Liquefied Natural Gas (LNG) Yard Hostler Demonstration and Commercialization Project Final Report

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The Port of Long Beach

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Executive Summary

Yard hostlers (also referred to as terminal tractors, yard trucks, utility tractor rigs, yard goats, yard hustlers and yard tractors) are heavy-duty off-road truck tractors purposely designed for moving cargo containers within port container terminals and other off-road areas. They are the most common type of cargo handling equipment (CHE) used at port container terminals. According to recent emissions inventories by the Port of Long Beach (POLB) and the Port of Los Angeles (POLA), yard hostlers are the single largest source of landside emissions of nitrogen oxides (NOx) and particulate matter (PM) at the ports.[1,2]

In August 2004, POLB and Sound Energy Solutions (SES) jointly initiated a project to determine the performance, emissions and business case impacts of yard hostlers powered by liquefied natural gas (LNG).[3] The LNG Yard Hostler Demonstration and Commercialization project directly supports the San Pedro Bay Ports Clean Air Action Plan (CAAP), jointly issued by POLB and POLA, which is dedicated to achieving measurable, long-term reductions in air pollutant emissions from port operations, especially PM and NO_x. The CAAP also serves as POLB's implementation of the air quality portion of its Green Port Policy, an aggressive, comprehensive and coordinated approach to reduce the negative environmental impacts of port operations.

The goals of the project were to assess the performance and emissions of LNG yard hostlers during in-use operations at a container terminal, and investigate the business case for expanded use of LNG yard hostlers at ports and similar applications (e.g., railroad yards and distribution centers). Three LNG yard hostlers were put into service at Long Beach Container Terminal (LBCT) at POLB for a period of eight months. During this time, data was collected on the performance of the LNG yard hostlers compared to a representative group of eight baseline diesel yard hostlers from LBCT's fleet. At the conclusion of the in-use performance testing period, yard hostler emissions testing was performed by the University of California, Riverside, Bourns College of Engineering Center for Environmental Research and Testing (UCR CE-CERT). In conjunction with performance and emissions testing, a high-level analysis of the LNG yard hostler business case was also performed.

The major areas of the performance testing program included fuel economy, operator acceptance, service and maintenance, and emissions. Table ES-1 shows the composition of the yard hostler test fleet including engine model year (MY), configurations, emissions certifications, fuels and exhaust aftertreatment.

Table ES-1 - Yard Hostler Test Fleet

UTR ID[1]	Engine Model Year	Certification Standard	Engine Make/Model[2]	Fuel[3,4]	After-treatment[5,6]
LNG 01	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst

[1] 2002 POLB Emissions Inventory, Starcrest Consulting, 2004.
[2] 2001 POLA Port-Wide Baseline Air Emissions Inventory, Starcrest Consulting, 2004.
[3] SES is a joint venture with ConocoPhillips formed for the purpose of importing foreign LNG to California.

LNG 02	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst
LNG 03	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst
UTR 117	2001	Tier 1 off-road	Cummins 8.3L 6CT, 215 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 118	2001	Tier 1 off-road	Cummins 8.3L 6CT, 215 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 125	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 126	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 129	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 130	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 140	2005	2004+ on-road	Cummins 5.9L ISB, 245 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 141	2005	2004+ on-road	Cummins 5.9L ISB, 245 hp	O_2Diesel™, ULSD	DOC + CCV

Notes:

1. UTR ID is the utility tractor rig identification number, an internal LBCT designation.
2. The vehicle make and model for all test vehicles including the LNG yard hostlers is the Ottawa Commando 50 4x2 Off-Road Terminal Tractor.
3. O_2Diesel™ was used during in-use performance testing of the diesel yard hoslters at LBCT.
4. Ultra low sulfur diesel (ULSD) was used during chassis dynamometer emissions testing of a subgroup of the diesel yard hostlers by UCR CE-CERT.
5. Exhaust aftertreatment on all LNG yard hostlers consisted of a 2-way oxidation catalyst provided as standard equipment by Cummins Westport, the natural gas engine original equipment manufacturer (OEM). The 2-way catalyst uses oxygen in the engine exhaust to convert hydrocarbons and carbon monoxide to carbon dioxide and water.
6. Exhaust aftertreatment on all diesel yard hostlers consisted of a diesel oxidation catalyst (DOC) and closed crankcase ventilation (CCV) for PM reduction.

Fuel economy testing was performed by collecting data on daily fuel usage vs. hours of engine operation for all test vehicles during the eight-month performance testing period. Fuel economy for yard hostlers is normally measured in gallons/hour (gal/hr) rather than miles per gallon (mpg). Since LNG has a lower energy content per gallon than diesel, LNG gallons were converted to diesel gallon equivalents (DGEs). The results of testing indicate that the average fuel economy was approximately 1.7 diesel gal/hr for the diesel yard hostlers and 3.8 LNG gal/hr for the LNG yard hostlers. After converting LNG gallons into DGEs, the LNG yard hostlers use about 30% more DGEs than the diesel yard hostlers.[4] This result is consistent with expectations for the relative efficiency of a spark-ignited natural gas engine compared to a compression-ignited diesel engine under light-loading conditions.[5]

Operator acceptance was assessed via surveys given to all LNG yard hostler drivers. Drivers were asked to rate the LNG yard hostlers as "better", "same" or "worse" in key vehicle

[4] There are approximately 1.73 gallons of LNG per DGE. Converting 3.8 gallons of LNG to DGEs yields 3.8/1.73 = 2.2 DGEs. The ratio of average LNG DGEs/hr to average diesel gallons/hr is therefore 2.2:1.7 = 1.3: 1.

[5] Telephone conversation with Scott Baker of Cummins Westport, May, 2007.

performance areas compared to typical diesel yard hostlers. The specific areas covered by the survey included maneuverability, pulling power, acceleration, shifting, steering, in-cab visibility, ride comfort, in-cab controls, braking, interior noise level, exterior noise level, HVAC (heating, ventilation and air conditioning) system, cab entry and exit and overall vehicle rating. A number of drivers also provided extensive additional comments. Based on the driver surveys, 97% of the drivers found the LNG yard hostlers to have the same or better performance than traditional diesel yard hostlers with 67% rating them as superior in general. The features of the LNG yard hostlers most consistently rated better than the diesel yard hostlers were steering, ride comfort and interior/exterior noise levels. The only feature of the LNG yard hostlers frequently rated as worse than diesel yard hostlers was cab entry and exit. Despite the overall positive results of the survey regarding the performance of the LNG yard hostlers, some drivers cited slow acceleration, vehicle "hesitiation" and problems with shifting of the automatic transmission in their comments. A detailed summary of driver survey data is provided in Appendix A.

Service and maintenance data was collected to assess the reliability, maintainability and serviceability of the LNG yard hostlers compared to typical diesel yard hostlers. The primary metric for reliability was vehicle availability. Over the eight-month performance testing period, the average availability of the LNG yard hostlers was 94.5% compared to 97.9% for the baseline diesel yard hostlers. While the LNG yard hostlers availability was slightly lower than the diesel yard hostlers, overall the results were quite good, especially considering that the LNG yard hostlers were prototypes. Initial problems with the LNG fueling system during the early part of the program were later addressed by Westport Innovations via fueling system upgrades. This may have improved the availability of the LNG yard hostlers in the latter part of the program but there was insufficient data to draw any conclusions.

In addition, LBCT mechanics were asked to provide subjective feedback on serviceability and maintainability of the LNG yard hostlers compared to diesel yard hostlers. Based on the mechanic surveys, 100% of the mechanics gave the LNG yard hostlers a rating of "acceptable" or better regarding LNG training, maintainability, serviceability and manufacturer support. It should be noted that LBCT mechanics were not responsible for service actions on the LNG yard hostlers beyond routine maintenance. A detailed summary of mechanic survey data is provided in Appendix B.

Serviceability and maintainability were assessed via surveys given to LNG yard hostler mechanics. Mechanics were asked to rate service and maintenance aspects of the LNG yard hostlers between 1 ("unacceptable") and 5 ("excellent)" compared to typical diesel yard hostlers. The specific areas covered by the survey included start-up problems (i.e., problems noted during the early phases of deployment), LNG systems and component training, design for maintainability, design for serviceability, quality of manufacturer support, and trends in service actions over the performance testing period. Based on the mechanic surveys, 100% of the mechanics gave the LNG yard hostlers an "acceptable" or better rating regarding LNG training, maintainability, serviceability and manufacturer support. However problems with LNG pressure regulation and leaks were noted by most of the mechanics during the initial phases of the demonstration.

Yard hostler emissions were evaluated via steady-state emissions testing performed on a chassis dynamometer using the ISO 8178-C1 8-mode cycle.[6] This cycle is used by the United States Environmental Protection Agency (U.S. EPA) and the California Air Resources Board (CARB) for emissions certification of heavy-duty off-road/nonroad engines on an engine dynamometer. In order to perform this test on a chassis dynamometer, the test protocol was modified slightly with all modifications approved by CARB prior to testing.[7] Details of the test modifications to accommodate testing on a chassis dynamometer are described in the yard hostler emissions testing report.[8] Although heavy-duty on-road engine emissions certification is performed using the Federal Test Procedure (FTP) heavy-duty transient engine dynamometer cycle, it was necessary to test all vehicles using the same emissions testing protocol and cycle in order to make an "apples-to-apples" comparison of the results.[9] Another driver for the decision to use ISO 8178-C1 8-mode cycle was that CARB had previously used this cycle to perform emissions testing of several yard hostlers at POLA and it was desired to make a direct comparison of LBCT's LNG and diesel yard hostler emissions to the POLA yard hostler emissions data.[10] In-use emissions testing was considered but eventually rejected due to uncontrolled variables affecting test reproducibility.

Emissions testing was performed by UCR CE-CERT under the direction of Dr. J. Wayne Miller. Table ES-2 shows the composition of the yard hostler emissions test fleet including certification standard, engine configurations, emissions certifications, fuels and exhaust aftertreatment. Note that all emissions testing of diesel yard hostlers was performed using ultra low sulfur diesel (ULSD) instead of O_2Diesel™ as this was believed to provide a more generic basis for emissions comparisons.

Table ES-2 - Emissions Test Vehicles

UTR ID[1]	Certification Standard	MY/Engine Make/Model[2]	Test Fuel	After-treatment[3,4]	Comments
LNG 02	2004+ on-road	2005 Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst	
UTR 117	Tier 1 off-road	2001 Cummins 8.3L 6CT, 215 hp	ULSD	DOC + CCV	Test Aborted[6]
UTR 118	Tier 1 off-road	2001 Cummins 8.3L 6CT, 215 hp	ULSD	DOC + CCV	Test Data Incomplete[5]
UTR 126	Tier 2 off-road	2003 Cummins 8.3L 6CT, 205 hp	ULSD	DOC + CCV	
UTR 141	2004+ on-road	2005 Cummins 5.9L ISB, 245 hp	ULSD	DOC + CCV	

Notes:

[6] International Organization for Standardization (IS0) 8178-4 *Reciprocating internal combustion engines - Exhaust emission measurement - Part 4:Test cycles for different engine applications*, First edition 1996-08-l 5. Note that the CARB 8-Mode Cycle is identical to the ISO 8178-C1 8-mode cycle.
[7] Modifications suggested by UCR CE-CERT and submitted to CARB for approval prior to yard hostler emissions testing at POLA in 2005 and 2006.
[8] A Study of Emissions from Yard Tractors Using Diesel and LNG Fuels, Dr. J. Wayne Miller, University of California, Riverside, College of Engineering, Center for Environmental Research and Testing, August 28, 2007.
[9] Code of Federal Regulations (CFR) Title 40, Part 86.1333.
[10] Cargo Handling Equipment Yard Truck Emission Testing, California Air Resources Board, September, 2006, http://www.arb.ca.gov/ports/cargo/documents/yttest.pdf.

1. UTR ID is the utility tractor rig identification number, an internal LBCT designation.
2. The vehicle make and model for all test vehicles including the LNG yard hostlers is the Ottawa Commando 50 4x2 Off-Road Terminal Tractor.
3. Exhaust aftertreatment on all LNG yard hostlers consisted of a 2-way oxidation catalyst provided as standard equipment by Cummins Westport. The 2-way catalyst uses oxygen in the engine exhaust to convert hydrocarbons and carbon monoxide to carbon dioxide and water.
4. Exhaust aftertreatment on all diesel yard hostlers consisted of a DOC and CCV for PM reduction.
5. UTR 118 was unable to generate full torque at rated speed so UTR 117 was tested to try to obtain complete data for the Tier 1 off-road engine configuration.
6. UTR 117 was also unable to generate full torque at rated speed and hence the test was aborted.

