Hybrid Yard Hostler Demonstration Project

Final Report

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Contents

1 Introduction

Yard hostlers (also referred to as terminal tractors, yard trucks, utility tractor rigs, yard goats, yard hustlers and yard tractors) are off-road truck tractors designed for moving cargo containers within a port container terminal. In a typical operation, a container is loaded from an ocean-going vessel onto the yard hostler's trailer by a ship-to-shore crane. The yard hostler then drives (tows) the trailer with the container to a destination within the terminal where the container is unloaded by another piece of cargo handling equipment (CHE) such as a top-pick, side-pick or rubber-tired gantry (RTG) crane. Yard hostlers are the most common type of cargo handling equipment used at the ports, and the CHE category comprises 24% of the total CO_2, 29% of total NO_x, 17% of total PM_{10} and 19% of total $PM_{2.5}$ emissions at the Port of New York and New Jersey. http://www.panynj.gov/about/pdf/CAS-FINAL.pdf

The unique duty cycle, or "stop and go" operation of yard hostlers in port container terminals makes them ideal candidates for a hybrid system coupled with the cleanest available diesel engine to potentially achieve an even higher level of emissions and fuel economy benefits.

In a conventional diesel yard hostler configuration, idling involves the sustained inefficient operation of the internal combustion engine. In a vehicle equipped with a diesel-electric hybrid drive system, the internal combustion engine can potentially be shut down during normal vehicle idling times with the vehicle operated in an all-electric mode of operation. Regenerative braking is an additional feature of hybrid systems that allows energy normally lost during mechanical braking to be captured by the hybrid drive system and used to recharge the on-board energy storage device, thereby increasing fuel efficiency and lower emissions.

1.1 Background

This hybrid yard hostler demonstration and commercialization project is a technology demonstration and evaluation program aimed at reducing fuel consumption and emissions in (non-road) marine terminal environments. An initial demonstration was performed at the Port of Long Beach utilizing on-road engines. For this project, two yard hostlers, one with an on-road engine and the other with an off-road engine, equipped with hybrid drive systems were placed into service at the New York Container Terminal in Howland Hook, Staten Island. Vehicle performance, including fuel consumption and operator acceptance were evaluated compared to baseline diesel yard hostlers.

Hybrid drive systems have been shown to significantly reduce fuel consumption and emissions in a variety of light-, medium- and heavy-duty applications including passenger vehicles, transit buses, parcel delivery vehicles, utility trouble trucks and military vehicles. Hybrid technology holds great promise in the yard hostler application due to the stop-and-go nature and high percentage of idling time in the yard hostler duty cycle. By demonstrating and quantifying the benefits and reduced fuel consumption potential of hybrid technology in the yard hostler application, the project will foster wider acceptance of the technology by marine terminal operators and accelerate commercialization of the technology by stimulating market demand.

2 Project Overview

While hybrid technology has been successfully demonstrated in on-road applications, off-road terminal tractors operating in demanding marine terminal environments are subject to different performance requirements. These yard hostlers operate in an extremely demanding, high-torque duty cycle. Long operational hours and reliability are critical elements. Therefore, it is important to determine in real-life settings and duty cycles whether these hybrid vehicles are up to the task and can achieve the fuel consumption and emission reductions desired while demonstrating a positive business case, and thus be viable for expanded use in marine terminals nationwide.

The aim of this project is to assess the commercial viability of off-road hybrid yard hostlers in marine terminal environments at the Port of New York and New Jersey. Hybrid drive systems have generally demonstrated very positive emissions and fuel consumption characteristics although incremental vehicle cost and vehicle performance are potential barriers to its acceptance. It was anticipated that the hybrid drive systems would at least partially offset the increased vehicle cost via reduced fuel consumption, thus paving the way to widespread acceptance of hybrid technology for this application.

New York Container Terminal (NYCT) purchased the hybrid yard hostlers from Kalmar and US Hybrid and placed them in service at the Howland Hook terminal in Staten Island. CALSTART, a nationally-known, fuel-neutral advanced transportation technology consortium, managed the evaluation project and to write up the results in a final report. CALSTART managed the NYCT project after an initial demonstration at the Port of Long Beach (POLB).

3 Project Implementation

The Hybrid Yard Hostler Demonstration Project is a technology demonstration and evaluation program aimed at reducing emissions in marine terminal environments.

3.1 Vehicle Prototype Development

Yard hostlers presented a new application for a proven technology that could potentially provide a higher level of emissions and fuel economy benefits due to the unique characteristics of the yard hostler duty cycle.

3.1.1 Hybrid Drive System Suppliers Request for Information/Request for Proposals

Initial POLB project

In August 2007, the Port of Long Beach released a Request for Information (RFI) soliciting expressed interest from potential hybrid drive system suppliers to supply and integrate hybrid drive systems into Kalmar's Ottawa 4X2 line of terminal tractors. The RFI included specifications for the prototype hybrid yard hostlers as developed by Kalmar and the project team. The RFI was sent to 41 companies known to develop hybrid drive systems through their participation in CALSTART's Hybrid Truck Users Forum. The Port received 16 responses to the RFI. Responses to the RFI included various questions and comments from potential hybrid drive system suppliers which were used to develop the subsequent Request for Proposals (RFP) issued to hybrid drive system suppliers.

