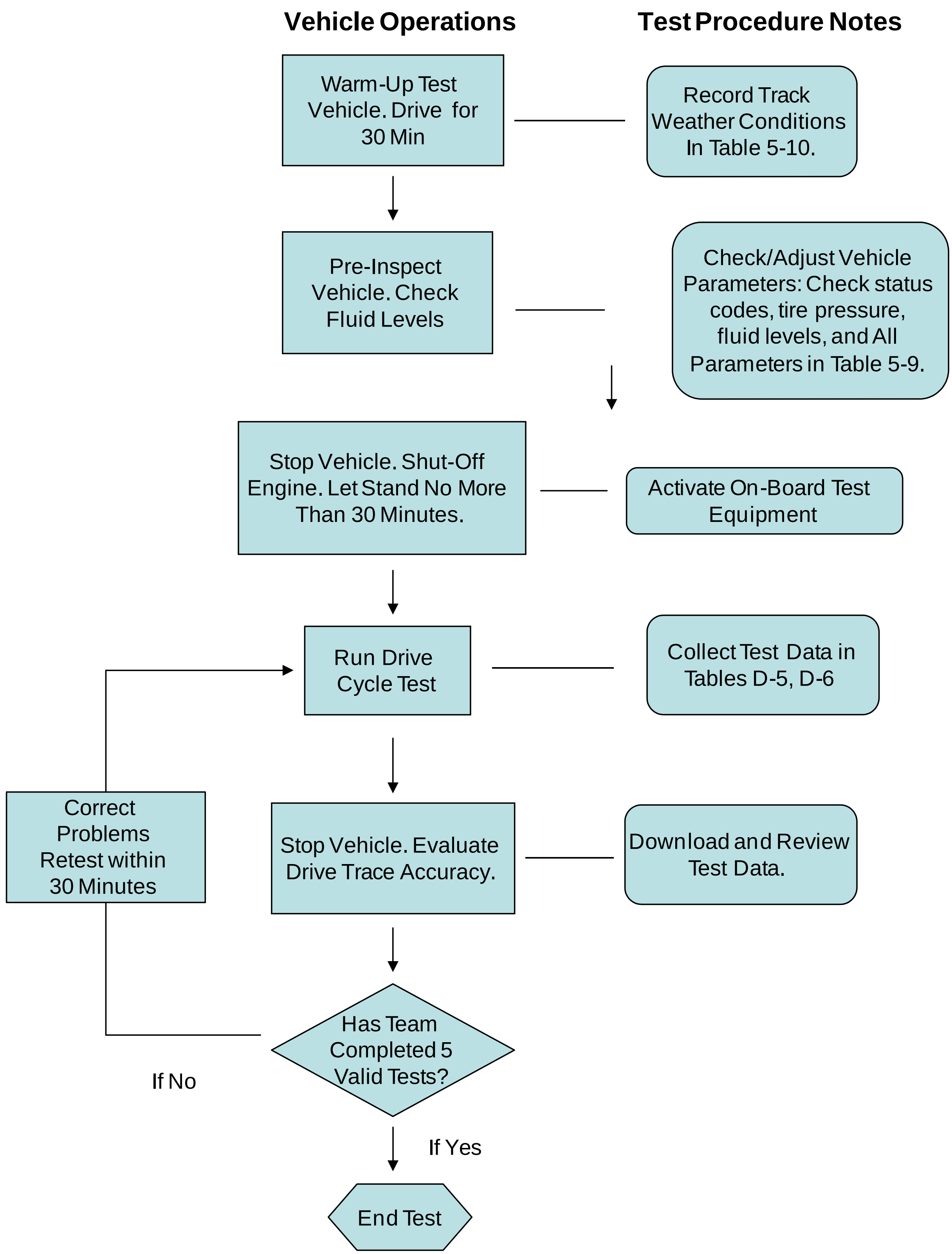


Figure 5-14. Flow Chart of Drive Cycle Test Procedure

2) **Install Vehicle Test Equipment:** Install temporary on-board portable instrumentation for the recording time, vehicle speed, engine speed, torque, and fuel consumption. (Figure 5-15 shows the actual instrument setup.) Install sound level meters on-board the trucks, and at the designated drive-by points. Capture digital photos of the vehicle identification number, engine label, truck body, and hybrid battery or hydraulic system.

Figure 5-15. On-board Instrumentation for Fuel Economy Data Collection (Photo by Chris Shires, US Army ATC)

3) **Configure Fuel Metering System.** Install factory-calibrated fuel metering system on board the test vehicle. Connect to existing supply and return fuel lines to the engine. Fill on-board tank with diesel fuel as specified in Table 5-8.

Table 5-8. Test Fuel Specification

Sulfur content	15 parts per million (ppm) maximum
Cetane index and aromatic content	40 minimum cetane index or 35 volume percent maximum aromatics content
Flash/Fire point	52º C minimum
Water/Sediment	0.05% volume maximum
Particulate Contaminant.	10 mg/L maximum
Viscosity KIN/CS at 40ºC	1.9 to 4.1

4) **Equip Vehicles with Payloads.** Place and secure weights on-board the refuse trucks to simulate payload. Load each refuse truck with a 4,000 pound load that consists of 1,000 pound weight in each trough. Figure 5-16 shows a payload in one of the refuse truck troughs. Weights included water holding totes loaded empty onto the truck and subsequently filled with water.

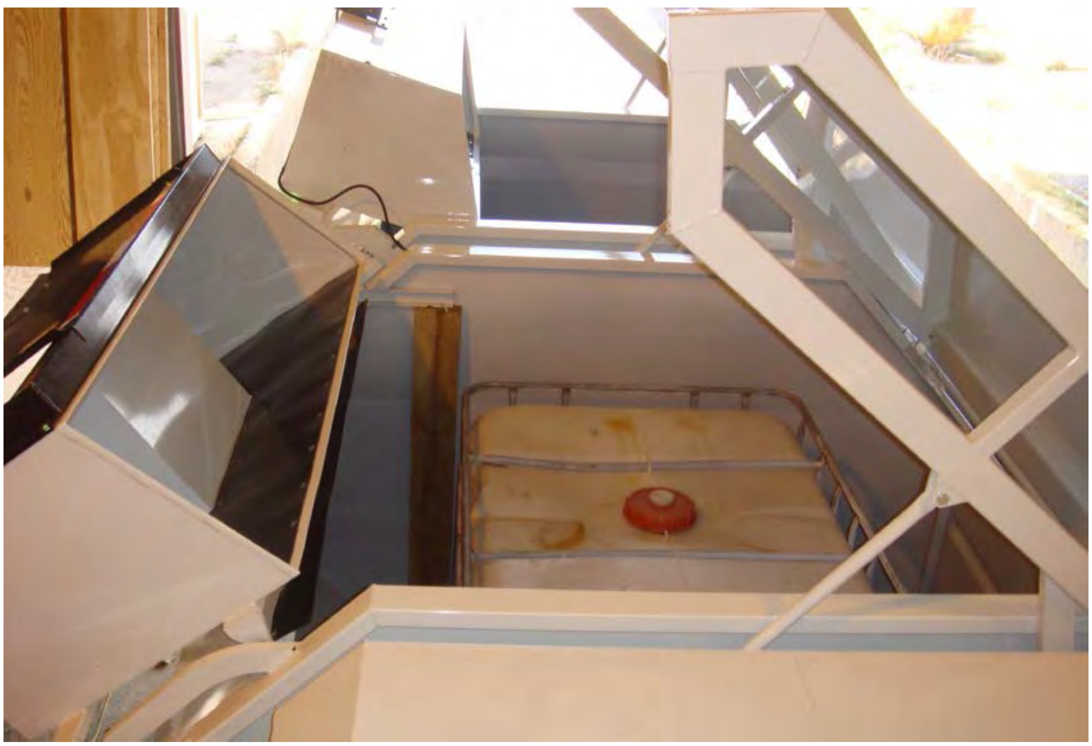


Figure 5-16. Refuse Truck Payloads Consisted of Water-Filled Containers (Photo by Chris Shires, US Army ATC)

5) **Warm-up Test Vehicles.** Drive vehicles for a minimum of 30 minutes to warm up the power train. Carefully listen to the engine. Observe the dash board controls for any engine trouble codes. Also observe data transmitted and received on-board ATC's mobile data acquisition system (MDAS) trailer. ATC staff will note any unusual conditions that may interfere with the testing.

6) **Check Vehicle Conditions.** Check operating parameters, fluid systems, tire pressure, against manufacturer specifications as indicated by Table 5-9. If trouble codes are present, resolve prior to beginning the test.

Table 5-9. Pre-Track Test Vehicle Checks

• Vehicle Fluid Levels
• Vehicle Tire Pressure
• Vehicle Status Codes
• Vehicle Engine Temperature
• Hybrid System Temperature
• Hybrid SOC

7) **Check/Set Vehicle Settings.** Temporarily adjust and record vehicle settings to ensure consistent parameter for both vehicles as listed in Table 5-10.

Table 5-10. Vehicle Settings for Track Testing

• Cabin Ventilation Fan – Off
• Cabin Air Conditioning – On
• Diesel Particulate Filter Regeneration – Off
• Anti-lock Brake – Off
• Vehicle Performance (Torque/Horsepower) – Economy
• Anti-lock Braking System – Off

8) **Record Track Conditions.** Measure and record weather conditions in accordance with Table 5-11. Ensure conditions are in accordance with controls stated in Section 5.3.4 Test Controls (i.e., average wind at or below 12 mph, peak wind at or below 15 mph). Document all instances of deviation from the specified conditions.

Table 5-11. Track Weather Condition Measurements

Ambient Temperature	Deg F or Deg C
Barometric Pressure	Inches Hg
Relative Humidity	0 to 100 percent
Wind Speed	Mph
Wind Direction	0-360 degrees

9) **Precondition Vehicle.** Pre-condition the test vehicle by driving the test course in order to raise engine and exhaust emission control equipment to operating temperatures. Drive for 30 minutes. Engine coolant, oil, and drive-train lubricants must reach an operating temperature that is consistent throughout the repeated test runs. Allow a 20 to 30 minute (maximum) hot soak. The hot soak occurs when the vehicle is shutdown and operating temperature initially

rises due to halting of the radiator and cooling fan effects. After the 20 to 30 minute hot soak, begin test runs.

10) **Conduct Drive and Hydraulic Cycle Tests.** Place instrumentation in a ready state, including fuel metering system, datalogger, and sound level meters. Operate the trucks through the drive cycle. Collect outside sound level data during the hydraulic load cycle testing. Conduct a minimum of five test runs. Keep intervals between test cycles between 10 and 30 minutes. Repeat tests if any change in test equipment or vehicle (i.e., calibration test fails, vehicle trouble code displays, vehicle falls out of tire specification or exhibits fluid leak). Manually regenerate the on-board diesel particulate filter after each test cycle to prevent regeneration during a trial run.

For utility vehicles, ATC staff will operate the aerial boom of each test vehicle as an integral part of the drive cycle. Staff will operate the boom while the truck is stationary and secured with the outriggers in-place, over a 50 minute load cycle. ATC staff shall continuously measure current flowing into and out of the hybrid truck's battery.

11) **Conduct Post Drive-Cycle Checks.** After each test run, ATC staff will determine drive trace accuracy in accordance with the test track specifications. At the conclusion of each test run down-load and review fuel metering and vehicle operation data. For hybrid vehicles, also record hybrid energy system SOC. Review data generated for each truck. Check for any engine trouble codes that are present.

Following drive cycle testing, ATC and NAVFAC EXWC staff will summarize test data for project team review. ATC will provide a report to CALSTART and NAVFAC EXWC within 45 days of test completion. Staff will also review fuel economy, noise, and test conditions data within two working days of each test run completion.

5.4. Site Test Protocol

After track testing, each pair of trucks will be sent to corresponding host sites for six-months of testing. The demonstration will follow similar procedures at both sites, with variations in the application and data parameters of interest. Sections below further describe site testing guidelines for each site.

NAVFAC Northwest

NAVFAC Northwest's Solid Waste Operations Team oversaw refuse hauler testing. The project team accomplished the following activities at NBK Bangor in order to support the launch activities.

Kick-Off Activities

Kickoff Meeting: The project team conducted a kick-off meeting with NAVFAC EXWC, CALSTART, NAVFAC Northwest Regional Fleet Manager, and the Solid Waste Team manager in attendance. The meeting agenda included review of validation objectives, data collection procedures, servicing logistics, and routine inspection.

Training: Both chassis and hybrid manufacturer representatives conducted operator and technician training. Training included specific attention to the hybrid hydraulic system. Driver training orientation shall last approximately four hours. Hybrid supplier representative explained that the hybrid hydraulic equipped truck driving and lifting procedures were comparable to the conventional trucks. Project team instructed that drivers observe and monitor the truck console display and any new warning lights. Technicians training included servicing requirements and diagnostic checks required for the HLA system. Maintenance for the hybrid system is very similar to system hydraulics used to operate the lift arm on the refuse trucks.

Baseline Inspection: The local base operating services contractor provided vehicle maintenance support, including baseline and routine truck inspections. Vehicle technicians inspected trucks to verify basic truck condition and conformance with manufacturer specifications. Inspections included system checks shown in Table 5-12. Inspectors were requested to complete the Refuse Truck Inspection Form in Appendix B. CALSTART checked the Telematics system following installation to ensure it was fully functional for all selected operating parameters. This inspection was the first of routine inspections to occur throughout the demonstration period.

Table 5-12. Refuse Truck Inspection Parameters and Collection Frequency

Inspection Parameter	Description	Frequency
Accumulator	Visually Inspect	Baseline, Weekly
Engine Diagnostics	Check for Trouble Codes	Baseline, Weekly
HLA System	Check for Fault Codes	Baseline, Weekly
HLA Pump, Components	Visually Inspect for Leaks	Baseline, Weekly
HLA Sub-Frame	Visually Inspect Welds/Mounts	Baseline, Weekly
Tires	Air Pressure	Baseline, Weekly
Engine Oil	Check Level	Baseline, Monthly
HLA System Oil	Check Level	Baseline, Monthly
HLA Fluid Reservoir	Check Breather Indicator	Baseline, Monthly
Radiator Coolant	Check for Leaks	Baseline, Monthly
Transfer Case Oil	Check Level	Baseline, Monthly
Hose/Fittings	Visually Inspect	Baseline, Monthly
Brake Pads	Thickness	Baseline, 6-Months

Vehicle Operations

The Solid Waste Team dispatched trucks for daily collection of recycling materials. Originally, both refuse trucks were to support alternate collection routes for Bangor, Keyport and Bremerton. The project team’s intention was to prevent test bias due to terrain, distance, and driving patterns associated with a single route. Two factors changed during actual execution. First, operators did not alternate collection routes due to the complications with the collection procedures. Second, the team eliminated Bremerton from the collection routes due to insufficient clearances to accommodate the side loaders and potential hazards. Lastly, the Solid Waste team deployed the hybrid truck to NAS Whidbey in June 2012. This change helped mitigate the disproportionate duty cycles although deployment to this location was not in the original test plan.

Site Data Collection

After launching the test program, the project team collected the following data for the duration of the test period:

- **Fuel Logs/Operator Surveys:** Regional fleet management captured records for fuel consumed by both trucks using Defense Logistics Agency (DLA) fuel management data. Card readers capture this data at the point of fueling using a specified card reader. Information improved data consistency as compared with operator-capture via completion of Utility Truck Inspection Form and Utility Truck Driver Survey in Appendix B. On-site fleet manager consolidated the logs and emailed copies to NAVFAC EXWC and CALSTART. Fleet management and operator team provided input at the beginning, middle, and end of the demonstration period during teleconference discussions.

- **Inspection/Maintenance Data.** Project assigned technicians overseeing maintenance were requested to conduct inspections approximately weekly. Technicians did not provide complete inspection forms (Appendix B) for each inspection visit. The intent was to identify problems requiring further resolution. No such chassis or hybrid related service was required for input into the service log forms.

- **Automated Data:** On-board dataloggers captured and transmitted vehicle operating data each day via an on-board Telematics system. Telematics recorded operational parameters defined in Appendix C, every two seconds. Data uploaded to a commercial website maintained by the third party datalogger manufacturer each day. Data collection was independent of the host site activities. CALSTART collected and distilled the data into summary reports for internal project team review.

CALSTART, with NAVFAC EXWC oversight, consolidated and summarized NBK Bangor site data each month. CALSTART emailed bimonthly data for stakeholder review. The interim data assessments helped identify bias or inconsistencies, and prompted CALSTART and NAVFAC EXWC follow-up with the operator team. These investigations helped resolve specific stakeholder review comments.

NAVFAC Southwest

NAVFAC Southwest’s Utilities IPT oversaw the utility truck testing. The manufacturer drove both trucks from APGM to Pomona once track testing concluded. The following site testing activities took place.

Kick-Off Activities

Kickoff Meeting: The team conducted a kick-off meeting with NAVFAC EXWC, CALSTART, NAVFAC Southwest Regional Fleet Manager, the Utility Team IPT Lead, and field drivers all in attendance. The meeting agenda included review of validation objectives, data collection procedures, truck servicing logistics, and routine inspections under the test protocol. NAVFAC Southwest hosted the kick-off meeting in conjunction with the operator and service training described below.

Training: Manufacturer representatives conducted operator and technician training with specific attention to the hybrid electric system and differences with the conventional truck system. Training included instruction on important electrical system safety procedures for the hybrid utility truck. Driver training included training on hybrid system and aerial lift operation. The driver orientation lasted approximately four hours. Hybrid manufacturer representative provided training on the hybrid electric truck's high voltage battery pack and additional driving options. Trainers instructed drivers to be aware of new hybrid display module, indicators, operational procedures, and data collection objectives. Technician training was more extensive and provided NAVFAC Southwest technicians with further detail on operation, servicing requirements, and diagnostic checks required for the hybrid electric system.

Baseline Inspection: Host activities coordinated with NAVFAC Southwest BSVE Office, which oversees vehicle maintenance, to conduct a baseline truck inspection. Vehicle technicians inspected trucks to verify the basic truck condition conformed to manufacturer specifications. Inspections included system checks shown in Table 5-13. During the baseline inspection, CALSTART checked the Telematics system to check functionality of with objective operating parameters. Operators conducted daily inspections throughout the demonstration period.

Table 5-13. Utility Truck Inspection Parameters and Collection Frequency

Inspection Parameter	Description	Frequency
Engine Diagnostics	Check for Trouble Codes	Weekly
Tires	Air Pressure	Weekly
*HEV System Cases	Inspect for Damage, Cleanliness	Monthly
*HEV System Fasteners	Check for Damage, Looseness, Corrosion	Monthly
*HEV High-Voltage Labels	Ensure Labels are Intact and Readable	Monthly
HEV Liquid Cooling System	Check Case Connector Fittings for Leakage Check Hoses for Cracks, Nicks, Corrosion Check Tank/Fin for Leakage, Obstructions Ensure Radiator Fan Latches Every 6" to 12" Check Radiator Fan for Damaged Blades	Monthly
HEV Low Voltage Cables	Ensure Anchors Every 12" and 6" from Connectors Check for Heat Damage from Exhaust Pipe Ensure Proper Heat Shield In-Place Near Exhaust	Monthly
Engine Oil	Check Level	Monthly
Hydraulic Fluid	Check Level	Monthly
Radiator Coolant	Check for Leaks	Monthly
Transfer Case Oil	Check Level	Baseline, 6-Months
Brake Pads	Thickness	Baseline, 6-Months

*HEV Sub-System Cases: Power Electronics Carrier, Inverter, Motor Generator, APGEN, Direct Current/Direct Current Converter, Electronic Clutch Actuator

Vehicle Operations

The Utilities Team dispatched trucks for service calls to sites within a 25 mile radius, surrounding NAVSTA San Diego, Utilities IPT base office. The electrical team performs service at seven (7) installations in the Metropolitan San Diego area, including Naval Outlying Landing Field Imperial

Beach, Naval Submarine Base Point Loma, MCAS Miramar, Naval Amphibious Base Coronado, Naval Air Station North Island, Anti-Submarine Warfare, and NAVSTA San Diego.

Utility operators periodically exchanged trucks early in the demonstration in order to prevent bias due to personnel driving habits and route differences. Truck rotation did not continue as this encumbered the normal dispatching practice that matches operators to the specific installations. As a result, the hybrid truck made longer distance trips than the conventional truck, including extensive travel to MCAS Miramar.

Site Data Collection

Site testing included the following data collection objectives:

- **Fuel Logs/Operator Surveys:** Operator shall manually complete Utility Truck Driver Survey Forms in Appendix B. Drivers did not complete the fuel logs as the trucks were filled separately and independently by a fuel truck operator. This was necessary to ensure consistent fueling with conventional diesel instead of biodiesel blend that is the standard product at the fuel stations. Operators completed surveys at the beginning, middle, and end of the demonstration period. Utilities Team manager consolidated surveys and provided copies to CALSTART during site visits. The Team Lead, as well as the operators of the hybrid and non-hybrid utility trucks, completed the surveys. Any questions or gaps were addressed during follow-up site visits.

- **Maintenance Data:** Truck operators inspected both trucks daily. Operators completed Utility Truck Inspection Form in Appendix B, for each inspection. Purpose of the inspections was to identify missing/damaged components. Utilities team manager provided copies of the inspection data and service logs to CALSTART during site visits along with the operator surveys.

Data Collection Issues

Inspection forms were not filled out every day but interviews conducted with the drivers showed that problems associated with the utility trucks were immediately reported to the service staff so that trucks were called in for repairs. The service team used work orders in place of the inspection forms to detail problems that occurred during the performance test period.

NAVFAC maintenance staff raised additional issues in the submitted work orders. Work orders include actual start dates and actual completion dates of service work performed on the vehicles. However, there were issues where the actual start and completion dates went on for an extended period of time. In comparing the data collected from the data logger and the work orders, CALSTART found that the vehicles were being operated during the scheduled service start and completion dates. In follow-up discussions with NAVFAC Southwest service staff, CALSTART determined actual service start and completion dates were inconsistent with work order records. Therefore, CALSTART used actual labor hours as the primary metric for determination of truck service availability.

- **Automated Data:** Onboard data-loggers captured vehicle operating data each day. The on-board Telematics system transmitted the data to a hosted web-site. Telematics systems recorded operational parameters defined in Appendix C. Telematics data subsequently uploaded to the commercial website each day. CALSTART downloaded and distilled the Telematics data into summary reports for project team review and discussion.

CALSTART, with NAVFAC EXWC oversight, consolidated and summarized utility truck operational data monthly. CALSTART emailed reports to the stakeholders for review after the first month, and bi-monthly thereafter (i.e., after Month 1, 2, 4, and 6). Interim review assessments solicited project team and stakeholder feedback to validate the data summaries. The project team conducted follow-up investigations and solicited stakeholder review comments. This process was employed in order to enhance data collection procedures and to address any stakeholder questions or concerns.