The relative weighted emissions factors for NOx and PM in g/whp-hr are reproduced from the yard hostler emissions testing report in Figures ES-1 and ES-2 below. *By agreement, PM emissions for the LNG yard hostler were not tested and are not therefore reported.*[11] Note that since testing was performed on a chassis dynamometer and horsepower is measured at the wheels (not the engine), emissions factors are reported in g/whp-hr (vs. g/bhp-hr). As a general rule of thumb, g/whp-hr may be estimated as approximately 25% higher than g/bhp-hr for conversion purposes based on typical heavy duty vehicle drivetrain power losses.[12]

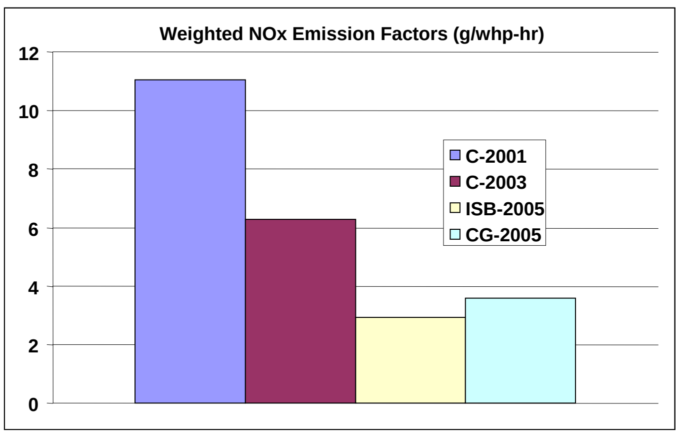

Figure ES-1 - Relative Weighted Emissions Factors for NOx (g/whp-hr)

[11] Earlier LNG yard hostler emissions testing at POLA indicated PM emissions of approximately 0.008 g/whp-hr, well below the current standard of 0.01 g/bhp-hr. Based on this data, a decision was made to omit PM emissions testing for the POLB LNG yard hostlers in order to reduce overall emissions testing costs.
[12] Estimate provided by Dr. Wayne Miller, UCR CE-CERT, telephone conversation, July, 2007.

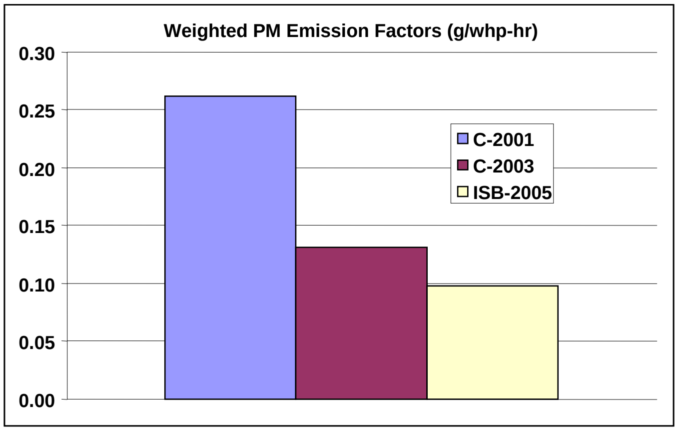

Figure ES-2 - Relative Weighted Emissions Factors for PM (g/whp-hr)

Table ES-3 shows the emissions factors for all criteria pollutants including total hydrocarbons (THC), carbon monoxide (CO), NOx and PM as well as carbon dioxide (CO_2). Emissions factors for each vehicle are calculated by weighting the mean emissions data from the eight modes in the steady-state test. A detailed discussion of emissions factor calculations can be found in the yard hostler emissions testing report.

Table ES-3 - Yard Hostler Weighted Emissions Factors (g/whp-hr)

Engine Model - Year	*Emissions Certification*	*Weighted Emissions Factors (g/whp-hr)*				
		THC	*CO*	*NOx*	*PM*	*CO_2*
C8.3L – 2001	Tier 1 off-road	0.29	0.63	11.06	0.26	1013
C8.3L – 2003	Tier 2 off-road	0.16	0.24	6.28	0.13	815
ISB 5.9L – 2005	2004+ on-road	0.05	0.51	2.94	0.10	791
CG 8.3L – 2005	2004+ on-road	2.92	0.09	3.57	0.00	658

Based on the steady-state emissions testing data, the lowest NOx were produced by the 2005 on-road diesel vehicle. Due to the inherently low PM emissions of LNG engines, it is assumed that the lowest PM emissions were produced by the 2005 LNG vehicle. NOx emissions from the LNG yard hostler were approximately 21% higher than NOx emissions from the 2005 on-road diesel yard hostler. This result was unexpected and while hypothetical explanations have been offered by Dr. Miller in his report, no definitive reason has been confirmed at this time. It should also be noted that all diesel off-road and on-road engine configurations tested included a diesel oxidation catalyst (DOC) and closed crankase ventilation (CCV) filter exhaust aftertreatment system for NOx and PM reductions.

A detailed summary of yard hostler emissions testing procedures and results can be found in "A Study of Emissions from Yard Tractors Using Diesel and LNG Fuels", by Dr. J. Wayne Miller, University of California, Riverside, College of Engineering, Center for Environmental Research and Testing, August 28, 2007.[13]

[13] A Study of Emissions from Yard Tractors Using Diesel and LNG Fuels, Dr. J. Wayne Miller, UCR CE-CERT, August 28, 2007.

A business case analysis for LNG yard hostlers was performed based on data collected during the demonstration period. Interviews with industry experts were performed to estimate costs where hard data was unavailable. Based on a simplified life cycle cost analysis using current fuel costs, the results show that in the absence of vehicle purchase incentives, the life cycle costs for diesel and LNG yard hostlers are approximately equal over a 10-year vehicle life.[14] The analysis does not take into account the capital costs of LNG refueling infrastructure which are significant (estimated at $700K per refueling station). LNG refueling infrastructure costs would generally tend to increase costs for the LNG yard hostler scenario (although the more LNG vehicles in a fleet, the smaller the impact on a per vehicle basis). In addition, the analysis is based on existing cost information and does not attempt to estimate the impact of costs associated with 2010 emissions regulations compliance. Given the current marginal business case and the cost of LNG refueling infrastructure, it is unlikely that there will be a significant demand for LNG yard hostlers in the near-term without strong financial or regulatory incentives for yard hostler fleet operators to adopt LNG technology.

The major findings of the report are summarized below:

- **LNG yard hostlers exhibit comparable performance to diesel yard hostlers in port applications. However LNG yard hostler product maturity is currently below that of diesel yard hostlers.**

- **The LNG yard hostlers were received positively by operators and mechanics.**

- **Measured NOx emissions of MY 2005 LNG yard hostlers were 21% higher than MY 2005 diesel yard hostlers with on-road engines. These results are unexpected and the root cause remains unclear at this time.**

- **By agreement, PM emissions of MY 2005 LNG yard hostlers were not measured but were assumed to be significantly below the current EPA standards of 0.01 g/bhp-hr.**

- **Measured CO_2 emissions of MY 2005 LNG yard hostlers were 18% lower than MY 2005 diesel yard hostlers with on-road engines.[15] As one of the primary greenhouse gases (GHGs) contributing to climate change, CO_2 emissions are coming under increasing scrutiny at the ports.**

- **In the absence of vehicle purchase incentives, life cycle cost estimates for LNG yard hostlers are currently about the same as diesel yard hostlers excluding LNG refueling infrastructure costs. Where vehicle purchase incentives are available, LNG yard hostlers have a life cycle cost advantage equal to the amount of the incentives.**

[14] Off-road diesel fuel costs of $2.60/gallon and LNG fuel costs of $0.50/gallon were used based on current fuel prices at the time of the analysis.
[15] However it should be noted that neither the MY 2005 diesel on-road or MY 2005 LNG engines have been optimized by the manufacturer for CO_2 emissions reductions.

- **Current incentive programs and policies including the Energy Policy Act (EPAct) of 2005, the Carl Moyer Program, the San Pedro Bay Ports Clean Air Action Plan (CAAP) and the CARB Cargo Handling Equipment (CHE) Regulations are insufficient to stimulate significant near-term demand for LNG yard hostlers. While life cycle costs for diesel and LNG yard hostlers are similar without vehicle purchase incentives, fleets generally make shorter term payback decisions and are often unwilling to wait more than two to three years to see a payback on their investment.**

- **California state policies currently under development and other state funding sources for clean vehicles, including the State Alternative Fuels Plan and the recently passed Alternative Fuels and Vehicle Technologies Bill, support the use of LNG yard hostlers in lieu of diesel yard hostlers and may have a positive, long-term impact on the business case for LNG yard hostlers.**

A summary of the major recommendations of the report is given below:

- **Develop a standard yard hostler duty cycle to measure emissions.**

- **Measure LNG vs. diesel yard hostler emissions using yard hostlers with current engines certified to meet (or exceed) the most recent heavy-duty engine emissions standards.**

- **Evaluate the in-use performance of new LNG yard hostlers when they become available to verify that all performance issues noted in this project, (e.g., LNG fuel pressure regulation problems), have been adequately resolved by the manufacturer.**

- **Update the business case analysis based on actual costs for new LNG yard hostlers when they become available.**

- **Investigate methods of streamlining the LNG refueling infrastructure permitting process at POLB.**

- **Optimize vehicle refueling procedures for LNG yard hostler fleets.**

- **Consider port-based incentives to help address the incremental cost of LNG yard hostlers and capital costs associated with LNG refueling infrastructure.**

- **Consider port-based incentives to help address the incremental costs of technologies and fuels that reduce both criteria pollutant emissions and GHGs. The reduced carbon footprint of LNG should be considered as part of a long-term strategy.**

- **Advocate for policy changes to provide additional funding for incremental costs of alternative fueled CHE and associated refueling infrastructure costs.**

Despite the concerns noted in the report regarding lower than expected NOx emissions for LNG yard hostlers and the need for vehicle purchase incentives to bolster the business case, there are advantages to LNG yard hostlers that should not be overlooked. These include increased energy security, the potential for generating LNG from renewable sources, and reduced CO_2 emissions.

1 Introduction

1.1 Background

Yard hostlers (also referred to as terminal tractors, yard trucks, utility tractor rigs, yard goats, yard hustlers and yard tractors) are heavy-duty off-road truck tractors designed for moving cargo containers (see Figure 1). They are the most common type of cargo handling equipment (CHE) used at container terminals. Normally the yard hostler is connected to a trailer which it uses to help transport containers. In a typical operation, a container is loaded onto the trailer by a piece of CHE such as a crane, top-pick, side-picks or rubber-tired gantry (RTG). 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 CHE.

Figure 1 – Typical Yard Hostler

The Port of Long Beach (POLB) is located in the South Coast Air Basin, a region characterized as having some of the nation's worst air quality. POLB has launched a number of environmental programs including the Healthy Harbor Program in 2003 and the Green Port Policy adopted in 2005. In 2006, POLB and the Port of Los Angeles (POLA) jointly adopted the San Pedro Bay Ports Clean Air Action Plan (CAAP) designed to achieve measurable, long-term reductions in air pollutant emissions from port operations, especially particulate matter (PM) and nitrogen oxides (NO_x). PM and NO_x are of particular concern due to potential impacts to public health and ozone formation. The CAAP simultaneously serves as POLB's implementation of the air quality element of its Green Port Policy.

In 2001 POLB initiated the Port Terminal Alternative Fuels Study to examine ways of reducing diesel emissions from terminal equipment and operations. One of the findings of this study was to recommend further investigation into the potential use of liquefied natural gas (LNG) for yard hostlers. In 2002 POLB performed a port-wide emissions inventory which identified yard hostlers as the largest source of landside emissions within port operations.[16] As a result of these two studies, POLB and Sound Energy Solutions (SES) jointly launched an LNG yard hostler demonstration and commercialization project in August, 2004.[17]

The primary goals of the project were:

- to formally evaluate the in-use performance of LNG yard hostlers in a demanding, marine terminal environment;
- to evaluate the emissions of LNG yard hostlers compared to typical diesel yard hostlers used at ports; and,
- to assess the business case for LNG yard hostlers at ports and similar applications such as rail yards and distribution centers.

The project also supports the goals of the CAAP Source Specific Performance Standards for Cargo Handling Equipment, specifically measure CHE-1 which includes options for using alternative-fueled engines meeting the cleanest available NOx and PM emissions standards. The project now falls under the CAAP Technology Advancement Program (TAP) which is designed to verify the emissions reductions that can be achieved by new and emerging technologies through demonstration and evaluation.

2 Description of Project

2.1 Project Overview

The project was divided into three phases. During Phase I, LNG yard hostler specifications were developed, the vehicles were ordered and temporary LNG refueling infrastructure was arranged. During Phase II, the LNG yard hostlers were put into service at a container terminal for a total of eight months. During this time, data was collected on the performance of the LNG yard hostlers compared to a group of baseline diesel yard hostlers from the same fleet. Emissions testing was also performed at the end of Phase II. During Phase III, a high-level analysis of the LNG yard hostler business case was performed for inclusion in the final report.

The project team consisted of POLB, SES, CALSTART, Long Beach Container Terminal (LBCT) and the United States Environmental Protection Agency (U.S. EPA). POLB and SES shared the role of overall project management and provided the bulk of project funding. CALSTART was contracted by POLB to provide technical project management.[18] LBCT

[16] 2002 POLB Emissions Inventory, Starcrest Consulting, 2004.
[17] SES is a joint venture with ConocoPhillips formed for the purpose of importing foreign LNG to California.
[18] CALSTART is a fuel neutral, non-profit organization dedicated to expanding a high-tech transportation industry that cleans the air, creates jobs and improves energy efficiency.

volunteered to test the LNG yard hostlers in their container terminal operations during the eight-month evaluation period. The U.S. EPA provided additional funding for portions of Phase II and Phase III. Gladstein, Neandross and Associates was contracted by SES to provide technical support for the project, particularly in the areas of LNG infrastructure, training and other LNG-related issues. The LNG and diesel yard hostlers were manufactured by Kalmar Industries who also provided technical support throughout the project. Cummins Westport, the manufacturer of the natural gas engine used in the LNG yard hostler, also provided technical support to the project.