The Port of Long Beach's grant agreement with the EPA required that a hybrid drive system supplier be selected through a competitive bid process. A Request for Proposals (RFP) was developed by the project team based on responses to the RFI. In February 2008, the Port of Long Beach released the RFP to hybrid drive system suppliers. The RFP included detailed project information, vehicle specifications, and bidding instructions. The RFP for the project was technology and fuel neutral, and all proposals were considered regardless of the hybrid architecture, technology or supporting infrastructure proposed. A total of 4 responses were received. Hybrid technologies proposed included hydraulic hybrid, series electric hybrid, and parallel electric hybrid, and all battery/full electric.

A committee consisting of representatives from the ports, CALSTART, and Kalmar reviewed the proposals received and rated them based on the technology's estimated emissions reductions and fuel reductions, business case proposal, as well as the schedule and cost to design and develop the hybrid drive system. The qualifications of the proposed supplier's team were also considered.

After an extensive proposal review process, US Hybrid Corporation, based in Torrance, California was selected in June 2008 as the hybrid drive system supplier for the project. Three yard hostlers were built for the POLB project. All of the POLB yard hostlers used on-road engines to comply with the requirements at the port.

NYCT Project

This project was derived from the original demonstration project at POLB. Upon the selection of US Hybrid as the hybrid drive system supplier, two additional vehicles were developed based on NYCT specifications. One of the yard hostlers utilized an on-road engine while the second yard hostler had an off-road engine. The off-road engine was developed as all of the baseline yard hostlers that are currently being operated at NYCT only uses off-road engines. There are no requirements for the use of on-road engines at NYCT. The next section details the vehicles used for the NYCT project.

Test Vehicles and Operations

The test vehicles used for the performance testing and evaluation were comprised of two prototype diesel-electric hybrid yard hostlers and six conventional diesel-fuel yard hostlers from NYCT's fleet that served as the baseline comparison group.

The baseline diesel yard hostlers consisted of Kalmar Ottawa Commando 4x2 terminal tractors with 2009 Cummins QSB 6.7 off-road engines. The diesel yard hostlers were selected to be representative of the most common engine configurations in NYCT's yard hostler fleet.

The hybrid drive systems designed and developed by U.S. Hybrid were integrated into two Kalmar Ottawa 4x2 yard hostlers. As integration of the hybrid drive systems into the vehicles was completed, they were transported to NYCT, where the maintenance staff prepared the vehicles for operation at the terminal. The first hybrid yard hostler was delivered to NYCT in August 2010 with the second in September 2010.

Table 1 summarizes the specifications of the test vehicles and the operation each vehicle was assigned during the performance test.

Table 1. Conventional Diesel Yard Hostler Test Fleet

Vehicle ID	Make	Model	Model Year	Engine	HP	Rear Diff Ratio
Conv 1	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1
Conv 2	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1
Conv 3	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1
Conv 4	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1
Conv 5	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1
Conv 6	Kalmar	Ottawa 4x2	2009	Cummins QSB 6.7	173	12.28:1

Table 2. Diesel Conventional Yard Hostler Test Fleet

Vehicle information							Energy Storage		
Vehicle ID	Make	Model	Model Year	Engine	HP	Rear Diff Ratio	Type	Composition	kW-hr
On-road HEV	Kalmar	Ottawa 4x2	2009	ISB 6.7	200	12.28:1	Battery	Li-ion	2.3
Off-road HEV	Kalmar	Ottawa 4x2	2009	QSB 6.7	173	12.28:1	Battery	Li-ion	2.3

Table 3. Hybrid Yard Hostler Test Fleet

3.2 U.S. Hybrid Post Transmission Hybrid System

Kalmar Industries, a supplier of yard hostlers, participated in the project and was actively involved in the development of the hybrid yard hostler specifications and the selection of a hybrid drive system supplier.

The selected hybrid drive system supplier, U.S. Hybrid, designed and developed a parallel hybrid, post transmission configuration with electric accessories and engine shut down for the hybrid yard hostler application. U.S. Hybrid's post transmissions system integrates the electric drive system behind the vehicle's transmission and is designed to be installed as a "drop-in" component to an OEM production line, or retrofitted in post-production vehicles. U.S. Hybrid's Post Transmission Hybrid System "PTHS" utilizes most of the existing OEM components and does not require re-certification of any components with enhanced reliability and compatible service and maintenance. In addition, the post transmission offers the most fuel efficient hybrid configuration for the port application, while being applicable to support other port vehicles and applications such as the distribution trucks with much higher average load power demand.

The hybrid powertrain utilizes a high performance Permanent Magnet (1150 Nm, 110kW), IGBT inverter with Digital Controllers, CAN diagnostic capabilities, Li-Ion Batteries, and safety protection system. The powertrain also includes electric driven OEM hydraulic pump and air-compressor and the existing Cummins 2007 OEM engine and after treatment with the OEM Allison 3000 transmission. U.S. Hybrid also integrated their proprietary hybrid control unit (HCU) vehicle controller based on the J1939 CAN interface. The controller was designed to contain all the components necessary to control the powering of a vehicle in a single package. The main component is an inverter, which converts DC electricity to AC electricity. US Hybrid developed controllers for the hydraulic and air system, 12V DC-to-DC converter for vehicle auxiliary loads. This approach simplifies the vehicle wiring harness and increases system reliability. Using U.S. Hybrid's proprietary software package, vehicle interfaces and control parameters can be programmed in-vehicle, which was used throughout the test phase to alter vehicle configuration for optimization of vehicle operations. Real-time vehicle performance parameters can also be monitored and collected. The complete drive system is air cooled to minimize the vehicle packaging and maintenance.