6. Performance Assessment

6.1. Track Testing

Sections 6.1.1 and 6.1.2 cover the results of fuel economy and noise testing, respectively, conducted at APGM. The Army's ATC team oversaw fuel economy testing while NAVFAC EXWC was responsible for noise testing. Testing was conducted sequentially beginning with the conventional refuse truck and concluding with the conventional utility truck. The project team conducted testing on individual trucks in order to reduce the logistics. Simultaneous testing would have incurred higher costs for equipment, personnel, and setup time.

Refuse Truck Fuel Economy

The Army's ATC conducted fuel economy testing on the conventional and hybrid refuse trucks in October 2010 and December 2010, respectively. Testing occurred without any use of the lifting mechanism, and as described in the test procedures detailed in Section 5. Testing on the conventional refuse truck proceeded without issues. ATC accomplished a total of five acceptable fuel economy drive cycle trials for the conventional truck, and five comparable runs on the hybrid while the truck was in the "Economy" mode. Figure 6-1 shows the fuel economy testing in-progress. Refer to Appendix D for ATC's fuel economy test report.

Table 6-1 below presents test data for each of the 10 test trials. Fuel economy values for each of the test trials were within four percent of the average. Of note, the measured conventional refuse truck economy was 13 percent higher than the hybrid refuse truck. ATC's test driver expressed concern during testing of the hybrid truck. The driver indicated the hybrid truck's strong regenerative braking effect was more severe than the drive cycle's speed. This effect required the driver to use the accelerator during deceleration events in order to prevent the truck from slowing sooner than the cycle allowed. Natural coasting of the truck during deceleration events would have resulted in the truck falling below the cycle's established speed and invalidation of the test trial.

Figure 6-1. Photo of Conventional Refuse Truck (foreground) with Mobile Data Acquisition System (MDAS) Trailer in the Background (Photo by Chris Shires, US Army ATC)

Table 6-1. Refuse Truck Fuel Economy Results

Conventional Diesel						
Test Number	1	2	3	4	5	Average
Test Date (2010)	22 Oct	22 Oct	26 Oct	26 Oct	26 Oct	NA
Drive Cycle Precision (%)	2.6	2.5	1.4	1.8	1.1	NA
Fuel economy (mpg)	5.2	5.4	5.5	5.4	5.4	5.4
Hybrid Hydraulic (Tested in "Economy" Mode)						
Test Date (2010)	2 Dec	2 Dec	2 Dec	2 Dec	2 Dec	NA
Drive Cycle Precision (%)	2.4	1.6	1.9	1.5	1.4	NA
Fuel economy (mpg)	4.6	4.8	4.8	4.8	4.7	**4.7**
Hybrid fuel economy is 13% lower than the conventional truck for the selected cycle.						

ATC conducted further hybrid testing due to the results in the "Economy" mode. These modes were not in the original test plan or budget, and therefore did not include the five trials per mode. Testing in the “Performance” mode yielded the same result as the “Economy” mode. This suggests the drive cycle did not include a sufficient number of accelerations to significantly increase fuel economy relative to the conventional truck. “Off” mode testing (i.e., hybrid disengaged) also yielded a fuel economy lower than the conventional truck, as shown in Table 6-2. The resultant “Off” economy mode suggests the weight burden of the hybrid cost the truck approximately 0.3 mpg.

Table 6-2. Refuse Truck Fuel Economy Results for Alternative Operating Modes

Platform Mode	DoD Cycle (mpg)	Change from Baseline	Test Objective	Met Objective?
Conventional (Baseline)	5.4	Baseline	Baseline	Baseline
Hybrid (Economy)	4.7	-13%	20% Increase	No
Hybrid (Performance)	4.7	-13%		No
Hybrid (HLA Off)	5.1	-6%		No

ATC monitored the SOC of the refuse truck’s HLA system to observe and confirm its operation throughout the drive cycle. Figure 6-2 shows a plot of refuse truck’s speed versus the HLA’s SOC. The plot confirms the way in which the HLA system operates, which is contingent upon the speeds of the truck.

The manufacturer configured the HLA to operate at speeds up to 22 mph setpoint. When the truck speed exceeds this setpoint, the HLA system disengages. As indicated by the plot, the HLA activated for approximately 60 percent of the drive cycle acceleration and deceleration peaks, or for 12 of the 20 braking events. During an acceleration event that is within the 22 mph, the HLA engages as the driver lets up on the accelerator. The accumulator charges and launch assist is provided for the subsequent acceleration. When the 22 mph speed threshold is exceeded, the HLA disengages and neither launch assist nor regenerative braking is available until the truck comes to a full stop and the system resets.

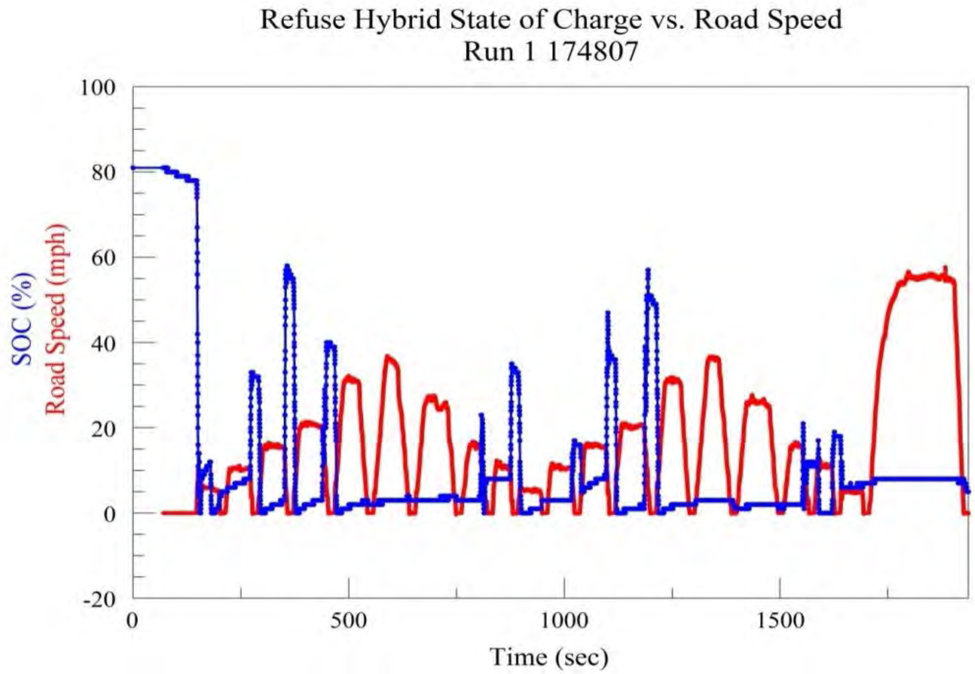


Figure 6-2. HLA SOC Activation during Fuel Economy Testing
(US Army ATC Report No. 10546)

Utility Truck Fuel Economy

ATC conducted fuel economy testing on the utility trucks in January 2011 at Aberdeen Proving Grounds. Figure 6-3 is a photo of testing-in-progress for the conventional utility truck. Testing included both DoD lift cycle trials and commercial drive cycle trials using the CILCC. ATC accomplished a total of five valid lift cycle trials on the conventional truck and three valid trials on the hybrid. All testing occurred while the truck was in the "economy" mode.

Table 6-3 and Table 6-4 summarize the results of the DoD Lift Cycle trials for both trucks. Three of six lift trials on the hybrid truck disqualified due to deviations outside the two percent speed tolerance. Fuel economy results for both trucks were consistent and conclusive. Data consistency or standard deviation of the results is 0.1 mpg, and within five (5) percent of the average fuel economy for each truck. The hybrid demonstrated a 75 percent improvement over the conventional truck, well above the established performance acceptance criterion of 20 percent.

Figure 6-3. Fuel Economy Testing on the Conventional Utility Truck.
(Photo by Chris Shires, US Army ATC)

Table 6-3. Lift Cycle Fuel Economy Summary (Conventional Utility Truck)

Test Number	1	2	3	4	5	Average
Test Date (2011)	20 Jan	20 Jan	20 Jan	20 Jan	24 Jan	NA
Drive Cycle Precision (%)	1.3	0.6	0.8	2.3	2.4	NA
Measured fuel economy (mpg) [a]	2.4	2.3	2.3	2.4	2.4	**2.4**
Measured fuel consumption (gph)[a]	1.11	1.14	1.11	1.11	1.10	**1.11**

[a] Values are normalized to 60 degrees Fahrenheit

Table 6-4. Lift Cycle Fuel Economy Summary (Hybrid Utility Truck)

Test Number	**1**	**3**	**6**	**Average**
Test Date (2011)	5 Jan	5 Jan	10 Jan	NA
Drive Cycle Precision	2.9	1.8	1.8	**NA**
Fuel economy (mpg) [a]	4.1	4.3	4.2	**4.2**
Fuel efficiency (gph) [a]	0.62	0.62	0.63	**.62**

[a] Values are normalized to 60 degrees Fahrenheit for comparison

ATC complemented the combination DoD cycle testing that includes both lift/drive operations with the drive-only testing that included a portion of the CILCC cycle trace. The dedicated (drive-only) testing included five (5) trials on the conventional truck and three valid trials on the hybrid truck as shown by Table 6-5 and Table 6-6. Data sets for both trucks were consistent, with standard deviations of 0.09 and 0.12 mpg, or within two (2) percent of the fuel economy result averages for each truck. When compared side-by-side, the hybrid showed a consistent improvement, averaging 7.5 mpg as compared with the conventional truck's 6.5 mpg. The 15 percent improvement for this dedicated driving compares with a 23 percent improvement for the driving segment of the DoD Lift Cycle. The difference reflects the advantage of the hybrid truck for driving with lower speeds and greater stopping frequency. This increase is almost trivial as compared with benefits in the DoD Lift cycle.

ATC monitored engine operation status on both trucks through the lift cycles to observe operation of the hybrid electric system. Figure 6-4 shows a plot of engine RPM versus time into the DoD Lift Cycle. As shown in the plot, the conventional truck operated continuously at 760 RPM for the DoD Lift Cycle's duration. In contrast, the hybrid truck alternated between 15 minutes in the pure battery or "ePTO" mode, and four (4) minutes in the "Recharge" mode with the engine idling.

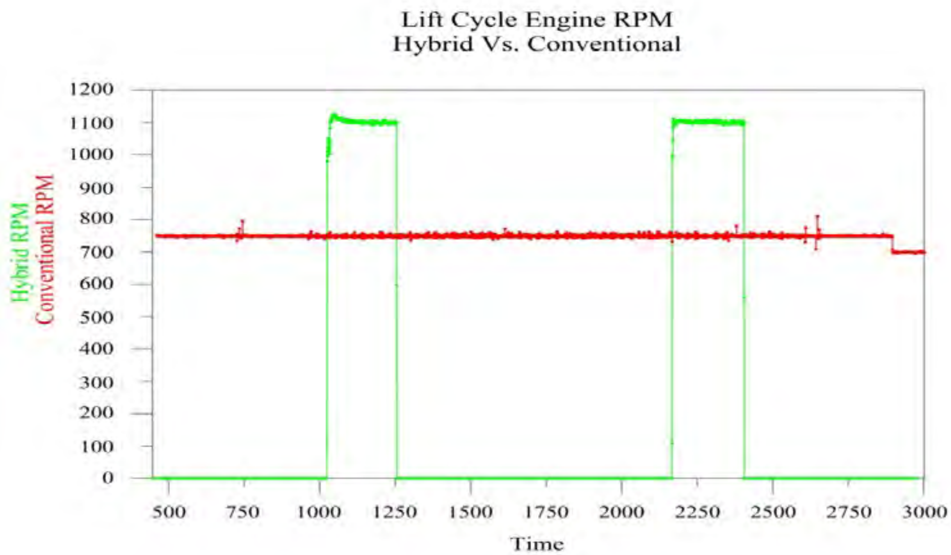


Figure 6-4. Plot of Hybrid (green) and Conventional (red) Engine RPM during Utility Truck Fuel Economy Testing (US Army ATC Report No. 10546)

Table 6-5. Conventional Utility Truck Test Results, CILCC Cycles

Test Number	**1**	**2**	**3**	**4**	**5**	**Average**
Test Date (2011)	20 Jan	20 Jan	20 Jan	24 Jan	24 Jan	NA
Drive Cycle Precision (%)	2.0	1.0	1.6	0	0.8	NA
Measured fuel efficiency (mpg)	6.3	6.5	6.6	6.6	6.6	**6.5**

Table 6-6. Hybrid Utility Truck Test Results – CILCC Cycle

Test Number	**1**	**2**	**3**	**Average**
Test Date (2011)	10 Jan	10 Jan	11 Jan	NA
Drive Cycle Precision (%)	1.3	1.9	2.6	NA
Measured fuel efficiency (mpg) [a]	7.4	7.6	7.4	**7.5**

Table 6-7 summarizes fuel economy improvements for both the conventional and hybrid trucks for both cycles. The hybrid truck meets the performance objective for DoD's lift cycle, but falls below the objective if the truck is used solely for driving. The drive cycle assumes a combination of low and high speed driving that is representative of most commercial utility truck applications. The drive cycle will be more severe than applications on small DoD installations with low speed driving and fewer stops. As such, the projected fuel economy improvement for on-base driving for similar hybrid platforms is at or below the 15 percent objective. Applications would need to involve considerably more start/stop or extended idling to meet the objective.

Table 6-7. Utility Truck Fuel Economy Overall Results Summary

Platform	DoD Cycle	CILCC Cycle	Test Objective	Met Objective?
Conventional	2.4	6.5	20% Increase	Yes
Hybrid	4.2	7.5		
Hybrid Percent Improvement	75%	15%		

Refuse Truck Noise Measurements

NAVFAC EXWC collected noise measurements for both the refuse and utility trucks while ATC operated the trucks in several different modes. The team's noise testing included both in-cabin and external noise measurements. NAVFAC EXWC measured noise levels while the trucks were at idle and driving. Driving noise included constant speed, acceleration, and deceleration. Tables and charts summarize noise measurements for the refuse trucks. Appendix I includes additional noise data in tabular format. Refer to Table I-1 and Table I-2.

Much of the noise testing occurred separate from the fuel economy testing. This was due to the logistics and time constraints of the fuel economy cycles. Noise testing required repetition of several modes at specified speeds that could did not fit in with the fuel economy test schedule. Separate of the testing procedures allowed the team to focus on the respective test events and collect repeat measurements as necessary.

In-cabin testing included measurements at several modes. NAVFAC EXWC collected measurements with the trucks at several speeds (i.e., 10, 20, 25 mph) in the constant speed, acceleration, and deceleration modes. Testing also included noise measurements while the trucks were at idle.

Table 6-8 below provides results of the in cabin measurements. Values displayed include averages noise levels in each mode. Figure 6-5 provides a plot of the same data. The hybrid refuse truck showed a moderate benefit when accelerating, approximately 40 percent lower sound levels. The hybrid refuse truck was louder than the conventional truck during deceleration events. Noise from deceleration is generally lower and less significant than noise of acceleration. Explanation for the reduced noise during acceleration is due to the HLA offsetting the engine power required by the conventional engine. In the deceleration mode, the hybrid's higher noise appears to be due to the recharging of the HLA's accumulator. There is no difference in the conventional engine operation in the static mode, as both engines idle at the same capacity and the accumulator neither charges or discharges.

Table 6-8. Refuse Truck In-Cabin Noise Levels (dBA)

	Static	**Accel.**	**Decel.**	**Constant Speed**
Conventional	71	81	72	76
Hybrid	71	77	74	77
% Change	0%	-39%	+32%	+12%
Objective Met?	No	Yes	No	No

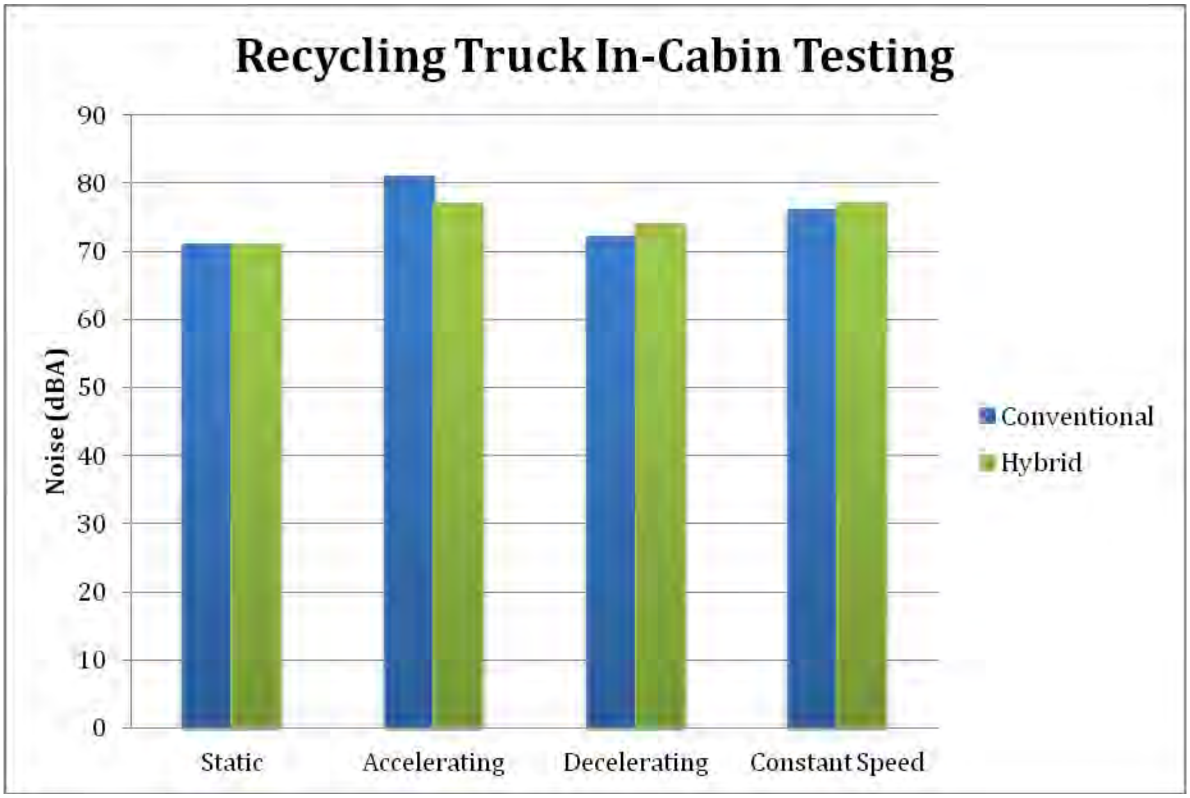


Figure 6-5. Refuse Truck In-Cabin Noise Levels: Conventional vs. Hybrid

Table 6-9 below provides a summary of outdoor noise measurements. Figure 6-5 is a bar chart summary of the fuel economy testing results. Hybrid truck's noise levels measured higher than the conventional truck across all operating modes. Highest noise levels occurred during the acceleration events. There was a significant increase in noise while the trucks were decelerating. External noise for constant speed driving was also significantly higher for the hybrid truck. Testing engineers also noted a different noise signature for the hybrid system. Potential sources of the hybrid noise include the accumulator or motor which support launch assist during accelerations, and regenerative braking during the decelerations, respectively. The higher level during the constant speed is also likely due to the same components (recall the HLA system, when engaged, readily goes into the regenerative braking mode when the driver releases the accelerator).

Table 6-9. Refuse Truck Outdoor Noise Levels (dBA)

	Static	Acceleration	Deceleration	Constant Speed
Conventional	82	83	73	76
Hybrid	83	85	81	79
Percent Change	+16%	+20%	+166%	+43%
Objective Met?	No	Yes	No	No

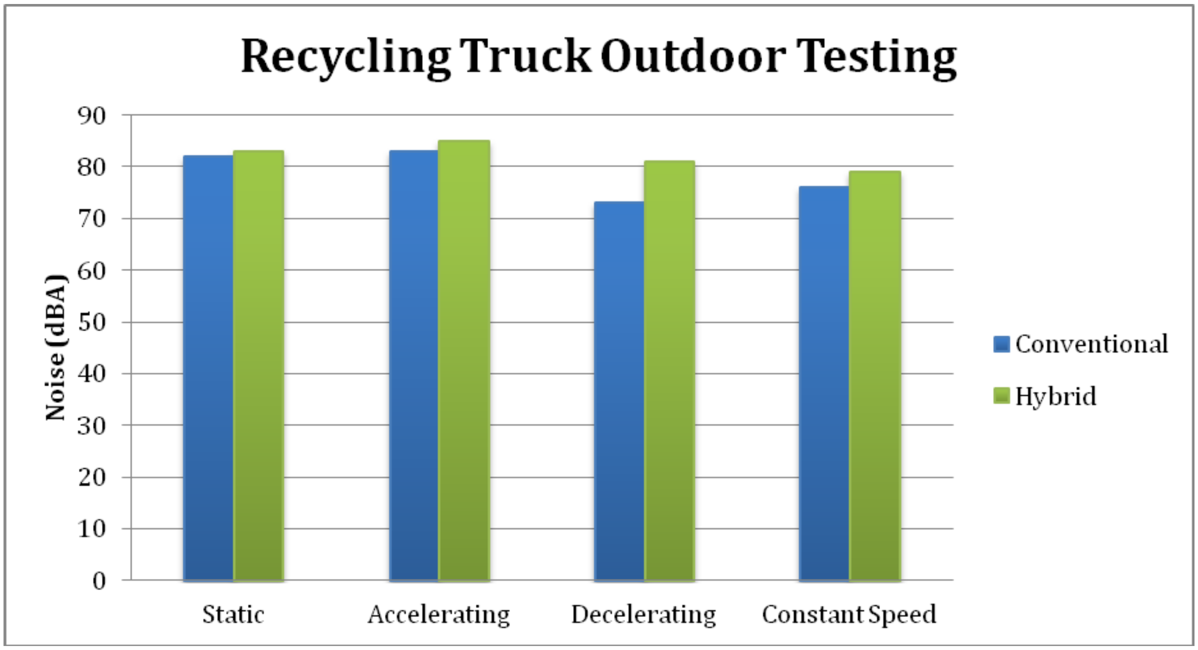


Figure 6-6. Refuse Truck Outdoor Noise Levels: Conventional vs. Hybrid

While the results indicate higher external noise levels for the hybrid refuse truck, there appears potential for improvement. Indoor noise levels are lower due to the cabin enclosure and insulation, as well as position of the HLA system. Similarly, outdoor noise levels could also be potentially improved through further insulation or design changes. While the lower in-cabin noise is a benefit to the drivers, reduction of outdoor noise would be a welcome improvement by miscellaneous personnel outside the truck.