2.2 Test Program Overview

In order to evaluate the performance of the LNG yard hostlers, a test program was developed covering the following areas:

- Fuel economy
- Operator acceptance
- Service and maintenance
- Emissions

All performance and emissions testing was performed during Phase II of the project between June 2006 and January 2007. Fuel economy data was collected daily by LBCT refuelers for the LNG yard hostlers and a representative group of baseline diesel yard hostlers. All drivers assigned to the LNG yard hostlers were surveyed on a monthly basis to evaluate the performance of the LNG yard hostler compared to diesel yard hostlers. Vehicle availability as well as maintenance and service events for the LNG and baseline diesel yard hostlers were tracked by LBCT maintenance staff. In addition, all mechanics assigned to the LNG yard hostlers were surveyed to evaluate the maintainability and serviceability of the vehicles compared to typical diesel yard hostlers. CALSTART performed the analysis of all raw data collected by LBCT. Emissions testing and analysis was performed by the University of California, Riverside, Bourns College of Engineering, Center for Environmental Research and Technology (UCR CE-CERT) in Riverside, California. Note that a comparison of relative greenhouse gas (GHG) emissions of diesel vs. LNG yard hostlers was not a specific goal of this project and hence was not included as part of emissions testing. However, a comparison of relative carbon dioxide (CO_2) emissions was performed and results are included in this report. (Note that CO_2 is one of the primary GHGs contributing to climate change.)

2.3 Test Vehicles and Fuels

Three LNG yard hostlers were deployed for performance testing and evaluation during the project. Specifications for the LNG yard hostlers were based on the Ottawa Commando 50 4x2 Off Road Terminal Tractor performance specifications. Since LBCT's diesel yard hostler fleet is 100% comprised of Ottawa Commando 50 4x2 off road terminal tractors in various engine configurations, this allowed for more direct comparisons between the LNG and diesel yard hostlers.

Eight diesel yard hostlers were selected from LBCT's fleet to form a baseline yard hostler group for comparison purposes. The diesel yard hostlers were specifically selected to be representative of the most common engine configurations in LBCT's yard hostler fleet. Data was collected on the baseline diesel yard hostlers in parallel with the LNG yard hostlers under similar operating conditions during the performance testing period. In addition, a sub-group of the LNG and baseline diesel yard hostlers were subjected to emissions testing at the end of the performance testing period.

Prior to the start of the project, LBCT's diesel fleet fueling infrastructure had been converted to O_2Diesel™, a proprietary blend of aproximately 7.7% ethanol, 91% ultra low sulfur diesel (ULSD) and 1% special additives.[19] Since there is only a minor difference in energy content between ULSD and O_2Diesel™, the impact on fuel economy results was expected to be minimal. Therefore in order to minimize the impact to LBCT operations during performance testing, it was decided that fueling the diesel yard hostlers with O_2Diesel™ would be acceptable. However during emissions testing, ULSD was used to fuel the baseline diesel yard hostlers tested in order to directly compare the emissions results between LNG and ULSD.

Table 1 provides a summary of the specifications for the yard hostler test fleet and fuels.

Table 1 – Yard Hostler Test Fleet

UTR ID[1]	Engine Model Year	Certification Standard	Engine Make/Model[2]	Fuel[3,4]	After-treatment[5,6]
LNG 01	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst
LNG 02	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst
LNG 03	2005	2004+ on-road	Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst
UTR 117	2001	Tier 1 off-road	Cummins 8.3L 6CT, 215 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 118	2001	Tier 1 off-road	Cummins 8.3L 6CT, 215 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 125	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 126	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 129	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 130	2003	Tier 2 off-road	Cummins 8.3L 6CT, 205 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 140	2005	2004+ on-road	Cummins 5.9L ISB, 245 hp	O_2Diesel™, ULSD	DOC + CCV
UTR 141	2005	2004+ on-road	Cummins 5.9L ISB, 245 hp	O_2Diesel™, ULSD	DOC + CCV

Notes:

1. UTR ID is the utility tractor rig identification number, an internal LBCT designation.

[19] O_2Diesel™ is a trademark of O2Diesel Corporation.

2. The vehicle make and model for all test vehicles including the LNG yard hostlers is the Ottawa Commando 50 4x2 Off-Road Terminal Tractor.
3. O_2Diesel™ was used during in-use performance testing of the diesel yard hostlers at LBCT.
4. ULSD was used during chassis dynamometer emissions testing of a subgroup of the diesel yard hostlers by UCR CE-CERT.
5. Exhaust aftertreatment on all LNG yard hostlers consisted of a 2-way oxidation catalyst provided as standard equipment by the natural gas engine original equipment manufacturer (OEM), Cummins Westport, to reduce carbon monoxide and hydrocarbons.
6. Exhaust aftertreatment on all diesel yard hostlers consisted of a diesel oxidation catalyst (DOC) and closed crankcase ventilation (CCV) for PM reduction.

2.4 Yard Hostler Operations

Yard hostlers activities generally fall into three main categories: ship work, rail work and dock work. Ship work involves loading and unloading containers to/from cargo ships. Rail work involves loading and unloading containers to/from cargo trains. Dock work (also called yard work) involves moving containers within the yard, e.g., for purposes of consolidation. Yard hostlers operate two eight-hour shifts per day, seven days a week, however not all kinds of yard hostlers activities are performed each day and each shift.

During the performance testing period, every attempt was made to subject the LNG yard hostlers to the same type of conditions and tasks as the baseline group of diesel yard hostlers. For this reason, two of the LNG yard hostlers were assigned to ship/rail work while the remaining LNG yard hostlers was dedicated to dock work. Within the baseline group of diesel yard hostlers, six of the vehicles were assigned to ship/rail work while the remaining two vehicles were dedicated to dock work.[20]

Most of LBCT's yard hostler drivers are hired from the local union on a short-term basis (typically 1 – 5 days). In order to avoid the potential need for daily LNG yard hostler driver training, LBCT arranged to hire monthly LNG yard hostler drivers from the local union. The monthly drivers were trained in LNG yard hostler operation at the beginning of the month and thereafter assigned to a specific LNG yard hostler for the duration of the month. Each month, a total of four monthly drivers were hired and assigned to two of the LNG yard hostlers: two for day shift and two for second shift. In addition, two "regular" LBCT drivers were assigned to the remaining LNG yard hostler: one for day shift and one for second shift. In keeping with normal LBCT operations, daily drivers were used for the eight diesel yard hostlers in the baseline comparison group.

A summary of yard hostler work and driver assignments is shown in Table 2.

Table 2 – Yard Hostler Work and Driver Assignments

UTR ID	Type of Vehicle	Work Assignment	Drivers[1]
LNG 01	LNG	Dock	"Regular"
LNG 02	LNG	Ship/Rail	Monthly

[20] UTRs 129 and 130 were added to the baseline comparison group in November, 2006 when it was discovered that none of the original baseline diesel yard hostlers had been assigned to dock work.

LNG 03	LNG	Ship/Rail	Monthly
UTR 117	Diesel	Ship/Rail	Daily
UTR 118	Diesel	Ship/Rail	Daily
UTR 125	Diesel	Ship/Rail	Daily
UTR 126	Diesel	Ship/Rail	Daily
UTR 129	Diesel	Dock	Daily
UTR 130	Diesel	Dock	Daily
UTR 140	Diesel	Ship/Rail	Daily
UTR 141	Diesel	Ship/Rail	Daily

Notes:

1. In general, there were two drivers per vehicle per day: one on day shift and one on second shift.

2.5 LNG Refueling Infrastructure

Temporary LNG refueling infrastructure was arranged at LBCT to refuel the LNG yard hostlers during the eight-month performance testing period. The primary piece of LNG refueling infrastructure equipment was a 3,450 gallon capacity ORCA™ mobile LNG refueling truck manufactured by NexGen Fueling™ and leased from Applied LNG Technologies (ALT).[21,22] The ORCA was parked in a fixed location for the duration of the performance testing period and was effectively treated as a "fixed" piece of LNG refueling infrastructure", i.e., LNG vehicles were driven to the ORCA for refueling.

In order to conform with local permitting requirements, the ORCA was inspected for electrical safety by an approved independent testing agency. As a result of this inspection, several minor electrical modifications were made to the ORCA at which time approval was given and a permit for the equipment was granted.

ALT was contracted to provide bulk LNG fuel deliveries for the project. Approximately once each month, ALT made a bulk fuel delivery to LBCT to "top off" the ORCA. A complete record of LNG bulk fuel deliveries during the eight-month performance testing period is shown in Appendix C.

2.6 Training

Prior to deployment of the LNG yard hostlers at LBCT, various types of training were provided to LBCT staff. LBCT management was provided with a basic understanding of LNG, an overview of the project and the expected impact on terminal operations during the demonstration phase of the project. LNG yard hostler drivers were provided with training to familiarize themselves with the minor differences between the LNG yard hostlers and typical diesel yard hostlers. LBCT maintenance personnel were instructed in routine service for the LNG yard hostler's natural gas engine and LNG refueling system components. Since maintenance staff were responsible for refueling the LNG yard hostlers, they were also trained in ORCA operation and LNG refueling procedures.

[21] NexGen Fueling™ is a division of Chart Industries, Inc. which manufactures LNG/CNG fueling stations, onboard LNG fueling systems and components, and other LNG-related products.

[22] In 2006 ALT was acquired by Apollo Resources-Earth Biofuels and is now operated by their Earth LNG business unit.

3 Performance Testing Results

This section describes the individual elements of the test program. Topics covered include the purpose of each test, a brief description of the test procedure, a summary of test results and any conclusions that may be reasonably drawn from the data.

3.1 Fuel Economy

3.1.1 Purpose

The purpose of fuel economy testing was to compare average fuel economy for the LNG vs. diesel yard hostlers during in-use operations. Due to the nature of the yard hostler duty cycle, fuel economy is normally measured in gallons/hour (gal/hr) rather than miles per gallon (mpg). Since LNG has a lower energy content per gallon than diesel, a conversion from LNG gallons to diesel gallon equivalents (DGEs) must be applied to the results in order to make a direct comparison.[23]

3.1.2 Procedure

Fuel economy testing was performed by collecting data on daily fuel usage vs. hours of engine operation for all test vehicles during the eight-month performance testing period. Data collection was performed manually using LNG and diesel fueling log sheets filled out each day by LBCT refueling staff.

Diesel yard hostler refueling was performed by dedicated LBCT refueling staff at the end of each day after second shift. LNG yard hostler refueling was normally performed by LBCT maintenance staff at the beginning of each day prior to day shift.[24] At LBCT, diesel yard hostler refueling is normally performed via “wet hosing”, (i.e., refueling via a mobile refueling truck). Due to the restrictions imposed by the temporary LNG refueling infrastructure permit at LBCT, the LNG yard hostlers could not be “wet hosed” and were instead driven to to the ORCA which was operated as a “fixed” piece of refueling infrastructure during the performance testing period.

3.1.3 Results

A summary of the average monthly fuel economy in gallons per engine operating hour (gal/hr) for all test vehicles is shown in Table 3 below. A summary of 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.

[23] Based on energy content, 1.73 gallons of LNG is generally considered 1 Diesel Gallon Equivalent (DGE). This assumes that on average, 1 gallon of LNG contains about 75,000 British Thermal Units (BTUs) and 1 gallon of diesel contains about 129,800 BTUs.

[24] Anecdotal reports from maintenance personnel indicate that there were isolated instances of LNG yard hostlers that ran out of fuel before the end of second shift and had to be refueled but this was not the general case. Unfortunately records of these events were not kept so a quantitative analysis is impossible.

Table 3 – Summary of Average Yard Hostler Fuel Economy By Month

	June '06	July '06	Aug. '06	Sept. '06	Oct. '06	Nov. '06	Dec. '06	Jan. '07	*Average*
LNG									
LNG 01	3.2	4.6	4.6	3.7	4.6	6.1	3.7	3.1	*4.2*
LNG 02	3.6	3.1	3.9	3.5	3.9	3.4	4.1	3.6	*3.6*
LNG 03	3.2	3.5	4.2	4.0	3.3	3.8	3.9	3.4	*3.7*
Diesel									
UTR 117	1.9	2.0	1.8	1.6	1.7	1.8	1.5	1.8	*1.8*
UTR 118	1.4	1.1	1.6	1.5	1.4	1.5	1.5	1.7	*1.5*
UTR 125	1.4	1.4	1.5	1.6	1.7	1.7	N/A	N/A	*1.6*
UTR 126	1.8	1.5	1.6	1.6	1.3	1.8	1.7	1.6	*1.6*
UTR 129	N/A	N/A	N/A	N/A	N/A	2.2	2.3	2.7	*2.4*
UTR 130	N/A	N/A	N/A	N/A	N/A	2.9	1.4	2.2	*2.2*
UTR 140	1.7	1.6	1.9	1.7	1.5	1.7	1.7	1.9	*1.7*
UTR 141	1.7	1.9	1.8	2.1	1.5	1.7	1.7	1.9	*1.8*

Notes:

1. All fuel economy figures are given in gal/hr.
2. UTR 125 was out of service during December, 2006 and January, 2007.
3. Data collection for UTRs 129 and 130 did not begin until November, 2006.