4 Performance Test and Results

An important element of the demonstration project is to determine the capability and reliability of the hybrid terminal tractors in real-life settings and duty cycles at port terminals. A test program was developed to evaluate the vehicles' fuel economy, operator acceptance, and maintainability and serviceability. Evaluations of the fuel consumption and, operational characteristics of the hybrid vehicles are necessary to understand the business case for expanded use of hybrid terminal tractors in marine terminals and other terminal tractor applications such as intermodal rail yards and distribution centers. Performance testing was conducted between April 2011 and April 2012. Details of the performance test program are described below.

This section describes the outcome from individual elements of the test program as stated above. A summary of test results and any conclusions that may be reasonably drawn from the data is presented in the following sections.

4.1 Fuel Economy

Fuel Economy Testing

To compare the average fuel economy for the hybrid yard hostler compared to diesel yard hostlers during in-use operations, daily fuel usage and hours of engine operation for the hybrid yard hostlers and a representative group of baseline diesel yard hostlers were evaluated during the fourteen-month performance testing period using fueling log sheets from NYCT's refueling system. The amount of fuel used to fill up the fuel tank and the operating hours were recorded whenever the vehicles were refueled and provided in the fuel logs. CALSTART performed the analysis of all raw data collected by NYCT.

In practice, the engine hours and fuel consumption varied considerably from vehicle to vehicle as well as from month to month. Independent of fuel type, fuel consumption is affected significantly by the actual duty cycle and engine loads experienced by the vehicle as well as the operator's driving style. Fuel economy calculations were based on cumulative amount of engine hours and gallons of fuel used during the fourteen (14) month testing period.

4.1.1 Results

A summary of the gallons of fuel consumed per month for all test vehicles is shown in Table 4. A summary of engine hours per month for all test vehicles is shown in Table 5. A summary of the average monthly fuel economy in gallons per engine operating hour (gal/hr) for all test vehicles is shown in Table 6 below.

	Conv 1 (gal)	Conv 2 (gal)	Conv 3 (gal)	Conv 4 (gal)	Conv 5 (gal)	Conv 6 (gal)	Off-road HEV (gal)	On-road HEV (gal)
May-11	385.5	365.7	387.6	252.6	392.5	338.4	142.7	132.4
Jun-11	309.9	272.6	326.1	249.1	269	223	172.5	111
Jul-11	157	197.9	287	210.6	211.8	205	99	103
Aug-11	208	174	220	180	275.6	198	58	243
Sep-11	166	197	218	222	207	177	NA	86
Oct-11	119	180	97	198	194	155	139	NA
Nov-11	249	263	194	293	286	286	189	NA
Dec-11	204	196	180	259	463	385	59	NA
Jan-12	241	267	132	366	503	331	134	111
Feb-12	376	386	401	416	496	390	188	216
Mar-12	169	216	154	328	457	377	137	102
Apr-12	307	330	385	392	362	319	189	131
May-12	261	205	164	217	294.3	211	89	186
Jun-12	218	177	184	231	178	133	350	NA
Total	3370.4	3427.2	3329.7	3814.3	4589.2	3728.4	1946.2	1421.4
Average	240.7	244.8	237.8	272.5	327.8	266.3	149.7	142.1

Table 4: Summary of gallons of fuel used per month

	Conv 1 (hr)	Conv 2 (hr)	Conv 3 (hr)	Conv 4 (hr)	Conv 5 (hr)	Conv 6 (hr)	Off-road HEV (hr)	On-road HEV (hr)
May-11	311	303	335	164	389	396	164	100
Jun-11	286	274	290	328	222	291	152	87
Jul-11	224	240	286	274	244	276	64	70
Aug-11	320	264	372	338	374	379	106	270
Sep-11	288	304	275	341	356	304	NA	149
Oct-11	247	259	143	324	292	327	164	NA
Nov-11	212	246	239	242	312	303	158	NA
Dec-11	252	254	303	350	301	332	46	NA
Jan-12	246	246	150	290	293	298	245	132
Feb-12	277	266	259	360	329	311	226	139
Mar-12	203	231	150	308	289	304	155	48

Apr-12	280	276	329	352	270	300	219	89
May-12	267	263	259	234	296	278	172	137
Jun-12	155	250	276	264	182	187	374	NA
Total	3568	3676	3666	4169	4149	4286	2245	1221
Average/ month	254.9	262.6	261.9	297.8	296.4	306.1	172.7	122.1

