Pluggable Hybrid Electric Terminal Tractor (PHETT™) Demonstration at the Port of Long Beach

Technical Report: Duty Cycle and Emissions Estimates

Prepared for
The Port of Long Beach
925 Harbor Plaza
P.O. Box 570
Long Beach, CA 90801

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Prepared by
Patrick Couch
Wendy Bockholt
Jon Leonard

TIAX LLC
1 Park Plaza
6th Floor
Irvine, California 92614
Tel 949-833-7130
Fax 949-833-7134

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Executive Summary

The Port of Long Beach, in conjunction with Capacity, PortsAmerica, and Hanjin terminal, conducted a three-week field trial of the Capacity PHETT™ at Pier T from June 8th to June 25th, 2009. The goal of this project was to evaluate the performance and emissions of the Capacity Pluggable Hybrid Electric Terminal Tractor (PHETT) in operation at the Port of Long Beach. Testing included an assessment of the PHETT's™ fuel economy; a characterization of its duty cycle and load factors; and a review of the host site personnel's opinions regarding operation and maintenance parameters.

This testing consisted of equipping the PHETT™ with a multi-channeled data logging system to first characterize the duty cycle of the PHETT™ by measuring its load factor. Using the collected data supplemented with information supplied by Capacity and Ports America, TIAX estimated the fuel economy of the PHETT™ and compared it to the baseline diesel fleet average fuel economy and emissions. Additionally, TIAX developed surveys to be completed by operators and maintenance personnel to assess the overall capability of the PHETT™.

Key findings in this report are:

- The load factor for the PHETT was determined by measuring the diesel generator output over the entire operating time of the PHETT. During the demonstration period, the PHETT load factor was calculated to be 0.58; equivalent to an average engine load of 23.3 horsepower.
- Based on the CARB OFFROAD 2007 methodology, the PHETT™ is expected to achieve:
    1. A 77% reduction in NOx and 82% reduction in PM compared to the baseline fleet (2002 levels).
    2. Emissions rates that are lower than a 2009 diesel yard tractor
- Fuel economy improvements were difficult to verify based on a lack of fueling logs but improvements were estimated to be in the range of 28% to 60% over the baseline fleet.
- Survey data from the operator and maintenance personnel involved with the PHETT demonstration were not available. Informal conversations with PortsAmerica personnel indicated no significant problems with the PHETT and comparable performance to diesel yard tractors.

1. Introduction / Test Program Objective

Terminal tractors (also known as utility tractor rigs, yard hostlers, drayage trucks, and yard goats) are categorized as cargo handling equipment[1] (CHE) -- one of five major types of diesel-powered equipment commonly used to move cargo at sea ports. Terminal tractors are primarily off-road vehicles that are specifically used to move cargo containers within and around terminals in three applications: 1) to and from cargo ships (ship work), 2) to and from cargo trains (rail work), and 3) within terminal yards (yard work).

Terminal tractors and other types of CHE are essential elements of the goods movement infrastructure. However, they also consume major volumes of diesel fuel and generate significant levels of harmful diesel emissions within the ports they serve. Development and deployment of low-emissions, high-efficiency terminal tractors (and other CHE) are high priorities for the Port of Long Beach under its Clean Air Action Plan.

In response to the need for environmentally friendly yard hostlers, Capacity of Texas, Inc. has developed and is now testing its Pluggable Hybrid Electric Terminal Tractor (PHETT™). According to Capacity, this diesel-electric hybrid terminal tractor (see Figure 1) is a "charge sustaining series hybrid that utilizes a constant and efficient rate generator to supply power, reducing fuel consumption by 60 percent and audible db by 30 percent."[2]

The Port of Long Beach, in conjunction with PortsAmerica and Hanjin terminal, conducted a three-week field trial of the PHETT™ at Pier T from June 8th to June 25th, 2009. The Port tasked TIAX with helping to plan and oversee this testing, with the objective of evaluating certain elements of the PHETT's™ performance. To the extent feasible under the budget, this evaluation was conducted relative to typical (baseline) conventional diesel-fueled terminal tractors manufactured by Capacity. The testing included an assessment of the PHETT's™ fuel economy; a characterization of its duty cycle and load factors; and a review of the host site personnel's opinions regarding operation and maintenance parameters.

[1] Other types of cargo handing equipment include cranes, top handlers, side handlers, forklifts and loaders.