Utility Truck Noise Testing

ATC and NAVFAC EXWC conducted noise testing on the utility trucks for the same driving modes (i.e., with 10 mph, 20 mph, and 25 mph speed points) as with the refuse trucks. Testing included acceleration, deceleration, and constant speeds. Noise characterization also included static testing with the trucks at idle (Figure 6-7). As with the refuse truck testing, receptor locations included both in-cabin and outdoor microphones. Tables and charts below summarize utility truck noise measurements. Appendix I provides additional noise data in tabular format.

Figure 6-7. Photo of Personnel Collecting Perimeter Noise Measurements During Static PTO mode (Photo by Chris Shires, ATC)

Table 6-10 and Figure 6-8 present results of in-cabin testing. Refer to Appendix I, Tables I-3 through I-5, for additional data. The hybrid demonstrated an improvement, providing lower in-cabin noise levels in the static and accelerating modes. This is apparently due to the electric motor's peak shaving effect during truck accelerations, and engine-off operation during the PTO mode. Hybrid utility truck noise was significantly higher than the conventional for deceleration and constant speed modes. This is likely due to the hybrid systems recharging generator, which assists with slowing of the truck during coasting or slowing.

In-cabin noise reductions reduce driver distraction and fatigue (for extended driving). Peak noise for the baseline truck is 77 dBA, and is generated during acceleration. The hybrid's quieter acceleration would be considered an overall benefit. The hybrid effectively reduced the peak noise (i.e., during accelerations) by 39 percent, to 73 dBA. Static PTO mode measurements resulted in a hybrid noise reduction of 49 percent relative to the conventional truck. The static benefit is less important given that the utility crew is unlikely to be in the cabin during PTO operations.

Table 6-10. Utility Truck In-Cabin Noise Testing (dBA)

	Conventional	Hybrid	Hybrid Improvement	Objective Met (20% Improvement)
Static	66	60	49%	Yes
Accelerating	77	73	39%	Yes
Decelerating	64	68	-71%	No
Constant Speed	66	69	-42%	No

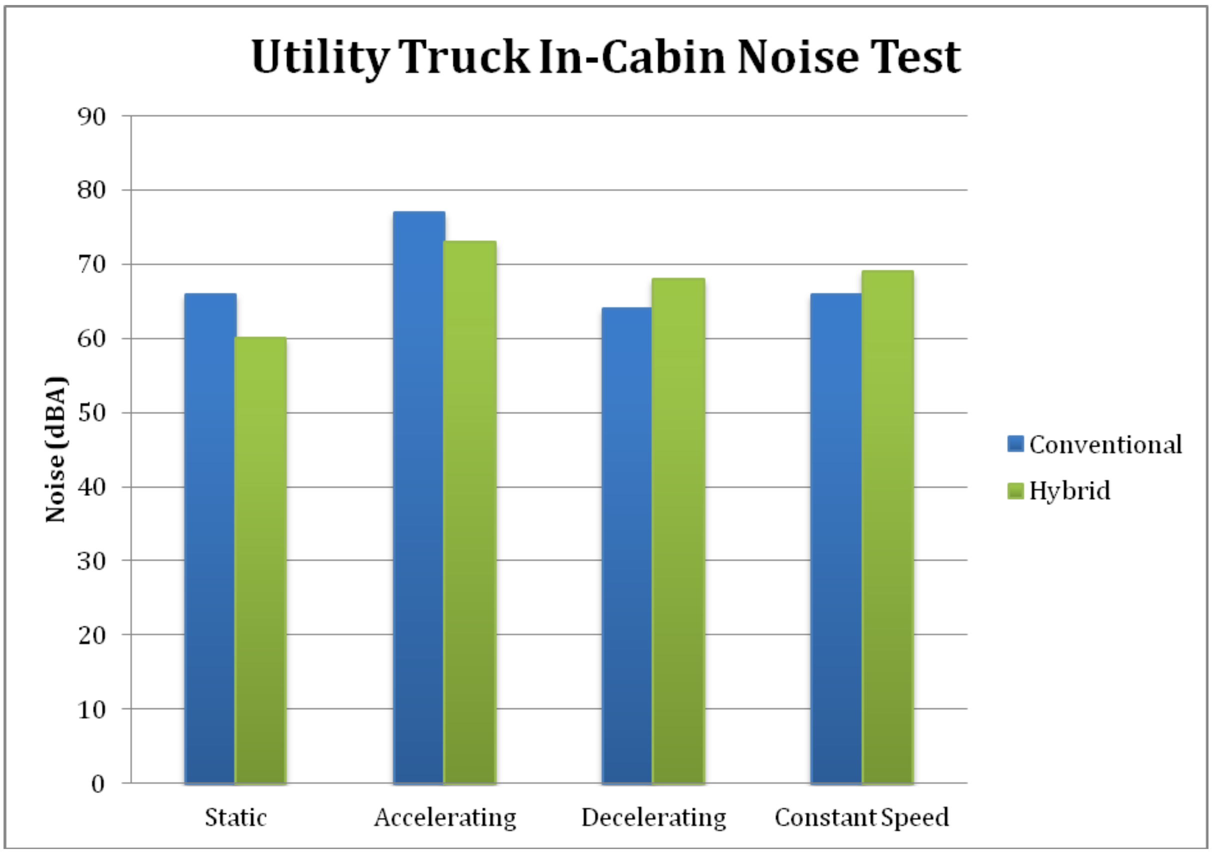


Figure 6-8. Utility Truck In-Cabin Noise Levels: Conventional vs. Hybrid

Table 6-11 and Figure 6-9 show outdoor noise levels for both utility trucks. In contrast with the in-cabin measurements there was no significant improvement during acceleration testing. Also, the hybrid noise was higher during the deceleration and constant speed modes, consistent with the in-cabin increases. For constant lower speeds outdoor noise from the hybrid noise was slightly higher on the driver's side of the truck. This is due to the hybrid truck's regenerative braking system emitting a pitch noise that is audible when the truck decelerates at speeds of 20 mph and lower. As expected, the hybrid was substantially quieter for idling operations as the hybrid system supplies power to the PTO, allowing shutdown of the conventional engine. PTO noise reduction of 49 percent is an important benefit as there is greater likelihood that the extended work site operations will present a significant distraction to utility crew or extreme annoyance to personnel residing or working in the area.

Table 6-11. Utility Truck Outdoor Noise Testing (dBA)

	Conventional	Hybrid	Hybrid Improvement	Objective Met (20% Improvement)
Static	85	70	83%	Yes
Accelerating	80	81	-12%	No
Decelerating	70	74	-55%	No
Constant Speed	74	76	-23%	No

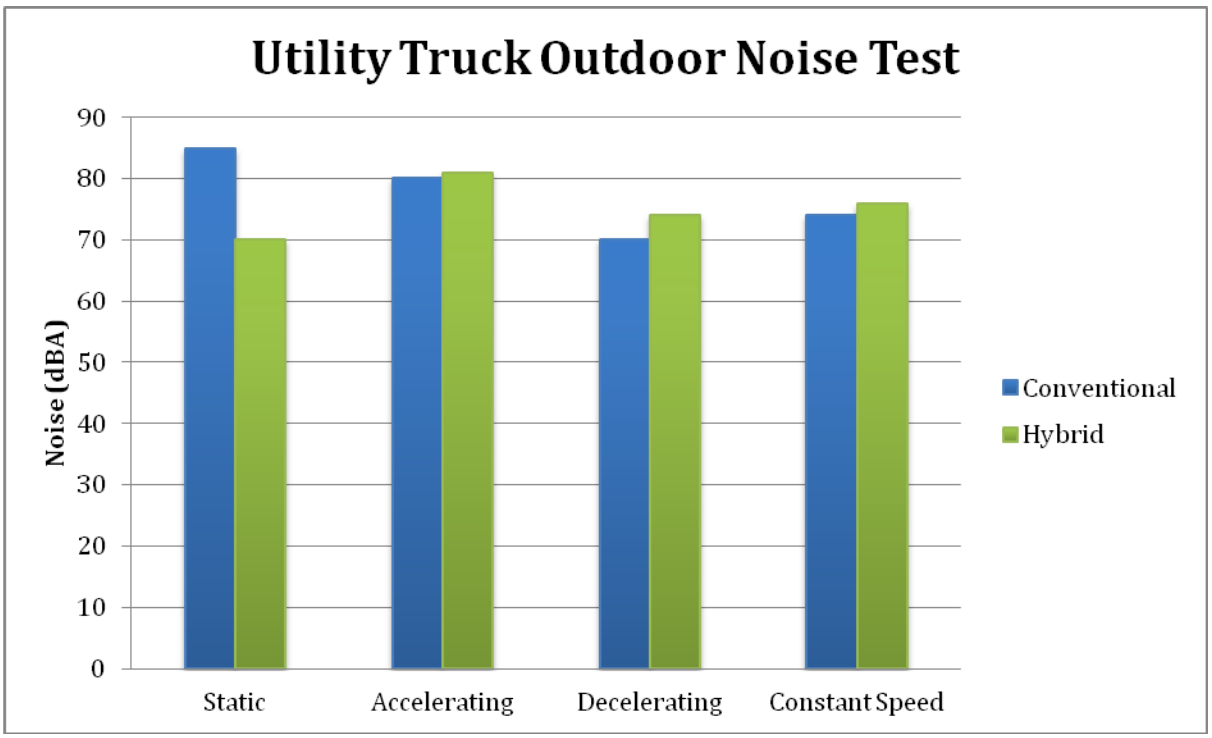


Figure 6-9. Utility Truck Outdoor Noise Levels: Conventional vs. Hybrid

Noise Monitoring Summary

In summary, the noise benefits for both the refuse trucks and the utility trucks were limited. Neither the hybrid refuse truck nor the hybrid utility truck reduced noise across all modes of operation as compared with the baseline trucks. Both hybrid platforms provided in-cabin benefits during acceleration testing. The hybrid utility truck provided a clear benefit in the engine-off PTO mode. Both hybrid systems increased noise during deceleration mode tests.

6.2. Site Testing

Refuse Truck Site Testing

Kick-Off Activities

The project team held a site kick-off event with the NAVFAC Northwest operator and service team at NBK Bangor WA from February 7-10, 2011. The event included a hands-on truck inspection, hands-on operator training, and class-room training for the service team. The meeting also included discussion of data collection objectives. Training occurred at the transportation maintenance shop Building 1202 at NBK Bangor, WA. Participants were NAVFAC Northwest operators, fleet management, solid waste team, contracted vehicle service team, NAVFAC EXWC, CALSTART, chassis supplier, and hybrid system supplier. Appendix E lists agenda topics covered during the training event.

Training/Baseline Inspection

Training began with an interactive hands-on inspection of the truck. During that time the chassis supplier provided an overview of the truck chassis and trough loader system. A demonstration of the trough loader operation followed the interactive overview. During the hands-on inspection, the Northwest team identified several items on both trucks requiring repair or corrective action (refer to Appendix F). The list included items such as back-up camera relocation, “stabilizer” warning light, high-idle switch, trough loader controls repair, and force neutral for side loader “lift” position. The only fix pertaining to the hybrid was the request for brake light illumination during regenerative braking events.

Chassis supplier representatives provided classroom instruction covering primary maintenance items such as line checks, fluid checks, and fault checks. An application engineer from hybrid supplier provided guidance on the best operation and service practices to achieve maximum performance from the HLA system. It was suggested the NBK Bangor contact the dealership for hybrid service-related issues.

Ride-Along Observations

CALSTART conducted a ride-along on Day 4 of the event. This event allowed CALSTART to witness and record observations on a representative collection route and duty cycle. Appendix G provides an observation record. The ride-along trip included a portion of each of the three bases, but was limited due to security access limitations. The ride-along identified several concerns with the suitability of the collection routes and hybrid benefits. First, over one-third of the stops were preceded by speeds above 25mph. Since the HLA system disengages above a 22 mph setpoint, the regenerative braking system disengages and there are no energy conservation benefits. Second, the routes include relatively long distances between long stops. This means the hybrid system, specifically the regenerative system, is minimally used. Thirdly, collection stops are relatively long, ranging from 20 to 55 minutes at each location. This allows for operator consolidation of waste into central containers before being emptied into the truck troughs. In contrast to the hybrid electric, the hybrid hydraulic system offers no advantages for extended idle time, as there is no associated engine-off feature. The system relies on frequent braking to capture energy of braking, and subsequently reuse this energy to offset part of the energy required for acceleration. Based on the ride-along, CALSTART concluded the inherently mild duty cycle did not fit the target stop/go application considered optimal for the HLA system. Subsequent discussion considered potential alternative collection routes to confirm a benefit for the hydraulic system.

Site Testing Schedule

Following the kick-off event, NAVFAC Northwest delivered the refuse trucks to the local dealership in order to accomplish the corrective changes. By late March 2011, the dealership had completed the repairs on the list. However the changes completed at the dealership did not correct the side loader handling issues, as this action was to be addressed by the body supplier. Initial solutions did not resolve the problem. Recycling body supplier identified the solution and the recycling team confirmed the solution worked on the first truck by December 2011, and provided a matching kit for the conventional truck in January 2012. The issues stemmed from the side arm incompatibility with the newer type of tote containers used by NBK Bangor, resulting in the totes either being released early during the emptying process, or release upon the return motion down to the ground level. By February 2012, NBK Bangor's service team retrofitted the second truck with the compatible latching system and the trucks were dispatched into service. The following notes summarize schedule for monitoring of the refuse truck operations at NBK Bangor with Telematics.

March 1, 2012 – Start of Data Collection (telematics)
June, 15 2012 – Hybrid truck moved to NAS Whidbey Island WA
September 30, 2012 – End of Data collection

Vehicle Operations Summary

Table 6-12 summarizes refuse truck operational statistics collected from the Telematics system during the test period. Appendix J provides additional Telematics data, including monthly averages. In terms of operations, a general observation is the hybrid's higher mileage and average speed. Despite the difference in mileage, total idling hours and number of stops were relatively similar. These differences would favor the fuel economy performance of the hybrid, which was 21 percent higher over the test period.

Table 6-12. Cumulative Operating Statistics, Refuse Trucks

	Hybrid	Diesel	
Miles Traveled (Test Period)	3167	1696	Miles
Miles Traveled (Monthly Average)	452	242	Miles
Gallons Fuel Used (Test Period)	811	528	Gallons
Gallons Fuel Used (Monthly Average)	116	75	Gallons
Vehicle Hours (Test Period)	482	422	Hours
Vehicle Hours (Monthly Average)	69	60	Hours
Idling Hours (Test Period)	297	268	Hours
Idling Hours (Monthly Average)	42.5	36.4	Hours
No. of Stops	1495	1481	
Stops per Mile	0.47	0.86	
Average Speed (Test Period)	6.69	4.06	mph
%Idling Hours(Test Period)	62%	64%	%
%Idling Fuel (Test Period)			
mpg (Test Period)	3.90	3.21	miles/gal
gph (Test Period)	1.71	1.26	gal/hr

A closer look indicates substantial differences in duty cycles over the seven-month test period. During the first three months, the hybrid had a high mileage route, and averaging approximately 800 miles per month. Refer to Figure 6-10 for plot for of the month-to-month mileage for both trucks. In contrast, the conventional trucks logged less than one quarter the distance, or 160 miles per month on average. During the same timeframe, the average speed was 80 percent higher on the hybrid than the conventional truck. Idling was also 20 percent higher on the hybrid truck. Given the differences, it is not fair to draw conclusions regarding the hybrid's higher fuel economy demonstrated in the first three months.

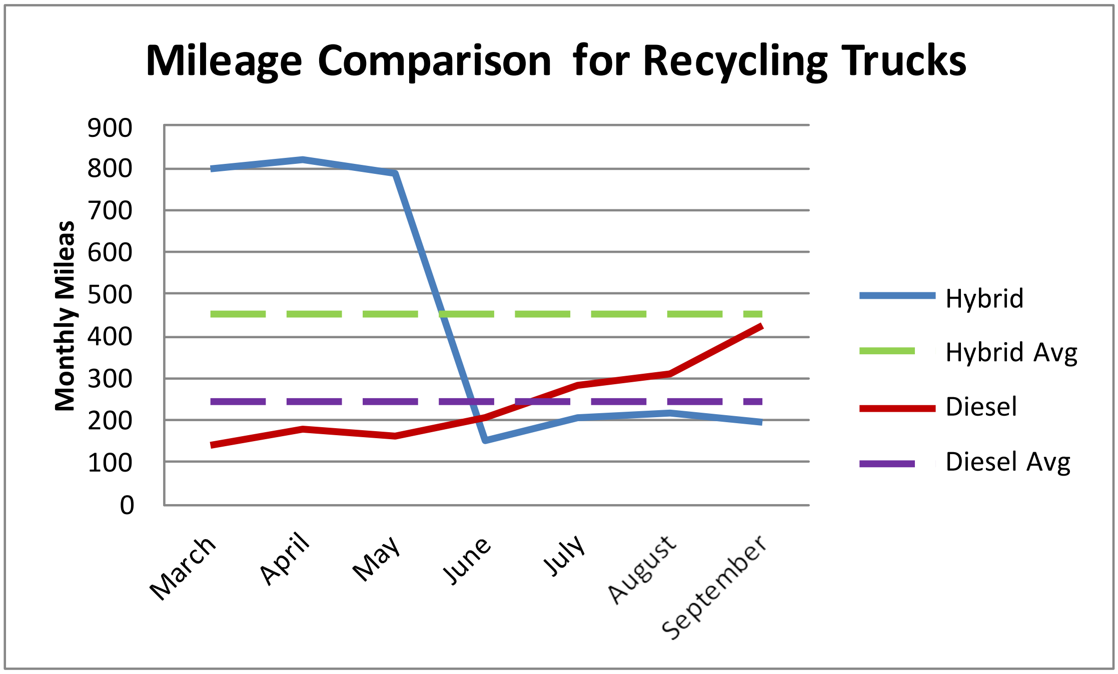


Figure 6-10. Mileage Comparison for Refuse Trucks

In June 2012, Solid Waste Team adjusted collection routes in order to attain comparable duty cycles. After the route adjustments, monthly average speeds for the conventional trucks were within three to seven percent of each other (refer to Figure 6-11). Idle profiles did not fully correct disparity in idle profiles. Figure 6-12 illustrates the differences in idle times. Beyond June, conventional truck idling was three to 12 percent higher than conventional truck idling time. Changes to the routes resulted in comparable fuel economy for both trucks, as Figure 6-13 illustrates. Specifically, overall fuel economy averages from July through September were 3.01 and 3.05 mpg for the hybrid and conventional trucks, respectively. This one percent variation is insignificant considering inherent bias due to the different collection routes. The results are expected considering the way the hybrid system captures energy. With so few stops, the regenerative braking system has limited opportunities to recover energy. As a result, the energy recovered does not sufficiently offset the loss in fuel economy due to the weight burden of the hybrid system.

In conclusion, during July 2012 through September 2012, when the trucks operated on similar collection routes, there was no significant difference in fuel economy. The project team attributes the lack of benefit to the mild drive cycle, which does not capitalize on the hydraulic hybrid's energy conservation principles. To achieve a fuel economy benefit, truck operations must comprise low average speeds (less than 10 mph), have limited top speeds (i.e., below 20 mph), and include frequent stops or decelerations (500 stops per day).