Table 5: Summary of engine hours per month

	Conv 1 (gal/hr)	Conv 2 (gal/hr)	Conv 3 (gal/hr)	Conv 4 (gal/hr)	Conv 5 (gal/hr)	Conv 6 (gal/hr)	Off-road HEV (gal/hr)	On-road HEV (gal/hr)
May-11	1.24	1.21	1.16	1.54	1.01	0.85	0.87	1.32
Jun-11	1.08	0.99	1.12	0.76	1.21	0.77	1.13	1.28
Jul-11	0.70	0.82	1.00	0.77	0.87	0.74	1.55	1.47
Aug-11	0.65	0.66	0.59	0.53	0.74	0.52	0.55	0.90
Sep-11	0.58	0.65	0.79	0.65	0.58	0.58	NA	0.58
Oct-11	0.48	0.69	0.68	0.61	0.66	0.47	0.85	NA
Nov-11	1.17	1.07	0.81	1.21	0.92	0.94	1.20	NA
Dec-11	0.81	0.77	0.59	0.74	1.54	1.16	1.28	NA
Jan-12	0.98	1.09	0.88	1.26	1.72	1.11	0.55	0.84
Feb-12	1.36	1.45	1.55	1.16	1.51	1.25	0.83	1.55
Mar-12	0.83	0.94	1.03	1.06	1.58	1.24	0.88	2.13
Apr-12	1.10	1.20	1.17	1.11	1.34	1.06	0.86	1.47
May-12	0.98	0.78	0.63	0.93	0.99	0.76	0.52	1.36
Jun-12	1.41	0.71	0.67	0.88	0.98	0.71	0.94	NA
Average	0.94	0.93	0.91	0.91	1.11	0.87	0.87	1.16

Table 6: Gallons of average fuel consumption rate (gallons/hour) per month

4.1.2 Discussion

Fuel economy calculations were based on the cumulative gallons of fuel and engine hours of the test vehicles based on fueling logs provided by NYCT. It should be noted that the engine hours and fuel consumption can vary considerably from vehicle to vehicle due to a number of variables. Independent of fuel type, fuel consumption is affected significantly by the actual duty cycle and engine loads experienced by the vehicle as well as the operator's driving style.

For this demonstration project, the hybrid off-road yard hostler will be the only hybrid yard hostler used in this evaluation as the on-road hybrid yard hostler has a different engine compared to the diesel yard hostlers and because it saw extended period of time where was not operational due to vehicle issues.

The cumulative average fuel consumption rate of the diesel delivery trucks is 0.95gal/hr. With the fuel consumption rate of the hybrid off-road yard hostler at 0.87gal/hr, this resulted in an improvement of 8% for the hybrid off-road yard hostler.

4.1.3 Data Collection Issues

The fueling logs provided by NYCT included, Issues regarding the reliability and accuracy of the raw fuel economy data collected for both the diesel and hybrid yard hostlers, included instances of missing or obviously inaccurate data discovered in the fueling logs over the course of the fourteen-month performance testing period. CALSTART employees reviewed the data from the fuel logs and found a number of errors. For example, the fuel logs would show entries where an extremely high amount of fuel was dispensed on one vehicle, which was not feasible. The following entry would show an entry of a negative number for the fuel dispensed where combined with the previous entry, would so the actual amount of fuel used. However, CALSTART staff found that these erroneous entries were not consistent and additional variables may be involved to be used in the calculation. Therefore, those entries were removed from the calculations. In addition, CALSTART found a number of entries where the results showed extremely high or low fuel consumption rates that fell outside of the acceptable range for the data and were also removed. In addition, vehicle issues on the on-road hybrid yard hostler attributed to errors in the data which resulted in faulty data. As these issues were identified during analysis of the data, and were subsequently corrected, therefore providing a reasonably accurate and useful picture of the hybrid yard hostlers used in this demonstration.

4.2 Operator Acceptance

To assess the drivers' impressions of the performance of the hybrid yard hostlers during in-use operations compared to typical diesel yard hostlers, written surveys were distributed to and completed by drivers of the hybrid yard hostlers.

A one-page hybrid yard hostler driver survey was used identical to the driver survey previously developed a similar project conducted at the Port of Long Beach in 2011. The survey questions covered key vehicle performance areas and other characteristics of the vehicle that would directly affect the driver. The survey contained a total of 14 questions and a section for drivers to record additional comments. Due to the subjective nature of driver impressions, a simple, relative rating scheme of "better," "same" or "worse" was used to compare hybrid yard hostler performance characteristics to those of a typical diesel yard hostler. The driver survey is included in Appendix A.

The specific areas covered by the Hybrid Yard Hostler Driver Survey questions included:

- Maneuverability
- Pulling power
- Acceleration
- Shifting
- Steering
- In-cab visibility
- Ride comfort
- In-cab controls
- Braking
- Interior noise level
- Exterior noise level
- HVAC system
- Cab entry and exit

- Overall vehicle rating
- Additional comments

Results

A summary of hybrid yard hostler driver survey results is provided in Table X. Only 2 surveys were provided by NYCT. Results for each of the fourteen items in the survey are shown below as the surveys showed identical results.

