Summary Report: Supplemental Demonstration to Calstart's "Hybrid Yard Hostler Demonstration and Commercialization Project"

Prepared for
Port of Long Beach
Port of Los Angeles

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1 Introduction

In September 2006, the United States Environmental Protection Agency's (EPA) West Coast Diesel Collaborative awarded a grant to the Port of Long Beach to fund the design and development of diesel-electric hybrid technology for yard hostlers.. Through a competitive bid process, the ports selected US Hybrid to design and develop the hybrid drive system. The project team, led by the Port of Long Beach, included the Port of Los Angeles, Long Beach Container Terminal, Inc., Kalmar Industries, and US Hybrid. Calstart provided technical management of the project.

The goals of the demonstration project were to assess the fuel economy and emissions of the hybrid yard hostlers during in-use operations at a port container terminal. In 2010, three hybrid yard hostler prototypes entered a six-month demonstration conducted at Long Beach Container Terminal in the Port of Long Beach. The demonstration included in-use monitoring and assessment of hybrid tractors compared to conventional diesel yard hostlers performing ship, rail, and yard work. Supplemental emissions testing was also performed at UC Riverside's CE-CERT laboratory[1] using a yard hostler duty cycle developed by West Virginia University. In addition to performance and emissions testing, the project team conducted a business case analysis for commercial use of hybrid yard hostlers. The business case analysis was based on the chassis dynamometer testing results rather than the in-use fuel economy data, as a difference in rear-axle differential ratios between the hybrid and diesel vehicles did not allow a direct in-use fuel economy comparison.

Results from the initial demonstration conducted in 2010 were mixed. Fuel economy improvements from the hybrid system were negligible or difficult to discern, both from the terminal fuel logs and initial emissions tests. According to the in-use fuel data, the hybrid yard hostler performing ship work demonstrated no fuel benefit or penalty over its diesel counterpart, whereas the hybrid yard hostlers performing rail work and yard work showed a fuel penalty and improvement of approximately 14% and 4% over their diesel counterparts, respectively. During preparation of the hybrid yard hostlers for testing on the chassis dynamometer, UCR learned that the prototype hybrid yard hostlers were limited by U.S. Hybrid to a maximum speed of 18.5 miles per hour (mph), while the peak speed for medium- heavy and heavy- heavy loads were 27 mph and 23 mph, respectively. As a result, the duty cycle developed by West Virginia University had to be modified at a peak speed of 18.5 mph. The chassis dynamometer testing indicated that emission rates generated by the hybrid yard hostler using the modified transient cycle were similar to the emission rates generated using the original transient cycle developed by West Virginia University. Emissions testing indicated 3% to 7% reductions in NOx compared to the conventional diesel yard hostlers. Following the emissions testing performed in 2010, US Hybrid modified the hybrid system in an attempt to improve the vehicles' performance and fuel economy. Subsequent chassis dynamometer testing indicated that modifications to the hybrid system significantly improved the fuel economy of the hybrid yard hostlers. Because the modifications were made towards the end of the original demonstration period, there was no opportunity to verify the improvements through in-use monitoring at LBCT under the original demonstration program.

[1] Center for Environmental Research and Technology (CE-CERT) www.cert.ucr.edu

To assess the potential fuel economy performance of the modified hybrid yard hostlers, the ports, US Hybrid, and LBCT agreed to a limited follow-up demonstration of the yard hostlers for the remainder of their one-year lease from February through June 2011. The ports engaged Tetra Tech and TIAX to monitor this limited demonstration and analyze fuel economy data collected during the demonstration period.

Figure 1. U.S. Hybrid Yard hostler operating at Long Beach Container Terminal

2 Background

Terminal operators at the Port of Los Angeles and Port of Long Beach currently operate more than 1,500 yard hostlers[2] in three service types: ship, rail, and yard service. Ship service consists of the transport of containers between a ship and the container stacks inside the terminal. Rail service is similar to ship service except that containers are transferred to and from rail cars. Yard service (also called dock work) involves moving containers between stacks or to/from loading areas for drayage trucks.

Of the three services, ship service is the most consistent at LBCT. Drivers work fixed shift durations and travel a relatively consistent path within the yard. Rail service drivers, in contrast, end their shift as soon as they have completed loading or unloading the rail cars. Therefore rail

[2] *San Pedro Bay Ports Clean Air Action Plan 2010 Update*, Appendix A, 2010

service tends to be conducted at a faster pace than ship service (higher average vehicle speeds). The amount of yard service fluctuates greatly from month to month and is generally much less in terms of vehicle operating time compared ship and rail services.