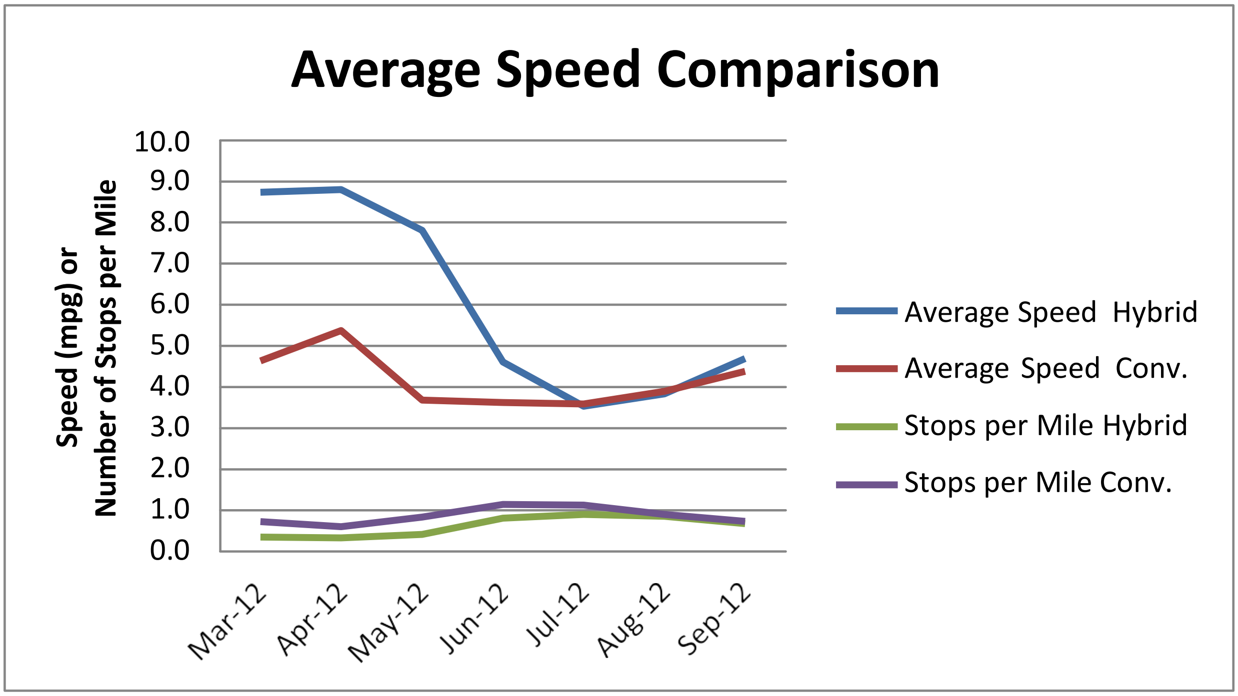


Figure 6-11. Average Speed Comparison for Refuse Trucks

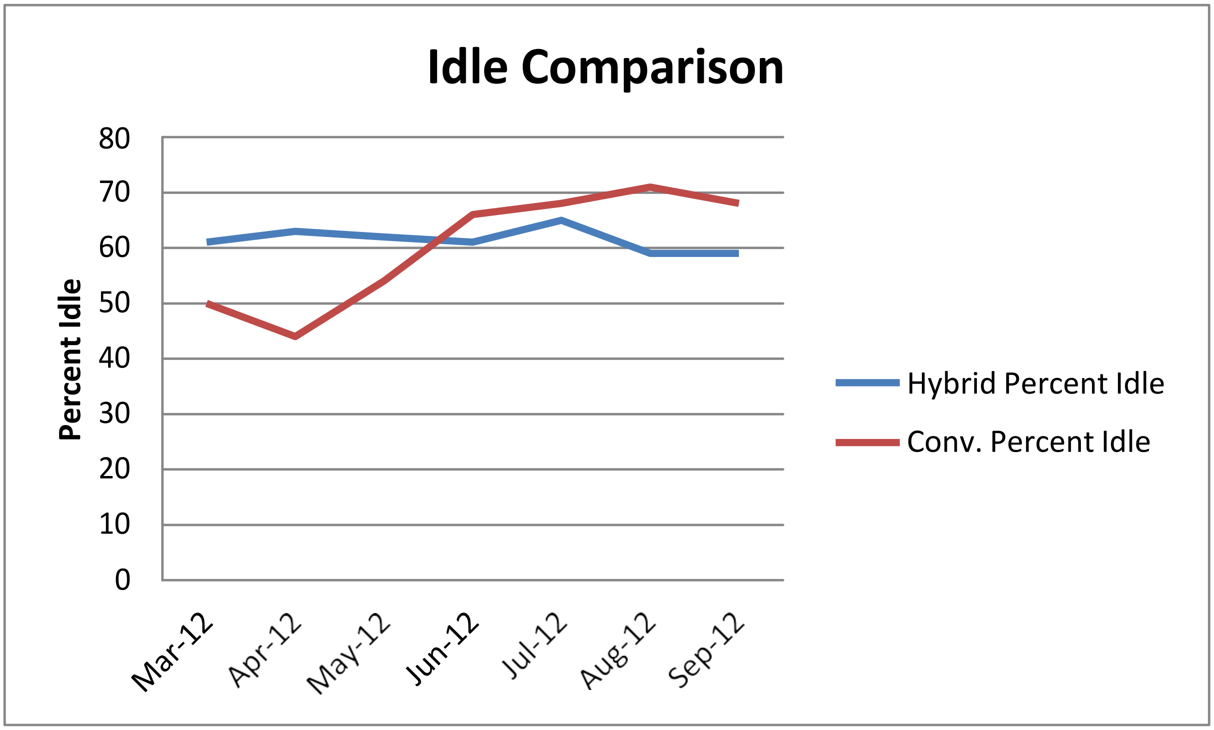


Figure 6-12. Idle Comparison for Refuse Trucks

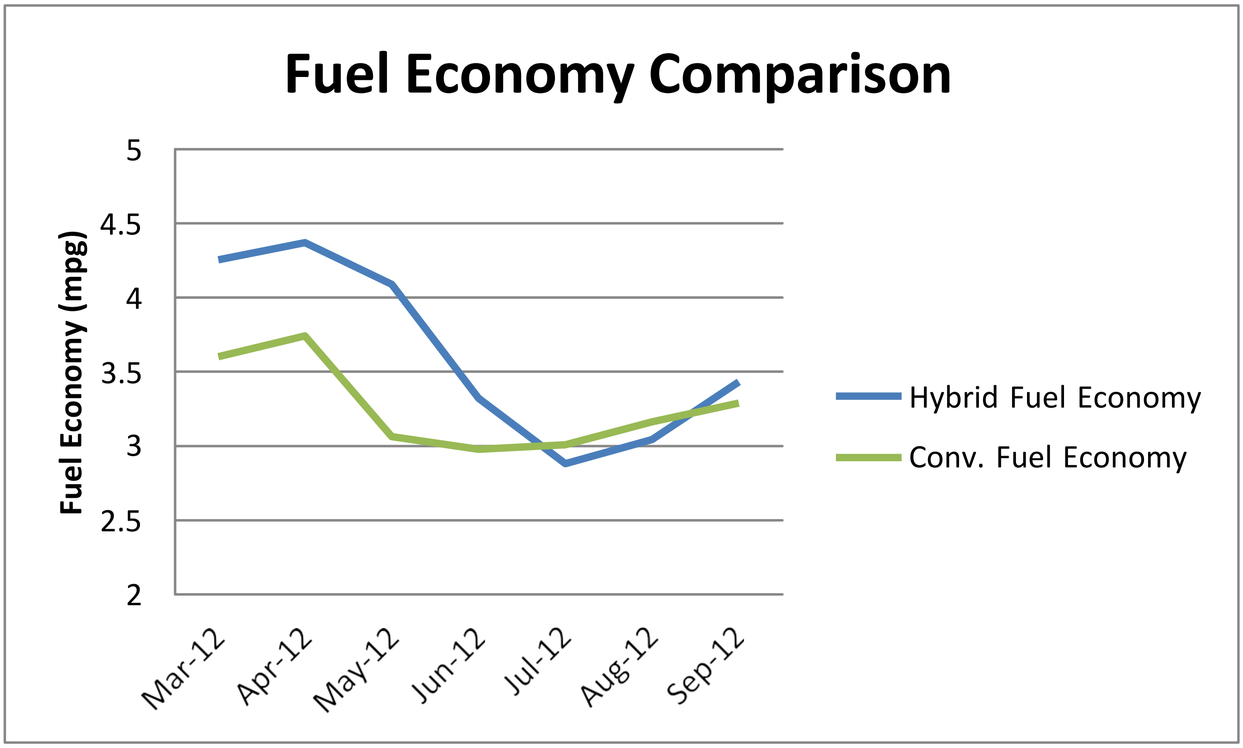


Figure 6-13. Fuel Economy Comparison for Refuse Trucks

Service and Maintenance

Refuse trucks experienced extended downtime due to incompatibilities with the lift units and the tote containers. Downtime was related to the trough loader bodies and no way related to the hybrid technology. Once deployed into service, the refuse truck chassis and power trains, including the hydraulic hybrid system, presented no significant maintenance or operational issues. Upon inspecting the trucks one year after the launching into service, the trucks were reported to be in excellent condition with no maintenance required on the chassis or power train.

Brake Wear Evaluation

NBK Bangor's service team measured final brake thickness to compare wear for both trucks. The team was to have collected initial measurements at the outset of the site testing. Issues with the truck side loaders brought the focus onto the side loaders. Brake wear evaluation assumes an initial brake lining thickness of one-inch. Manufacturer specifications did not include an initial lining thickness.

Table 6-13 presents a brake wear rate analysis. Despite the higher mileage on the hybrid truck, conventional truck wear was an estimated 0.25 inches, as compared with 0.125 inches wear for the brake linings on the hybrid truck. Overall, the conventional truck wear rate was an estimated four times the wear rate of the hybrid truck. If an acceleration factor is applied to the conventional truck wear for the sake of comparison, the conventional truck brakes would exceed 1/2 inch at 6,700 miles. At this wear rate, the conventional truck would require a brake change after three years of operations, or four changes over a 12 year life cycle. This considers a mild cycle with approximately one stop per mile, and higher speeds where there HLA disengages. If the hybrid truck is placed in a severe application, it would have approximately 15 to 20 stops per mile. For a severe duty cycle, the conventional truck would require a brake change approximately once per year. Considering the hybrid's regenerative braking, which minimizes wear, it would require an estimated two brake replacements over a 12-year life cycle.

Table 6-13. Brake Wear Evaluation on Conventional and Hybrid Refuse Trucks

	Baseline Thickness (in.)	Thickness at 18 Mos. (in)	Odometer	*Est. Wear	Mileage Specific Wear Rate (in./100k mi)	Minimum Lining Thickness (in.)	Estimated Brake Changes per 100,000 miles
Conventional	1.00	0.75	3,076	0.250	8.13	0.25	8
Hybrid	1.00	0.875	6,721	0.125	1.86	0.25	2

*Assumes an initial brake lining thickness of one-inch.

Drivability

Table 6-14 provides a summary of comments related to refuse truck drivability. Both refuse trucks provided comparable driving performance, well suited for driving on the installations' hilly roads and interconnecting highways. Routes and collection cycles were well within the trucks' capability. The operator team reported excellent driveability, with the only comment related to the regenerative braking. The heavy drag of the HLA's regenerative braking system is more severe than required for the mild duty cycle. This hybrid feature required the operators to release the accelerator closer to the stopping point as opposed to the normal practice of coasting and braking for signal stops. The operator team also provided a recommendation that the hybrid truck activate brake lights for all HLA pump engagement. This would help prevent rear-end collision hazards by alerting the following vehicle traffic of the impending stop.

Table 6-14. Drivability Comments for the Hybrid Refuse Truck

Mode	Drivability Comments
Accelerations	Truck has sufficient power when accelerating from a signal stop or highway onramp.
Coasting	Regenerative braking is more severe than needed for the mild duty cycle routes.
Grade-Ability	Trucks have sufficient power to climb hills in and around NBK.
Stopping	Brake lights should illuminate for safety purposes.

Ease-of-Use

With the exception of the regenerative braking, the hybrid hydraulic is transparent to the driver. Operator training on the braking system requires a brief awareness training session of approximately one hour. Operators will adjust to the regenerative braking after several hours of driving that includes repeated stopping. There were only mild comments noted in the drivability section referring to the regenerative system being more severe than necessary for the mild duty cycle. Assuming the trucks are issuance to a duty cycle involving multiple stops the comment would tend to aid the driver by enabling a single pedal (accelerator) control of the truck vice a combination of both the accelerator and the brake. As such, the hydraulic hybrid system meets the “ease of use” acceptance criterion.

Summary

Overall, the refuse truck engines and power-trains performed well throughout the site testing. The only issues pertained to the trough loader body mechanisms, which turned out to be a incompatibility for interface between the side loaders and the tote containers. The supplier eventually identified corrective parts however the process was iterative and delayed the testing schedule for approximately 10 months.

From the truck operator perspective, the hybrid hydraulic system met acceptance criteria achieving drivability and ease-of-use criteria. Service team reported no issues on the trucks or power-trains with respect to maintainability. Maintenance items were unrelated to the drive-train. In regard to fuel economy, the hydraulic hybrid fell short of the performance objective. By all indications, this is due to the mild drive cycle that results in trivial energy recovery through regenerative braking system. The results generated at NBK Bangor can be extended to the greater heavy duty non-tactical fleet. It appears the hydraulic hybrid has minimal application within DoD the non-tactical community.

Utility Truck Site Testing

Upon the project team’s completion of the track testing task, NAVISTAR drove the trucks from Aberdeen Proving Grounds, MD, to utility truck supplier’s Southwest service center at Pomona CA. Following a final manufacturer inspection of the truck, Utility truck supplier delivered the trucks to NAVFAC Southwest at the NAVSTA San Diego transportation shop. The project team subsequently scheduled the site kick-off activities that included a preliminary inspection and training for the operator and service team.

Kickoff Meeting

BSVE hosted a kick-off event at NAVSTA San Diego 29-30 March 2011. Local stakeholders, including the operators and service team, attended the event. The event began with class-room overview, followed by a truck walkthrough inspection, hands-on operator training, and a maintenance course for the service team. Appendix E lists agenda topics covered during each event. The meeting also included discussion of data collection objectives with the Coastal Utilities IPT operator team and the BSVE service team. All primary system suppliers attended and provided instruction for the event (i.e., chassis, utility body, and hybrid suppliers). Also, NAVFAC EXWC and CALSTART attended and provided background on the ESTCP project, and discussed requirements for the site validation testing.

Training/Baseline Inspection

NAVFAC Southwest and other stakeholders conducted a complete inspection of the utility trucks’ cabin and controls, underneath the chassis, and engine compartment. No issues were identified during the hands-on inspection. Upon adjournment of the event, the service team conducted final certification testing of the aerial lift. This weight bearing testing confirmed the trucks' ability to lifting the loads specified by the body supplier. The certification testing requirement is internal to the Navy's weight handling equipment program and was completed by early June 2011.

Ride-Along Observations

CALSTART conducted a ride-along audit in July 2011, shortly after Southwest Utilities Team dispatched the trucks into service. The event allowed CALSTART to observe the route and duty cycle for a typical day. Table 6-15 provides a summary of the ride-along observation results. Comments also covered truck drivability. The ride-along route included a dispatch to/from NAVSTA San Diego and SUBASE Point Loma.

Table 6-15. Hybrid Utility Truck Results of Ride-Along Event

Category	Comment
Driveability	- Abrupt transition from electric motor to engine - Limited acceleration - Engine may stall when driving up hill from standstill - Transmission has delayed shifting and gear hunting - Ride quality is very rough on uneven surfaces - Brakes work well - Engine starts well - Poor cornering stability
Cabin Controls	- Seats are loose, uncomfortable driving over rough surfaces - Cab not made for 6 foot person and above - Radio turns off every hour - A/C is great - Great visibility out of cab - Ergonomics is good - Easy entry and exit from vehicle
Boom Controls	- New controls configuration are difficult to operate - Cannot shut off engine during battery re-charging - Engine must be re-started after each ePTO event - Outriggers work well

Appendix G provides a complete written record of the ride-along observations. Important remarks include ride quality, acceleration performance, and transmission shift quality. Driving over bumps caused excessive movement without sufficient damping. With regard to performance, the truck displayed poor acceleration from a stop, lacked uphill power, and shifted abruptly during downhill driving.

Fuel Logs

The project team encountered complications that resulted in the utility truck operators' non-collection of fuel data. Available government fueling facilities include supply and dispensing of biodiesel blends. To promote consistency and based on manufacturer guidance the trucks were filled strictly with 100 percent petroleum based diesel. In order to achieve this BSVE setup routine filling of the utility trucks with mobile fueling trucks. The truck fills did not include metering and records of fuel deliveries.

Operator Surveys

CALSTART and NAVFAC EXWC conducted interviews with the NAVFAC team operating the hybrid and conventional utility trucks throughout metropolitan San Diego, CA. The purpose of the interviews was to gain an understanding of vehicle operation characteristics. The hybrid and conventional utility trucks replaced older utility trucks in a fleet of six (6) utility trucks and ten (10) other vehicles that included vans and light duty trucks performing simple tasks around the base. At the time of the interview, a total of four (4) drivers were qualified and operated the utility trucks.

Results from the first and second surveys were generally positive with the drivers viewing the hybrid utility truck as equal to or better than the conventional truck on most vehicle characteristics including overall vehicle rating. A majority of the feedback provided by the drivers of the hybrid utility truck were positive.

Both the conventional and hybrid utility trucks rated consistently for aspects including engine starting, braking quality, low speed maneuverability, deceleration/coasting, bucket/boom operation, hydraulic power, noise levels, and in-cab ergonomics. The hybrid scored consistently lower on acceleration in both of the surveys with ratings of 1.5 and 2. After the hybrid truck received a software update in August 2011, its ratings improved from a “worse” (2) rating to a “good/great” (4.5) rating in pulling grade and transmission shift quality.

In-Person Interviews

In addition to written surveys, CALSTART interviewed utility truck operators for additional comments and clarifications. Interviews occurred on-site at NAVSTA San Diego in August 2011 and October 2011 (i.e., before and after the transmission software upgrade). Comments ranged from a few words to one or more paragraphs on a variety of subjects. Appendix H provides a list of comments for both interviews. Comments were grouped into four basic categories—Performance, Comfort and Convenience, Safety, and general Additional Comments. Many of the same comments appeared several times indicating a common perception or experience among different drivers. The comments also substantiate input from the driver surveys. In terms of drivability, the comments noted issues with acceleration performance, uphill driving, and coasting.

The electrical team operated the vehicles on bases that cover an area with a radius of approximately 25 miles surrounding NAVSTA San Diego, Utilities IPT base office. The electrical team performs service at seven (7) installations in the Metropolitan San Diego area, including Naval Outlying Landing Field Imperial Beach, Naval Submarine Base Point Loma, Marine Corps Air Station Miramar, Naval Amphibious Base Coronado, Naval Air Station North Island, Anti-Submarine Warfare, and NAVSTA, San Diego.

Maintenance Data

NAVFAC Southwest provided maintenance data in the form of work orders for both trucks. Refer to Table 6-16 and Table 6-17 below. While providing detailed information on the service events, work orders did not identify the actual date/time the vehicle went out-of-service. Work orders may have been placed while the trucks were still in operation. Therefore, the actual labor hours were used to determine how long the mechanic was providing service to the vehicle. Based on discussions with the maintenance staff, eight (8) hours is equivalent to one day. A breakdown on the work, cost, actual labor hours performed, and the estimated number of days the truck were unavailable are provided below.

Table 6-16. Maintenance on the Conventional Utility Truck

Date	Description of vehicle issue	Corrective action	Labor Hours	Days unavailable	Actual labor cost
Aug-11	Hydraulic leak at the upper boom	Trouble shoot and repair hydraulic leak	3	1	$291.12
Aug-11	Send to dealer for recall services	Sent for recall services, Post inspection	4	1	$416.62

Table 6-17. Maintenance of the Hybrid Utility Truck

Date	Description of vehicle issue	Corrective action	Labor Hours	Days Off-Line	Actual labor cost
Jul-11	Coolant hose for hybrid damaged	Repair damaged coolant hose, fill coolant to acceptable levels	4	1	$370.89
Aug-11	Upper Boom Controls work intermittently	Contact Utility truck supplier for warranty service, inspection	0	1	$0, covered by warranty
Sep-11	Replace Left-Front Tire	Replace LF Tire, perform static load test	6	1	$683.30
Oct-11	Upper Boom Controls not working	Troubleshoot and repair controls	8	1	$797.53

*Note: While no labor hours were spent for the corrective action in August 2011, the team estimated the vehicle would have been out of service for 1 day.

Using the above data on days unavailable, Table 6-18 presents the availability data throughout the site-testing period: July 2011 to March 2012. The conventional and hybrid utility trucks demonstrated availabilities of 99 percent and 98 percent, respectively, over the test period. The analysis assumes each working month contains 20 days.

Table 6-18. Availability of the Conventional and Hybrid Trucks (Percent)

	Jul 2011	Aug 2011	Sep 2011	Oct 2011	Nov 2011	Dec 2011	Jan 2012	Feb 2012	Mar 2012	Average
Conventional	100	90	100	100	100	100	100	100	100	98.9
Hybrid	95	95	95	95	100	100	100	100	100	97.8

Hybrid Mechanics Surveys

The project team solicited input from the mechanics in order to identify any service or maintenance issues related to the hybrid truck. Surveys included a total of eight questions.

Questions 1, 7, and 8 allowed detailed input from the mechanics team. Table 6-19 summarizes the mechanic's detailed input. Questions 2 through 6 of the survey request mechanic's ratings on various maintenance and service characteristics of the hybrid truck. Scores ranged from a scale of 1 through 5, with 1 being "unacceptable" and 5 being "excellent". Table 6-20 summarizes the mechanics ratings for the different aspects of the training.

Table 6-19. Mechanic Survey Responses for Questions 1, 7, 8

Hybrid Utility Truck Mechanic Survey Question	**Response**
1. Describe any hybrid utility truck problems observed during the early part of the demonstration period that were subsequently corrected by the manufacturer.	• No major problems were observed during the early part of the project. A bolt was missing on the left front shock and the coolant levels were a little low. The problems were easily corrected. • Other issues were minor and easily resolved.
7. Describe any trends observed regarding non-routine service actions associated with the hybrid utility trucks including the long-term effectiveness of corrective actions.	• The hybrid utility truck is identical to the conventional diesel truck and maintenance was fairly straightforward. • Damage was done to coolant hose on hybrid utility truck and was easily replaced.
8. Additional comments	• No comments were provided.

Table 6-20. Summary of Mechanic Survey Ratings for Questions 2 – 6

Hybrid Utility Truck Mechanic Survey Question	***Rating***
2. Hybrid systems and component training	5
3. Design for maintainability	4
4. Design for serviceability	4
5. Manufacturer support	NA
6. Hybrid system manufacture support	NA

Ratings Key: 1 = unacceptable; 5 = excellent

Based on the mechanic survey and interview, the mechanic gave the hybrid utility truck a positive general rating. The mechanic provided a rating of "excellent" regarding vehicle training. At the beginning of the project, hybrid and chassis manufacturer personnel were on hand to provide the maintenance staff an all-day training event. The training provided detailed information on the operation of the hybrid system and troubleshooting procedures in both a classroom setting and also hands-on training.

For maintainability and serviceability, the maintenance staff gave a rating of "good" as the hybrid utility truck design was identical to the conventional utility truck with the exception of the added hybrid system. Maintaining the hybrid truck was fairly straightforward with minimal issues during the demonstration period. Mechanics did not score the utility body supplier and hybrid system manufacturer as no related support was required during the demonstration period.

Brake Wear

Brake pad thickness was measured on the right front wheel for both of the vehicles. At the conclusion of the project, the hybrid utility truck had a thickness of .38 in or 9.65mm while the conventional had a thickness of .365 in or 9.27mm. This is a 36 percent reduction in wear based on the 0.75" specification thickness for the factory brake linings. The baseline thickness is from the brake lining specification for the make and model specified for the trucks. Table 6-21 presents a long-term wear analysis based on the cumulative wear from the time the truck left the factory.

Table 6-21. Summary of Brake Lining Wear for the Utility Trucks

	Baseline Thickness (in.)	Thickness at 18 Mos. (in)	Mileage	Wear	Mileage Specific Wear Rate (in./100k mi)	Minimum Lining Thickness (in.)	*Brake Changes per 100,000 mi.
Conventional	0.75	0.365	6,855	0.39	5.62	0.25	11
Hybrid	0.75	0.38	10,342	0.37	3.58	0.25	7

*Assumes minimum brake lining thickness and replacement at 0.25 inches.

Automated Data (Telematics System)

Coastal Utilities team launched the utility trucks into service in June 2011. Monitoring began in July, and continued through March 2012. The project team encountered problems with remote data collection from the vendor's website. This required periodic site visits to capture the data directly from the onboard data-logger and OEM computer. Issues stemmed from a supplier software upgrade, and resulted in limited ability to capture J1939 CAN Bus information. The hybrid drive-train supplier made changes to the vehicle software to improve transmission shift-quality. The following list outlines the data collection schedule during the testing phase of the project.

July 20, 2011 – Start of Data Collection (Telematics)
August, 2011 – First (hybrid system) software update performed
March 31, 2012 – End of Data collection

Table 6-22 summarizes the data collected by the on-board computer and Telematics systems during the eight (8) month testing period. Appendix J provides additional data including monthly averages. On average, the trucks drove between 18 and 35 miles per day. Over the entire test period, the hybrid truck logged approximately double the miles as the conventional truck. This was due to the hybrid dispatching more frequently to the more remote sites such as MCAS Miramar.

Table 6-22. Cumulative Driving Statistics, Utility Trucks

	Hybrid	Diesel	
Miles Traveled (Test Period)	5562.5	2959	Miles
Miles Traveled (Monthly Average)	695.3	369.9	Miles
Gallons Fuel Used (Test Period)	710.8	499.8	Gallons
Gallons Fuel Used (Monthly Average)	88.8	62.5	Gallons
Vehicle Hours (Test Period)	378	258.9	Hours
Vehicle Hours (Monthly Average)	47.3	32.4	Hours
Idling Hours (Test Period)	92.4	92.1	Hours
Idling Hours (Monthly Average)	11.6	11.5	Hours
Idling Fuel Use (Total)	0.24	0.27	gal/hr
Average Speed (Test Period)	14.7	11.4	mph
%Idling Hours(Test Period)	24.4%	35.6%	
%Idling Fuel (Test Period)	3.1%	5.0%	
mpg (Test Period)	7.83	5.92	miles/gal
gph (Test Period)	1.88	2.16	gal/hr

For PTO usage data, CALSTART employed the hybrid supplier's software application for the hybrid truck and the chassis supplier's software program for the conventional truck. The daily PTO data was not available through the Telematics system. Table 6-23 summarizes the PTO data of the vehicle operations data collected by the hybrid supplier and chassis supplier.