Hybrid Yard Hostler Performance Characteristic	***Results***
1. Maneuverability for connection to chassis	Same
2. Pulling power with full container	Worse
3. Acceleration with no container	Same
4. Smoothness of shifting under acceleration	Worse
5. Steering (turning radius, ease of parking, negotiating tight places and steering effort)	Worse
6. In-cab visibility (no blind spots, rear view)	Same
7. Ride comfort (vibration and shocks, feel of seat)	Same
8. In-cab controls (convenience & functioning of switches, controls, etc.)	Same
9. Braking (stops load quickly and smoothly)	NA
10. Interior noise level	Better
11. Exterior noise level	Better
12. HVAC system (heating, ventilation, A/C)	NA
13. Cab entry and exit	Same
14. Overall vehicle rating	Worse

Based on the driver surveys, the drivers found the hybrid yard hostlers to be worse than the standard diesel conventional yard hostlers. While the responses were limited to only 2 drivers, both drivers felt the NYCT hybrid yard hostlers showed worse pulling power with load, smoothness of shifting and steering. In addition, comments from the surveys showed the drivers did not like the short idle time before engine shut off, which caused problems when the hybrid vehicles are in the queue when waiting to accept containers. Only interior and exterior noise levels of the hybrids were seen as an improvement over the conventional yard hostlers.

4.3 Service and Maintenance

To assess the reliability, maintainability and serviceability of the hybrid yard hostlers compared to typical diesel yard hostlers, NYCT mechanics were asked to provide subjective feedback on various service and maintenance aspects of the hybrid yard hostlers compared to diesel yard hostlers. Surveys were distributed to mechanics to gather subjective feedback on serviceability and maintainability of the hybrid yard hostlers compared to diesel yard hostlers. NYCT maintenance staff also tracked vehicle maintenance events for the hybrid and baseline diesel yard hostlers. Vehicle service events during the performance test period and mechanics' responses in the surveys are summarized in this section.

4.3.1 Vehicle Maintenance Events

Typically, vehicle reliability is based off of vehicle availability. Vehicle availability is defined as the percentage of full days each month that a particular vehicle was available for service. Vehicles undergoing routine maintenance or being repaired were considered “unavailable” until they were put back into service. However, for this project, CALSTART team members were not able to extract the number of days the vehicles were unavailable from the work order provided. Therefore, this report will focus on the non-routine maintenance events to understand the areas where problems occurred on the vehicles. Table 7 shows a summary of maintenance events for the entire test fleet during the vehicle testing phase.

Table 7 – Summary of maintenance events for each vehicle

	CONV 1	CONV 2	CONV 3	CONV 4	CONV 5	CONV 6	Off-road HEV	On-road HEV
May-11	0	1	0	0	0	1	0	0
Jun-11	0	0	0	0	0	0	0	0
Jul-11	0	0	0	0	1	0	3	0
Aug-11	0	1	0	0	0	1	3	0
Sep-11	0	0	1	0	1	1	2	0
Oct-11	0	1	2	1	1	0	1	1
Nov-11	0	0	1	0	0	0	0	0
Dec-11	0	0	1	0	0	0	0	0
Jan-12	1	1	0	0	1	2	4	1
Feb-12	0	2	0	0	1	0	2	2
Mar-12	2	0	0	0	0	0	0	2
Apr-12	0	2	1	0	0	0	2	0
May-12	2	1	1	0	1	0	0	2
Jun-12	3	0	0	1	1	0	8	2
Total	**8**	**9**	**7**	**2**	**7**	**5**	**25**	**10**
Average	**6.3**						**17.5**	

Maintenance events in Table 6 includes all work performed on the vehicles during the 14-month performance test period. The maintenance events includes servicing issues relating to driver error, satisfy OSHA requirements, fixing broken parts found during standard inspection, and mechanical breakdowns on the vehicles. It should be noted that during discussions with NYCT and looking at the performance data, it was found that the hybrid yard hostlers were used less than the conventional and the lower usage rate should be considered. From the data, we find the conventional yard hostlers had an average of 6.3 maintenance events with the hybrids averaging 17.5 maintenance events. On a per month basis, the conventional yard hostlers saw an average of 0.45 maintenance event per month while the hybrids had an average of 1.25 maintenance events per month.

Upon further investigation, only one of the 38 maintenance events on the 6 conventional trucks was due to mechanical issues relating to the vehicle (exhaust leak). Majority of the service on the conventional hybrids were on fenders, headlights, wiper blades, and other repairs due to driver error or to satisfy safety requirements. The hybrids, on the other hand, had 12 maintenance events of 35 total events relating to issues relating to mechanical breakdowns. The mechanical breakdown events includes repairing or replacing blown fuses for the hybrid system, alternators, fan belts, exhaust components, steering column and two instances when the vehicle will not run. Overall the results showed the hybrids to be much more unreliable than the conventional yard hostlers, especially when looking at mechanical breakdowns.

4.3.2 Mechanics Survey

To evaluate the maintainability and serviceability of the hybrid vehicles compared to typical diesel yard hostlers, a survey was given to NYCT mechanics assigned to the yard hostlers at the end of the demonstration period. The survey contained a total of seven questions and a space for mechanics to record additional comments. For subjective questions, a rating scheme of 1 to 5 was used, 1 being “unacceptable” and 5 being “excellent”. A copy of the survey form distributed to mechanics is provided in Appendix B.

The NYCT maintenance staff completed the survey at the conclusion of the performance testing period. Two surveys were completed by NYCT maintenance staff based on their experience working with hybrid yard hostlers. In addition, a phone interview was conducted by CALSTART at the end of the project to gain additional information on the hybrid yard hostlers.