Table 4 - Summary of Yard Hostler Fuel Consumption Per Month

	June '06	July '06	Aug. '06	Sept. '06	Oct. '06	Nov. '06	Dec. '06	Jan. '07	*Total*	*Average*
LNG										
LNG 01	35.2	273.4	576.9	107.3	269.6	122	119.4	165.5	*1669.3*	*208.7*
LNG 02	93.2	457.2	201.8	648.6	648.8	120.4	532.6	302.1	*3004.7*	*375.6*
LNG 03	344.1	476.2	704.4	699.3	476.2	281.8	642.7	342.4	*3967.1*	*495.9*
Diesel										
UTR 117	109.3	112.6	99.4	154.4	212	146.1	100.3	143.2	*1077.3*	*134.7*
UTR 118	68.5	59	165.1	120.7	82	85.2	76.3	180.7	*837.5*	*104.7*
UTR 125	136.1	250.6	251.3	171.2	330	241.1	N/A	N/A	*1380.3*	*230.1*
UTR 126	141.4	302.7	258.8	315.4	273.9	218.5	255.5	263.9	*2030.1*	*253.8*
UTR 129	N/A	N/A	N/A	N/A	N/A	91.4	54.6	8	*154*	*51.3*
UTR 130	N/A	N/A	N/A	N/A	N/A	46.6	73.1	82.5	*202.2*	*67.4*
UTR 140	177.5	337.3	336.9	312.8	370	340.9	290.9	377.3	*2543.6*	*318*
UTR 141	142.4	312.4	313.3	246.6	325.4	222	200	122.1	*1884.2*	*235.5*

Notes:

1. All fuel consumption figures are given in gal/month.
2. UTR 125 was out of service during December, 2006 and January, 2007.
3. Data collection for UTRs 129 and 130 did not begin until November, 2006.

Table 5 – Summary of Yard Hostler Engine Operating Hours Per Month

	June '06	July '06	Aug. '06	Sept. '06	Oct. '06	Nov. '06	Dec. '06	Jan. '07	*Total*	*Average*
LNG										
LNG 01	11	59	125	26	58	19	32	54	*384*	*48*
LNG 02	26	146	52	162	166	34	131	83	*800*	*100*
LNG 03	106	138	166	174	146	71	164	100	*1065*	*133.1*
Diesel										

UTR 117	58	56	56	98	125	82	65	79	*619*	*77.4*
UTR 118	50	52	101	82	57	56	51	107	*556*	*69.5*
UTR 125	95	182	163	105	196	142	N/A	N/A	*883*	*147.2*
UTR 126	80	197	165	202	211	123	151	163	*1292*	*161.5*
UTR 129	N/A	N/A	N/A	N/A	N/A	42	24	3	*69*	*23*
UTR 130	N/A	N/A	N/A	N/A	N/A	16	54	37	*107*	*35.7*
UTR 140	104	216	178	188	244	198	169	203	*1500*	*187.5*
UTR 141	84	165	175	119	212	130	120	64	*1069*	*133.6*

Notes:

1. UTR 125 was out of service during December, 2006 and January, 2007.
2. Data collection for UTRs 129 and 130 did not begin until November, 2006.

3.1.4 Data Collection Issues

There were some issues regarding the reliability and accuracy of the raw fuel economy data collected for both the diesel and LNG yard hostlers. Examples of these issues include numerous instances of missing or obviously inaccurate data discovered in the fueling logs over the course of the eight-month performance testing period. In addition, unrecorded incidents of fueling and de-fueling connected with service actions may have also inadvertently contributed to data quality issues. As these issues were identified during analysis of the data, follow-up investigations usually resulted in correction of erroneous data, reasonable estimation of missing data or modifications to LBCT data collection procedures. Despite the fact that the data was less than perfect, when viewed as a whole the project team believes that it yields a reasonably accurate values for the average fuel economy of diesel and LNG yard hostlers.

3.1.5 Conclusions

Based on the data collected during the project, the average fuel economy for the eight diesel yard hostlers over the eight-month performance testing period was approximately 1.7 gal/hr with a standard deviation of 0.35 gal/hr. By comparison, the average fuel economy for the three LNG yard hostlers was approximately 3.8 gal/hr with a standard deviation of 0.65 gal/hr. The ratio of average LNG fuel economy to average diesel fuel economy is therefore 2.2:1. Converting LNG gallons into DGEs yields a ratio of 1.3:1.[25] In other words, the LNG yard hostlers use about 30% more DGEs than the diesel yard hostlers. This result is consistent with expectations for the relative efficiency of a heavy-duty spark-ignited natural gas engine compared to a compression-ignited diesel engine under light-loading conditions such as would be experienced in the yard hostler duty cycle.[26]

Fuel economy calculations were based on the assumption that all average monthly fuel economies are weighted equally. 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.

[25] As previously footnoted, there are approximately 1.73 gallons of LNG per DGE. Converting 3.8 gallons of LNG to DGEs therefore yields 3.8/1.73 = 2.2 DGEs. The ratio of average LNG DGEs/hr to average diesel gallons/hr is therefore 2.2:1.7 = 1.3: 1.

[26] Telephone conversation with Scott Baker of Cummins Westport, May, 2007.

3.2 Operator Acceptance

3.2.1 Purpose

The purpose of operator acceptance testing was to assess drivers' impressions of the performance of the LNG yard hostlers during in-use operations compared to typical diesel yard hostlers. Due to the subjective nature of driver impressions, a simple, relative rating scheme of "better", "same" or "worse" was used to compare LNG yard hostler performance characteristics to those of a typical diesel yard hostler.

3.2.2 Procedure

Operator acceptance testing was performed via a survey that the LNG yard hostler drivers were asked to fill out at the end of each month. In order to evaluate feedback from as many drivers as possible, LBCT made efforts to recruit different monthly drivers from the union each month (although this was not entirely in their control). In theory there should have been six driver surveys filled out each month corresponding to the day and second shift drivers for each of the three LNG yard hostlers. (Note that the two regular LNG yard hostler drivers at LBCT were also asked to fill out driver surveys at the end of each month.) For various reasons, however, not all LNG yard hostler drivers filled out surveys each month.

A one-page LNG driver survey form was developed based on input from multiple sources including LBCT staff. The survey questions were designed to cover key vehicle performance areas and other characteristics of the vehicle that would directly affect the driver. The survey contained a total of fourteen (14) questions and a space for drivers to record additional comments if they so desired. (Some drivers provided a page or more of typewritten comments.) The specific areas covered by the LNG 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

A copy of the LNG Driver Survey form is included in Appendix A.

3.2.3 Results

A summary of LNG driver survey results is provided in Table 6. A total of thirty (30) LNG driver surveys were filled out during the eight-month performance testing period. Results for each of the fourteen (14) items in the survey are expressed as percentages of the total responses for each of the three possible ratings ("better", "same" or "worse") . Driver survey results for each month can be found in Appendix A.

Table 6 - Summary of LNG Driver Survey Results

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability for connection to chassis	53%	44%	3%
2. Pulling power with full container	23%	67%	10%
3. Acceleration with no container	30%	50%	20%
4. Smoothness of shifting under acceleration	43%	54%	3%
5. Steering (turning radius, ease of parking, negotiating tight places and steering effort)	83%	14%	3%
6. In-cab visibility (no blind spots, rear view)	43%	57%	0%
7. Ride comfort (vibration and shocks, feel of seat)	77%	23%	0%
8. In-cab controls (convenience & functioning of switches, controls, etc.)	43%	57%	0%
9. Braking (stops load quickly and smoothly)	53%	47%	0%
10. Interior noise level	87%	13%	0%
11. Exterior noise level	80%	20%	0%
12. HVAC system (heating, ventilation, A/C)	43%	54%	3%
13. Cab entry and exit	23%	30%	47%
14. Overall vehicle rating	67%	30%	3%

3.2.4 Additional Driver Comments

A total of twenty-one (21) drivers provided additional comments. Comments ranged from a few words to one or more typewritten pages on a variety of subjects. Comments were grouped into three basic categories—Performance, Comfort and Convenience, and Safety. Individual items within each category were further categorized as either positive or negative depending on the nature of the comment. Many of the same comments appeared several times indicating a common perception or experience among different drivers. A summary of driver comments arranged by category and frequency of occurrence is provided below. (The number in parentheses indicates the number of times that comment was received.)

Performance

- Good truck! (9)
- Accelerates slowly/hesitates (6)
- Quieter than diesel truck (4)
- Poor engine operation when fuel level is low (4)
- Poor engine operation in general including engine shutdowns (3)
- Problems with automatic transmission shifting (3)

- Handles well/good maneuverability (2)
- Poor engine operation with low fuel pressure (2)
- Poor engine operation during hard deceleration (1)
- Soft brakes (1)
- Poor vehicle reliability (1)

Comfort and Convenience

- Inconvenient cab entry/exit (7)
- Needs air conditioning[27] (7)
- Needs better LNG fuel gauge[28] (2)
- Suggest keeping emergency radio in cab (2)
- Needs fish-eye mirror to improve visibility (1)

Safety

- Methane detection alarm inaudible[29] (2)
- Multiple unexplained incidents of chassis wheel lockup (1)
- LNG safety concerns based on LNG odor in truck[30] (1)

3.2.5 Conclusions

Based on the driver surveys, 97% of the drivers found the LNG yard hostlers to have the same or better performance than traditional diesel yard hostlers with 67% rating them as superior in general. A positive overall impression of the LNG yard hostler was also the most frequently cited comment in the additional comments provided by drivers. The features of the LNG yard hostlers most consistently rated better than the diesel yard hostlers were steering, ride comfort and interior/exterior noise levels. Of these, interior and exterior noise levels are most directly related to the operation of the LNG engine. A number of drivers also emphasized the relative quietness of the LNG yard hostlers in their comments.

The only feature of the LNG yard hostlers frequently rated as worse than diesel yard hostlers was cab entry and exit, however this is a mechanical design issue related to the placement of the LNG fuel tank and not a performance issue. Despite the overall positive results of the survey regarding the performance of the LNG yard hostlers, some drivers cited slow acceleration, vehicle "hesitiation" and problems with shifting of the automatic transmission in their comments.

It is interesting to note that the majority of drivers rated the LNG yard hostlers superior despite the fact that some of their comments indicated serious (if not necessarily frequent) problems with the vehicles. Of particular interest are the comments regarding poor engine operation under various conditions including unexpected vehicle shutdown. Given the prototype nature of the

[27] Note that the baseline diesel yard hostlers at LBCT do not have air conditioning and hence the LNG yard hostlers are no different in this respect.
[28] Problems with the accuracy and reliability of the LNG fuel gauges in the cabs are discussed in section 4.
[29] While there were no reports of the methane detection alarms being triggered, the systems included a manual self-test feature similar to a smoke alarm. Some drivers noted that the alarm level during the self-test was so low that they would not be able to hear it if it were triggered during actual vehicle operation.
[30] This comment is assumed to be invalid since LNG is odorless.

vehicles, however, it is assumed that these kind of problems would be resolved by the manufacturer prior to production.[31] Likewise, other obvious issues such as difficulty in hearing the methane detection alarm and placement of the cab entry/exit would also be addressed prior to production.

3.3 Service and Maintenance

3.3.1 Purpose

The purpose of collecting service and maintenance data was to assess the reliability, maintainability and serviceability of the LNG yard hostlers compared to typical diesel yard hostlers. One of the primary metrics used for this assessment was vehicle availability. Yard hostlers are the workhorse of cargo handling operations and container terminal operators rely on them being available a high percentage of the time. In addition, LBCT mechanics were asked to provide subjective feedback on various service and maintenance aspects of the LNG yard hostlers compared to diesel yard hostlers.

3.3.2 Vehicle Availability

3.3.2.1 Procedure

Vehicle availability was defined as the percentage of full days each month that a particular vehicle was available to be used. Vehicles undergoing routine maintenance or being repaired were considered “unavailable” until they were put back into service. Vehicle availability was tracked via a combination of methods including:

- Notes in the LNG and diesel fueling logs
- LBCT vehicle maintenance and service records
- E-mails sent by LBCT maintenance staff

Vehicle availability was determined by cross-referencing the above information for each vehicle in the test group on a monthly basis.

Routine preventative maintenance actions (e.g., oil changes, engine tune-ups, etc.) were performed by LBCT maintenance staff according to the manufacturer’s recommended schedule. For off-road engines, preventative maintenance is scheduled every 300 engine operating hours. For on-road engines, preventative maintenance is scheduled every 500 engine operating hours. LBCT maintenance staff document all yard hostler routine preventative maintenance on Equipment Repair Report (ERR)/Preventative Maintenance (PM) forms which are saved in vehicle maintenance files. Any non-routine service actions performed by LBCT maintenance staff are also documented on ERRs. Copies of the ERR/PM forms for the LNG and baseline

[31] It should be noted that Westport Innovations made a major upgrade to the vehicle’s LNG fuel delivery system in October and November, 2006 to address vehicle performance issues associated with low LNG fuel pressure. Preliminary data indicates that the upgrade was effective in resolving at least some of the vehicle performance problems although further testing is necessary to draw definitive conclusions.

diesel yard hostlers during the performance testing period were provided to CALSTART by LBCT.