[2] Capacity News Release. March 18, 2009. "Capacity Launches Pluggable Hybrid Electric Terminal Tractor"

Figure 1. PHETT™ at Pier T charging stall

2. Test Methodology

The PHETT™ is a diesel-electric plug-in hybrid terminal tractor that uses a small diesel generator and a large lead-acid battery pack to provide power for vehicle operation. Table 1 summarizes the PHETT's powertrain specifications. As a plug-in hybrid, the PHETT™ offers a modest all-electric range and higher overall efficiency, which can significantly reduce fuel consumption and emissions compared to a conventional diesel-fueled terminal tractor. To estimate these potential environmental benefits relative to the conventional (baseline) counterpart, TIAX developed a test plan. This consisted of equipping the PHETT™ with a multi-channeled data logging system to first characterize the duty cycle of the PHETT™ by measuring its load factor. Using the collected data supplemented with information supplied by Capacity and Ports America, TIAX was able to estimate the fuel economy of the PHETT™ and compare it to the baseline diesel fleet average fuel economy and emissions. Additionally, TIAX developed surveys to be completed by operators and maintenance personnel to assess the overall capability of the PHETT™. Note that due to the limited time of the demonstration, a direct comparison to the baseline fleet data that spans months or years of operation is difficult. Additional testing of the PHETT over several months, coupled with similar monitoring of comparable traditional diesel yard tractor will yield a much better "apples to apples" comparison.

Table 1. PHETT Powertrain Specifications

Feature	Details
Gross Combined Weight Rating	100,000 lbs
Hybrid Configuration	Charge sustaining
All-electric Operation	All electric operation while in battery mode
On-board generator	Cummins Onan diesel, 40 HP, Tier 4i emissions
Traction Motor	225 HP, 3 phase AC
Diesel Fuel Capacity	40 gallons
Battery Type	Lead acid

2.1 Duty Cycle and Load Factor

The California Air Resources Board (CARB) estimates emissions from off-road equipment through its OFFROAD model. To estimate emissions from a particular equipment group, such as yard tractors, the model makes certain assumptions about how the equipment is typically operated. An important parameter in the model is the equipment's load factor, which is defined as the "average operation level in a given application as a percent of the engine manufacturer's maximum horsepower rating."[3] In other words, load factor is the engine's average horsepower divided by its maximum horsepower.

In December, 2008, the Port of Long Beach and the Port of Los Angeles released the "San Pedro Bay Ports Yard Tractor Load Factor Study Addendum."[4] The purpose of the study addendum was to determine if the average load factors used by CARB reasonably represent the activity of conventional diesel ICE yard tractors at the Port of Long Beach and the Port of Los Angeles. The study determined that CARB's load factor of 65% is too high for yard tractors typically used at the two ports. A revised load factor of 39% was proposed and eventually approved by CARB.

To determine the load factor for a non-conventional yard tractor like the PHETT™, it is important to consider the operation of the series hybrid drive system with plug-in capability. To actuate the electric drive system, the PHETT™ can draw power simultaneously from the diesel generator and the energy stored in the batteries from grid charging. To remain consistent with CARB's definition of load factor, the energy produced by the diesel generator must be separated from the total energy used by the vehicle in operation. Using an AVIT data logging system from HEM Data (see section 3.2), TIAX collected operating data including information from the three on-board power inverters and the diesel generator. Data were collected over 14 days and analyzed to determine the relative contribution of the energy produced by the diesel generator to the total energy used by the PHETT over the course of the demonstration.

2.2 Fuel Economy

Determination of the fuel economy for the PHETT™ requires recording or estimating both the volume of diesel fuel consumed and the electrical energy used. Because terminal tractor operational parameters are generally measured in hours of operation rather than miles traveled, energy per hour is an appropriate measure of terminal tractor activity and allows comparison on a fuel-equivalent basis.

The total electrical energy available to the PHETT™ electric drive system consists of electrical energy produced by the diesel generator and the electrical energy taken from the grid during the battery recharging process. Total electrical energy available to the PHETT™ was determined from power measurements reported by the on-board electrical inverters. The portion of electrical energy produced by the diesel generator was subtracted from the total electrical energy used to determine the portion of electrical energy derived from the grid. This method was used as no direct measurement of grid supplied electrical energy is available from the charging station or the systems on-board the PHETT.

[3] California Air Resources Board, Technical Mailout MSC# 99-32, 1999

[4] San Pedro Bay Ports Yard Tractor Load Factor Study Addendum, Starcrest LLC, 2008

Diesel fuel use was anticipated to be tracked using the current terminal tractor refueling logs maintained for PortsAmerica's terminal tractor operations, and through the power output reported by the generator. However, fueling logs for the PHETT™ were not available to TIAX during the demonstration period. As a result, diesel fuel use was determined solely by the diesel generator load.

Vehicle operating time was ultimately determined from the data collected using the data logging system, monitoring the total time the vehicle's ignition voltage remained on (discussed further in Section 3.1).