The specific areas covered by the survey included:

- Start-up problems (i.e. problems noted during the early phases of deployment)
- Hybrid systems and component training
- Design for maintainability
- Design for serviceability
- Quality of manufacturer support (OEM and Hybrid Drive System)
- Trends in service actions over the performance testing period
- Additional comments

A summary of hybrid mechanic survey results is provided below.

Question 1 of the survey was: *“Describe any hybrid yard hostler problems observed during the early part of the demonstration period that were subsequently corrected by the manufacturer.”*

Responses to Question 1 and explanations are summarized below:

“Drive Shaft coming loose”
According to NYCT maintenance staff, the drive shaft was found to be loose at times during the early part of the project. This was due to the driveshaft not being aligned with the hybrid drivetrain. US Hybrid provided support and specific procedures to secure the driveshaft and the issue was resolved.

“Water in connections”
Water was able to enter the areas where connectors between the motor, controllers, and battery box are located. This caused corrosion on the wires and was replaced.

"Needs a fail-safe system to shut down motor on drive shaft when pushing machine"
When issues with the motor arise causing the motor to malfunction, the nonfunctional motor cannot be disengaged from the driveline. This produces extra resistance on the driveline that causes the vehicle to

Questions 2 – 6 of the survey asked the mechanics to rate various maintenance and service characteristics of the hybrid yard hostlers on a scale of one to five where 1 was "unacceptable" and 5 was "excellent." An average of the two surveys scores are summarized below in Table 8.

Table 8 - Summary of hybrid Mechanic Survey Results for Questions 2 – 5

Hybrid Mechanic Survey Question	*Rating*
2. Hybrid systems and component training	1
3. Design for maintainability	4
4. Design for serviceability	3
5. Manufacturer support	4
6. Hybrid System Support	4

The mechanics surveyed gave the hybrid yard hostlers a rating of 1, or "unacceptable" when asked to rate the hybrid drive systems and component training. NYCT maintenance staff noted that they would like to have a formal class arranged for the service and maintenance of the hybrid yard hostlers.

For maintainability, serviceability and manufacturer support, the NYCT Maintenance staff gave an average rating of "acceptable" due to the similar design of the vehicles. The service work from US Hybrid was excellent but needed to travel from California which added delays to the repairs. In addition, while most of the service work was performed under warranty by US Hybrid, the NYCT staff found that replacing components was easy with the instructions provided by US Hybrid.

Question 7 of the survey was: *"Describe any trends observed regarding non-routine service actions associated with the hybrid yard hostlers including the long-term effectiveness of corrective actions"*

Responses to Question 7 (including the frequency of each response in parentheses) are summarized as follows:

"Shortage of parts resulted in increased number of days the vehicles are out of service."
The NYCT staff noted that there were two occurrences during the early part of the test period where US Hybrid did not have the parts on hand to quickly resolve the issues with the hybrid yard hostlers.

Question 8 of the survey provided a space for additional comments and is summarized below:

"Would like some type of training on operations and system functions and a wiring schematic for entire truck with hybrid system"
Again, the drivers felt that the training provided by US Hybrid was lacking and additional information is desired by the NYCT Staff.

5 Emissions Test

Emissions tests were planned for this project to assess the hybrid yard hostlers in a controlled test. However, due to unforeseen circumstances, the emissions test was removed from the program.

6 Business Case Assessment

Due to the omission of the chassis dynamometer test for this project, the following section of the report was derived from the POLB hybrid yard hostler final project, utilizing the fuel economy benefits determined from the POLB chassis dynamometer tests.

6.1 Introduction

This project developed and tested the few prototypes ever created of a diesel battery electric yard hostler in this configuration (parallel hybrid design), and so all business case conclusions must be considered preliminary. In addition, hybrid yard hostlers have only recently been offered as a standard commercial product by any of the major yard hostler original equipment manufacturers (OEMs). Kalmar has recently introduced a hydraulic hybrid yard truck, and Capacity has a Plug-in Hybrid Electric Terminal Tractor (PHETT), a series battery-electric vehicle.

Because much of the detailed cost and market information is considered confidential information by the project stakeholders, and in some cases, values are estimates of future costs at higher (production) volumes, since the costs for a first-of-its-kind prototype are not the same as actual costs when the vehicle becomes available for purchase.

Given these constraints, in this section of the report we will examine the major factors affecting the business case for hybrid yard hostlers and attempt to draw some general conclusions. Note also that the scope of this business case analysis will be limited to off-road yard hostlers (as opposed to on-road yard hostlers), which include the vast majority of yard hostlers used in port applications.

6.2 Vehicle Costs

For the vehicle costs, the main difference between the POLB project and the NYCT project is the cost of a baseline diesel yard hostler. Depending on the vehicle options (including engine configuration), a new diesel yard hostler purchased by NYCT costs around $95,000. For the purposes of this analysis, the average cost of a new diesel yard hostler is assumed to be approximately $95,000.

As previously stated, hybrid yard hostlers have only recently been offered as a commercial product. Incremental costs are not well known, but the costs for the prototypes in this test are known. Educated assumptions of future cost changes, based on volumes and technology improvements, can also be made. The cost of the hybrid components below were taken from the POLB report.