For the majority of the demonstration period, LBCT had use of only one US Hybrid yard hostler. Based on the consistency of ship service relative to the other two service types, LBCT elected to use the US Hybrid yard hostler in ship service. This had the positive effect of producing the greatest amount of vehicle operation and fuel consumption data possible, relative to the other two service types. Late in the demonstration, a second US Hybrid unit was made available to LBCT and this unit was placed into rail service. The configuration of the hybrid power trains for both of the US Hybrid units differed from each other and the hybrid units tested in the previous demonstration, as discussed below.

The US Hybrid yard hostler consists of a standard Kalmar® Ottawa yard hostler augmented by a parallel hybrid-electric power train as shown in Figure 2. The electric motor is installed between the transmission and rear differential, allowing the tractor to be propelled by the diesel engine, electric motor, or a combination of both the diesel and electric systems. This configuration offers the potential for fuel economy savings by allowing the diesel engine to be shut down during idle and creep[3] operation. As previously noted, US Hybrid modified certain portions of the hybrid system to address the lack of fuel economy improvements seen in the previous demonstration. In particular, US Hybrid altered the battery management algorithm, hybrid control algorithm, idle management strategy, and increased the capacity of the traction battery. These modifications resulted in a Generation 1.1 configuration. Near the end of the current demonstration, US Hybrid provided a second unit to LBCT that incorporated several additional modifications, including changes to the transmission control algorithm, electric motor, and motor control unit. This configuration is referred to as Generation 2.0. Specifications for the baseline diesel tractors and all three generations of the hybrid tractors are provided in Table 1.

[3] Creep operation is characterized by brief periods of acceleration and deceleration separated by long periods of idle. This is often referred to as stop-and-go operation.