2.3 Operator and Maintenance Personnel Acceptance

In addition to estimating the duty cycle and fuel economy of the PHETT™, an objective of this abbreviated testing program was to assess the overall capability of the PHETT™ in terminal service, and its acceptance by host fleet personnel compared to conventional diesel-fueled tractors. To make a fair comparison of fuel economy and emissions between the two technologies, the PHETT™ must be capable of performing the same work as a typical, comparable conventional terminal tractor. TIAX created two separate surveys to be completed by operators and maintenance personnel who worked with the PHETT™ during the demonstration. The surveys ask respondents to rate the PHETT™ in several key areas of design and performance as "Better, Same, or Worse" compared to a standard, comparable diesel terminal tractor. Additionally, the surveys provide a free-response section for additional comments. Copies of the surveys are provided in Appendix B.

3. Experimental Setup

3.1 PHETT™ Configuration

The PHETT™ operates as a series diesel-electric hybrid. In this configuration, all of the energy demands of the vehicle are supplied through the battery; regardless of whether the energy is stored in the battery by a grid-connected charger or the on-board diesel generator[5]. Given a fully charged battery, the PHETT™ will operate entirely from battery power, providing a limited “all-electric range” with zero tailpipe emissions. Once the battery has been depleted to a predetermined state of charge, the diesel generator will start and attempt to sustain the current level of charge in the battery.

There are three electrical inverters that are used to supply the vehicle subsystems with power. The inverters convert the DC voltage of the battery pack into AC voltage that is better suited to operate the numerous AC electrical motors in the PHETT™. The three electrical inverters are:

1. Traction Motor Inverter – provides power to the drive motor for propulsion. Nominally rated at 150 kW.

2. Hydraulics Inverter – provides power to the hydraulic pump. Hydraulics are used primarily for operation of the fifth wheel that connects to the container chassis. Nominally rated at 15 kW.

3. Cooling Fan Inverter – provides power to the cooling fan; used to dissipate heat from the inverters and other subsystems. Nominally rated at 1.5 kW.

Each of the above inverters can be monitored via an analog output signal that indicates the percentage of nominal power output of the inverter. Both the traction motor inverter and the hydraulics inverter supply a 0 to 10 VDC signal, while the cooling fan inverter supplies a 0 to 5 VDC signal (see in Table 2 below).

Additionally, several systems on the vehicle use a 12VDC auxiliary power supply. However, no means of measuring the load on this system was available. Therefore, a fixed power draw of 500 watts was estimated by Capacity and assumed to be constant while the vehicle was in use

Speed and load data for the generator were obtained from the J1939 bus. The J1939 standard defines a method of communication between the on-board vehicle controllers/computers. It is also used to send and receive data between the on-board

[5] Capacity uses the Cummins Onan 20HDKAW-2008A. Datasheet available at http://www.cumminsonan.com/www/pdf/specsheets/a-1538.pdf

controllers and external devices like the AVIT data logger. Because the PHETT™ is not an on-road vehicle, many of the J1939 parameters are unused by the PHETT™. Capacity engineers use parameter group number (PGN) 61450, normally reserved for the EGR mass flow rate under the J1939 specification, to report the generator load. Data is reported in percentage of full load. Generator speed is reported on PGN 61444 and is always zero or 1,800 RPM. This is because the generator is a synchronous 60 HZ motor and runs at a fixed speed of 1,800 RPM.

Because the hybrid system can run in a pure electric mode, it is not sufficient to monitor the generator speed to determine whether or not the vehicle is in use. To record when the vehicle was in use, the ignition system voltage was monitored. Specifically, certain accessory systems are only powered when the ignition switch is in the "Run" position. By monitoring when these systems are powered, the position of the key can be determined and, by extension, whether or not the vehicle was in operation. When the vehicle was in operation the parameters in Table 2 were recorded at a frequency of 1 Hz.

Table 2. Data logged signal types and ranges

Parameter	Physical Range	Signal Range	Signal Source
Traction Motor Power	0 to 150 kW (nominal)	0 to 10V	Analog output from inverter
Hydraulics Power	0 to 15 kW (nominal)	0 to 10V	Analog output from inverter
Cooling Fan Power	0 to 1.5 kW	0 to 5V	Analog output from inverter
Diesel Genset Power	0 to 20 kW (nominal)	0 to 100%	J1939 Bus - PGN 61450
Diesel Genset Speed	0 to 1800 RPM	0 to 14,400 (RPM x8)	J1939 Bus - PGN 61444
Ignition	0 to 12V	0 to 12 V	Analog signal from ignition powered line

3.2 Data Logging Equipment

To support this study, TIAX (on the Port's behalf) purchased a J1939 capable AVIT[6] data logger with analog inputs and the associated DAWN software package from HEM Data[7]. This allows a single data logger to record all of the parameters shown in Table 2. To interface the data logger to the vehicle and provide for long term data logging, several additional hardware changes were required and are shown in Figure 2. These changes included the following:

1. Addition of a 5 amp-hour rechargeable battery pack.

[6] http://www.drewtech.com/products/avit.html

[7] http://hemdata.com/products/dawn

2. 2:1 voltage divider networks to reduce the 0-10V inverter signals down to the 0-5V measurement range of the data logger.