Item	Original proposal	Actual prototype	Production (2000 units/yr)

Base Yard Truck	$95,000	$95,000	$95,000
Electric Motor & Controller	$28,000	$28,000	--
Battery	$24,000	$14,000	--
Auxiliaries	$6,000	$7,000	--
TOTAL INCREMENTAL	$58,000	$49,000 (15.5% reduction)	$26,730 (54% reduction)
Percent Incremental	68%	58%	32%
COMPLETE TRUCK COST	$153,000	$144,000	$121,730

It should be noted that other recently released (production) hybrid yard hostlers, are have an approximate incremental cost of about 60% compared to conventional diesel yard hostlers. So, the prototypes in this test are reasonable and within the range of other prototypes that have gone into production.

6.3 Maintenance and Service Costs

The frequency of periodic maintenance for yard hostlers is based on both engine manufacturers' recommendations and the experience and maintenance strategy of individual fleet operators. In general, the maintenance intervals recommended by the engine manufacturer appear to correlate strongly with engine certification, i.e., whether the engine is off-road or on-road. Specifically, recommended maintenance intervals for off-road engines are about 40% shorter than the corresponding maintenance intervals for on-road engines. Therefore periodic maintenance costs for off-road engines would be expected to be approximately 40% higher than for on-road engines.

The hybrid yard hostlers use certified on-road engines and have similar recommended maintenance intervals to on-road diesel engines. Since the hybrid system components are designed to be 'maintenance free' the hybrid yard hostlers present no advantages or disadvantages compared to existing diesel yard hostlers with on-road engines. Therefore, periodic maintenance costs have been ignored in the business case analysis.

It is reasonable to assume that fleet operators will expect the same warranty for hybrid yard hostlers as diesel yard hostlers. Outside the warranty period, there are no major expected service expenses (e.g., an engine overhaul or replacement) for diesel yard hostlers during the average service life of the vehicle in the port application. (Note that the first owner of a yard hostler will typically sell the vehicle before an engine overhaul is required.)

A potential concern regarding service of the hybrid yard hostlers outside of the warranty period is the replacement cost of the major hybrid system components, in particular the batteries and electric motor(s). While there is insufficient data available on hybrid yard hostler service costs to make a comparison with diesel yard hostler service costs, general field experience with heavy-duty hybrid vehicles gives little evidence to suspect that the major hybrid system components will require more service than their diesel counterparts. For this reason, service costs have been ignored in the business case analysis.

6.4 Resale Value

Depending on the condition of the vehicle, diesel yard hostlers can have a resale value of anywhere between 5% and 50% of their original price. For port applications, older yard hostlers often show a lot of wear and reported resale values tend to be on the low end of this range, typically between $3,000 and $7,000. For the purposes of this analysis, we will use the "worst case" of 5% retained value. It is not expected that hybrid yard hostlers, which share many components with conventional hostlers, will have significantly different resale values.

In actuality, the business case analysis shows that the relatively low resale value for yard hostlers means this factor ultimately has very little impact on the life cycle costs for these vehicles.

6.5 Simplified Life Cycle Cost Analysis

Looking at the data during the 14-month performance testing phase, the conventional yard hostlers averaged 265 gallons of fuel used per month. This amounts of an average of 3180 gallons of fuel used per year. For this analysis, 3200 gallons of fuel per year will be used.

Based on the data and assumptions given above, we can construct a simplified life cycle cost (LCC) model for the hybrid and diesel yard hostlers by focusing solely on initial vehicle cost, fuel costs and resale value and ignoring all costs which are unknown, insignificant or are not expected to vary significantly between diesel and hybrid yard hostlers. The business case was also developed based on production values provided by US Hybrid at 2000 units per year. In addition, it should be noted that the fuel economy data was derived from the emissions test from the POLB project. The LCC analysis was performed by using a model developed by CALSTART. To help understand what is involved in LCC analysis, a simplified LCC equation is given below:

$$LCC = (\text{Initial Cost of Vehicle}) - \text{Purchase Incentives} + PV_{Fuel} - PV_{Resale}$$

where

Purchase Incentives = Value of Grants, Tax Credits, etc. Applied to Vehicle Purchase
PV_{Fuel} = Present Value of Fuel Expenses During Vehicle Service Life
PV_{Resale} = Present Value of Resale Value of Vehicle at End of Service Life
$PV = F_t /(1 + d)^t$
F_t = Future Cash Flow in Year t
d = Discount Rate

A summary of the LCC parameters associated with the business case for diesel vs. hybrid yard hostlers is shown in Table 11.

Table 1 - Summary of LCC Parameters for Yard Hostler Business Case

	Diesel	Hybrid
Initial Cost of Vehicle	95000	144000
Purchase Incentives	0	0
Fuel Cost/Gallon After Tax Credits	3.25	3.25
Gallons/Operating Hour	1.709775	1.46354*
Annual gallons of fuel used	3200	2750
Annual Fuel Costs	$10,400	$8,944
Service Life	10 Years	10 Years
Discount Rate	3%	3%
Resale Value	$4,250	$7,200
LCC	$182,238	$218,901

* NOTE: this value is based on the secondary analyses, as the in-use comparison data was not representative of the hybrid system performance due to the differential ratio issue. The lower value found in that analysis (14.4 gal/hour) is used for this LCA.