Table 6-23. Cumulative PTO Operation Statistics, Utility Trucks

	Hybrid	Diesel	
PTO Hours (Monthly Average)	4.9	6.8	Hours
PTO Hours (Engine-on for Hybrid)	1.15	NA	Hours
PTO Fuel Use (Total)	*NA	0.73	gal/hr
%PTO Hours (Total)	10.4%	21.0%	
%PTO Fuel Used (Total)	NA	4.3%	

*PTO fuel use data was not available on the hybrid.

Operating Hours, Utility Trucks

Figure 6-14 and Figure 6-15 are plots of the monthly engine hours and monthly miles traveled for the utility trucks. For the hybrid utility truck, the time interval between key-on and key-off was captured and included under PTO hours of operation. This ensured the time when the engine is off is included in the overall vehicle operation hours. For the conventional utility truck, operating hours included all "engine-on" hours as the engine does not turn off during PTO mode. As noted previously, the hybrid utility truck was used to a greater extent in part due to routine dispatches to MCAS Miramar which is further away than the other work sites. Initially, utility operating hours for both trucks were similar. Drivers alternated between trucks for the initial three months of testing (August through October). After October, the operator sharing of trucks discontinued and reverted back to their normal practice of assigned trucks. This explains the substantial disparity between daily duty cycles after October 2011, where the hybrid logged up to three times the operating hours as the conventional truck, and up to four times the mileage.

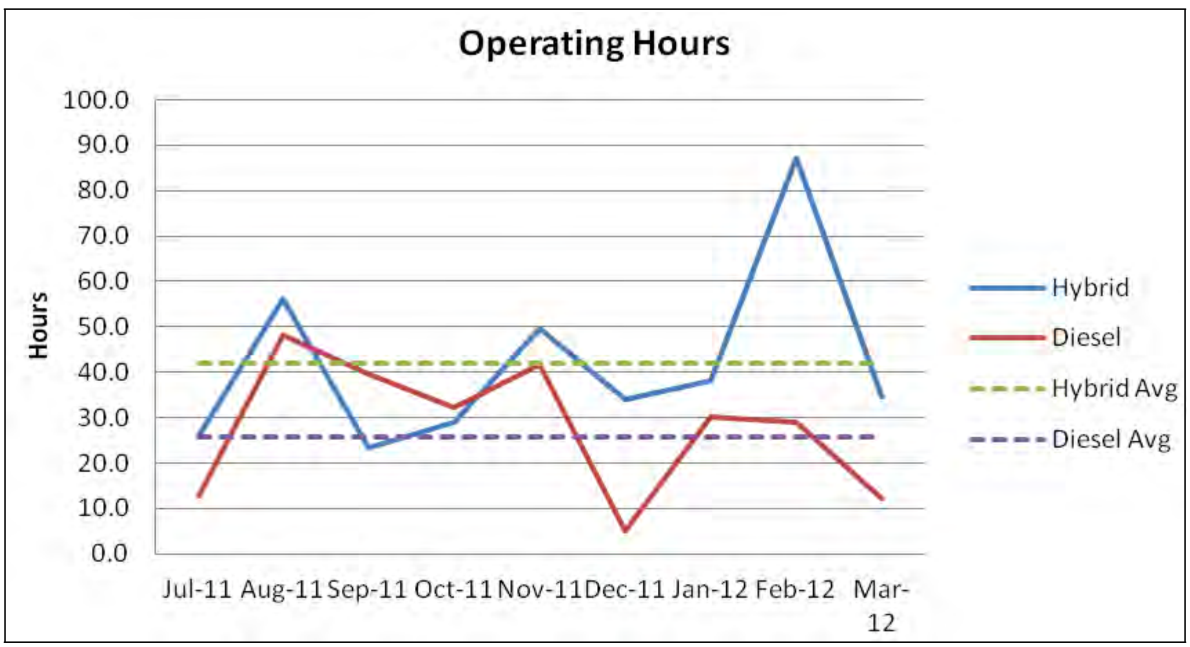


Figure 6-14. Plot of Monthly Engine Hours for Utility Trucks

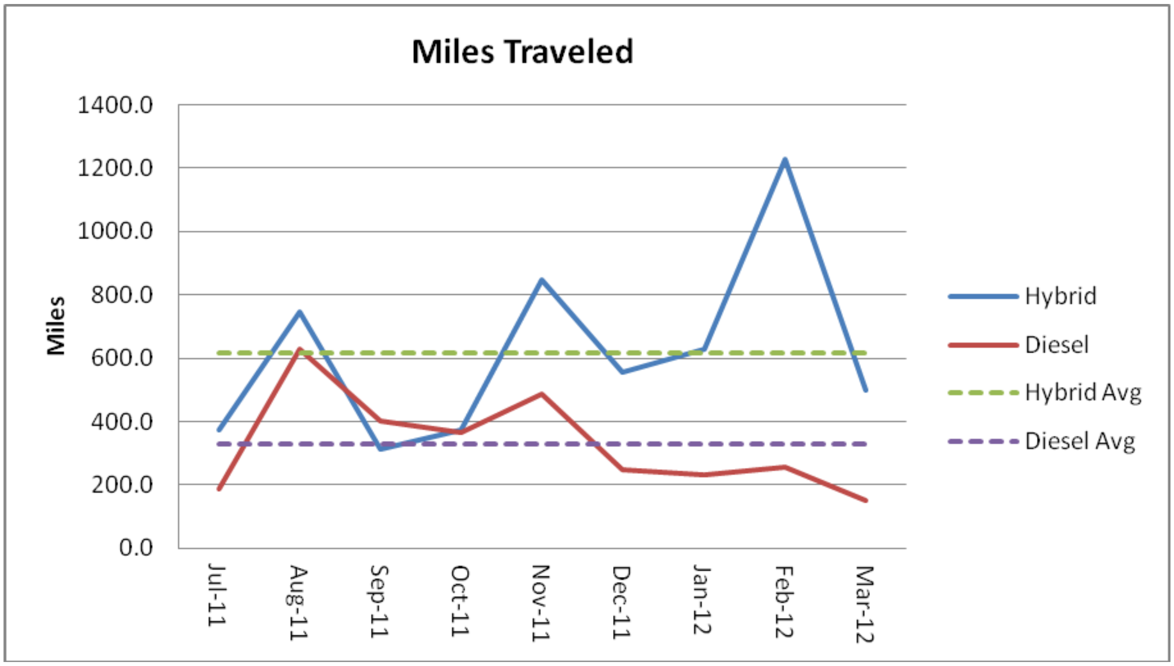


Figure 6-15. Plot of Monthly Vehicle Miles for Utility Trucks

Fuel Efficiency

Using the truck operational data above, the monthly fuel economy (mpg) of each vehicle was calculated and provided in Table 6-24. The plot in Figure 6-16 compares fuel consumption rates between the hybrid and conventional utility trucks.

Table 6-24. Monthly Average Fuel Economy Hybrid Electric Utility

mpg	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Average
Hybrid	8.0	7.4	8.1	7.7	8.1	7.6	7.9	7.8	8.0	7.8
Diesel	6.1	6.0	5.8	5.8	6.0	6.4	5.5	5.7	5.9	5.9

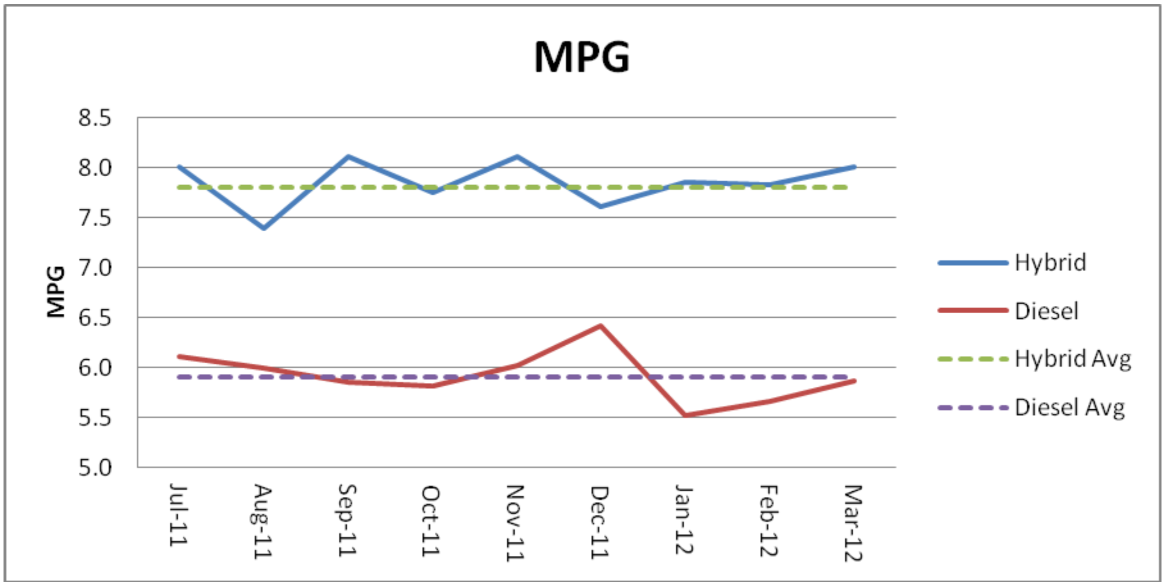


Figure 6-16: Fuel Economy for Conventional and Hybrid Utility Trucks

There was only one month (December 2011) where the hybrid economy improvement dropped just below the 20 percent performance objective. For the remainder of the test period, the hybrid was well above the objective. On average, the hybrid demonstrated a 32 percent improvement in fuel economy (mpg) over and above the conventional truck. As shown by Figure 6-17, the hybrid truck's fuel consumption rate was 13 percent lower than the conventional diesel truck's rate for typical usage. This considers operations with minimal PTO usage, and primarily driving. As was seen during the track testing, the hybrid does not meet the fuel economy performance criteria based on driving alone.

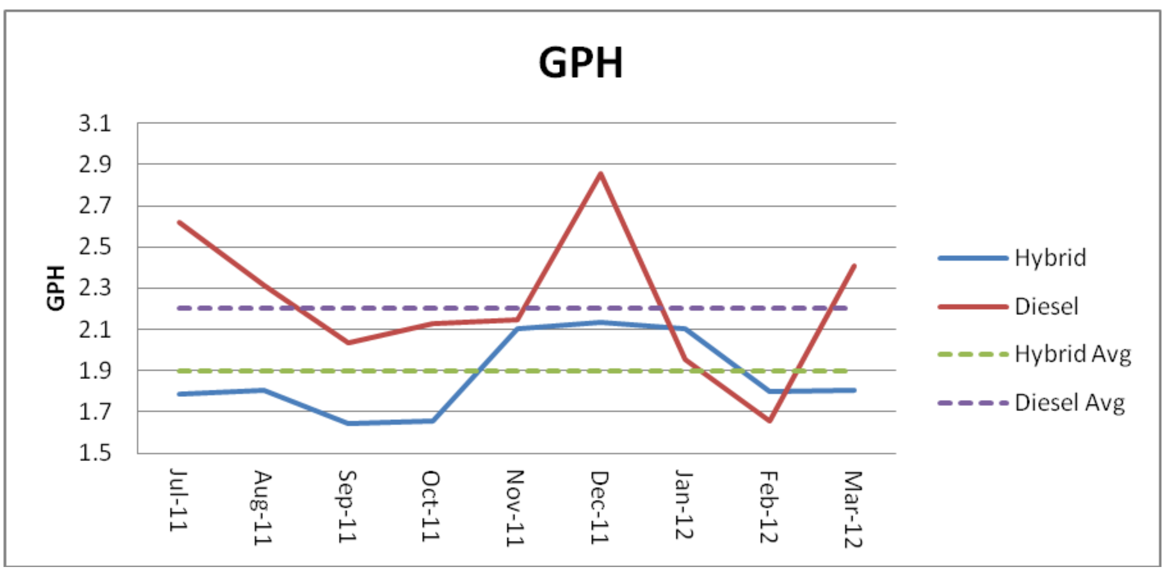


Figure 6-17: Plot of Average Monthly Fuel Consumption Rates for Utility Trucks

The cumulative average miles per gallon and gph of the hybrid utility truck were determined to be 7.8 mpg and 1.9 gph, respectively. For the conventional diesel vehicle, the data collected showed the vehicles to have 5.9 mpg and 2.2 gph. This resulted in a 32% overall improvement in fuel economy (mpg) and a reduction of 13% in fuel consumption rate. As for the PTO usage rates, it was found that the trucks' PTO usage was lower than originally assumed. Upon further review, the team found the hybrid and the conventional utility trucks dispatched for random service calls on a day-to-day basis, and the utility work was not dedicated to line work requiring the use of the boom. This resulted in the low PTO usage rate and high miles traveled for both of the vehicles.

To explain the difference in the fuel economy and fuel consumption rate, it is important to consider the duty cycle of the vehicles. The vehicles were originally intended to operate under similar routes during the test as was conceived for the test program. In addition to the low PTO usage rate, the hybrid dispatched more often to bases farther away from the Naval Base, San Diego utility base office. The extended highway driving is more efficient and results in greater fuel savings.

6.3. Performance Summary

This section provides an overall summary of test results and conclusions.

Refuse Truck Test Summary

Fuel Economy
Hydraulic hybrid refuse truck showed no fuel economy improvement for either the track or the site testing. Track testing showed the hydraulic system can be detrimental in cases where trucks frequently coast at higher speeds for long periods of time. These results are attributed to the characteristic mild drive cycle, and not the hydraulic hybrid system itself. In the site testing, the trucks stopped 10 to 20 times per day, which is far below a suggested 800 stops per day to fully benefit from the hydraulic hybrid system. The vast majority of DoD applications are expected to fall well below the severe multi-stop application needed to realize a benefit.

Noise Analysis
The hydraulic hybrid truck showed lower in-cabin noise and higher outdoor noise. While the in-cabin noise reduction is important from the operator perspective, outdoor noise reduction was a primary objective for this demonstration. Peak noise for the hybrid truck was 20 percent higher than the conventional truck. The hydraulic hybrid system therefore fell short of the objective noise reduction criterion. This result is not considered a final conclusion, as manufacturers design evolutions can reduce noise with shielding and dampening material.

Brake Wear
The refuse truck met the performance acceptance objective for brake wear. When engaged, the hydraulic launch assist unit avoids brake use. Under actual use conditions, the HLA disengages at speeds in excess of 20 mph and will incur related brake wear. Despite higher speed use during site testing, the truck still met the 50 percent wear reduction objective. If matched with the appropriate application, the HLA would result in a significant reduction in brake wear and related cost savings to the fleet owner.

Maintainability
The HLA system met the "maintainability" performance acceptance criterion. Although both trucks required to service or repair to the refuse body, there was no drive-train or hybrid related maintenance required during the demonstration testing.

Drivability
The refuse trucks fully achieved the drivability criteria. Both the hybrid and the conventional truck performed well throughout the test period. HLA system provided additional power and improved acceleration over the baseline conventional truck. Operator team noted the truck's strong regenerative brakes were not compatible with the mild duty cycle. Driving at low-speeds and coasting required operators' extended accelerator use to maintain normal speeds. It is assumed that the HLA will be better received by driver's of a severe multi-stop duty cycle.

Ease of Use
The HLA system met the Ease-of-Use acceptance criteria. With the exception of the regenerative braking, the hybrid system is transparent to the operator. There are no special procedures or controls that require the operator's attention. A brief one-hour training class and two to three hours of driving is sufficient orientation for the operators to adjust to the HLA's braking response.

Overall
In summary, the refuse truck equipped with the hybrid HLA system failed to meet the critical performance objective for fuel economy. This result is not tied to the hybrid system itself, but due to the mild driving conditions that are characteristic of most non-tactical truck applications on DoD installations. The project team feels the same truck, if placed in a severe duty cycle, would yield entirely different results. The hydraulic hybrid also fell short of the noise reduction objective for outdoor noise, showing a 20 percent increase in noise rather than a reduction. The noise result will likely be addressed by next generation technologies. Recommendation is for fleet management to further investigate candidate cycles and next generation hydraulic hybrid systems prior to finalizing procurement plans.

Utility Truck Test Summary

Fuel Economy
The hybrid truck demonstrated higher fuel economy than the conventional truck for both track and site testing. Track testing showed a 75 percent improvement for DoD Test Cycle (drive/lift cycle), and 15 percent improvement for the CILCC (drive) cycle. Site testing results indicated a 32 percent improvement over the test period. As long as substantial field work being performed requiring use of the PTO, the hybrid utility trucks met the demonstration objectives.

Noise Analysis
In-cabin noise levels on the hybrid electric truck were 40 to 50 percent lower for the acceleration and static modes. The hybrid truck's outdoor noise was 12 percent lower during acceleration tests, and 80 percent lower during work-mode PTO tests. Both interference with the crew communications, and annoyance noise impact on the surrounding public are the primary

concerns. As such, the hybrid truck is considered to have successfully decreased peak noise from the mode of interest, well above the 20 percent performance objective.

Brake Wear
Normalized brake wear on the hybrid truck was 3.58 inches per 100,000 miles, as compared with 5.62 inches for the conventional truck. This is a 36 percent wear rate reduction for the hybrid truck, short of the 50 percent performance objective. Differences in driving habits or duty cycle are a potential source of bias. Manufacturer adjustments to the regenerative braking system could reduce the wear rate.

Maintainability
All maintenance performed on trucks was related to the chassis or body, and was independent of the hybrid system. The hybrid displayed no service issues that would impose additional burden on the operator or service teams. The hybrid truck met the maintainability performance objective.

Drivability
Operators complained of the hybrid truck's lack of power for low speed acceleration, and sub-optimal or excessive shifting when driving on hilly terrain. Drivers expressed no related complaints on the conventional truck. Given the success criteria for "comparable approval ratings by users", the hybrid truck fell short of the drivability rating. This indicates that more engineering is required to optimize the transmission and shifting software. This suggests that military buyers confirm the truck power and acceleration is sufficient for the intended application.

Ease of Use
The hybrid system successfully achieved the "Ease of Use" performance criterion. Operating procedures for the hybrid electric utility were straightforward, and initial training was sufficient for the operator team. Primary difference was the transmission program and shifting. Neither the driving nor work modes for the hybrid system entailed complex operating procedures.

Overall
In summary, the hybrid utility truck successfully achieved four of the six the performance acceptance parameters, including fuel economy, noise, maintainability, and ease of use. The truck fell short of the drivability and brake wear objectives. While the drivability characteristics were expressed as a considerable annoyance. The project team concludes drivability will improve with further refinement and engineering for next generation trucks. This was demonstrated in August 2011, when reprogramming addressed the operators complaints about gear hunting. The hybrid utility brake wear was 37 percent less, falling short of the 50 percent objective. As with drivability, brake wear can be increased with further optimization to meet the objective. Hybrid electric utility truck is considered acceptable by the project team, with the recommendations that purchasing agents specify the driving performance requirements for the intended application.

7. Cost Assessment

This section provides an economics review for the heavy hybrid technologies demonstrated under this project. Economics are based on anticipated non-tactical applications and benefits for DoD vehicle fleets for domestic public works applications. From a cost/payback perspective, this type of application is conservative as non-tactical delivery logistics are routine in contrast to deliveries for remote field operations. Additional considerations come into play for the tactical user by increasing the value of enhanced capabilities.

7.1. Cost Model

Cost assessment for public works fleet applications is relatively straightforward. The two predominant economic factors are: 1) Upfront incremental cost for the auxiliary hybrid system; and 2) Reduced fuel use per mile. Additional and less important factors include: 3) operation and maintenance considerations; 4) indirect environmental benefits; and 5) capability and energy security benefits. This assessment estimates the overall return on upfront investment by subtracting value of the beneficial features from the hybrid's cost premium. Paragraphs below discuss each factor. These costs consider an industry in the early commercial state. Hybrid electric and hybrid hydraulic technologies for both platforms premiered in 2006 and 2010, respectively. In contrast to the high volume and homogenous nature of the light vehicle market, the medium and heavy diesel trucks include a broad range of applications, bodies, and chassis configurations. Engineering and integration play a major role in the cost of each different diesel platform. Any expected payback in the near term is optimistic for all but the severe duty cycle truck applications. As the technology and market develop, a recent industry study anticipates premiums for hybrid systems will drop by approximately 40 percent.[vi] This prediction applies for both hybrid electric and hybrid hydraulic technologies.

This cost assessment assumes approximately 25 percent increase in fuel cost considering market demand, development of supply channels, and limited global supplies. The rationale for this assumption considers increasing global fuel demand as the global economy improves. Also, prospective development of new pipelines will improve economics for delivery of fuel to overseas customers. Despite the recent increase in domestic supplies through hydraulic fracturing, the general trend shows a decline in energy return on investment. According to this prediction, petroleum companies must drill deeper to receive heavier petroleum, thus incurring higher refining costs.[vii]

The operation and maintenance cost assessment considers reduced labor hours for fueling and maintaining hybrid trucks. One instance includes avoided operator time spent for fueling, and travel to/from the fueling event. As the mileage and or duty cycle severity increases, the cumulative savings of this avoided labor effort for hybrid trucks becomes more significant. Also, increased engine-off capabilities for hybrid electrics will see a substantial reduction in oil changes and fuel filter changes. Applications with more severe start/stop duty cycles will reduce brake maintenance, although such applications are more prevalent in commercial fleets, and less common for DoD non-tactical applications.

Indirect environmental benefits consider the costs for the global warming, engine noise, and petroleum processing and delivery. Avoided fuel consumption also means a reduction in CO2 emissions, associated effects, and market cost. The estimated market cost may not be recovered by

DoD, but this savings offers national (and global) indirect benefits that are not easily quantified. Quiet engine operations will reduce the number of noise related distractions and improve communications among the work crew. The analysis does not include information on noise complaint data but assumes quieter trucks generally result in improved quality of life.

Other cost factors include enhanced capability and energy security. Enhanced capability for the hybrid hydraulic system includes power for improved acceleration. Hybrid electrics provide enhanced PTO capability. The quiet engine-off lift feature adds efficiency to utility worker operations. This enables communication exchange between the aerial platform and the ground crew, reduces general noise distraction, and allows the crew to work near residential or office building with minimal disturbance to personnel. That means the crew may be able to conduct the work near a residential area with minimal advance notice or permissions, or may allow crew to perform work during evening or early morning hours. The system also promotes energy security by reducing overall demand. Every gallon of petroleum fuel increases availability for other uses both the agency fleets and the nation as a whole.