3. Custom cable to interface the analog signal wires on the PHETT™ with the serial port connector on the data logger.

4. Extended J1939 cable to allow the logger to be appropriately positioned in the cab.

5. Hard case to protect the data logger during the extended field deployment.

6. Diodes to protect the logger and the vehicle from improper discharge of the battery pack.

Figure 2. AVIT Data Logger with Added Equipment

The data logger also includes a voltage input that will place the logger into a low power "sleep" mode when the voltage signal drops below a certain threshold. This input was connected to the vehicle ignition circuit so that the logger would enter sleep mode when the key to the vehicle was turned to the off position. The battery pack is required for proper operation of the logger because the logger will lose data if power is disconnected before it is sent a shutdown command.

3.3 Test Parameters

The test plan originally called for a two- to three-week demonstration period, during which time the PHETT™ would be operated by PortsAmerica in regular cargo handling service. It was anticipated that the test parameters listed in Table 3 would be recorded while the PHETT™ was in operation. At the conclusion of the demonstration period surveys were to be completed by operators and maintenance personnel, comparing the PHETT™ to the existing diesel fleet.

Table 3. Intended Test parameters

Test Parameter	Source	Purpose
Vehicle data	Data logger	Measure duty cycle, energy splits
Fuel use	Terminal fueling logs	Record total fuel consumption
Hours of operation	Terminal service/operations logs	Determine rate of fuel consumption
Maintenance incidents	Terminal service logs	Note hybrid specific issues

Unfortunately, detailed fuel use logs were not kept for the PHETT during the demonstration period. The short duration of the demonstration prevents less detailed reports of fuel consumption to provide an accurate assessment of the fuel use. As a result, the fuel use is inferred from diesel generator load, discussed further in Section 4.2.

4. Results

Data were recovered from the data logger twice during the demonstration period. TIAX inspected the data logger once while the demonstration was in progress and downloaded all available data. All remaining data were recovered at the end of the test when the data logger was removed from the PHETT™. In total, the data logger recorded 13.8 hours of operation (approximately 49,700 data points). The data set is shorter than expected due to a failure of the backup battery during the demonstration period, resulting in a loss of recorded data. However, the data set covers approximately half of the demonstration period and should provide a representative sample of the operation during the demonstration.

4.1 Duty Cycle and Load Factor Measurements

Power from each of the three inverters and the generator were recorded for each point in the data set. By totaling these data, an estimate for the total amount of energy collectively provided by the generator and the electrical grid can be calculated. In addition, the amount of energy used by the PHETT™ subsystems can be calculated. These calculations, including the relative percentages of the total energy production and consumption, are shown in Table 4.

Table 4. Energy production and consumption by subsystem

Subsystem	Total Energy (kilowatt-hours)	Percentage of Total
Grid-charged battery	167	45.6%
Diesel-fueled generator	199	54.4%
Total Generated	**366**	**100%**
Traction Motor	-330	90.2%
Hydraulics	-21	5.7%
Cooling	-8	2.2%
Accessory	-7	1.9%
Total Consumed	**-366**	**100%**

Once the energy produced by the generator is known, the average load on the generator can be calculated from the following equation:

$$EngineLoad_{Average} = \frac{E_{gen}}{T_{operation}} * \frac{1}{\eta_{electric}}$$

Figure 3. Equation to calculate Average Engine Load

Where:
$EngineLoad_{Average}$ is the average engine load in kW
E_{gen} is the total energy produced by the diesel generator
$T_{operation}$ is the total time the vehicle was operating (i.e. ignition-on)
$\eta_{electric}$ is the mechanical-to-electrical conversion efficiency of the diesel generator's alternator.

The total energy produced by the generator is taken as 366 kW-hours from Table 4 above. Using a total vehicle operating time of 13.80 hours and an estimated 83% alternator efficiency[8], the average engine load is 17.37 kW or 23.28 HP.