Yard hostler repairs under warranty are normally performed by Cal-Lift, the local distributor for Kalmar yard hostlers. Given the specialized nature of the LNG components and subsystems, EnviroMech Industries was contracted to provide warranty service for LNG-related issues on the LNG yard hostlers. According to LBCT service procedures, an Equipment Repair Report (ERR) is supposed to be filled out by maintenance personnel for all yard hostler warranty work and the ERR forms are saved in vehicle maintenance files. Copies of the ERR forms for the LNG and baseline diesel yard hostlers during the performance testing period were provided to CALSTART by LBCT.

3.3.2.2 Results

A summary of LNG and diesel yard hostler availability is provided in Table 7.

Table 7 - Summary of Average Yard Hostler Availability by Month

	June '06	July '06	Aug. '06	Sept. '06	Oct. '06	Nov. '06	Dec. '06	Jan. '07	*Average*
LNG									
LNG 01	100%	100%	93.5%	63.3%	93.5%	100%	100%	100%	*93.8%*
LNG 02	94.7%	100%	41.9%	100%	93.5%	100%	100%	100%	*91.3%*
LNG 03	100%	100%	93.5%	100%	93.5%	100%	100%	100%	*98.4%*
Diesel									
UTR 117	100%	96.8%	67.7%	100%	100%	96.7%	100%	100%	*95.2%*
UTR 118	100%	100%	96.8%	96.7%	100%	100%	96.8%	100%	*98.8%*
UTR 125	94.7%	100%	96.8%	100%	96.8%	93.3%	N/A	N/A	*96.9%*
UTR 126	94.7%	100%	96.8%	100%	93.5%	93.3%	100%	100%	*97.3%*
UTR 129	N/A	N/A	N/A	N/A	N/A	96.7%	100%	100%	*98.9%*
UTR 130	N/A	N/A	N/A	N/A	N/A	100%	100%	100%	*100%*
UTR 140	100%	100%	96.8%	100%	96.8%	100%	100%	100%	*99.2%*
UTR 141	100%	100%	96.8%	96.7%	100%	96.7%	100%	100%	*98.8%*

Notes:

1. UTR 125 was out of service during December, 2006 and January, 2007 due to problems associated with implementation of a new container tracking system.
2. Data collection for UTRs 129 and 130 did not begin until November, 2006.

3.3.2.3 Data Collection Issues

Cross-referencing of the notes in the fueling logs with maintenance records and e-mail communications with maintenance staff revealed many discrepancies and conflicts in the data regarding vehicle availability. For example, in those cases where the driver reported a problem with the vehicle to maintenance staff, an ERR was only filled out if the problem could be duplicated by maintenance staff. Due to the transient nature of many of the LNG fueling system problems, maintenance was often unable to duplicate the problem and the vehicles were returned to service with no documentation that they had been out of service. Likewise it was discovered that ERRs were generally only filled out by maintenance staff for routine preventative maintenance actions. In addition, engine operating hours data in the PM forms sometimes contradicted data collected directly from the vehicles. It was also noted that the documentation of several EnviroMech service actions on the LNG yard hostlers was incomplete. Follow-up investigations allowed at least partial resolution of many of these issues. Overall the vehicle availability figures should be representative although there is a possibility that actual availability figures may be slightly lower than reported for the LNG yard hostlers.

3.3.2.4 Conclusions

Based on the data collected during the project, the average availability of the eight diesel yard hostlers over the eight-month performance testing period was 97.9%. By comparison, the average availability of the three LNG yard hostlers was 94.5%. (Due to problems noted with data collection, the actual vehicle availability of the vehicles may have been slightly lower than reported, especially for the LNG yard hostlers.)

While the LNG yard hostlers availability was slightly lower than the diesel yard hostlers, overall the results were quite good, especially considering that the LNG yard hostlers were prototypes. It is believed that problems with the LNG fueling system during the first five months of the program were responsible for many of the instances where the LNG vehicles were unexpectedly removed from service. Following a major LNG fueling system upgrade by Westport Innovations in October, 2006, availability of the LNG yard hostlers during the last three months of the program appeared to be similar to the availability of the diesel yard hostlers during that time (although there is insufficient data to draw conclusions).

3.3.3 LNG Mechanic Survey

3.3.3.1 Procedure

LBCT mechanics working on the LNG yard hostlers were asked to fill out a survey at the end of the performance testing period to solicit their feedback regarding maintainability and serviceability aspects of the LNG yard hostlers compared to typical diesel yard hostlers. The survey questions were designed to cover those aspects of the vehicle design and support that would directly affect the mechanic. The survey contained a total of six 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 total of seven mechanics filled out the survey at the conclusion of the performance testing period. The specific areas covered by the survey included:

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

A copy of the LNG Mechanic Survey form is included in Appendix B.

3.3.3.2 Results

A summary of LNG mechanic survey results is provided below. A total of seven LNG driver surveys were filled out by LBCT mechanics who worked on the LNG yard hostlers during the eight-month performance testing period.

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

Responses to Question 1 (including the frequency of each response in parentheses) are summarized as follows:

- LNG pressure regulation problems/leaks (6)
- LNG fuel gauges inaccurate – problem never resolved. (2)

Questions 2 – 5 of the survey asked the mechanic to rate various maintenance and service characteristics of the LNG yard hostlers on a scale of one to five where 1 was "unacceptable" and 5 was "excellent". A summary of the responses is given in Table 8.

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

LNG Mechanic Survey Question	*Average Rating*
2. LNG systems and component training	3.1
3. Design for maintainability	3.1
4. Design for serviceability	3.1
5. Manufacturer support	3.4

Question 6 of the survey was: *"Describe any trends observed regarding non-routine service actions associated with the LNG yard hostlers including the long-term effectiveness of corrective actions:"*

Responses to Question 6 (including the frequency of each response in parentheses) are summarized as follows:

- LNG fuel gauge problems not resolved (2)
- LNG pressure regulation/leaking problems not resolved (1)
- LNG fuel delivery system icing noted (1)

Question 7 of the survey provided a space for additional comments however there were no additional comments from the mechanics who filled out the survey.

3.3.3.3 Conclusions

Based on the mechanic surveys, 100% of the mechanics gave the LNG yard hostlers a rating of "acceptable" or better regarding LNG training, maintainability, serviceability and manufacturer support. According to LBCT maintenance records, LBCT mechanics did perform routine maintenance on the LNG yard hostlers several times during the eight-month performance testing period which would provide some basis for comparisons with routine maintenance of diesel yard hostlers. It should be noted that LBCT mechanics were not responsible for service actions on the LNG yard hostlers beyond routine maintenance.

The fact that six out of the seven mechanics who filled out the survey noted LNG pressure regulation and leaking problems with the vehicles during the initial phases of the project is significant and indicates that the problem was common. Westport Innovations in particular devoted a large amount of effort into addressing these problems which resulted in a major vehicle LNG fueling system upgrade in October and November, 2006. While this upgrade was effective in eliminating the low fuel pressure faults detected by the vehicle engine control module (ECM) under certain operating conditions, the relatively short data collection period after the upgrade did not provide sufficient data to conclude whether the upgrade adequately resolved all fueling system problems noted by drivers and mechanics. Further testing would be required to properly evaluate the long-term effectiveness of the LNG fueling system upgrade implemented in the latter stages of the project.

The problem noted with the accuracy of the LNG fuel level gauges in the cabin is a common problem in the LNG industry. It is assumed that these problems arise from the difficulty in measuring total energy content of the multiple phases (liquid and gaseous) and pressures of LNG over time when stored in LNG fuel tanks. At present, it does not appear that an effective solution for this problem has been implemented for heavy-duty LNG vehicles. As a result, the LNG fuel gauges in the vehicle cabin were taped over approximately two months into the project in order to prevent drivers and mechanics from acting on unreliable data.

3.4 Emissions

3.4.1 Purpose

The primary goal of emissions testing was to compare relative emissions of criteria pollutants from the LNG yard hostlers with those of the engine configurations represented by the diesel yard hostlers in the test group.[32] A secondary goal of emissions testing was to quantify yard hostler emissions during in-use operations for both the LNG and diesel test vehicles. In order to achieve the first goal within budget and schedule constraints, steady-state emissions testing was performed at the chassis level. In-use emissions testing was proposed to achieve the second goal however this approach was ultimately rejected due to objections regarding the lack of sufficient controls to ensure reproducibility of results.

3.4.1.1 Steady-State Vs. In-Use Emissions Testing

Emissions certification of heavy-duty engines is normally performed using an engine dynamometer where the engine is not physically connected to a vehicle. The U.S. EPA and the California Air Resources Board (CARB) have approved use of steady-state emissions testing based on the ISO 8178-C1 8-mode cycle for emissions certification of heavy-duty off-

[32] Given that GHG emissions are not currently regulated, there was no specific testing performed to determine the relative GHG emissions of LNG yard hostlers vs. diesel yard hostlers.

road/nonroad engines.[33] For heavy-duty on-road engines, emissions certification is performed using the Federal Test Procedure (FTP) heavy-duty transient engine dynamometer cycle.[34] In order to make an "apples-to-apples" comparison, it was necessary to test all vehicles using the same emissions testing protocol and cycle. After reviewing several options, it was decided that steady-state emissions testing using the ISO 8178-C1 8-mode cycles was the best choice. The primary driver for this decision was that CARB had previously used this cycle to test emissions of a number of yard hostlers at POLA and this would allow for a direct comparison of LBCT's LNG and diesel yard hostler emissions to that data.[35] One major modification to the ISO-8178-C1 test protocol was that the engine was tested as part of the vehicle rather than separately to avoid having to remove the engine from the vehicle. (This modified test protocol was also followed during the earlier CARB testing.)

3.4.2 Procedure

Steady-state emissions testing was performed by UCR CE-CERT in Riverside, California. A total of five vehicles were tested: one LNG yard hostler and four diesel yard hostlers.[36] The specific vehicles tested and their engine configurations are shown in Table 9 below.

Table 9 - Emissions Test Vehicles

UTR ID[1]	Test Dates	Certification Standard	MY/Engine Make/Model[2]	Test Fuel	After-treatment[3]	Comments
LNG 02	1/31/07 – 2/1/07	2004+ on-road	2005 Cummins Westport C-Gas Plus 8.3L, 250 hp	LNG	OEM 2-Way Catalyst	
UTR 117	1/31/07	Tier 1 off-road	2001 Cummins 8.3L 6CT, 215 hp	ULSD	DOC + CCV	Test Aborted[5]
UTR 118	12/14/06	Tier 1 off-road	2001 Cummins 8.3L 6CT, 215 hp	ULSD	DOC + CCV	Test Data Incomplete[4]
UTR 126	12/13/06	Tier 2 off-road	2003 Cummins 8.3L 6CT, 205 hp	ULSD	DOC + CCV	
UTR 141	12/15/06	2004+ on-road	2005 Cummins 5.9L ISB, 245 hp	ULSD	DOC + CCV	

Notes:

1. UTR ID is the utility tractor rig identification number, an internal LBCT designation.
2. The vehicle make and model for all test vehicles including the LNG yard hostlers is the Ottawa Commando 50 4x2 Off-Road Terminal Tractor.
3. Exhaust aftertreatment on all diesel yard hostlers consisted of a DOC and CCV for PM reduction.
4. UTR 118 was unable to generate full torque at rated speed so UTR 117 was tested to try to obtain complete data for the Tier 1 off-road engine configuration.
5. UTR 117 was also unable to generate full torque at rated speed and hence the test was aborted.

[33] International Standard Organization IS0 8178-4 *Reciprocating internal combustion engines - Exhaust emission measurement - Part 4:Test cycles for different engine applications*, First edition 1996-08-l 5. Note that the ARB 8-Mode Cycle is identical to the ISO 8178-C1 8-mode cycle.

[34] Code of Federal Regulations (CFR) Title 40, Part 86.1333.

[35] Cargo Handling Equipment Yard Truck Emission Testing, California Air Resources Board, September, 2006, http://www.arb.ca.gov/ports/cargo/documents/yttest.pdf..

[36] Only three diesel yard hostlers—corresponding to Tier 1 off-road, Tier 2 off-road and 2004+ on-road engine configurations—were originally intended to be tested. However a second Tier 1 off-road yard hostler (UTR 117) was tested after the first Tier 1 off-road yard hostler (UTR 118) failed to satisfy all of the steady-state mode (i.e. load vs. engine speed) requirements. Unfortunately the second Tier 1 off-road yard hostler (UTR 117) also failed to satisfy all of the steady-state mode requirements and hence the test was aborted.

The test vehicles were transported from LBCT to Johnson Machinery in Riverside, CA for testing on a heavy-duty chassis dynamometer located at the facility. Steady-state emissions testing was performed by UCR CE-CERT staff under the direction of Dr. Wayne Miller. Diesel yard hostlers were tested using an external supply of ULSD fuel to avoid letting the O_2Diesel™ in the diesel fuel tanks affect the emissions testing results. The LNG yard hostler was tested using the LNG that was in the fuel tank when the vehicle was delivered from LBCT. After load-mapping the engine for each vehicle, the 8-mode steady-state emissions test was performed twice to check the correlation between tests. Results for each vehicle were then reported as the average values of the two tests.