The project team coordinated with each demonstration site in order to monitor and collect operations and maintenance data for comparison and assessment of hybrid systems. Fleet management offices captured maintenance cost through normal business practices. This includes documenting vehicle mileage and fuel use operations. The analysis also covers labor and parts required for vehicle maintenance. The team also reviewed available market studies to project costs for mass produced hybrid trucks in the future.

7.2. Cost Analysis and Comparison

In practical terms, economics of commercial hybrid vehicles are relatively straightforward from the user perspective. The hybrid vehicle has an initial capital cost that is substantial, and the user must somehow justify this cost based on enhanced performance, operational savings, or environmental benefits. Hybrid systems achieve better fuel efficiency than a conventional vehicle, given comparable drive cycles. The typical economic analysis is based on upfront additional capital cost versus annual fuel savings. Minor cost factors include additional/avoided operation and maintenance. Users remain concerned about the life of the battery system (versus warranty) for a HEV. Fleets may also see additional requirements for maintenance operations and training for aging hybrid trucks that are not yet apparent.

This section evaluates cost payback for both the refuse and the utility trucks. Evaluations are specific to each platform and application. Technologies differ in the way they recover and expend energy, and subsequent payback is reliant on the specific use application. Payback for the hybrid refuse truck relies on an application that is high use, low-speed, and includes multiple starts and stops. Payback for the hybrid utility truck relies on a duty cycle with moderate driving and high-use of the aerial lift system. Each analysis provides assumptions on hybrid capital cost, annual operating scenario, maintenance, and environmental benefits.

Payback for the hybrid electric is proportional to the duration of engine-off work mode use. In this mode, the trucks displaced petroleum by up to 75 percent. If the hybrid truck is merely driven and not used in the PTO mode, payback is below the 20 percent acceptance criterion. Trucks must be used four (4) to six (6) hours per day in the work mode to see a payback.

The batteries in a hybrid electric system are assumed to last throughout the will be addressed in the analysis considering the warranty period and standard fleet replacement cycle. For example, the hybrid electric battery pack, assumed rated for eight years or 80,000 miles, is assumed to be replaced once during a 150,000 mile life cycle of a heavy duty truck.

Refuse Trucks

Based on the results of the performance assessment, the hydraulic hybrid saw no fuel economy improvements over and above the conventional truck. This was due to the relatively mild duty cycle and routine driving speeds over 20 mph as discussed in Section 6 of this report. As such, the typical DoD fleet cannot justify an investment into the hydraulic hybrid system. In order to justify the hybrid hydraulic system, the application would require a severe duty cycle. The cycle must have continuous low-speed pickups/deliveries approximately six hours per day, with the balance of time for trips to the primary collection center. Also, the initiative would require further testing to validate fuel economy performance under actual use conditions. The following analysis assumes an application scenario that improves fuel economy by 20 percent over the baseline.

Table 7-1 presents a lifecycle cost assessment. Cost premium for the hydraulic hybrid system in this demonstration was $50,000. The hydraulic hybrid system was in its first year of general commercial production. The hybrid hydraulic system shows potential for cost reduction with full market penetration. Studies suggest commercial off-the-shelf cost, if mass produced, would drop to approximately $30,000, as suggested by the National Research Council assessment in reference 2. The greater cost reduction potential is due to the system's ability to readily install and integrate onto existing drivelines without substantial changes to the chassis or drive train. There are no high cost parts or sophisticated software programs.

Fuel cost savings assumes an operating scenario where the truck is driven 30 miles per day five days per week throughout the year. For a low-speed start and stop application, this would include six hours of driving per day. Baseline fuel economy for this scenario is assumed at three (3) miles per gallon. This is based upon the 3.2 mpg demonstrated for the conventional refuse truck in this demonstration. Assumed cost of fuel is $5 per gallon of petroleum diesel. With a fuel economy improvement of 20 percent, the hybrid truck would avoid 5,000 gallons of fuel use, valued at approximately $25,000, over a 12-year life cycle.

Fuel economy improvements also reduce operating cost and boost productivity by avoided fueling events. Estimated operator time per fueling event is 30 minutes. The analysis assumes the operator refuels when the tank reaches the one-quarter fuel tank level. Under a 7,500 annual use scenario, and baseline fuel economy of 3 mpg, the conventional truck would fill 50 times per year, and the hybrid truck would fill 42 times per year. This savings becomes significant over the life of the truck, avoiding an estimated 96 fueling events and 48 hours of labor. At an estimated labor cost of $75, savings would be $3,750. Also, the time saved can generate additional revenue for the organization. In addition to the reduced labor cost for the refuse team, the fuel station operations avoid approximately one fuel delivery to the on-base diesel fueling point. The avoided fuel delivery results in savings of approximately $300 assuming four hours of labor for fuel delivery operations (i.e., truck filling, transportation to and from the fuel station, fueling the storage tanks, and administrative documentation).

Hybrid hydraulic technology will avoid substantial brake maintenance over the 12-year life cycle. This assumes the hydraulic braking avoids nearly all use of the brakes, which occurs when driven below 20 mph. A truck with conventional brakes will require new brake linings and maintenance approximately every 18 months or 12,000 miles for severe duty cycle applications. This compares with an estimated 50,000 mile brake service for the hybrid truck, potentially avoiding six brake pad changes over a 12-year truck life. Cost considerations for brake changes include $50 in parts, and three hours of labor for scheduling, servicing, pickup/delivery to the service point, and administrative support for maintenance records updates.

The scenario assumes brief training class for the hybrid hydraulic system. For the operators, basic orientation is sufficient to discuss the hydraulic system fundamentals The hydraulic system is transparent to the operator, and is relatively maintenance free for the service team. Service training requirements are minimal due the straightforward maintenance and simplicity of the system. A two or three hour orientation course will be sufficient, with an estimated cost of $1,500.

The avoided fuel use has an indirect cost benefit associated with reduced impacts of greenhouse gases. This includes avoidance of impacts to agricultural productivity, human health, property damage, and ecological resources. An Interagency Working Group that modeled the impacts arrived at a central value of $19 (2007 US dollars) per ton of GHG avoided.[viii] The study suggested a three percent increase to this 2007 base value for every year thereafter to compensate for cumulative impacts. This suggests the 2017 value for avoided GHG emissions is $25/ton. Estimated GHG reduction over the 12 year life cycle is 56 tons, assuming the combustion of one gallon of diesel produces 22.4 lbs of GHG.[ix] This considers emissions of CO2, methane, nitrous oxide, and air conditioning refrigerant (HFC-134a). Estimated GHG avoided over the, or $1,400.

Table 7-1. Cost Analysis for Hydraulic Hybrid in Severe Duty Cycle Scenario

Hybrid Program Costs				Indirect Environmental Activity Costs		12-Year Hybrid Cost Total
Capital Equipment and Infrastructure		Operation and Maintenance[1]				
Activity	$	Activity	$	Activity	$	
Hydraulic Hybrid System Cost[1]	$30,000	Reduced Fuel Use (20% Less Consumption) (4,668 gal saved @ $5.00/gal)[2]	-$23,333	Air Emissions (reduce 56 tons over truck life @ estimated $25/ton)[7]	-$1,400	
		Fueling Time and Frequency (46 hours less labor)[3]	-$3,500			
		Avoided Delivery to Fuel Storage Tank (one per year)[4]	-$467			
		Avoided Labor for Brake Maintenance[5]	-$1,650			
		Training Event for Operators, Service Crew[6]	N/A			
Totals:	$30,000		-$29,223		-$1,900	-$1,123

1. Assumes full commercial production volumes for hydraulic hybrid system, and purchases in the 2015 to 2020 timeframe.
2. Assumes 12-year life truck cycle, annual estimated 7,500 miles of use, including five days per week, six hours per day, six mph average speed, and multi stop duty cycle. Fuel economy for the baseline conventional truck is 3 mpg.
3. Assumes baseline refueling of refuse trucks every 50 gallons or 150 miles when the truck is at 20 percent full. Assumes a total of 46 fueling events per year for the conventional truck. For a 20 percent efficient improvement, hybrid technology would avoid seven fueling events per year, or 96 fueling events over the life of the truck. The analysis assumes each event requires 30 minutes of the operator's time and labor is $75 per hour.
4. The hybrid's reduced fuel use will avoid a single delivery of 5,000 gallons of fuel to the station. Assumes four hours of labor for driving, fueling, and administrative operations at $75/hr.
5. Assumes conventional truck brake lining replacement once every 12,000 miles and hybrid hydraulic brake pad replacements every 50,000 miles. Over a 12-year life cycle, hybrid would require approximately six fewer replacements. Assumes each service visit requires three hours of labor at a rate of $75/hour and $50 in parts.

6. The hydraulic hybrid system is very similar to the conventional truck and will not require substantial training beyond basic orientation by the local distributor. Also, most service teams are familiar with and work routinely on hydraulic systems for equipment with lifts.
7. Assumes 22.4 lbs. of GHG emissions are generated per gallon of diesel, and the market value of CO2 is $25 per ton.

In summary, the hybrid equipped refuse truck is not cost effective for the mild duty cycles as tested during the demonstration. Further, DoD appears to have very few promising severe duty applications that would substantially benefit from the technology and realize simple payback over a 12-year life cycle. A hypothetical scenario where the truck would be cost effective includes six hours of daily use at low average speeds and multiple stops. The duty cycle assumes a 7,500 mile annual mileage, a $30,000 cost premium for the hybrid system, and $5 per gallon for petroleum diesel. This scenario would realize simple payback during its life cycle due to reduced fuel savings ($23,333), reduced labor for fueling events ($3,967), avoided brake service events ($1,650), and fewer GHG impacts ($1,400). Under the above scenario, the return on investment is approximately $4/mile for every mile above 90,000 miles.

Utility Trucks

Results of the performance testing indicate the hybrid electric utility platform will be economically viable with further market development. Assuming greater production volumes, and price reductions of approximately 40 percent, the hybrid technology and utility platform are suitable and cost effective for non-tactical fleet applications. The utility trucks are a common platform among the DoD fleets and thus show substantial integration potential. Also, the hybrid electric system works well for military duty cycles, helping reduce engine use for idling and work applications. Considering the industry's integration efforts with commercial utility provider fleets, the technology will continue to be refined for optimal performance. Integration into the military non-tactical fleets over the next four to eight years appears to be a promising approach to improve the services' energy security profile for medium and heavy platforms.

Table 7-2 presents a lifecycle cost assessment. Cost premium for the hydraulic hybrid system in this demonstration was $63,000. Studies suggest commercial off-the-shelf cost, if mass produced, would drop to approximately $37,000, as suggested by the National Research Council assessment.[x] Cost reduction potential is due to the system's broad application for several platforms. Electric technology plays a role in the overall cost savings and a trend shows lower battery costs with the volume production.

Economics for the utility trucks depends on moderate driving and consistent use of the trucks in the work mode. Appendix K evaluates cost for a range of PTO-use scenarios assuming 7,500 miles per year annual driving (approximate operating scenario for the NAVFAC Southwest utility trucks. Minimum PTO use to achieve simple payback is approximately 750 hours per year. Under this duty cycle, average use include 30 miles of driving and 3 hours of aerial lift use daily. The cost analysis assumes the hybrid truck provides 15 percent better fuel economy in the driving mode (i.e., 7.5 mpg vs. 6.5 mpg) and a 140 percent improvement in fuel economy improvement for the engine-off PTO work (0.36 gph vs. 0.88 gph). The fuel economy assumptions are based on the results of the track testing conducted by the Army at APGM. Resultant 12-year life cycle fuel avoidance is $32,631 under this scenario.

Fuel economy improvements also reduce fueling events. Over the life of the truck, the improved efficiency of the hybrid will avoid an estimated 130 fueling events and 65 hours of labor. At an estimated labor cost of $75, cost savings is an estimated $4,895. The time saved can instead be used to boost productivity and generate revenue for the organization. In addition, avoided fueling of the trucks extends savings to the fuel station mobile delivery truck operations. The efficiencies equal approximately one fewer mobile truck deliveries to the station, or $300 assuming four hours of labor for fuel truck filling, transportation to and from the fuel station, tank filling operations, and administrative documentation.

Regenerative braking on the hybrid electric system reduces brake wear by approximately one-third as compared with the conventional truck. Over the 90,000 mile life cycle, the hybrid platform will prevent approximately four brake service events (i.e., 6 events vs. 10 events for the conventional truck). This assumes wear rates are similar to cumulative effects during the demonstration testing, and an estimated service and replacement approximately every 18 months or 12,000 miles for severe duty cycle applications. Cost considerations for brake changes include $50 in parts, and three hours of labor for scheduling, servicing, pickup/delivery to the service point, and administrative support for records updates.

Under this cost analysis scenario, the hybrid electric truck reduces engine use and related preventive maintenance. The engine-off PTO avoids approximately 560 hours of annual running time. Based on the 550 hour oil change interval, the hybrid avoids 12 oil changes over the life of the truck, or $3,820 assuming 3 hours of labor for the service team and administration, and $95 for the replacement parts (oil filter), consumables (replacement oil), and waste processing (used oil, oily rags, etc.).

The cost analysis includes a cost for replacing the hybrid's battery pack in one-half of the trucks after 8 to 10 years. While battery technology continues to improve, battery life and probability for failure during a 12-year life cycle is unclear. Estimated replacement cost per hybrid is $8,000, assuming a 10 kWh battery pack and pricing of $800/kWh. It is likely this figure will drop significantly in the near future as technology develops further.

The hybrid utility truck reduces GHG by an amount proportional to the fuel savings. For 6,526 gallon avoidance in diesel fuel consumption, GHG is reduced by approximately 73 tons using the same assumptions as for the hybrid hydraulic truck (i.e., 22.4 lbs/gal diesel) as discussed above. The estimated indirect benefit for impacts avoided (i.e., to agricultural productivity, human health, property damage, and ecological resources) is $25/ton[xi] or $1,825.

Another benefit of the hybrid truck's engine-off PTO is increased productivity. This is due to improved communications between the crew on the ground and the crew in the lift. The quiet operation also enables work in locations and at times that might otherwise require special scheduling due to the engine idling noise. Estimated productivity increase is one percent, or 7.5 hours per year, combined, for a crew of two on the utility truck. The resultant estimated cost savings is $6,750 over the 12 year life cycle.

Table 7-2. Cost Analysis for Hybrid Electric Under Severe Lift Cycle Scenario

Hybrid Program Costs				Indirect Environmental Activity Costs		12-Year Net Cost for Hybrid
Capital Equipment and Infrastructure		Operation and Maintenance[2]				
Activity	$	Activity	$	Activity	$	
Hybrid Electric System Cost[1]	$37,000	Reduced Fuel Use (6214 gal @ $5.00/gal)[2]	-$31,071	CO2 Emission Reductions (73 fewer tons over truck life @ estimated $25/ton)[8]	-$1,554	
		Fueling Time and Frequency[3]	-$4,661	Increased Productivity (1% increase)[9]	-$6,300	
		Avoided Cost Brake Maintenance[4]	-$550			
		Avoided Oil Service (once per year at $320 per event)[5]	-$3,520			
		Battery Replacement Cost[6]	$4,800			
		Training for operators, service team[7]	$3,000			
Totals:	$37,000		($32,002.00)		($7,854.00)	($2,856.00)

1. Operating Scenario: Assumes a 12-year truck life, full commercial production volumes for hybrid electric systems. Assumes truck operates 7,500 miles annually, with 3 hours of daily aerial lift operations in the PTO mode.
2. Fuel Savings: Conventional utility truck fuel consumption is 1,770 gallons, including 1,154 gallons for driving (7,500 miles at 6.5 mpg) and 616 gallons for PTO operations (700 hours at 0.88 gph). Hybrid truck fuel consumption is 1,252 total, including 1,000 gallons for driving (7,500 miles at 7.5 mpg) and 252 gallons for PTO Operations (700 hours at 0.36 gph).
3. Fueling time and Frequency: Avoided fueling estimate considers filling the tank when fuel level drops to one-quarter full. The hybrid avoids 124 events, or 62 labor hours (assuming 30 minutes of operator time per event) and $4,650 in labor assuming $75 hourly rate.
4. Brake Maintenance: Brake change occurs every 15,000 miles (or 3-years) for the conventional truck, and every 20,000 for the hybrid truck. Each event requires four hours of labor, including the drop-off and pick-up, at a rate of $75/hour, and estimated cost of brake linings at $50. The hybrid avoids two brake service events.
5. Oil Service: Assumes one service event every 550 hours. The hybrid truck avoids 562 hours per year of engine operation through engine-off PTO, or one oil service event per year. Each event assumes 3 hours in labor and $95 for replacement parts and consumables.
6. Battery Replacement: Assumes replacement of a 6 kWh battery pack at a cost of $800/kWh.

7. Training: Assumes a 4-hour training event for the service team, and a 2-hour training event for two operators.
8. GHG Production: Assumes 22.4 lbs per gallon of diesel, and an indirect benefit of $25/ton GHG.
9. Productivity: Engine-off PTO increases productivity by an estimated 1% over and above the conventional truck due to with enhanced operationally capability to due to improved communications between the ground and work crew.

In summary, the hybrid electric utility truck is cost effective for scenarios involving moderate driving (i.e., 7,000 miles per year) and high use of the PTO system (i.e., 3 hours daily). DoD applications meeting this criteria the realize cost benefits from the technology's efficiency and quiet operation. Simple payback will occur over a 12-year life cycle assuming the above scenario. Overall cost savings include: avoided fuel payments ($31,071), avoided labor for fueling events ($4,661), avoided oil and brake service events ($4,070), enhanced productivity ($6,300), and GHG emission reductions ($1,554). Assumed investments include $37,000 for the hybrid system, initial operation and maintenance training for $3,000 and a battery replacement for approximately $4,800. All benefits are direct with the exception of GHG emission reductions, which reduce the potential impacts due to global warming.

8. Implementation Issues

Fleet managers are the responsible entity that must integrate heavy hybrid technology into the vehicle fleets. A primary hurdle slowing the integration of heavy hybrid trucks into the fleet is the additional $50K to $70K investment. The decision to purchase hybrid technologies means the agency's fleet purchases will involve fewer trucks at a higher cost. While the heavy hybrid market is in the early stage of commercial development, incremental costs still remain prohibitively high. As such, discounts or other incentives are needed. Incentives may be made available through government or industry groups.

For the military, one of the critical steps to planning for heavy hybrid implementation is identification and selection of the most beneficial applications. Identifying the applications with the greatest payback will result in the highest efficiency benefits, so that return on investment will justify the cost premium. Overall, the larger military fleet will realize extended benefits as the technology matures.

A primary implementation issue for hybrid technology is application selection. This is critical if the DoD is to realize fuel savings. Within DoD, this is an inherent problem where many characteristic duty cycles consist of sporadic or occasional use. Hybrid systems offer the most benefit for applications with consistent daily use patterns. DoD's challenge relies upon 1) characterizing the inventory subject to those high use or abusive cycles; and 2) pairing the hybrid technology and application sets that promise the greatest benefit. In addition to reviewing daily use patterns, US General Services Administration has data acquisition technologies on their vehicle contract schedules capable of characterizing duty cycles. For a relatively small cost, a survey will help verify that candidate replacements have suitable duty cycles.

Training is the other item that is critical to successful technology implementation and integration. Fleets will realize greater support, and improved chance of user acceptance, if operators understand operating concepts and best operational practices. Also, in the interest of safety, all service and maintenance training should accompany delivery of all new hybrid trucks. The high energy systems are potentially hazardous and could result in injury or death unless fleet management takes proper precautions and ensures mechanics are trained for servicing the energy storage systems. While hybrid systems will require minimal or no attention, there are scenarios where the service team must know proper procedures to work on or around these systems. This may occur at a point that is five to eight years into hybrid truck ownership. If work on the hybrid systems is sporadic, it is prudent to invite service support or oversight from the local authorized dealership personnel.

Accidents involving hybrid platforms also present new challenges and potential hazards to emergency responders and vehicle operators. Personnel must have training on accident response procedures including system shutdown or isolation procedures. Battery packs and high pressure accumulator systems present potential for electrocution, toxic gas inhalation, or overpressures if compromised by fire or physical damage. In the event that accidents involving the hybrids, ER crew must have more than an awareness of the high energy hazards of the hybrids. Crew must be trained to watch for the hybrid labels and be instructed in the procedures to de-energize electric or gas lines that are compromised and present a hazard. Also, if the vehicle is on-fire, crew must maintain a safe distance and be advised of toxicity in the event of a burning battery pack. National Highway Safety

Transportation Administration has generated interim guidance for emergency responders that is provided as Appendix L. Such Fact Sheets should be circulated to appropriate claimant commands within the agency to promote awareness.

9. References

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4. U.S. Environmental Protection Agency, Transportation and Regional Programs Division Office of Transportation and Air Quality, “SmartWay Fuel Efficiency Test Protocol for Medium and Heavy Duty Vehicles”, Working Draft, EPA420-P-07-003, November 2007.

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8. Interagency Working Group on Social Cost of Carbon, “United States Government Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866”, February 2010.