Lifecycle Cost Analysis - Results Based on Selected Technologies and Inputs			
	Conventional Vehicle	**Advanced Tech Vehicle**	***Savings***
Initial Cost	$95,000	$144,000	*($49,000.00)*
Fuel Economy (MPG)	1.710	1.464	*14.39%*
Per Vehicle LCC - Present Value	$182,238	$218,901	*($36,663)*
Avg Annual Fuel Usage (gallons)	3,200	2,752	*448*
Avg Annual Fuel Costs (2009 $)	$10,400	$8,944	*$1,456*

According to the model, the life cycle costs for diesel yard hostler is less than the hybrid yard hostlers by at $36,663 *without vehicle purchase incentives*. Assuming that vehicle fleet operators will accept payback on the incremental cost of the vehicle over the full service life of the vehicle, there will be a need for incentives in the purchase of these vehicles to offset the incremental cost involved with the addition of the hybrid drive system. Typically, fleet operators require a payback on their investments within two to three years which can be easily met if there are purchase incentives available.

In an interview with U.S. Hybrid, it was also noted that the cost of the hybrid system will also decrease with increased unit production. The following shows the hybrid system production unit price for the quantities noted.

- Quantity = 500; $38,313
- Quantity = 1,000; $29,727
- Quantity = 2,000; $26,730
- Quantity = 3,000; $23,409

Using the above cost values for a production quantity of 2,000 hybrid drive systems, the LCC becomes even more attractive but purchase incentives will still be necessary to offset the increased cost of the hybrid system as the LCC of the hybrid will still be more by around $15,000

Lifecycle Cost Analysis - Results Based on Selected Technologies and Inputs			
	Conventional Vehicle	**Advanced Tech Vehicle**	***Savings***
Initial Cost	$95,000	$121,730	*($26,730.00)*
Fuel Economy (MPG)	1.710	1.464	*14.39%*
Per Vehicle LCC - Present Value	$182,238	$197,460	*($15,222)*
Avg Annual Fuel Usage (gallons)	3,200	2,752	*448*
Avg Annual Fuel Costs (2009 $)	$10,400	$8,944	*$1,456*

7 Summary of Findings

- Battery Electric Yard Hostlers can perform all the tasks required of a yard hostler in real world use, but the hybrid yard hostlers were not liked by the NYCT drivers due to poor performance characteristics and short idling time before engine shut-off
- Reliability of the hybrid yard hostlers would need to greatly improve before moving into production.
- Fuel savings at around 8% was found during the 14 month performance test.
- Additional development work is needed to improve the system software and controllers before production-ready designs are complete. Improvements based on duty-cycle understanding and real-world driver behavior are needed, in order to provide increased fuel and emissions savings.
- With the current pricing and assumptions used in the life cycle cost analysis, incentives are necessary to make the business case viable, given the levels of performance delivered by the prototypes. At production volumes, about $15,000 per vehicle in incentives or buy-down would be needed to make the business case, based on the assumptions used here.

APPENDIX A Driver Survey

Hybrid Yard Hostler Driver Survey

Dates of Operation: ________________________

Equipment ID: ________________________

Applicable Shifts Hybrid Yard Hostler Driven by Operator (circle all that apply):

Day Shift: Sun. Mon. Tues. Wed. Thurs. Fri. Sat.

2nd Shift: Sun. Mon. Tues. Wed. Thurs. Fri. Sat.

Assignment (circle all that apply): Ship Dock Rail N/A

Rate the hybrid yard hostler performance compared to typical diesel yard hostlers at LBCT.	*Better*	*Same*	*Worse*	Comments
15. Maneuverability for connection to chassis				
16. Pulling power with full container				
17. Acceleration with no container				
18. Smoothness of shifting under acceleration				
19. Steering (turning radius, ease of parking, negotiating tight places and steering effort)				
20. In-cab visibility (no blind spots, rear view)				
21. Ride comfort (vibration and shocks, feel of seat)				
22. In-cab controls (convenience and functioning of switches, controls, etc.)				
23. Braking (stops load quickly and smoothly)				
24. Interior noise level				
25. Exterior noise level				
26. HVAC system (heating, ventilation, A/C)				
27. Cab entry and exit				
28. Overall vehicle rating				

29. Any problems with the hybrid drive system (e.g. faults, shutdowns)? Yes No
    If yes, explain. ____

Comments: ____

____

APPENDIX B Mechanic Survey

Hybrid Yard Hostler Mechanic Survey

Mechanic: ____________________

Date: ____________________

Purpose: To solicit maintenance and service personnel feedback on the hybrid yard hostlers compared to conventional diesel yard hostlers.

1. Describe any hybrid yard hostler problems observed during the early part of the demonstration period that were subsequently corrected by the manufacturer:

   ____

   ____

   ____

   ____

Please rate the following issues related to hybrid yard hostler maintenance and service on a scale of 1 to 5 where 1 means unacceptable and 5 means excellent (circle the appropriate number):

	Unacceptable				*Excellent*
2. Hybrid Systems and Component Training:	1	2	3	4	5
3. Design for Maintainability:	1	2	3	4	5
4. Design for Serviceability:	1	2	3	4	5
5. Vehicle Manufacturer Support:	1	2	3	4	5
6. Hybrid System Manufacturer Support:	1	2	3	4	5

7. Describe any trends observed regarding non-routine service actions associated with the hybrid yard hostlers including the long-term effectiveness of corrective actions:

   ____

   ____

   ____

8. Additional Comments:

____

____

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