Once the average engine load is known, it is straightforward to calculate the load factor. As described in Section 2.1, load factor is determined by the following equation:

$$LoadFactor = \frac{Load_{Average}}{Load_{Maximum}}$$

Figure 4. Definition of Load Factor

The PHETT™'s diesel generator is rated for a maximum load of 40 HP. An average load of 23.28 HP results in a calculated load factor of 0.58.

Based on the collected data, it is also possible to determine the amount of time the PHETT™ operated in all-electric mode and charge-sustaining mode (generator operating). While the impact of all-electric operation on emissions is captured in the load factor, knowing the relative amount of time in all-electric mode may be of interest in future assessments of all-electric drayage truck designs. This information is summarized in Table 5 below.

Table 5. Summary of duty cycle and load factor data

Parameter	Units	Value	Notes
Vehicle Operating Time	Hours	13.80	Total ignition-on time
Generator Operating Time (Charge-sustaining)	Hours	10.79	Total time the generator operated
All-Electric Operating Time	Hours	3.01	Total Generator-off time
Charge-Sustaining Operation	%	78.2	
All-Electric Operation	%	21.8	
Average Generator Load (Generator-on Only)	kW	18.4	Average load based on time generator was running
Average Generator Load (Ignition-on)	kW	14.4	Average load based on total vehicle operating time
Load Factor	--	0.58	

The power levels required by the propulsion and hydraulic systems are shown in Figure 5 and Figure 6 below. From these histograms it can be determined that the PHETT™ required less than ten kilowatts of propulsive power for approximately 30% of its

[8] Estimate provided by Capacity engineers, based on conversations with Cummins.

operation. This includes idle, “coast” and deceleration and suggests that hybrid-electric drive of this type is well suited to yard tractor duty cycles. Note that no histogram is provided for the cooling system as it operated at a nearly constant 0.62 – 0.65 kW for 92% of the vehicle operating time. The remaining 8% of the time, the cooling system was off.