9. U.S. Environmental Protection Agency, Greenhouse Gas Emissions from a Typical Passenger Vehicle, EPA-420-F-11-041, Office of Transportation and Air Quality, December 2011

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Appendix A:

Points of Contact

Table A-1. Project Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
David Cook	USN, NAVFAC EXWC 1000 23rd Ave Port Hueneme, Ca, 93043	Phone: 805-982-3477 Fax: 805-982-4832 Email: david.j.cook@navy.mil	PI and NAVFAC EXWC AFV Team Lead
Rebecca Fraley	USN, NAVFAC EXWC 1000 23rd Ave Port Hueneme, Ca, 93043	Phone: 805-982-3098 Fax: Email: Rebecca.fraley@navy.mil	Acquisitions
Jim Gough	USMC HQ	Phone: 703-695-7010 Fax: Email: james.gough@usmc.mil	USMC Stakeholder
Tom Brotherton	CALSTART	Phone: 303-825-7550 Fax: Email: tbrother@weststart.org	Data Collection Oversite
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John Lacy	NAVFAC NW	Phone: 360-396-7005 Fax: Email: les.hastings@navy.mil	NAVFAC NW Integrated Waste Management Team
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Ray Akins	NAVFAC NW	Phone: 360-396-4130 Fax: Email: ray.akins@navy.mil	NAVFAC NW Trans. Operations
Dean Lewis	NAVFAC SW	Phone: 619-556-9761 Fax: Email: dean.lewis@navy.mil	NAVFAC SW AFV Program
Erik Kallio	USA, TARDEC	Phone: 586-574-7544 Fax: Email: erik.kallio@us.army.mil	Hybrid Vehicle Program Lead
Brad McNett	USA, TARDEC	Phone: 586-574-7207 Fax: Email: brad.mcnett@us.army.mil	CALSTART contract oversight

Appendix B

Datasheets (Logs, Surveys)

Refuse Truck Inspection Form

Inspector's Name (Printed): ________________________________

Vehicle Tag No.:____________**Mileage**___________________

Date (MM/DD/YY):_____/____/____

Inspection Type: Baseline____**Weekly**____**Monthly**____**6-Months**____

1. Accumulator (Weekly)

Check Nitrogen Pre-charge: Yes_____No_____Corrective Actions: _____

Visually Inspect Accumulator Yes_____No_____Corrective Actions: _____

2. Engine/HLA Diagnostic System Codes (Weekly)

Status or Trouble Codes: Yes_____No_____Description: ______________________________

Corrective Actions: ____

3. HLA Pump System (Weekly)

Leaky Pump/Components: Yes _No Corrective Actions:________

Damaged Warning Labels: Yes _No Corrective Actions:_____

Driver Module Working: Yes _No Corrective Actions:____

Fault Codes: Yes _No Corrective Actions:________________________

4. **HLA Sub-Frame: (Weekly)**

Cracked Welds: Yes _No Corrective Actions: ____

Loose Mounting Bolts: Yes _No Corrective Actions:_____

Worn Absorbers: Yes _No Corrective Actions:________________________

5. Tire Pressure: (Weekly) OK_____Low_____Add: ______________________________

6. HLA Reservoir Breather: (Monthly)

Worn Breather (i.e., Red Indicator?): Yes No Replaced________________________

7. Fluid Checks:	Oil	OK_____Need_____Added ________________________
(Monthly)	Brake	OK_____Need_____Added ________________________
	Steering	OK_____Need_____Added ________________________
	Coolant	OK_____Need_____Added ________________________
	Transmission	OK_____Need_____Added ________________________
	HLA fluid	OK_____Need_____Added ________________________

7. HLA Fluid Sample (3, 6 months):__________

8. Hose Inspection: (Monthly)

Abrasion or Wear: Yes_____No_____Corrective Actions: ______________________

Loose/Hanging: Yes_____No_____Corrective Actions: ______________________

9. Brake Pad Thickness: (Baseline, 6-Months) (Front Left/Front Right): _____________________

*Provide attached service log with details for adjustments and corrective actions.

Refuse Truck Driver Survey

Operator					
Vehicle Tag					
Date					
	Satisfaction				
	Not Satisfied				**Very Satisfied**
	1	**2**	**3**	**4**	**5**
Starting Engine	☐	☐	☐	☐	☐
Braking	☐	☐	☐	☐	☐
Low Speed Maneuverability	☐	☐	☐	☐	☐
Acceleration	☐	☐	☐	☐	☐
Deceleration	☐	☐	☐	☐	☐
Grade Pulling	☐	☐	☐	☐	☐
Transmission Shift Quality	☐	☐	☐	☐	☐
Control Arm Operation	☐	☐	☐	☐	☐
Hydraulic Power	☐	☐	☐	☐	☐
Noise Level	☐	☐	☐	☐	☐
In-cab Ergonomics	☐	☐	☐	☐	☐
Overall Rating	☐	☐	☐	☐	☐

Comments (Please Note Outstanding Features or Concerns):

Vehicle Fueling Log

Date and time	Vehicle (Tag No.)	Driver	Amount dispensed (gallons)	Comments

* Utility Truck Inspection Form

Inspector's Name (Printed): ________________________________

Vehicle Tag No.:_____________Mileage__________________

Date (MM/DD/YY):_____/____/____

Inspection Type: Baseline____Weekly____Monthly____6-Months____

1. Engine/HEV Diagnostic System Codes (Weekly)

Status or Trouble Codes: Yes No Description: _______

Corrective Actions: ____

2. Tire Pressure: (Weekly) OK____Low____Add: ______________________________

3. HEV System Cases (Monthly)

Case Damage/Mud: Yes _No Corrective Actions:_______

Damaged Warning Labels: Yes _No Corrective Actions:____________

Damaged/Loose Fasteners Yes No Corrective Actions: ________________________

4. **HEV Cooling System: (Monthly)**

Leaking Connector Fittings: Yes _No Corrective Actions:____________

Cracked/Loose Hoses: Yes _No Corrective Actions:_______

Tank/Fin Leakage: Yes _No Corrective Actions:_______

Tank/Fin Obstructions: Yes _No Corrective Actions:___________

Loose/Missing Latches: Yes _No Corrective Actions:___

Fan Blade Damage: Yes _No Corrective Actions:________________________

5. HEV Low Voltage Cables: (Monthly)

Missing/Loose Anchors: Yes _No Corrective Actions__________

Heat/Exhaust Damage: Yes _No Corrective Actions____

Heat Shield Intact: Yes _No Corrective Actions ________________________

6. Fluid Checks: (Monthly)

Oil	OK	Need		Added __
Brake	OK	Need		Added __
Steering	OK	Need		Added __
Coolant	OK	Need	Added ________________________	
Transmission	OK_____	Need_____	Added ________________________	
Hydraulic fluid	OK_____	Need_____	Added ________________________	

7. Brake Pad Thickness: (Baseline, 6-Months) (Front Left/Front Right): ____________________

*Please complete service log and enter details on any corrective actions.

Utility Truck Driver Survey

Operator					
Vehicle Tag					
Date					
	Satisfaction				
	Not Satisfied Very Satisfied				
	1	**2**	**3**	**4**	**5**
Starting Engine	☐	☐	☐	☐	☐
Braking	☐	☐	☐	☐	☐
Low Speed Maneuverability	☐	☐	☐	☐	☐
Acceleration	☐	☐	☐	☐	☐
Deceleration	☐	☐	☐	☐	☐
Grade Pulling	☐	☐	☐	☐	☐
Transmission Shift Quality	☐	☐	☐	☐	☐
Bucket/Boom Operation Electric Mode (Engine Off)	☐	☐	☐	☐	☐
Bucket/Boom Operation Mechanical Mode (Engine On)	☐	☐	☐	☐	☐
Hydraulic Power	☐	☐	☐	☐	☐
Noise Level	☐	☐	☐	☐	☐
In-cab Ergonomics	☐	☐	☐	☐	☐
Overall Rating	☐	☐	☐	☐	☐
Comments:					

Truck Maintenance Sheet

Date/Time	Vehicle Tag No.	Technician	Service Description (Item Adjusted, Parts Replaced, Trouble Code Addressed)

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Appendix C:

Automated Data Parameters

Automated Data Parameters for Refuse Haulers (Collected via the Telematics System)

Telematics Parameters List: (Hybrid)
• Accelerator Pedal Position • Automated Side Loader Operation • Brake Operation • Diesel Particulate Filter Regeneration • Engine Speed • Hydraulic System Pressure • Hydraulic System Temperature • Ignition (On/Off) • Odometer • Regenerative Braking System (On/Off) • Supplemental Power from Hydraulic System • Transmission Shift Position • Vehicle Speed • Vehicle Trouble Code
Telematics Parameters List: (Non-Hybrid)
• Accelerator Pedal Position • Automated Side Loader Operation • Brake Operation • Date/Time • Diesel Particulate Filter Regeneration • Engine Speed • Ignition (On/Off) • Odometer • Transmission Shift Position • Vehicle Speed • Vehicle Trouble Code

Automated Data Parameters for Utility Truck (Collected via the Telematics System)

Telematics Parameters List: (Hybrid) • Aerial Lift Unit Operation • Air Conditioning Operation • Auxiliary Power Unit Operation • Battery Pack Temperature • Battery State of Charge • Battery Current • Battery Voltage • Brake Operation • Diesel Particulate Filter Regeneration • Diesel Engine Operation/Power • Electric Motor Operation/Power • Engine Speed • Fuel Use • Hydraulic Tools Circuit Operation • Ignition On/Off • Odometer • Transmission Shift Position • Vehicle Speed • Vehicle Trouble Code
Telematics Parameters List: (Non-Hybrid) • Air Conditioning Operation • Auxiliary Power Unit Operation • Brake Operation • Diesel Particulate Filter Regeneration • Diesel Engine Operation/Power • Engine Speed • Fuel Use • Ignition On/Off • Odometer • Transmission Shift Position • Vehicle Speed • Vehicle Trouble Code

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Appendix D

Fuel Economy Test Report

Appendix E

Kick-Off Meeting Agendas

Agenda
NAVFAC Northwest Refuse Truck Testing
Kick-Off Meeting

Mon Feb 7th Operator Training; Test Program Overview
Location: (NBK Bangor Bldg 1202)

Time	Leader/Instructor	Description	Audience
0830	**Chassis Supplier, Recycling Body Supplier**	**Operator Instruction** (Truck Overview, General Operating Procedures, Cabin Controls, Safety Features, Cautions, Trough Loader Overview & Operating Procedures, HLA System Layout, Regenerative Braking, Driving)	**All Hands:** Operators, Service Team, Site Managers
0930	**Chassis Supplier, Recycling Body Supplier**	**Truck Walkthrough & Demonstration** Basic Truck Features & System Identification, Operator Controls, Dash-Board Indicators, Lighting, Gauges, Trough Loader Operation	**All Hands:** Operators, Service Team, Site Managers
1130		**Lunch Break**	
1230	**Chassis Supplier, Recycling Body Supplier**	**Service Training** Specifications, Routine Maintenance, Service Manuals, Additional Documentation, Technical Support, Safety Procedures and Cautions	**Service Team**
1600		**Adjourn for the Day**	

Tues Feb 8th Service Training (Location: NBK Bangor Bldg 1202)

Time	Instructor	Description	Audience
0700	**Chassis Supplier, Recycling Body Supplier**	**Service Training** Trough Loader Preventive Maintenance and Special Care, Spare Parts and Special Tools, Engine Diagnostics and Troubleshooting, Fault Codes	**Service Team, CALSTART, NAVFAC EXWC**
0930	**Chassis Supplier, Recycling Body Supplier, CALSTART, NAVFAC EXWC**	**Truck Inspection (Part 1: Engine, Chassis, Trough Loader)**	**Service Team**
1130		**Lunch Break**	
1230	**Hybrid Supplier**	**Service Training: HLA Overview** HLA: System Overview, Preventive Maintenance and Care, Diagnostics, Performance Mode Settings, Regenerative Braking, Monitoring	**Service Team, CALSTART, NAVFAC EXWC**
1400	**Hybrid Supplier**	**Truck Inspection (Part 2: HLA System Checks)** HLA Pump System, Diagnostics, Accumulator, Sub-frame, Hydraulic Fluid	**Service Team, CALSTART, NAVFAC EXWC**
1600		**Adjourn for the Day**	

Weds Feb 9th Service Training (NBK Bangor Bldg 1202)

Time	Instructor	Description	Audience
0800-1100	**CALSTART, NAVFAC EXWC**	***Demonstration Program Overview*** Operator Survey Forms, Monthly Inspections, Submittal Procedures, Telematics System, Quality Assurance Reviews, Bi-Monthly Meetings, Roles and	**All Hands:** Operators, Service Team, Site Managers

		Points of Contact	
1130		**Lunch Break**	
1300	**Telematics Supplier, CALSTART**	**Telematics Overview and Data Collection Plan**	**Site Managers**

Thurs Feb 10th CALSTART Baseline Ride-Along

Time	Leader	Description	Audience
0700	**NAVFAC NW Operator Team**	**CALSTART Baseline Survey** Ride-Along, Operations Team Interviews;	**CALSTART**
1500		**Adjourn Kick-Off Week**	

Agenda
NAVFAC Southwest Utility Truck Testing
Kick-Off Meeting

Tues Mar 29th Operator/Service Training; Test Program Overview Location: (NAVSTA San Diego Bldg 3509)

Time	Leader/Instructor	Description	Audience
0830	Chassis Supplier	**Chassis Operator Instruction** (Truck Overview, General Operating Procedures, Cabin Controls, Safety Features, Cautions, Hybrid System Layout, Regenerative Braking, Driving Procedures)	**All Hands:** Operators, Service Team, Site Managers
1000	**Utility Body Supplier, Hybrid Supplier**	**Hand-On Operator Instruction** Basic Truck Features, Lift System Controls, Dash-Board Indicators, Gauges, Lift System & PTO Operation for Hybrid vs. Non-Hybrid	Operators, Site Managers
1130		**Lunch Break**	
1230	**Hybrid Supplier**	**Hybrid System Instruction** Specifications, Routine Maintenance, Service Manuals, Additional Documentation, Technical Support, Safety Procedures and Cautions	**Service Team**
1600		**Adjourn for the Day**	

Weds Mar 30th Data Collection Overview (NAVSTA San Diego Bldg 3509)

Time	Instructor	Description	Audience
0830-1100	**CALSTART, NAVFAC EXWC**	**Demonstration Program Overview** Operator Survey Forms, Monthly Inspections, Submittal Procedures, Telematics System, Quality Assurance Reviews, Bi-Monthly Meetings, Roles and Points of Contact	**All Hands:** Site Managers
1130		**Lunch Break**	

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Appendix F

Correction Action List for Refuse Trucks

Correction Action List
(NAVFAC Northwest generated this list following the kick-off event.

Non Hybrid Unit – VIN 119418

Action Item	**Status as of 22 March 2011**
High Idle Switch	RAMPED UP TO 1200 RPM
Remount the back-up camera screen to the front of the truck	REMOUNTED MONITOR TO FRONT HEADER
Warning sound or buzzer when trough or container is lifted	DECIDED AGAINST
Stabilizer down warning light	REPLACED PROX SWITCH
Force neutral for any trough or container or stabilizer	DECIDED AGAINST, USE WARNING LIGHT

Hybrid Unit – VIN 121193

Action Item	**Status as of 22 March 2011**
#1 and #2 Troughs lift at the same time	REPLACED SELONIOD VALVE
#2 and #4 Troughs lift at the same time	REPLACED SELONIOD VALVE
Remount the back-up camera screen to the front of the truck	REMOUNTED MONITOR TO FRONT HEADER
sound or buzzer when trough or container is lifted Warning	DECIDED AGAINST
Stabilizer down warning light	REPLACED PROX SWITCH
Force neutral for any trough or container or stabilizer in up/down position	DECIDED AGAINST, USE WARNING LIGHT

Appendix G

Ride Along Observations

Ride-Along Observations (Refuse Trucks)
February 9, 2011

Geoff Jennings of CALSTART rode with refuse truck operators on February 9, 2011 in order to gain additional insight into vehicle operations at NBK Bangor. Even though the actual trucks – conventional and hybrid – that will be evaluated in the ESTCP project were not ready for use at that time, the ride along was interesting and helpful in understanding the work flow and how these trucks will be used.

Geoff was limited in which areas of base he could be taken to. The trips included a portion of each of the three bases. None of the normal routes could be seen in their entirety. He did see nearly all the areas the driver could take him to due to security clearances. In terms of workflow, based on conversations with the drivers, what he saw was pretty typical.

During the training overview with the hybrid supplier, we learned that the optimal duty cycle for the hydraulic launch assist (HLA) system is 700 to 1,000 stops a day and that full benefits of the system will be realized if it is used in a constant, low-speed operation.

Issues Associated with Vehicle Speed and Number of Stops

It is not uncommon at all for the NBK Bangor trucks to approach or exceed the 22-25 mph point at which the next stop will have no energy recapture. The HLA system on the hybrid refuse truck operates only when the truck is operated at approximately 25 mph or below. On the ride along route (which was not a regular route) he saw about 35% of the stopping events were preceded by a speed above 25mph. This is going to be very important to watch. Based on what he saw from the route that he rode, and in talking to the driver, we do not think this is unusual and would be representative of typical operations. They are generally covering reasonably long distances between long stops.

Most of the stops (for pickup, not traffic/road stops) were long, anywhere from 20 to 55 minutes. The driver told us that on a normal route they probably stop 10 to 14 times a day (to pick up recycling materials). Basically, the driver and a helper go collect the rolling bins from around the building, dump them into a medium sized hopper, and when it's full (5-6 small bins worth), use the front loader to lift the whole bin and dump it. The driver told us that several of the other buildings take them longer. As they do this they watch for things like toner cartridges and other materials, and do some limited sorting (basically pulling out materials that obviously don't belong). With the new trucks they will have to bring each of the smaller to the truck, and use the lift more often as there is no intermediary container. Drivers expressed concern that it would slow them down. They frequently load the trucks directly from a loading dock. Without wrestling the rolling bins down stairs, we wonder how the new trucks would be used there, taking the existing bins into consideration. Our concern is that the configuration of the new body style could limit the routes and applications the trucks are used for, thereby limiting the data we collect.

Additional Observations

The truck idles the whole time it is collecting material at a location so that the operators can use the hydraulic lifters. There was concern that the smaller capacity of the new trucks would require more frequent trips back to the recycling center, and based on what we saw, that could easily be true.

- There are residential facilities on base that could pose a more optimal situation for the new trucks. Trucks serving these facilities would operate in a more traditional manner (stop, drive a short distance, stop). Those housing units are subcontracted out and are not serviced by the group that has these new trucks.
- One of the key data parameters we intend to measure is brake life. We were told these trucks would normally only have that checked once a year. Given the short test period, and our observation that many of their stops will not take advantage of the HLA system, we're not sure the test timeframe will show much benefit to the brakes.

Takeaway Points

Based on our observation of the current recycling operations we are concerned that the application/route is not a good match for the style of truck chosen and that we probably won't see much, or any, benefit from the hybrid system. If we get very granular data we may be able to build a reasonable argument based on extrapolation, but we question if we'll see much of a "real world" benefit in this application.

From the operations we observed, a hybrid-electric frontloading trash truck, with energy storage to allow the "engine-off" operation of the lift, would likely have a far bigger impact. Since the HLA will not be utilized in its optimal environment, a hybrid system that took advantage of the long idling periods would be a better match for operations at NBK Bangor.

The operators we spoke to generally like the idea of bringing in advanced technology vehicles but they too question the choice of technology.

We understand that the new trucks are part of an overall plan to re-invent the way the recycling is done at the facility but unless routes are changed and/or vehicle loading operations are altered, these new trucks will not positively affect the recycling operations. The recycling manager indicated that he was willing to look for places where the new trucks would be a better fit but that he would probably continue to utilize the old trucks extensively.

Ride-Along Observations (Utility Trucks)
July 19, 2011

General Operation Information
The utility trucks operate out of the US Naval Base in San Diego and cover a radius of 25 miles, serving a total of seven bases in San Diego County. Along with US Naval Base in San Diego, other bases include Imperial Beach, Naval Amphibious Base (NAB), North Island, Pt. Loma, Anti-Submarine Warfare Base, and Miramar. The electrical team currently operates six utility bucket trucks with four drivers.

Typically, each utility truck is used during a 9 hour shift each day for 5 days a week. With each vehicle assigned an average of approximately 3 assignments per day, the trucks travel an average of 60 miles per day that consists of approximately 66% highway driving. It should be noted that time spent at each assignment can vary greatly. Preliminary data from fuel logs shows that each utility truck uses an average of 15 gallons of fuel per day but it largely depends on the usage. The vehicles run on ULSD instead of the Navy standard B20 diesel, in large part due to the fact that these vehicles are of high importance and their reliability is critical. In addition, the vehicles are fueled via wet hose fueled from a tanker. The vehicles undergo a complete inspection every 6 months with complete fluid changes every year.

Ride Along Purpose

The purpose of the ride along is to try to simulate a typical day in the operation of the hybrid utility truck currently being operated at the US Naval Base in San Diego. However, due to time restrictions, a short trip was planned to demonstrate the various aspects of the hybrid vehicle under various conditions to gain a better understanding of the vehicle characteristics.

The ride along took place between Naval Base San Diego and Pt. Loma on July 19, 2011.

Ride Along Observations

Upon leaving Naval Base San Diego, the roughness of the ride was instantly felt when traveling down Harbor Blvd, a rough patch of road just outside of the base. In addition to the vehicle suspension system, the vibrations are dampened through a pneumatic system on the seats. However, the seat dampening system is not effective in smoothing out the bumps. It was observed and mentioned by the driver that they would slow down substantially if they observe bumps in the roads ahead. In further discussions with the driver, he felt that the conventional utility truck provide a better, more rigid ride.

Acceleration of the vehicle is very poor. The vehicles continuously fall behind normal traffic flow when accelerating from a stop at a red light. Even with the accelerator complete depressed, the vehicle does not feel like it is providing additional power to accelerate at a quicker rate. It was also observed that during acceleration from a stop, when the vehicle transitions from the hybrid drivetrain to the engine, there is a delay and a jerking of the vehicle when the engine kicks in.

During coasting, when the vehicle is in battery regeneration mode, a noise can be heard in the cabin. The low frequency noise can be heard until the brake pedal is depressed and the vehicle stops battery regeneration mode. While it is a nuisance, speaking with the drive shows that the noise is tolerable.

During discussions with the drivers, it was found that the hybrid truck performs very poorly when driving uphill, largely due to excessive gear hunting. In order to evaluate the vehicle characteristics, the driver made a detour to drive up a hill at Pt. Loma. Two trips were made up and down the 0.5 mile stretch of road. As the drivers have been accustomed to the vehicle, the driver anticipated the gear change during the first trip up the hill. This required the drive to carefully control the accelerator so that the engine RPM does not hit the shifting point. The result of driving this way is a smooth ride, but speed was held at roughly 20 mph throughout the climb.

For the second trip up the hill, the driver depressed the accelerator completely to simulate how a driver would typically drive up an incline in a conventional diesel truck. The vehicle accelerated at a very slow rate moving up the gears and settling in 4th gear. After the vehicle hits the RPM shift point in 4th gear, the vehicles shifted up to 5th with a slight delay during shifting. Due to the delay, the vehicle lost road speed and cannot retain the momentum to continue the acceleration in 5th gear. This resulted in the vehicle automatically downshifted back down to 4th gear with another delay for the gear change. After the shift back down to 4th gear, the vehicle has lost speed and momentum which required the vehicle to accelerate back up to the shift point and the whole process repeats again. This caused for a very uncomfortable and slow drive up the hill.

The boom operation was fine with the exception of complaints on the controls from the operators. The control layout and location is different than what they are used to, which caused some adjustment issues and visibly problems when docking the boom. However, with the ePTO engaged, the lack of engine noise proved to be a welcomed benefit for these trucks from the viewpoint of the operators. However, once the engine turns on to recharge the batteries, it cannot be shut off like the conventional trucks. This proved to be a bigger problem as communication between the operation in the bucket and on the ground is greatly hindered.

During the drive back, the vehicle traveled on Interstate 5 to show the vehicle characteristics during mid to high speed operation. A top speed of 72 mph was observed on the freeway, typical of surrounding traffic. The vehicle performed well on the freeway and discussions with the driver confirmed the observation. However, there was one complaint from the driver regarding the cruise control as the system is limited to 55mph, 10 mph below the speed limit.