A detailed description of the steady-state emissions testing procedures can be found in "A Study of Emissions from Yard Tractors Using Diesel and LNG Fuels", by Dr. J. Wayne Miller, University of California, Riverside, College of Engineering, Center for Environmental Research and Testing, hereinafter referred to as the yard hostler emissions testing report.[37]

3.4.3 Results

3.4.3.1 Modal Emissions

A summary of the modal emissions for the Tier 1 and Tier 2 off-road diesel yard hostlers tested to completion are reproduced from the yard hostler emissions testing report in Figure 2. A summary of the modal emissions for the 2005 diesel and 2005 LNG on-road yard hostlers are reproduced from the yard hostler emissions testing report in Figure 3.[38] By agreement, PM emissions for the LNG yard hostler were not measured and are therefore not reported.[39] Note that emissions are reported in grams/wheel-horsepower-hour (g/whp-hr), not grams/brake-horsepower-hour (g/bhp-hr), due to the fact that testing was performed on a vehicle chassis dynamometer and horsepower was measured at the wheels rather than at the engine flywheel. While the exact relationship between g/whp-hr and g/bhp-hr depends on many factors, g/whp-hr are generally estimated to be about 25% higher than g/bhp-hr according to Dr. Miller. (The relationship between g/whp-hr and g/bhp-hr is discussed in much greater detail in the yard hostler emissions testing report.) A detailed discussion of modal emissions data can be found in the yard hostler emissions testing report.

[37] A Study of Emissions from Yard Tractors Using Diesel and LNG Fuels, Dr. J. Wayne Miller, University of California, Riverside, College of Engineering, Center for Environmental Research and Testing, August 28, 2007.
[38] The nomenclature used in labelling emissions figures is taken directly from the yard hostler emissions test report and can be slightly confusing. In general, "C" refers to an off-road 8.3L diesel engine, "ISB" refers to an on-road 5.9L diesel engine, and "CG" refers to an on-road 8.3L natural gas engine. Occasionally "CG250" is used for the on-road 8.3L natural gas engine, the "250" referring to the fact that the 8.3L natural gas engine is rated for 250 hp.
[39] Earlier LNG yard hostler emissions testing on identical engine configurations at POLA indicated PM emissions of approximately 0.008 g/whp-hr, well below the current standard of 0.01 g/bhp-hr. Based on this data, a decision was made to omit PM emissions testing for the POLB LNG yard hostlers in order to reduce overall emissions testing costs.

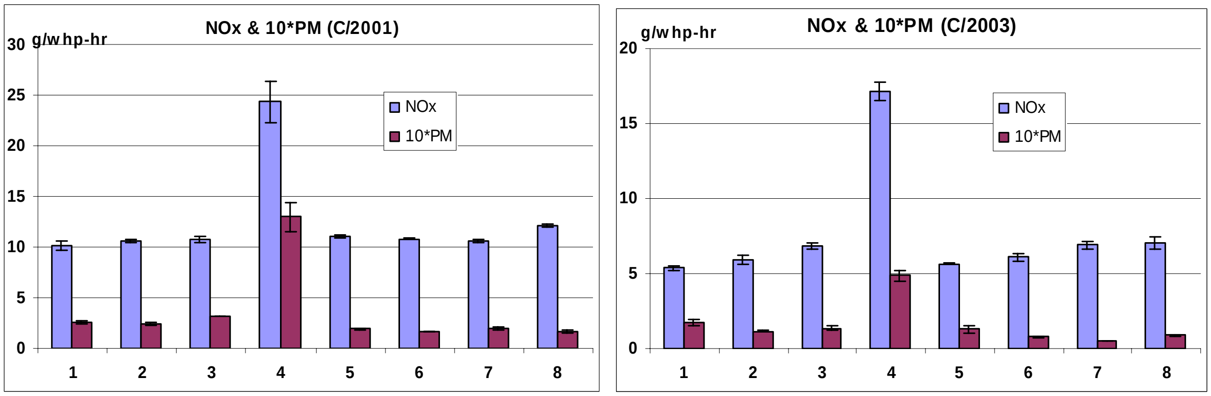

Figure 2 – Yard Hostler Modal Emissions in g/whp-hr for a) C/2001 (Tier 1) and b) C/2003 (Tier 2)

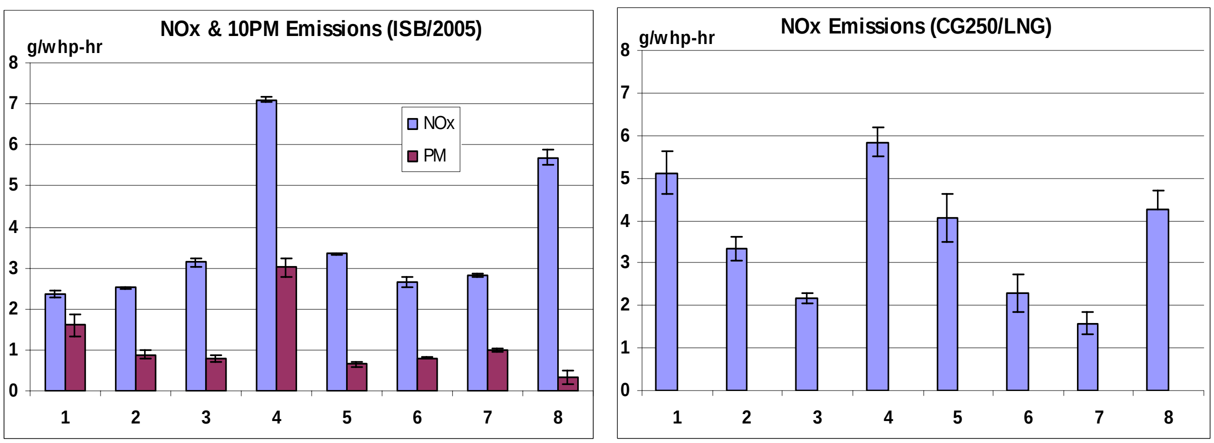

Figure 3 - Yard Hostler Modal Emissions in g/whp-hr for a) ISB/2005 and b) CG250/2005

3.4.3.2 Weighted Emissions Factors

A summary of the weighted emissions factors for the yard hostlers tested to completion are reproduced from the yard hostler emissions testing report in Table 10 below. Note that emissions factors are reported in g/whp-hr (vs. g/bhp-hr). According to estimates provided by Dr. Miller, g/whp-hr are approximately 25% higher than g/bhp-hr. Emissions factors are reported for all criteria pollutants including total hydrocarbons (THC), carbon monoxide (CO), NOx and PM as well as carbon dioxide (CO_2). Emissions factors for each vehicle are calculated by weighting the mean emissions data from the eight modes in the steady-state test. A detailed discussion of emissions factor calculations can be found in the yard hostler emissions testing report.

Table 10 - Yard Hostler Weighted Emissions Factors (g/whp-hr)

Engine Model - Year	*Emissions Certification*	*Weighted Emissions Factors (g/whp-hr)*				
		THC	*CO*	*NOx*	*PM*	*CO_2*
C8.3L – 2001	Tier 1 off-road	0.29	0.63	11.06	0.26	1013
C8.3L – 2003	Tier 2 off-road	0.16	0.24	6.28	0.13	815

ISB 5.9L – 2005	2004+ on-road	0.05	0.51	2.94	0.10	791
CG 8.3L – 2005	2004+ on-road	2.92	0.09	3.57	N/A	658

The relative weighted emissions factors for NOx and PM in g/whp-hr are reproduced from the yard hostler emissions testing report in Figures 4 and 5 below. As stated previously, PM emissions for the LNG yard hostler were not tested and are not therefore reported.

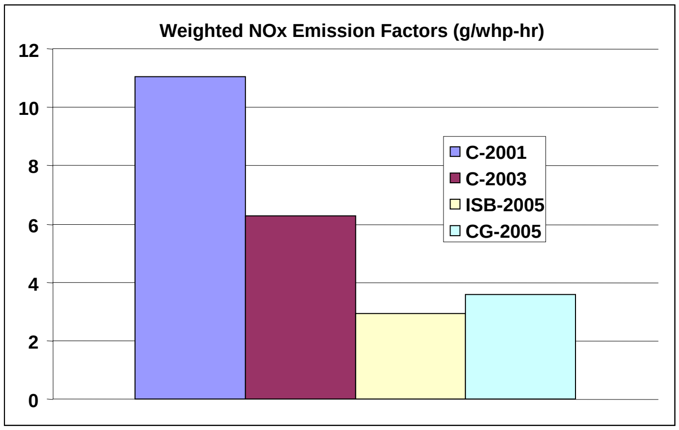

Figure 4 - Relative Weighted Emissions Factors for NOx (g/whp-hr)

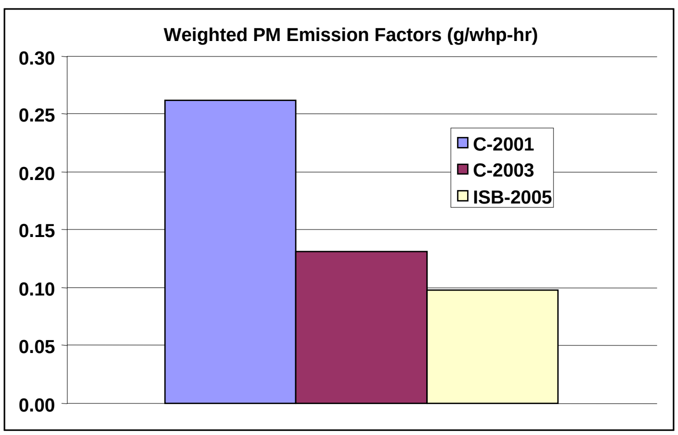

Figure 5 - Relative Weighted Emissions Factors for PM (g/whp-hr)

3.4.4 Conclusions

As expected, NOx and PM emissions decreased with increasingly stringent certification standards. Based on the steady-state emissions testing data, the lowest NOx emissions were produced by the 2005 on-road diesel vehicle. Due to the inherently low PM emissions of LNG engines, it is assumed that the lowest PM emissions were produced by the 2005 LNG vehicle. One unexpected result from emissions testing was that NOx emissions from the LNG yard hostler were approximately 21% higher than NOx emissions from the 2005 on-road diesel yard hostler. According to Dr. Miller at UCR, one possible explanation is that the LNG engine may be running lean at higher loads, thus leading to higher engine temperatures and higher NOx emissions. While this theory is supported by modal emissions data, it is only one of several possible explanations and the root cause for the higher NOx emissions remains unclear at this time. It should also be noted that all diesel off-road and on-road engine configurations tested included a DOC and CCV filter exhaust aftertreatment system for NOx and PM reductions.

Table 11 shows estimated NOx and PM emissions factors for the four test vehicles based on an assumed 25% loss in measured power between the engine and the wheels.[40] Table 10 also shows EPA heavy-duty engine emissions standards for NOx and PM as a reference. Readers should not draw conclusions based on comparisons between measured vehicle emissions factors vs. engine emissions standards due to the significant differences in testing procedures. As mentioned earlier, heavy-duty engines are certified on an engine dynamometer, not via vehicle-level testing on a chassis dynamometer. In addition, on-road engines are tested using a different test cycle (FTP heavy-duty transient engine dynamometer cycle) than off-road engines (ISO 8178-C1 8-mode cycle).

Table 11 - Estimated Yard Hostler NOx and PM Weighted Emissions Factors (g/bhp-hr)

Engine Model - Year	*Emissions Certification*	*Estimated Weighted Emissions Factors (g/bhp-hr)*		*EPA Standard (g/bhp-hr)*	
		NOx	*PM*	*NOx*	*PM*
C8.3L – 2001	Tier 1 off-road	8.84	0.21	6.90	0.41
C8.3L – 2003	Tier 2 off-road	5.02	0.10	4.95[1]	0.15
ISB 5.9L – 2005	2004+ on-road	2.35	0.08	2.4[1]	0.10
CG 8.3L – 2005	2004+ on-road	2.86	N/A	2.4[1]	0.10

Notes:

1. Emissions standard for combined NOx and non-methane hydrocarbons (NMHC).

During testing of UTR 118 (Tier 1 off-road engine configuration), it was discovered that it was not possible to obtain modal emissions data for some of the higher load points in accordance with the mode definitions in ISO 8178-C1. Emissions data was subsequently collected based on reduced loads at certain engine speeds. Based on the suspicion that there was a hardware problem with UTR 118 which prevented it from achieving all rated speed and load conditions, UTR 117 (which has the identical Tier 1 off-road engine configuration as UTR 118) was also tested. However load- mapping of UTR 117's engine revealed the same problem encountered with UTR 118 and testing of UTR 117 was aborted. The weighted emissions factors calculated for the Tier 1 off-road engine configuration are thus based on modified modal emissions data which is not in full accordance with the modes defined in ISO 8178-C1. It is believed that the resulting weighted emissions factors calculated for the Tier 1 off-road engine configuration are slightly lower than they would have been if modal emissions data had been collected in strict accordance with the engine speeds and loads specified in ISO 8178-C1.

For a detailed discussion of steady-state emissions testing results, refer to the yard hostler emissions testing report.

[40] Assumption of 25% loss in measured power between the engine and the wheels provided by Dr. J. Wayne Miller, UCR CE-CERT. According to Dr. Miller, the assumption is based on average efficiencies for the transmission and other drive train components and has proven to be reasonably accurate based on empirical observations.