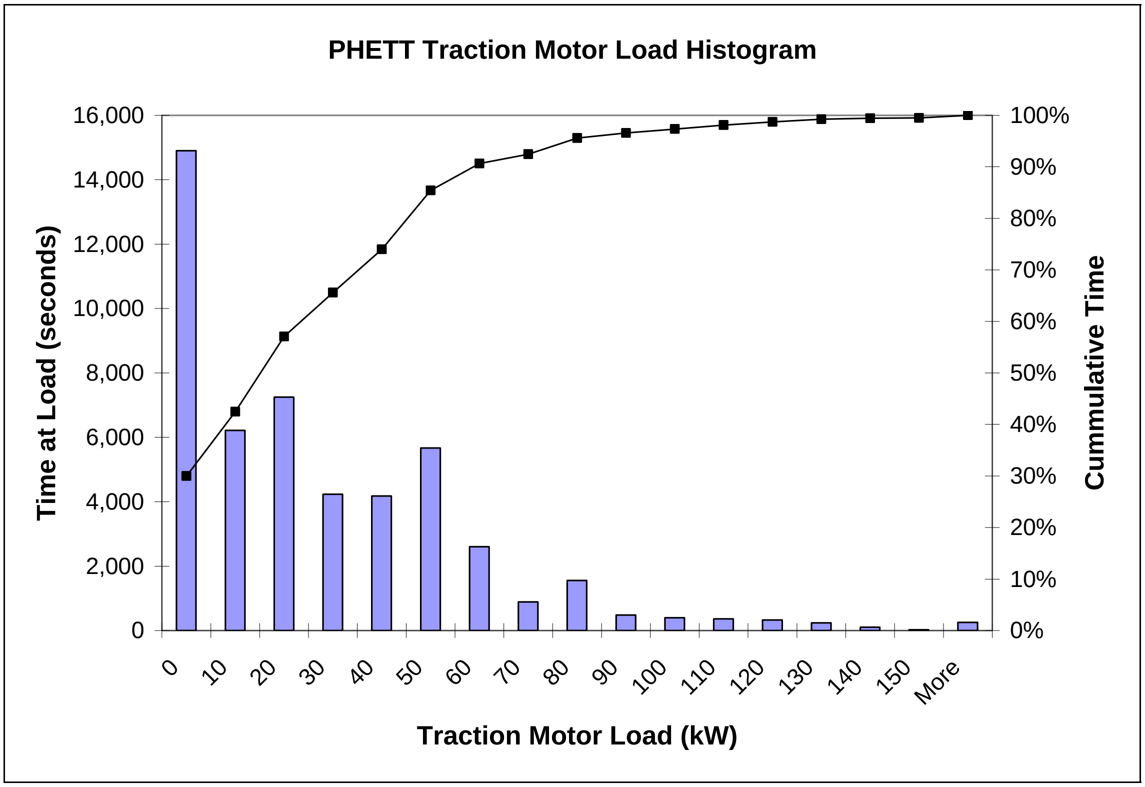

Figure 5. Histogram of traction motor power demand

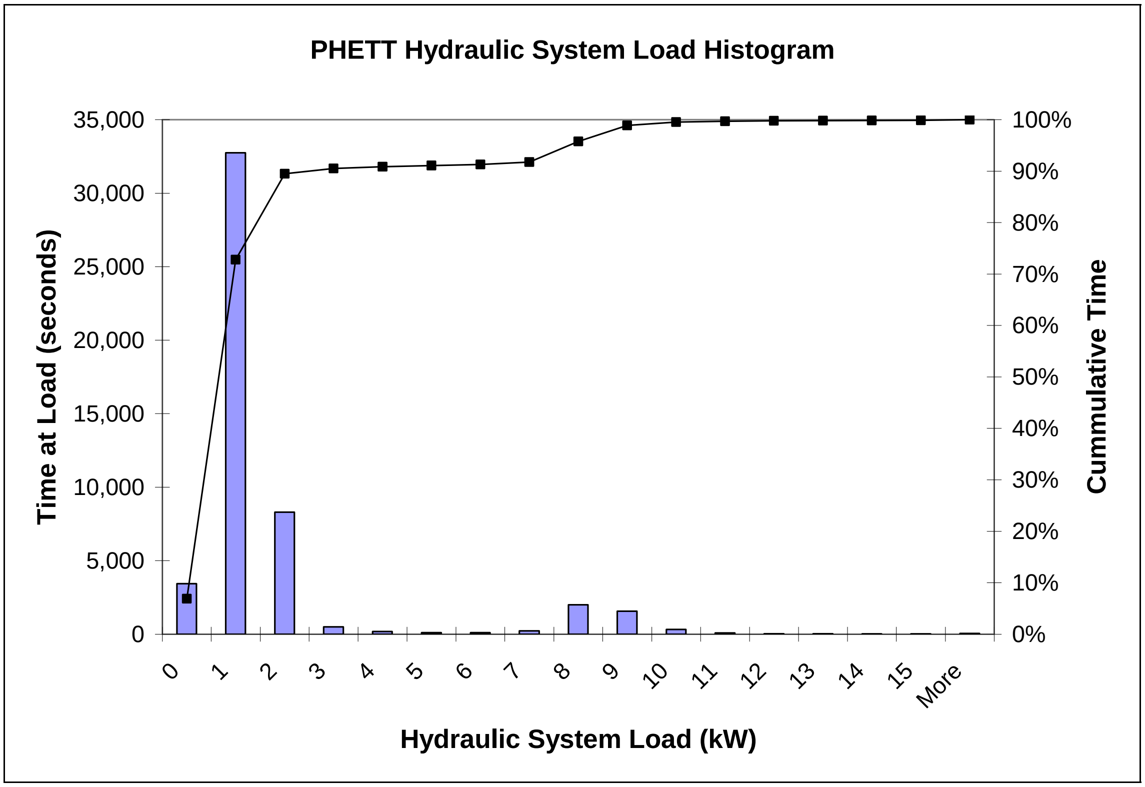

Figure 6. Histogram of hydraulic system power demand

4.2 Fuel Economy Estimates

Fuel economy improvement was determined by comparing the average fuel use rate for the PHETT™ to the baseline diesel fleet. Fuel rate, in gallons per hour, is the total fuel used divided by the vehicle's operating time. Ideally fuel usage data are obtained directly from the host fleet's fueling records over a substantial period of time. However, such data was available during the test period for the baseline diesel fleet, but not for the PHETT™.

In lieu of data from fueling logs, the fuel use at a particular load can be estimated from curves supplied by the engine manufacturer. This method is generally less accurate for engines that experience numerous transient load events, as the fuel rate curves supplied by the manufacturer typically assume steady state operation. However, the PHETT™ data does not show significant transients in the generator load due to the design of the PHETT™'s hybrid system. Therefore, fuel use estimates derived from the manufacturer's fuel rate curves should provide a reasonable estimate of the actual fuel use. Table 6 summarizes the fuel rate information provided by the manufacturer as well as calculated electrical power output and fuel-to-electric conversion efficiencies.