Conclusion

- Vehicle is lacking in power when accelerating from a stop.
- The vehicle performs well once it is up to speed.
- Transmission shifting strategy is not optimized for driving uphill driving.
    - Excessive gear hunting causes loss in power and speed
- Very rough ride over uneven surfaces

Additional Comments from Hybrid Utility Truck Drivers

Boom Operation

- Controls are different and difficult to operate on the boom
- Docking boom after use is difficult due to location of controls
- Cannot shut off engine when engine is charging the battery during ePTO operation
- Engine needs to be started after each ePTO event, can be troublesome when operating many stops in a short distance.
- Outriggers are good

Driving characteristics

- The switch between motor and engine is rough, jerky
- Inconsistent start gear, it starts in first or second gear
- Very low acceleration power
- Vehicles stalls out at times when driving up hill from standstill
- Driving up hills
    - Slow shifting: longer delay during gear shifts
    - Gear Hunting – a lot of jerking and loss of power
    - Can be avoided with pedal play and anticipating gear change. But slows down vehicle
- Ride Quality
    - Very rough ride on uneven surfaces
    - Seat rattles excessively
- Cruise control governed at ~55mph (too slow)
- Jerking during coasting – low frequency noise from engine
- Braking is good
- Stability during cornering is bad
- Engine starts very well

Comments about cabin

- Seats are loose, uncomfortable driving over rough surfaces − Cab not made for 6 foot person and above
- Radio turns off every hour
- A/C is great
- Great visibility out of cab
- Ergonomics is good
- Easy entry and exit from vehicle

Appendix H

NAVSTA San Diego Interview Comments

(The numbers in parenthesis indicates interview number: August 2011 (1) and October 2011 (2))

Boom Operation

- Controls are different from the old utility trucks on base and difficult to operate on the boom
  - During the second interview, the drivers got used to the new controls and it was no longer an issue
- (1,2) Docking boom after use is difficult due to location of controls
  - Due to the location of the controls, the view to dock the boom is limited from the position.
- (1,2) Cannot shut off engine when engine is charging the battery during ePTO operation
  - Example: When the operator is required to use the boom for an extended period of time, the engine on the diesel truck can be turned off manually. When the engine is running on the hybrid truck to charge the batteries, the engine cannot be turned off to minimize engine noise.
- (1,2) Engine needs to be started after each ePTO event, can be troublesome when operating many stops in a short distance.
  - Example: When working on overhead lights on a street, the engine on the diesel truck remains on between driving short distances and boom operations. The hybrid requires the operator to start and turn off the engine between driving and operating the boom.

Driving characteristics

- (1,2) The switch between motor and engine is rough, jerky
  - There is a slight delay from the transition from electric motor to engine when starting from stop. This results in a jerky shift during the transition
- (1,2) Inconsistent start gear, it starts in first or second gear
  - Dependent on the battery SOC, the hybrid truck may start in first or second gear.
- (1,2) Very low acceleration power
- Issues when Driving up hills (comments from 1st interview, the software upgrade corrected these problems)
  - Slow shifting: longer delay during gear shifts
  - Gear Hunting – a lot of jerking and loss of power
  - Can be avoided with pedal play and anticipating gear change. However, vehicle is slowed down dramatically.
- (1,2) Poor ride Quality
  - Very rough ride on uneven surfaces
  - Seat rattles excessively
- (2) Cruise control governed at ~55mph
  - Too slow for traveling on freeways
- Jerking during coasting
  - Low frequency noise from engine
- (1,2) Braking is good
- (1,2) Stability during cornering is bad.
  - Center of gravity feels higher on the hybrid truck which causes the vehicle to sway during cornering
- (1,2) Engine starts very well

- (2) Top speed on the hybrid is too low compared to the diesel

Comments about cabin

- (1,2) Seats are loose, uncomfortable driving over rough surfaces
- (1,2) Cab not made for 6 foot person and above
- (1,2) Radio turns off every hour
- (1,2) A/C is great
- (1,2) Great visibility out of cab
- (1,2) Ergonomics is good
- (1,2) Easy entry and exit from vehicle

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Appendix I

Noise Testing Summary Tables

Table I-1: Drive-by Noise Test Measurements for Conventional Refuse Truck (dBA)

Speed (mph)	Constant Speed			Acceleration			Deceleration		
	PS	DS	IC	PS	DS	IC	PS	DS	IC
0				82.8	84.5	82.6			
0				82.9	84.5	82.2			
0				-	-	-			
10	76.6	77.4	74.8	82.6	83.6	80.6	72.4	73.6	71.1
10	74.2	76.2	74.4	82.7	83.8	81.5	72.3	73.2	70.5
10	-	-	-	-	-	-	-	-	-
20	75.7	77.7	76.5	84.6	85.5	82.4	72.9	74	72.1
20	76.3	77.6	74.8	82.3	83.5	81	72.5	73.7	71.7
20	-	-	-	-	-	-	-	-	-
25	76.6	76.7	74.5	83	84.8	82	72.6	72.9	70.8
25	77.2	77.8	74.6	82.7	-	82.1	73.2	73.8	70.1
25	-	-	-	-	-	-	-		-

1. Measurements collected on 7 December 2010

Table I-2: Drive-by Noise Test Measurements for Hybrid Refuse Truck (dBA)										
Speed (mph)	Mode Setting	Constant Speed			Acceleration			Deceleration		
		PS	DS	IC	PS	DS	IC	PS	DS	IC
0	Econ.				82.9	82.5	-			
0	Econ.				83.1	82.6	-			
0	Econ.				83.3	83.0	-			
10	Econ.	76.5	76.2	-	83.7	83.1	-	75.8	74.7	-
10	Econ.	76.7	75.8	-	83.0	82.7	-	76.3	74.6	-
10	Econ.	76.8	75.6	-	82.8	82.7	-	76.1	74.6	-
20	Econ.	79.9	78.2	-	84.8	84.8	-	76.2	77.3	-
20	Econ.	79.1	78.2	-	83.9	85.2	-	75.5	75.2	-
20	Econ.	78.8	78.5	-	86.4	83.9	-	82.7	80.1	-
20	Econ.	-	-	-	-	-	-	82.5	78.4	-
25	Econ.	79.3	79.2	-	83.6	82.2	-	77.5	75.9	-
25	Econ.	75.7	75.5	-	86.4	84.0	-	83.7	80.1	-
25	Econ.	78.6	78.9	-	83.7	82.5	-	76.8	75.2	-
20	Prod.	79.3	77.3	60.7	85.0	83.2	62.3	75.7	75.3	59.4
20	Prod.	79.1	76.8	60.5	83.8	82.5	60.6	79.0	77.9	59.5
20	Prod.	79.7	77.2	60.5	84.8	82.9	61.6	nd	78.1	59.4
20	Prod.	nd	77.2	60.3	nd	77.8	61.0	nd	72.9	59.7
20	Prod.	nd	75.8	60.2	nd	76.5	61.1	nd	72.8	59.8

1. Measurements collected on 7 December 2010

Table I-3 Drive-By Noise Measurements for Utility Truck Testing

Measurement Location	Speed (mph)	Constant Speed Conv.	Constant Speed Hybrid	Acceleration Conv.	Acceleration Hybrid	Acceleration Hybrid	Deceleration Conv.	Deceleration Hybrid	Hybrid Battery State of Charge
Battery Charge Status			Charged		Charged	All-Electric		Dis-charged	
Passenger Side	0			80.8	81.1	68.0			
Driver Side	0			80.5	79.5	69.6			
In-Cabin	0			76.8	72.5	64.0			
Passenger	10	74.3	74.7	81.6	80.7		71.8	73.9	35%
Driver	10	73.8	75.6	80.9	79.6		70.3	74.7	25%
In-Cabin	10	66.3	69.4	76.5	72.3		64.0	68.7	25%
Passenger	20	76.2	76.3	80.2	81.2		70.2	74.0	<50%
Driver	20	75.8	75.4	79.4	80.4		70.7	73.2	<50%
In-Cabin	20	68.6	69.5	75.5	78.3		ND	66.4	<50%
Passenger	25	77.8	77.6	81.6	82.2		73.2	74.2	<50%
Driver	25	77.4	77.3	81.4	81.1		73.5	74.8	<50%
In-Cabin	25	67.9		76.1	72.8		ND	74.8	<50%

Table I-4: Deceleration Noise Levels for Battery at 80 Percent State of Charge

Speed	Deceleration 10 mph	Deceleration 20 mph	Deceleration 25 mph	Battery SOC
Passenger	73.8	71.8	75.9	80%
Driver	71.9	72.6	75.1	80%
In-Cabin	68.2	65.2	68.5	80%

Table I-5: Static Noise Testing, Utility Trucks

Mode	Measurement Location	Conventional Truck Measurement Location				Hybrid Truck Measurement Location			
		In-Cabin	1 meter	5 meters	10 meters	In-Cabin	1 meter	5 meters	10 meters
Idle	**Driver**		80.7	75.3	68.2		78.6	71.7	66.7
"	**Passenger**		82.0	73.1	66.1		79.1	73.3	65.1
"	**Front**		83.0	75.0	68.2		84.6	75.5	69.7
"	**Rear**		68.3				64.5		
"	**In-Cabin**	64.8				63.1			
PTO	**Driver**		81.9	75.6	69.0		76.0	67.0	63.6
"	**Passenger**		82.1	74.0	67.4		77.1	66.8	62.2
"	**Front**		85.6	77.2	70.7		70.3	66.1	63.2
"	**Rear**		70.1				68.8		
"	**In-Cabin**	66.4				60.6			

*** Background Noise Measured is 47.9 dB**

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Appendix J

Telematics Data Summaries

For Refuse and Utility Truck Testing

Table J-1. Telematics Data Summary: Refuse Truck Operations at NBK Bangor												
	Monthly Miles	Total Engine Time (hours)	Total Gallons of fuel used	Fuel Economy (mpg)	Fuel Use Rate (gph)	Average Speed (mph)	No. of Stops	Stops per Mile	Idle Ratio	Time in Transit (hours)	Idle Time (hours)	Key On Time (hours)
Hybrid Refuse Truck												
Mar-12	798.46	91.40	187.69	4.25	2.05	8.74	277	0.35	0.61	36.33	55.90	92.38
Apr-12	817.72	92.90	187.17	4.37	2.01	8.80	271	0.33	0.63	36.37	61.97	98.48
May-12	784.17	100.40	191.79	4.09	1.91	7.81	323	0.41	0.62	37.77	62.90	100.80
Jun-12	149.13	32.40	44.91	3.32	1.39	4.60	121	0.81	0.61	12.93	20.27	33.33
Jul-12	208.16	59.00	72.25	2.88	1.22	3.53	188	0.90	0.65	20.87	38.37	59.33
Aug-12	214.99	56.15	70.67	3.04	1.26	3.83	183	0.85	0.59	22.60	33.33	56.08
Sep-12	194.49	41.50	56.66	3.43	1.37	4.69	132	0.68	0.59	16.83	24.65	41.55
Total	3167.13	473.75	811.14				1495			183.70	297.38	481.97
Average (Months)	452.45	67.68	115.88	3.63	1.60	6.00	213	0.62	0.61	26.24	42.48	68.85
Average (Total)				3.90	1.71	6.69	106	0.31	0.62			
Conventional Refuse Truck												
Mar-12	139.81	30.15	38.83	3.60	1.29	4.64	101	0.72	0.50	15.07	14.83	29.95
Apr-12	175.85	32.75	47.02	3.74	1.44	5.37	106	0.60	0.44	18.30	14.28	32.63
May-12	162.18	44.10	52.97	3.06	1.20	3.68	136	0.84	0.54	20.47	23.75	44.33
Jun-12	203.19	56.00	68.29	2.98	1.22	3.63	232	1.14	0.66	19.02	36.95	56.10
Jul-12	282.72	78.90	94.05	3.01	1.19	3.58	318	1.12	0.68	25.18	54.95	80.23
Aug-12	308.20	79.05	97.48	3.16	1.23	3.90	277	0.90	0.71	24.00	58.33	82.52
Sep-12	423.78	96.75	128.92	3.29	1.33	4.38	311	0.73	0.68	30.98	65.40	96.58
Total	1695.72	417.70	527.55				1481			153.02	268.50	422.35
Average (Months)	242.25	59.67	75.36	3.26	1.27	4.17	211	0.87	0.60	21.86	38.36	60.34
Average (Total)				3.21	1.26	4.06	105	0.43	0.64			

Table J-2. Telematics Data Summary: Utility Truck Operations at NAVSTA San Diego						
	Monthly Miles	Engine Time (hours)	Fuel Used (gallons)	Fuel Economy (mpg)	Fuel Use Rate (gph)	Average Speed (mph)
Hybrid Utility Truck						
Jul-11	372.2	26.1	46.5	8.0	1.8	14.3
Aug-11	747.5	56.0	101.2	7.4	1.8	13.3
Sep-11	311.9	23.4	38.4	8.1	1.6	13.3
Oct-11	371.6	29.0	47.9	7.8	1.7	12.8
Nov-11	848.2	49.8	104.6	8.1	2.1	17.0
Dec-11	554.3	34.1	72.8	7.6	2.1	16.3
Jan-12	629.4	38.2	80.2	7.8	2.1	16.5
Feb-12	1227.2	87.0	156.7	7.8	1.8	14.1
Mar-12	500.2	34.6	62.5	8.0	1.8	14.5
Total	5562.5	378.2	710.8			
Avg (Months)	618.1	42.0	79.0	7.9		14.7
Conventional Utility Truck						
Jul-11	188.3	12.7	30.8	6.1	2.4	14.8
Aug-11	627.6	48.1	104.7	6.0	2.2	13.0
Sep-11	403.3	39.5	68.9	5.9	1.7	10.2
Oct-11	365.4	32.2	62.9	5.8	2.0	11.3
Nov-11	487.2	41.7	80.8	6.0	1.9	11.7
Dec-11	249.2	5.2	38.8	6.4	7.5	47.9
Jan-12	230.5	30.2	41.7	5.5	1.4	7.6
Feb-12	257.2	28.8	45.4	5.7	1.6	8.9
Mar-12	150.4	12.1	25.6	5.9	2.1	12.4
Total	2959.1	250.5	499.6			
Avg (Months)	328.8	27.8	55.5	5.9		15.3

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Appendix K

Cost Analysis Tables

Hybrid Hydraulic and Hybrid Electric Technologies

Table K-1: Cost Analysis for Heavy Hybrid Hydraulic Refuse Truck

Hybrid Technology Cost	O&M Training, Testing, Deployment	Annual Miles	Annual Operating Hours (at 6 mph)	Conventional Truck Annual Fuel Use	Hybrid Annual Fuel Use	Hybrid Annual Fuel Avoided	Hybrid Lifetime Fuel Avoided	Lifetime Fuel Cost Savings	Reduced Labor for Fueling	Reduced Labor for Fuel Station Drops	GHG Emission Reduction ($15/ton)	Reduced Brake Maintenance	Overall Cost Benefit
$30,000	$1,500	4,000	1,000	1,333	1,111	222	2,667	$13,333	$2,000	$200	$400	$1,099	-$14,468
$30,000	$1,500	4,500	1,125	1,500	1,250	250	3,000	$15,000	$2,250	$225	$450	$1,236	-$12,339
$30,000	$1,500	5,000	1,250	1,667	1,389	278	3,333	$16,667	$2,500	$250	$500	$1,374	-$10,210
$30,000	$1,500	5,500	1,375	1,833	1,528	306	3,667	$18,333	$2,750	$275	$550	$1,511	-$8,080
$30,000	$1,500	6,000	1,500	2,000	1,667	333	4,000	$20,000	$3,000	$300	$600	$1,649	-$5,951
$30,000	$1,500	6,500	1,625	2,167	1,806	361	4,333	$21,667	$3,250	$325	$650	$1,786	-$3,822
$30,000	$1,500	6,750	1,688	2,250	1,875	375	4,500	$22,500	$3,375	$338	$675	$1,855	-$2,758
$30,000	$1,500	7,000	1,750	2,333	1,944	389	4,667	$23,333	$3,500	$350	$700	$1,923	-$1,693
$30,000	$1,500	7,500	1,875	2,500	2,083	417	5,000	$25,000	$3,750	$375	$750	$2,061	$436
$30,000	$1,500	8,000	2,000	2,667	2,222	444	5,333	$26,667	$4,000	$400	$800	$2,198	$2,565

Table K-2: Cost Analysis for Heavy Hybrid Electric Utility Truck																	
Annual PTO Hours	Total Operating Hrs, Conv. (@ 12 mpg)	Total Operating Hrs, Hyb. (@ 12 mpg)	Life Cycle Op Hrs Reduced, Hybrid	Est. Reduction Oil Service, Hybrid	Conv. Annual Fuel Use (Driving)	Hyb. Annual Fuel Use (Driving)	Hyb. Annual Fuel Avoided (Driving)	Hyb. Annual Fuel Avoided (PTO)	Hyb. Lifetime Fuel Avoided	Lifetime Oil Serv Savings, Hybrid	Lifetime Fuel Cost Savings	Reduced Labor for Fueling	Reduced Labor for Fuel Station Drops	GHG Emission Reduction ($25/ton)	Reduced Brake Maintenance	Increased Productivity	Overall Cost Benefit
200	825	675	1,800	3	1,154	1,000	154	104	3,094	960	$15,471	$2,321	$309	773.5385	550	1800	-$22,616
300	925	700	2,700	5	1,154	1,000	154	156	3,718	1,600	$18,591	$2,789	$372	929.5385	550	2700	-$17,269
400	1,025	725	3,600	7	1,154	1,000	154	208	4,342	2,240	$21,711	$3,257	$434	1085.538	550	3600	-$11,923
500	1,125	750	4,500	8	1,154	1,000	154	260	4,966	2,560	$24,831	$3,725	$497	1241.538	550	4500	-$6,896
600	1,225	775	5,400	10	1,154	1,000	154	312	5,590	3,200	$27,951	$4,193	$559	1397.538	550	5400	-$1,550
700	1,325	800	6,300	11	1,154	1,000	154	364	6,214	3,520	$31,071	$4,661	$621	1553.538	550	6300	$3,476
750	1,375	813	6,750	12	1,154	1,000	154	390	6,526	3,840	$32,631	$4,895	$653	1631.538	550	6750	$6,150
800	1,425	825	7,200	13	1,154	1,000	154	416	6,838	4,160	$34,191	$5,129	$684	1709.538	550	7200	$8,823
900	1,525	850	8,100	15	1,154	1,000	154	468	7,462	4,800	$37,311	$5,597	$746	1865.538	550	8100	$14,169
1,000	1,625	875	9,000	16	1,154	1,000	154	520	8,086	5,120	$40,431	$6,065	$809	2021.538	550	9000	$19,196

***Investment Assumptions:**

$37,000 initial investment for hybrid electric technology.

$4,800 maintenance for replacement of the battery.

$3,000 for initial operation and service training.

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Appendix L

Interim Hybrid Electric Safety Guidance for Emergency Responders
National Highway Transportation and Safety Administration

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries

(Law Enforcement/Emergency Medical Services/Fire Department)

Electric and Hybrid-Electric Vehicle Considerations

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires, and HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

Vehicle Shutdown and High Voltage System Disabling

IDENTIFY VEHICLE

- Determine if the vehicle is an electric or hybrid-electric vehicle, and if it is, advise Dispatch and all responders that an electric or hybrid-electric vehicle is involved.

IMMOBILIZE VEHICLE

- Always approach vehicle from the sides to stay out of potential travel path. It may be difficult to determine if the vehicle is running due to lack of engine noise.
- If possible, chock the tires, place the vehicle into Park, and set the parking brake.

DISABLE VEHICLE

- Turn off the vehicle, activate hazard lights, and move vehicle keys at least 16 feet away from the vehicle.
- If your local standard operating procedures (SOPs) allow it and you are properly trained and equipped, disconnect the vehicle's 12-volt battery. CAUTION: Safety restraints, air bags and other safety systems may be active for up to five minutes after disconnecting the 12-volt battery.

CRASHES DAMAGING THE AREA OF THE HV BATTERY

Law Enforcement and Emergency Medical Services

NOTE: Follow local standard operating procedures (SOPs) for personal protection and safety.

- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling, popping or hissing noises from the HV battery compartment, ventilate passenger area (i.e., roll down windows or open doors) and request fire department response.
- If you detect any unusual odors or experience eye, nose, or throat irritation, move away from the vehicle and evacuate others from the immediate area. Rapid extrication may be needed for injured or trapped occupants.
- Remain a safe distance upwind and uphill from the vehicle and out of the way of oncoming traffic until other appropriately equipped emergency responders arrive.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.
- Be alert. There is a potential for delayed fire with damaged lithium ion batteries.

Fire Department

NOTE: Follow local standard operating procedures (SOPs) for personal protection and safety.

- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling or bubbling sounds from the HV battery compartment, assume there is a battery fire and ventilate the passenger area (i.e., roll down windows or open doors).
- Move away from the vehicle and evacuate others from the immediate area if you detect any unusual odors or experience eye, nose, or throat irritation. Wear full Personal Protective Equipment (PPE) and Self-Contained Breathing Apparatus (SCBA).
- Be alert. There is a potential for delayed fire with damaged lithium-ion batteries.

FIRES INVOLVING OR EXPOSING THE HV BATTERY

Law Enforcement and Emergency Medical Services

- If you are unable to quickly remove the occupants, use a fire extinguisher to protect them from the flames.
- As with any vehicle fire, the byproducts of combustion can be toxic and all individuals should be directed to move to a safe distance upwind and uphill from the vehicle fire and out of the way of oncoming traffic.

Fire Department

NOTE: If the fire involves a lithium-ion battery, it will require large, sustained volumes of water for extinguishment. Consider defensive tactics and allow fire to burn out.

- If there is active fire, follow local standard operating procedures (SOPs) for vehicle fires. Wear appropriate Personal Protective Equipment (PPE) and Self Contained Breathing Apparatus (SCBA).
- If occupants are still inside the vehicle or trapped, a fire extinguisher may be used to protect the occupants until a hose line is available or the occupants are removed. Consider establishing a water supply to support long-term operation.
- Use a hose line to apply water to extinguish the fire while continuing to cool the HV battery and its casing. Never attempt to penetrate the HV battery or its casing to apply water.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.
- Be alert. There is a potential for delayed ignition or re-ignition of a lithium-ion battery fire even after it is believed to be extinguished. This may remain an issue until the lithium-ion battery is properly discharged.
- As with any vehicle fire, the byproducts of combustion can be toxic and all individuals should be directed to move to a safe distance upwind and uphill from the vehicle fire and out of the way of oncoming traffic.

Post-Incident

- Always assume the HV battery and associated components are energized and fully charged.
- Ensure that passenger and cargo compartments remain ventilated (i.e., open window, door, or trunk).
- Notify an authorized service center or vehicle manufacturer representative as soon as possible as there may be other steps they can take to secure and discharge the HV battery.
- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Request fire department (if appropriate) if you observe leaking fluids, sparks, smoke, flames, or hear gurgling or bubbling from the HV battery.

U.S. Department of Transportation
National Highway Traffic Safety Administration

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