4 Lessons Learned

This section describes insights and experience gained during the course of the LNG yard hostler demonstration project which we feel may be valuable to future LNG vehicle demonstration projects. Our goal in sharing this information is to make future projects aware of these issues so that they can be prepared to address them in advance where possible.

4.1 LNG Infrastructure Permitting

The time needed to obtain a permit from the Long Beach Fire Department (LBFD) to install a temporary LNG refueling infrastructure at LBCT (i.e., the ORCA) was significantly longer than anticipated. The permitting process was initiated in September, 2005 and permits were finally approved in May, 2006. LNG infrastructure permits must normally be approved by the local fire department, in this case LBFD. The requirements that LBFD levied during the course of their review process were much greater and more time-consuming than expected.[41] Based on our experience in this project, it is recommended that the permitting process be initiated as early in the project as possible in order to accommodate any unexpected delays encountered during the process.

4.2 Refueling Operations

Safety requirements for LNG refueling infrastructure are addressed by the National Fire Protection Association (NFPA) standard NFPA 57, Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code (2002). The code does not specifically prohibit mobile LNG refueling infrastructure however interpretation of the code is left to the local authority having jurisdiction, in this case LBFD. LBFD required that the temporary LNG refueling infrastructure at LBCT be essentially fixed in place. Since LBCT normally refuels its diesel yard hostlers via a mobile diesel refueling truck (i.e., “wet-hoses” the vehicles), LBCT maintenance staff were asked to drive the LNG yard hostlers to the LNG refueling station for refueling at the start of each day. This did not present a significant problem for the small number of LNG yard hostlers involved in this demonstration project but would have created logistical and labor issues for a much larger fleet of LNG yard hostlers. In the case of a fixed LNG refueling infrastructure, it would therefore make sense to set up refueling procedures to make LNG yard hostler refueling operations as efficient as possible and minimize any additional labor requirements. For example, the LNG yard hostler drivers could be instructed to drop off the LNG yard hostlers in a refueling queue area close to the LNG refueling station at the end of their shift and pick them up in the same general area at the start of their shift.

4.3 On-Vehicle LNG Fuel Gauges

[41] By contrast, the permitting process for identical temporary LNG refueling infrastructure at Yusen Terminals, Inc. (YTI) at POLA, which is under the jurisdiction of the Los Angeles Fire Department (LAFD), was completed in approximately six weeks. Clearly the amount of time to obtain permitting for a project can vary dramatically.

LNG exists as both a gas and a liquid in the on-vehicle LNG fuel tank and the proportion of each often varies with time and other conditions. For this reason, on-vehicle LNG fuel gauges have difficulty in measuring the precise amount of LNG fuel in a tank under all conditions which sometimes results in misleading LNG fuel level indications to the driver. During the first couple of months of the project, it was suspected that misleading LNG fuel gauges were sometimes causing drivers to either bring vehicles in early for refueling or run out of fuel while they were in the yard. We therefore made a decision to tape over the LNG fuel gauges in all of the LNG yard hostlers and maintain a strict once-a-day refueling regimen. Since the LNG fuel tanks had been sized to accommodate a full day (two eight-hour shifts) of normal operations, this procedure worked well in general and there were very few incidents where the vehicles ran out of fuel in the yard during the remainder of the project.

4.4 On-Vehicle LNG Fuel Delivery System Problems

Reports of noticeable power loss and occasional engine shut-off were investigated by Westport Innovations and led to the conclusion that the problems were caused by low fuel pressure in the LNG fuel delivery system. In particular, the on-vehicle ECM was consistently recording "Low Fuel Pressure" faults during certain operating conditions. Westport Innovations made significant modifications to the LNG fuel delivery systems in October and November, 2006 in order to resolve these issues. Since the demonstration project ended in January 2007, there was insufficient time to collect enough data to verify that the fueling system upgrades were effective in eliminating the power loss and engine shut-off problems and preliminary results were inconclusive. It was verified, however, that after the LNG fuel delivery system modifications were made, there were no further "Low Fuel Pressure" faults recorded by the on-vehicle ECM.

4.5 On-Vehicle LNG Fuel Tank Sizing

The fuel tanks on the LNG yard hostlers were sized to hold enough fuel for the yard hostlers to operate for a full LBCT workday (i.e., two eight-hour shifts) without refueling. Informal data collection at LBCT prior to the start of the demonstration indicated that average daily diesel yard hostler fuel consumption was approximately 20 – 25 diesel gallons/day. This was multiplied by a factor of 2 to estimate the requirements for an LNG fuel tank. (Note that actual data collected during the demonstration indicates that a factor of 2.2 is a more realistic ratio for sizing LNG fuel tank capacity requirements vs. diesel fuel tank capacity for the port yard hostler application). Adding in 10% reserve capacity for ullage and unexpected operating conditions, a 65-gallon tank was assumed to be sufficient.[42] However during the project, it was discovered that occasionally an LNG yard hostler would run out of fuel partway through the second shift of the day. Whether this was because the tank was sized too small, the vehicle had not been properly fueled, or low fuel pressure faults made the driver believe that the vehicle had run out of fuel is difficult to say. Being conservative, a slightly larger fuel tank would probably have reduced or eliminated the

[42] Due to the fact that LNG expands in volume with increasing temperature, an LNG container can never be 100% filled with liquid LNG. In California, the California Department of Occupation Health and Safety (CAL OSHA) Title 8 requires a minimum of 10% "ullage space" to be reserved for LNG expansion in a "full" LNG container.

occasional incidents of an LNG yard hostler running out of fuel in the yard (although there may be cost tradeoffs and mechanical packaging issues to consider with a larger LNG fuel tank).[43]

5 LNG Yard Hostler Business Case Assessment

5.1 Introduction

It is difficult to present a detailed business case for LNG yard hostlers for several reasons. First, LNG yard hostlers are not currently offered as a standard commercial product by any of the major yard hostler original equipment manufacturers (OEMs).[44] In addition, the Cummins Westport natural gas engines used in the LNG yard hostlers in this project are no longer commercially available and have been replaced by more advanced engines with different costs. There are further complications in that much of the detailed yard hostler cost and market information related to the business case is considered confidential information by several of the project stakeholders. Given these constraints, in this section of the report we will examine the major factors affecting the business case for LNG yard hostlers and attempt to draw some general conclusions.

Note that the scope of this business case analysis will be limited to off-road yard hostlers (vs. on-road yard hostlers) which include the vast majority of yard hostlers used in port applications.

5.2 Yard Hostler Markets

In addition to ports, the major applications for yard hostlers include distribution centers, the parcel and package delivery industry, and intermodal yards serving as junctions between rail and other forms of container transportation. Distribution centers are by far the largest application for yard hostlers and represent more than half of the yard hostler market. While ports contain the greatest concentrations of yard hostlers, they represent less than 10% of the total North American yard hostler market.[45]

Yard hostlers are similar in appearance and function across applications however vehicle specifications can vary between and within industries. The major yard hostler options include engine size, power rating and gross combined vehicle weight (GCVW) rating as necessary to meet the requirements of the industry and the particular customer. Yard hostlers are available in both off-road and on-road configurations with off-road being the dominant type sold. Off-road yard hostlers are also available with on-road engines.

[43] To accommodate the 65-gallon LNG fuel tank vs. the shorter 50-gallon diesel tank, Kalmar increased the wheelbase of the LNG yard hostlers from 116 inches to 132 inches. Note that the increased wheelbase length was not a factor during the demonstration and went largely unnoticed by the LNG yard hostler drivers.
[44] In practice, customer requests to purchase a "non-standard" yard hostler, such as an LNG yard hostler, would be evaluated by the yard hostler OEM on a case-by-case basis.
[45] References to the North American yard hostler market are limited to the U.S. and Canada only.

5.3 Vehicle Costs

5.3.1 Base Vehicle Costs

Depending on the vehicle options (including engine configuration) selected, a new diesel yard hostler typically costs between $65,000 and $80,000 excluding taxes and delivery. Due to differences in typical options and taxes associated with on-road vs. off-road vehicles, there is often no major cost difference between the total cost of off-road vs. on-road yard hostlers. However the incremental cost for an off-road yard hostler with an on-road engine is significant, adding about 10% to the vehicle price due to the higher cost of 2007 on-road engines vs. Tier 3 off-road engines.

In California, CARB regulations require new yard hostlers purchased or leased after January 1, 2007 to include either an on-road certified engine or a Tier 4 off-road certified engine.[46] (Note that off-road engines certified to Tier 4 are not expected to be available for purchase until 2011.[47]) Therefore in California, the base cost of a diesel yard hostler starting in 2007 is assumed to include an on-road certified engine. For the purposes of this analysis, the average cost of a new diesel yard hostler in California is assumed to be approximately $80,000.[48]

5.3.2 Incremental Vehicle Costs

As previously stated, LNG yard hostlers are not currently offered as a commercial product and therefore exact incremental costs for these vehicles are not known. However based on incremental costs of the LNG yard hostlers purchased for this project in 2005 as well as subsequent published interviews with the manufacturer, an incremental cost of 50% appears to be realistic in the near-term. Assuming an average base vehicle cost of $80,000 in California, the incremental cost for an LNG yard hostler *before tax credits and incentive programs* is assumed to be $40,000 excluding taxes and delivery.

5.4 Fuel Costs

5.4.1 Diesel Fuel Costs

The price of diesel fuel has varied considerably during the past several years but the general trend has clearly been towards higher prices. As of this writing, global fuel supply and prices are in a period of high volatility. Average prices for on-road diesel in California in September, 2007, during the middle of the demonstration period were $3.02/gallon including taxes.[49] The

[46] Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards, California Air Resources Board, www.arb.ca.gov/regact/cargo2005/revfro.pdf.
[47] For off-road diesel engines between 175 and 750 hp (which includes yard hostler applications), 100% of engines must meet the PM/CO standards starting in 2011, however compliance with the NOx/NMHC standards may be phased in such that 100% compliance is not required until 2014.
[48] Average diesel yard hostler cost outside California = ($65,000 + $80,000)/2 = $72,500. Average diesel yard hostler cost in California = $72,500 + 10% ~ $80,000.
[49] Energy Information Administration (EIA), Weekly Retail Gasoline and Diesel Prices, Sept. 19, 2007, http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_sca_w.htm.

federal excise tax for on-road diesel fuel is $0.244/gallon. In California, the state excise tax on motor fuels is $0.187/gallon. The combined federal and state excise taxes on motor fuels in California amount to $0.427/gallon. However off-road diesel fuel is exempt from federal and state excise taxes (although state sales tax typically still applies). While bulk off-road diesel fuel prices vary between users, for the purposes of this analysis, we will assume an average off-road diesel fuel cost of $2.60/gallon during the demonstration period.

Referring to the fuel economy testing results described in section 3, the average diesel yard hostler fuel consumption was 1.7 gal/hr. Therefore the average off-road diesel yard hostler fuel cost/hr was 1.7 gal/hr x $2.60/gal = $4.42/hr.

5.4.2 LNG Fuel Costs

LNG fuel prices also vary over time, typically in conjunction with changes in diesel and gasoline prices. During the eight-month LNG yard hostler demonstration period (June 2006 – February 2007), LNG bulk fuel delivery prices ranged between $0.84 and $1.10/gallon. The average LNG bulk fuel delivery price paid by the project during the demonstration period was $0.98/gallon. LNG bulk fuel delivery prices to individual fleet customers on a per gallon basis are generally not publicly reported. For the purposes of this analysis, we will therefore assume an average off-road LNG fuel cost *before tax credits* of approximately $1.00/gallon.

Referring to the fuel economy testing results described in section 3, the average LNG yard hostler fuel consumption was 3.8 gal/hr. Therefore the average off-road LNG yard hostler fuel cost/hr *before tax credits* was 3.8 gal/hr x $1.00/gal = $3.80/hr.

5.5 Refueling Infrastructure Costs

5.5.1 Diesel Refueling Infrastructure Costs

Since most existing yard hostlers use diesel fuel, the necessary diesel refueling infrastructure is assumed to exist on the premises of the yard hostler fleet operator. Therefore there are assumed to be no additional capital equipment costs for diesel refueling infrastructure.

5.5.2 LNG Refueling Infrastructure Costs

Since there is no reason to assume that there will be any existing LNG refueling infrastructure on-site, LNG refueling infrastructure will typically need to be installed. Capital equipment and installation costs for an LNG refueling station can vary considerably depending on refueling requirements and location. The estimated cost for a typical permanent (i.e., non-mobile) LNG refueling station is around $700K.[50]

In some cases, LNG fuel suppliers will install LNG refueling infrastructure at their own expense in exchange for a long-term fuel agreement with a fleet operator. In these cases there must be

[50] Preliminary Fueling Recommendations for San Jose International Airport's Alternative Fuel Program, Steven Sokolsky, Bevilacqua-Knight, Inc., August 31, 2000.

sufficient LNG demand from the fleet operator to justify the investment in refueling infrastructure by the fuel provider. In addition, it is expected that the LNG fuel provider will pass on the costs of their investment in the refueling infrastructure via higher fuel costs to the fleet operator. This will certainly have an impact on the business case but it is difficult to predict the exact impact as it will depend on the particular situation.

Note that it is unlikely that LNG refueling infrastructure would be shared by different fleet operators in a port environment. One reason is that the majority of yard hostlers sold in the U.S. (approximately 75%) are off-road vehicles and therefore would not be allowed to drive on public roads to be refueled at an off-site LNG refueling station. Another major issue would be the additional labor cost associated with driving LNG yard hostlers off-site to be refueled.