Table 6. Fuel rates and conversion efficiencies for on-board generator

Electrical Load (%)	Fuel Rate (gal/hour)	Electrical Power Output* (kW)	Fuel to Electric Efficiency* (%)
0	0.523	0	0
50	1.09	10	23
100	1.89	20	26

*Calculated value based on manufacture supplied fuel rate, current, and voltage ratings

Table 7 summarizes the calculated fuel use rates for both the diesel fleet and the PHETT™. The PHETT™ achieved a 28% fuel economy improvement over the baseline. Comparing the average engine load of the baseline fleet and the PHETT™ suggests the potential for higher fuel savings. Assuming the baseline fleet has an average thermal efficiency of 38% (not uncommon for larger diesel engines), the anticipated fuel economy improvement based on the average engine load would be approximately 60%. However, a review of the data used to determine the baseline fleet's average engine load suggests that the average load may be significantly overestimated. If correct, this would bring the anticipated fuel economy improvement much more in line with the observed value of 28%.

Table 7. Baseline and PHETT™ fuel economy

Parameter	Units	Value
Baseline fuel use rate[9]	gal/hour	1.9
PHETT™ fuel use rate	gal/hour	1.37
Baseline fleet average engine load[9]	HP	72
PHETT™ average engine load	HP	23
Generator thermal efficiency*	%	31
PHETT™ fuel economy improvement over baseline	%	28

*Calculated based on estimated 83% efficient alternator

Based on the available data and calculations, the PHETT™ showed significant improvements in fuel economy compared to the existing diesel yard tractor fleet. This is in part due to the high levels of idle and low power operation measured in the current study, which is believed to be typical of yard tractor operation in general. Fuel economy improvements are partially offset by the relatively low thermal efficiency of the small generator motor compared to the larger diesel engines used to power the existing fleet.

4.3 Emissions Estimates

Using CARB's Offroad 2007 methodology, TIAX calculated estimates of the emissions from the PHETT™ based on the measured load factor reported in section 4.1. A complete description of the methodology is available in the CARB Technical Mailout MSC# 99-32. Emissions factors were calculated for three cases:

1. A baseline tractor reflecting the average of the baseline fleet

[9] San Pedro Bay Ports Yard Tractor Load Factor Study Addendum, Starcrest LLC, 2008

2. The PHETT™ as measured in this study
3. A yard tractor equipped with a 2009 diesel engine

Activity data are assumed to be the same in all three cases. This allows emissions comparisons to be made solely using the calculated emissions factors. Based on the CARB methodology, the PHETT™ is expected to achieve a 77% reduction in NOx and 82% reduction in PM compared to the baseline fleet (2002 levels). Additionally, emissions rates from the PHETT™ are lower than a 2009 diesel yard tractor. Table 8 summarizes the results of the emissions analysis and Figure 7 presents the results graphically.

Table 8. Comparison of estimated emissions rate for yard hostlers with different engine technologies

Engine	NOx Emissions factor	PM Emissions factor	NOx Reductions	PM Reductions
	grams/hr	grams/hr	from Baseline	from Baseline
Baseline (2002 Engine)	497.84	28.86	0.0%	0.0%
2009 Diesel (Tier 3)	187.59	10.82	62.3%	62.5%
PHETT™ (Tier 4i)	114.06	5.12	77.1%	82.3%