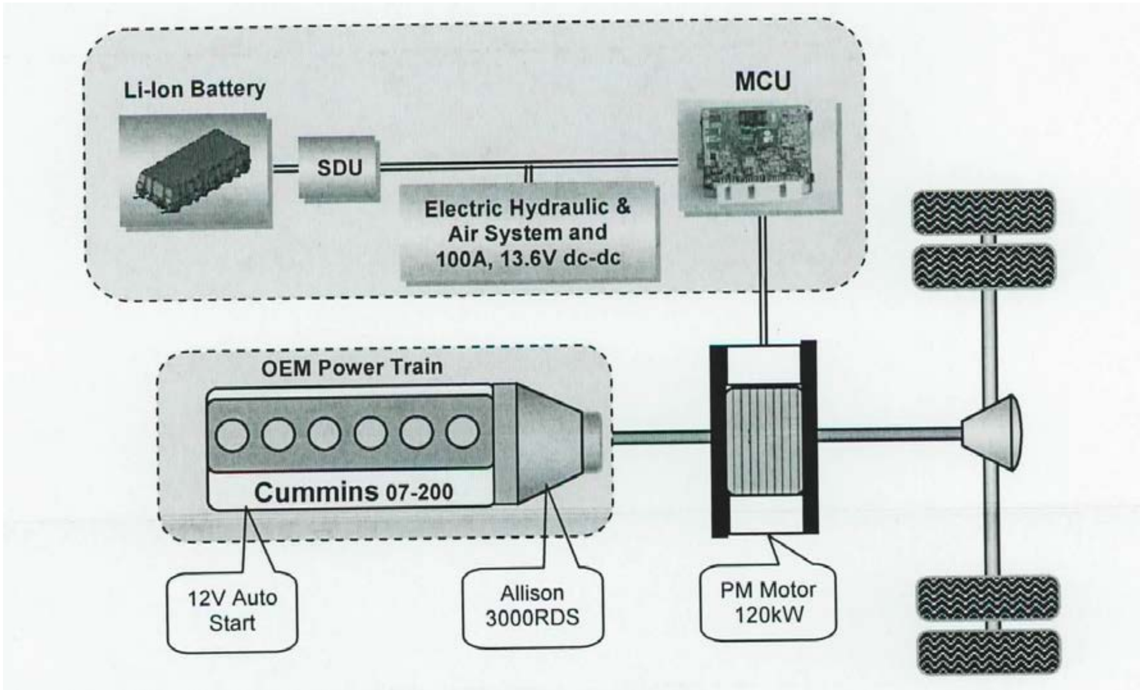

Figure 2. US Hybrid yard hostler powertrain

Table 1. Summary of yard hostler configurations

Parameter	Diesel Baseline	Hybrid Generation 1	Hybrid Generation 1.1	Hybrid Generation 2.0
UTR Numbers	180,159,172	02, 03, 04	03	04
Engine	Cummins ISB 6.7L, 240 HP	Cummins ISB 6.7L, 200 HP	Cummins ISB 6.7L, 200 HP	Cummins ISB 6.7L, 200 HP
Emissions Standard	2007 On-road	2007 On-road	2007 On-road	2007 On-road
Electric Motor	N/A	120 kW	120 kW	120 kW
Battery Pack	N/A	2.3 kW-hr Li-Ion	2.3 kW-hr Li-Ion	2.8 kW-hr Li-Ion
Rear axle ratio	10.62:1	12.28:1	12.28:1	12.28:1
Modifications from previous "Generation"	N/A	N/A	1. Modified battery Energy algorithm. 2. Modified the Hybrid control algorithm to better fit the drive cycle. 3. Modified the idle control strategy.	1. Designed a new motor that fits the 12.28:1 ratio and provide high speed operation. 2. Modified transmission control algorithm 3. Modified electric motor control unit to increase the torque

3 Yard Hostler In-Use Performance Data

The primary focus of the supplemental demonstration program is to assess any changes in fuel economy and/or reliability of the Generation 1.1 hybrid yard hostler compared to the first generation hybrid tractor tested in the original demonstration conducted in 2010. As such, no changes were made to the method of collecting fuel consumption data or maintenance logs for the current demonstration. Fuel logs were recorded by terminal personnel during each refueling event. These logs include the date, total fuel dispensed, and the tractor's current hour meter reading. In addition, electronic data were recorded for the hybrid tractors through a data acquisition system integrated into the hybrid power electronics. Maintenance logs were to be kept by LBCT, however, no routine maintenance was performed on the hybrid tractors during the demonstration period due to their low accumulated hours of operation.

Fuel logs were collected for three diesel tractors operating in ship, rail, and yard service. Additionally, fuel logs were collected for two hybrid units. A single hybrid unit operated primarily in ship service for the duration of the demonstration period and represents the majority of hybrid fuel consumption data. A second hybrid unit was placed into rail service approximately one month prior to the end of the demonstration and represents the remainder of hybrid fuel consumption data collected during the demonstration. Table 2 summarizes the data collected from the fuel logs for each tractor described above. Comparisons of the fuel consumption data between the hybrid and diesel units in rail service should be made with caution, as the hybrid unit only accumulated approximately 10% of the operating time and fuel use data compared to the baseline diesel unit.

Table 2. Summary of Collected Fuel Consumption and Vehicle Use Data

Service	Ship		Rail	
UTR	**Hybrid 03**	**Diesel 180**	**Hybrid 04**	**Diesel 159**
Gallons	590	976	106	817
Hours	325	555	53	504
Average Fuel Use (Gallons/Hour)	1.82	1.76	2.00	1.62

Based on the data presented in Table 2, the hybrid units showed no fuel economy improvement over their diesel counterparts. The hybrid unit in ship service showed nearly identical fuel consumption rates as the baseline diesel unit. Fuel consumption data for rail service suggests a possible fuel economy penalty associated with the hybrid system. However, the relatively limited fuel consumption data for the hybrid unit prevents an accurate comparison. An inspection of fuel consumption data for UTR 159 shows that fuel use rates vary by as much as 20% month to month. As the data for UTR 04 only represents a month of sporadic usage (a total of seven days of use), the differences in fuel economy between the baseline and hybrid units in rail service cannot be accurately quantified.

TIAX compared the current fuel consumption data to the results of the previous demonstration, as shown in Table 3. Fuel consumption results from the previous demonstration, as reported by Calstart, are included in the table. TIAX also reviewed the fuel logs from the previous demonstration and identified several data points that were influenced by errors in the data collection process. In particular, some fueling events appear to have been inadvertently omitted from the fuel logs. These errors exist in fuel logs collected during both demonstration periods and are likely a result of terminal personnel simply forgetting to complete a fuel log. The errors are detectable by identifying data points with excessively low fuel consumption rates. Additional errors exist in the fuel logs as improperly recorded data points ("typos"). These erroneous data points often result in excessively high fuel consumption rates, typically five to ten times higher than the average fuel consumption rate. When erroneous data points were identified, the data were removed from the data set. Corrections to the data sets for the previous demonstration and current demonstration were made and the resulting fuel consumption rates are shown in Table 3. These corrections typically resulted in only minor adjustments to the data reported by Calstart.

Table 3. Comparison of Recorded Fuel Consumption Rates Between the Current and Previous Demonstration, (gallons per hour)

Service	Ship		Rail		Yard	
UTR	**Diesel**	**Hybrid**	**Diesel**	**Hybrid**	**Diesel**	**Hybrid**
Fuel Rate Current Demonstration	1.76	1.82	1.62	2.00	1.87	N/A
Adjusted Fuel Rate Previous Demonstration	1.85	1.80	1.89	2.38	2.43	2.29
Reported Fuel Rate Previous Demonstration	1.90	1.90	1.99	2.27	2.40	2.31

Table 3 shows that fuel consumption rates for ship service were relatively consistent between demonstration periods. Rail and yard services show significantly lower fuel consumption rates for the current demonstration period compared to the previous demonstration. This may be partly influenced by a reconfiguration of the LBCT terminal that altered the location of container chasses.

U.S. Hybrid has equipped the hybrid yard hostlers used in the demonstrations with a data acquisition system known as iDrive. The iDrive system records several parameters including engine data, battery data, fuel use, and vehicle operating time. A similar system is not present on the baseline diesel tractors; therefore, iDrive data can only be compared between U.S. Hybrid units. Table 4 summarizes the iDrive data for the two hybrid yard hostlers utilized in the current demonstration. Data for UTR 01 and UTR 02, collected during the previous demonstration period, are also presented. Note that UTR 01 was modified, incorporating Generation 1.1 modifications, and rebadged as UTR 03. Similarly, UTR 02 was modified to incorporate Generation 2.0 changes and rebadged as UTR 04.

As shown by the last two columns of Table 4, the iDrive data consistently reported a lower fuel consumption rate than what was reported by the paper fuel logs. Comparing the iDrive data between UTR 01 and 03 in ship service, the average fuel economy for UTR 03 is nearly identical to UTR 01 (1.63 GPH and 1.58 GPH, respectively). The consistence of the paper fuel logs and the iDrive data support the conclusion that no significant improvement in fuel economy was achieved by either the Generation 1.0 or Generation 1.1 hybrids in ship service. Conclusions regarding rail service or the benefits of the Generation 2.0 hybrid are not drawn as the data is too sparse to average out short term fluctuations in fuel consumption rates.

Table 4. Summary of iDrive data for U.S. Hybrid Yard Hostlers

UTR	Date Range	Service	Power Cycles w/ Fuel Use	Fuel Consumed (gallons)	Operating Time (hours)	Avg Fuel Rate (GPH)	Paper Log Fuel Rate (GPH)
03	May 9, 2011- June 12, 2011	Ship	143	130	88	1.48	1.78
03	April 10, 2011- May 1,2011	Ship	108	190	115	1.66	1.72
03	Jan 31, 2011- April 9, 2011	Ship	280	434	261	1.66	1.84

03	Total	Ship	531	754	464	1.63	1.80*
01	June-Nov 2010	Ship	1,102	1,217	770	1.58	1.8
04	May 9, 2011-June 12, 2011	Rail	91	66	37	1.78	2.08
03	May 1, 2011-May 8, 2011	Rail	40	59	35	1.70	1.84
02	June-Nov 2010	Rail	190	314	148	2.12	2.38

Denotes data from previous demonstration

Notes: * Indicates a weighted average of data in each date range, based on fuel consumption
UTR 03 is UTR 01 with generation 1.1 upgrades
UTR 04 is UTR 02 with Generation 2.0 upgrades.

4 Summary

In 2010, Long Beach Container Terminal and U.S Hybrid conducted a six-month demonstration of three hybrid yard hostlers. The results of that demonstration indicated that the hybrid drive system design would need refinement to improve the yard hostlers' fuel economy over the baseline diesel tractors. Since the conclusion of the original demonstration, US Hybrid placed two new generations of hybrid yard hostlers into service at LBCT. From February to June 2011, LBCT collected additional fuel consumption data for the modified hybrid tractors and provided these records to TIAX for analysis. The results of the analysis support the following conclusions:

1. The Generation 1.1 yard hostler placed into ship service at LBCT did not demonstrate significantly different fuel economy compared to either the baseline yard hostler or the Generation 1.0 hybrid yard hostler tested during the previous demonstration.
2. Because the Generation 2.0 yard hostler was placed into service close to the end of the demonstration period, there was insufficient fuel consumption data collected to make any conclusions regarding its fuel economy.
3. Generation 2.0 yard hostlers have been redesigned to address the fuel economy performance issues encountered in the previous demonstration. The consistency of fuel consumption data and the high level of use of tractors in ship service make this the preferred service to demonstrate the Generation 2.0 or future generation hybrid yard hostlers.