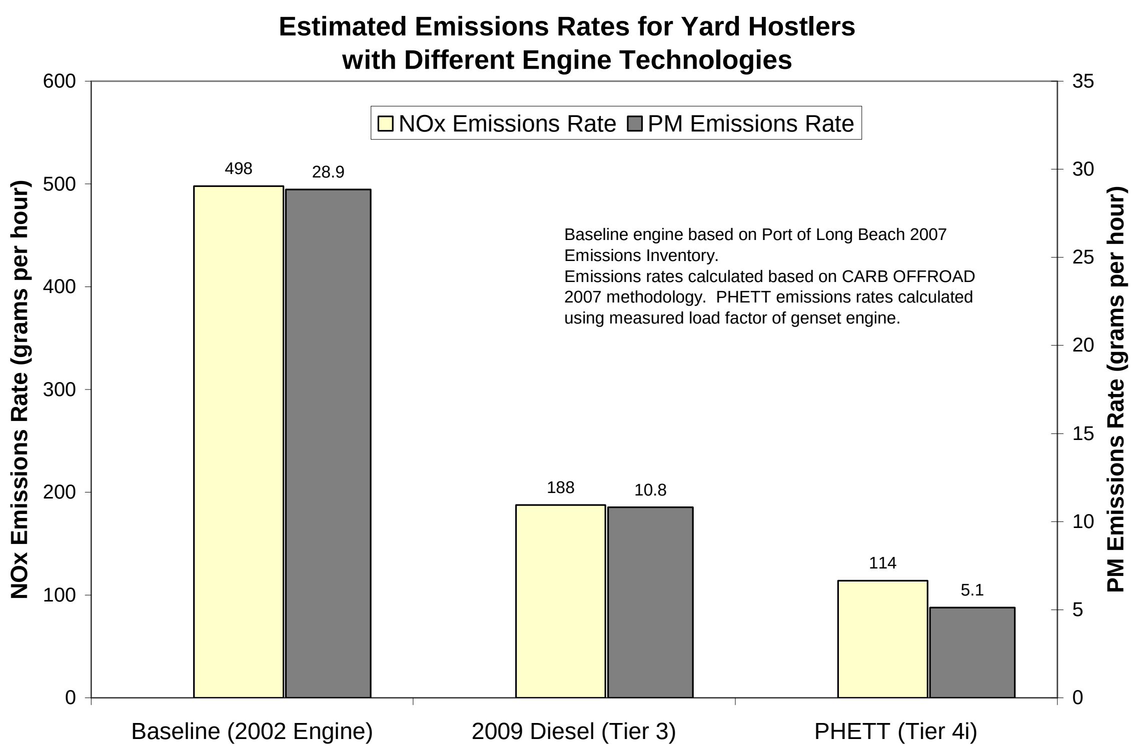

Figure 7. Comparison of estimated emissions rate for yard hostlers with different engine technologies

4.4 Operator and Maintenance Personnel Survey Results

TIAX attempted to meet with and administer surveys to the operators and maintenance personnel that were involved with the PHETT during the demonstration period. Unfortunately, operators and maintenance personnel were not available to complete the surveys during the scheduled meeting times. Both TIAX and Port of Long Beach staff have provided copies of the surveys to PortsAmerica. To date, no survey forms have been returned. However, TIAX staff did have an informal conversation with PortsAmerica personnel regarding the performance of the PHETT prior to the conclusion of the demonstration period. During that conversation, PortsAmerica personnel noted minor issues with the vehicle cruise speed but noted that the PHETT performance was comparable to diesel yard tractors.

Appendix A – Emissions Factors

Baseline Fleet

Engine Year		**2002**	From POLB 2007 EI
Engine Power	HP	**185**	From POLB 2007 EI
Load Factor		**0.39**	From POLB 2007 EI
Tier		**1**	From POLB 2007 EI
NOx Emissions Factor	g/bh-hr (Zero hour)	**6.9**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf
PM Emissions Factor	g/bh-hr (Zero hour)	**0.4**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf

PHETT™

Engine Year		**2009**	From PHETT data sheet
Engine Power	HP	**40**	From PHETT data sheet
Load Factor		**0.58**	From data logging results
Tier		**4i**	From PHETT data sheet
NOx Emissions Factor	g/bh-hr (Zero hour)	**4.9**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf
PM Emissions Factor	g/bh-hr (Zero hour)	**0.22**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf

2009 Diesel

Engine Year		**2009**	
Engine Power	HP	**185**	From POLB 2007 EI
Load Factor		**0.39**	From POLB 2007 EI
Tier		**3**	
NOx Emissions Factor	g/bh-hr (Zero hour)	**2.6**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf
PM Emissions Factor	g/bh-hr (Zero hour)	**0.15**	http://www.arb.ca.gov/msprog/ordiesel/documents/PM_NOx_Emis_Factors.pdf

Appendix B – Survey Forms

Operator Survey

Name: ______________________________
Dates of operation: ______________________________
Equipment ID: ______________________________
Assignment *(circle all that apply)*: Ship Rail Yard

How does the PHETT compare to a diesel terminal tractor? *(Check one)*	**Better** ☺	**Same** 😐	**Worse** ☹	**Comments**
Maneuverability				
Pulling power with full container				
Acceleration with no container				
Smoothness of shifting under acceleration				
In-cab visibility (no blind spots, rear view)				
Ride comfort (vibration and shocks, feel of seat)				
In-cab controls (convenience and functioning of switches, controls)				
Braking (stops load quickly and smoothly)				
Interior noise level				
Exterior noise level				
HVAC system (heating, ventilation, A/C)				
Cab entry and exit				
Overall vehicle rating				

What safety incidents or unusual experiences did you encounter?

____
____
____
____

What other feedback can you provide about the PHETT?

____
____
____

Service and Maintenance Survey

Name: ____

Date: ____

How does the PHETT compare to a diesel terminal tractor? ***(Check one)***	**Better** ☺	**Same** 😐	**Worse** ☹	**Comments**
Design for maintainability				
Design for serviceability				
Manufacturer support				
Overall rating				

How adequate was the manufacturer's systems and component training?

____

____

____

____

What PHETT problems or issues did you observe?

____

____

____

____

What other feedback can you provide about the PHETT?

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