5.6 Tax Credits

5.6.1 LNG Vehicle Tax Credits

The Energy Policy Act (EPAct) of 2005 contains provisions for on-road LNG vehicle tax credits. As of January 1, 2006, the buyer of a new on-road LNG vehicle qualifies for a tax credit of up to 50% of the incremental cost of the vehicle plus an additional 30% of the incremental cost if the vehicle meets the most stringent applicable EPA or CARB emissions standards. For heavy-duty vehicles such as yard hostlers with a Gross Vehicle Weight Rating (GVWR) greater than 26,000 lbs, the total incremental cost is capped at $40,000.[51] Assuming that the purchaser of a new on-road LNG yard hostler (e.g., a container terminal) is able to take full advantage of the tax credit, the LNG vehicle tax credit is assumed to be worth 80% of the incremental cost of the vehicle or 0.8 x $40,000 = $32,000. This implies that the effective incremental cost of an on-road LNG yard hostler to the buyer would potentially be reduced to $40,000 – $32,000 = $8,000 excluding taxes and delivery. While LNG vehicle tax credits do not apply to off-road yard hostlers, they would apply to on-road yard hostlers regardless of whether the on-road yard hostlers were used on-road or off-road.[52] Therefore it may make economic sense for off-road yard hostler fleets to consider purchasing on-road LNG yard hostlers in order to receive the LNG vehice tax credit.

5.6.2 LNG Fuel Tax Credits

The EPAct of 2005 also contains provisions for LNG fuel tax credits. As of October 1, 2006, the seller of LNG fuel (actually the "dispenser" would be a more technically correct description) qualifies for a federal rebate of $0.50/gallon. (The EPAct of 2005 also raised the federal motor fuels excise tax on LNG from $0.119/gal. to $0.243/gal. but this tax does not apply to LNG fuel for off-road vehicles.) Assuming that the entity dispensing the LNG fuel is a tax-paying entity (e.g., a container terminal), they can qualify for the $0.50/gallon rebate. If the entity dispensing the LNG fuel is not a tax-paying entity (e.g., a government fleet operator), they can arrange to pass the rebate to the LNG bulk fuel supplier and negotiate with the LNG bulk fuel supplier for a reduced fuel price.[53]

[51] International Association for Natural Gas Vehicles, US Federal Incentives, www.iangv.org/content/view/86/107/.
[52] Personal communication from Rich Kolodziej, Natural Gas Vehicle Coalition, Sept. 24, 2007.
[53] International Association for Natural Gas Vehicles, US Federal Incentives, www.iangv.org/content/view/86/107/.

Assuming that the entity dispensing the LNG fuel is a tax-paying entity and qualifies for the \$0.50/gallon rebate, we will assume an average off-road LNG fuel cost *after tax credits* of \$1.00/gallon pre-rebate – \$0.50/gallon rebate = \$0.50/gallon final cost. Therefore the average off-road LNG yard hostler fuel cost/hr *after tax credits* is 3.8 gal/hr x \$0.50/gal = \$1.90/hr.

5.6.3 LNG Refueling Infrastructure Tax Credits

The EPAct of 2005 also contains provisions for LNG fueling station equipment tax credits. As of January 1, 2006, an entity installing new LNG refueling infrastructure qualifies for a tax credit of up to 30% of the cost of the equipment. The tax credit is capped at \$30,000 per property per year and will expire at the end of 2009. One issue which has yet to be clarified by the Internal Revenue Service is whether the tax credit applies to each individual refueling station or to the refueling property as a whole.[54] Assuming that the LNG yard hostler fleet operator installs one LNG refueling station on-site and is able to take full advantage of the tax credit, the LNG refueling infrastructure tax credit is assumed to be worth \$30,000/year through 2009.

5.7 Other Incentives Programs

5.7.1 Carl Moyer Program

In 1999 the state of California established the Carl Moyer Program to provide funds to encourage public and private fleets to adopt cleaner-than-required engine technology. The grants cover some or all of the incremental cost of cleaner engines and are administered by the local air quality management districts. To qualify for a Carl Moyer Program grant, new vehicles must be certified to at least 30% lower NOx emissions compared to current emissions standards (i.e., surplus emissions reductions). For off-road yard hostlers in California, as of January 1, 2007, the applicable emissions standards are 2007 heavy-duty on-road engine standards or Tier 4 off-road engine standards.[55] Since there are currently no certified Tier 4 off-road engines, the 2007 on-road engine standards of 1.2 g/bhp-hr NOx and 0.01 g/bhp-hr PM are assumed to apply.[56]

In addition to meeting the requirements for surplus emissions reductions, funding in the air quality district encompassing POLB and POLA is limited to a maximum reimbursement of \$5,000/ton of surplus NOX, weighted PM and Volatile Organic Compounds (VOC) combined emissions per year regardless of the annualized incremental cost of the technology.[57] Given an assumed incremental cost of \$40,000 for LNG yard hostlers and a 10 year service life, the annualized incremental cost of the vehicle is \$4,000/year. Based on the LNG yard hostler emissions testing results for the 2005 on-road natural gas engine, the LNG yard hostler would not provide any surplus NOx emissions reductions relative to the 2007 on-road engine standards

[54] International Association for Natural Gas Vehicles, US Federal Incentives, www.iangv.org/content/view/86/107/.

[55] Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards, California Air Resources Board, www.arb.ca.gov/regact/cargo2005/revfro.pdf.

[56] On-road heavy-duty engine NOx emissions limits of 0.2 g/bhp-hr are phased in between 2007 and 2010. In practice, very few on-road heavy-duty diesel engines meeting the 0.2 g/bhp-hr NOx limits will be available before 2010. Instead, most engine manufacturers have chosen to certify their products to a Family Emissions Limit of 1.2 – 1.5 g/bhp-hr NOx during the transition period betwwen 2007 and 2010.

[57] For purposes of the Carl Moyer Program, weighted PM emissions are equal to 20 times actual PM emissions.

of 1.2 g/bhp-hr NOx. However under the assumption that an LNG yard hostler with a 2005 on-road natural gas engine has virtually no PM emissions, we can assume that the LNG yard hostler would provide surplus weighted PM emissions reductions of 0.068 tons/year.[58] Therefore based on these assumptions, LNG yard hostlers with 2005 on-road natural gas engines would potentially qualify for Carl Moyer Program incentive funding of approximately $2,720.[59] Note that this analysis is based on the emissions testing results of an LNG yard hostler with a particular 2005 on-road natural gas engine and does consider the potential NOx emissions reductions associated with a 2007 on-road natural gas engine. Hence while there are a number of uncertainties associated with the potential amount of Carl Moyer Program funding for LNG yard hostlers using current model year technology, the general level of funding is assumed to be relatively small compared to the incremental cost of the technology. Therefore for the purposes of the LNG yard hostler business case analysis, any potential Carl Moyer Program funding will be ignored.

5.7.2 SCAQMD MSRC Natural Gas Yard Hostler Incentive Program

On December 7, 2007, the South Coast Air Quality Management District (SCAQMD) Mobile Source Air Pollution Reduction Review Committee (MSRC) announced a Clean Transportation Funding™ program to establish incentives to purchase natural gas yard hostlers. The program, titled Incentives for the Purchase of Heavy Duty Natural Gas Off-Road Cargo Handling Equipment (Yard Tractors & Hostlers), provides $1 million in grants to cover all or some of the incremental costs of natural gas yard hostlers for use at POLB, POLA and distribution centers in the SCAQMD.[60] The grants are specifically targeted at new natural gas yard hostlers with engines certified to meet the 2010 heavy duty on-road NOx emissions standard of 0.2 g/bhp-hr or less. At the moment, the only engine meeting this standard is the 2008 Cummins Westport ISL G.[61] The maximum incentive level for each qualifying vehicle is $40,000. Assuming an incremental cost of at least $40,000 for each qualifying vehicle, this program may provide funding for up to twenty-five (25) natural gas yard hostlers. Note that the deadline for applications for this program was Feb. 15, 2008.

5.7.3 SCAQMD MSRC Alternative Fuel Infrastructure Funding Opportunities

On December 7, 2007, the SCAQMD MSRC announced a Clean Transportation Funding™ program to assist in the construction, upgrade and expansion of alternative fuel infrastructure in the SCAQMD. The program, titled Alternative Fuel Infrastructure Funding Opportunities, provides $2.5 million in grants to cover up to 50% of the capital equipment costs associated with alternative fuel infrastructure projects, including LNG, compressed natural gas (CNG), liquefied/compressed natural gas (L/CNG), hydrogen and hydrogen/natural gas blends.[62] The maximum funding per qualifying project is $400,000 for new construction, and $200,000 for

[58] Annual weighted PM emissions = 20 x 0.01 g/bhp-hr x 215 hp x 2500 operating hrs/yr x 0.57 CARB off-road load factor = 61,280 grams/yr = 0.068 tons/yr.

[59] (0.068 tons of surplus emissions/year) x ($4,000/year annualized incremental cost) = $272/year. $272/year x (10 years expected service life) = $2,720.

[60] www.cleantransportationfunding.org/document/rfp/word/FY_2007-08_Off-Road_Engine_Program_fnl.doc.

[61] www.cumminswestport.com/products/islg.php.

[62] http://www.aqmd.gov/rfp/attachments/2008/P2008-12.doc.

upgrading and/or expansion of existing facilities. Note that the deadline for applications for this program was March 28, 2008.

5.8 Annual Operating Hours

According to the 2002 POLB baseline emissions inventory, the average annual operating hours for yard hostlers at POLB is approximately 2,500.[63] Based on field data collected at LBCT during this project, the average annual operating hours for an LBCT yard hostler is approximately 1,500 engine operating hours/year. Based on interviews with yard hostler manufacturers, an average value for port applications lies within the range of 1,500 – 2,500 hours/year. For purposes of this analysis, we will assume an average annual operating hours figure of 2,000 hours/year for port applications.

Average annual engine operating hours for yard hostlers varies by application. Based on interviews with yard hostler manufacturers, the port application has the lowest average annual operating hours. Estimated annual operating hours for yard hostlers used at distribution centers varies over a wide range of 2,000 – 6,000 hours/year. Estimated annual operating hours for yard hostlers used in the parcel and package delivery industry is 3,600 hours/year. Intermodal yards have the highest average annual operating hours at 3,000 – 6,000 hours/year.[64]

5.9 Service Life

5.9.1 Diesel Yard Hostlers

Depending on the application, diesel yard hostlers typically have a service of life of five to twelve years. First owners of yard hostlers generally expect about 20,000 – 25,000 engine operating hours from a yard hostler. Therefore applications with higher average annual engine operating hours tend to have shorter service lives and vice-versa. For port applications, an average diesel yard hostler service life is about ten (10) years.

5.9.2 LNG Yard Hostlers

Due to the limited field data on LNG yard hostlers, it is difficult to estimate the potential service life of LNG yard hostlers with a high degree of confidence. However looking at the traditional service life of the primary LNG-related components in vehicle applications, i.e., the natural gas engine and the LNG fuel tanks, achieving a minimum 10 years/25,000 engine operating hours service life is not expected to be a problem.

5.10 Maintenance and Service Costs

5.10.1 Periodic Maintenance Costs

[63] 2002 POLB Emissions Inventory, Starcrest Consulting, 2004.
[64] Telephone interview with Randy Dennis, Vice President Sales and Customer Support, Kalmar Industries USA LLC, August 29, 2007.

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 natural gas engines used in the LNG yard hostlers are certified as on-road engines and have similar recommended maintenance intervals to on-road diesel engines. Since the LNG yard hostlers present no advantages or disadvantages compared to existing diesel yard hostlers with on-road engines, periodic maintenance costs have been ignored in the business case analysis.

Note that one possible additional maintenance item for LNG yard hostlers could be periodic recertification of the LNG fuel tanks (e.g., every five years), however this is a relatively inexpensive procedure.

5.10.2 Service Costs

It is reasonable to assume that fleet operators will expect the same warranty for LNG 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 LNG yard hostlers outside of the warranty period is the replacement cost of the major LNG system components, in particular the natural gas engine and the LNG fuel tank, which are significantly more expensive than their diesel counterparts. While there is insufficient data available on LNG yard hostler service costs to make a comparison with diesel yard hostler service costs, general field experience with heavy-duty LNG vehicles gives little evidence to suspect that the major LNG system components will require more service than their diesel counterparts. For this reason, service costs have been ignored in the business case analysis.

5.11 Resale Value

5.11.1 Diesel Yard Hostlers

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 assume an average diesel yard hostler resale value of $5,000.

5.11.2 LNG Yard Hostlers

At the moment, there is no significant market for used LNG yard hostlers. Due to the need for LNG refueling infrastructure to support the use of LNG yard hostlers and the high cost of installing such infrastructure, it would probably not make sense for a buyer to purchase a used LNG yard hostler unless there was already LNG refueling infrastructure in place for other LNG vehicles at the facility. Since this would represent a very unique set of circumstances, for the purposes of this analysis we will assume a resale value of $0 for an LNG yard hostler at the end of its normal service life (although this may certainly change if a market for used LNG yard hostlers should develop in the future). In actuality, the business case analysis shows that the relatively low resale value for yard hostlers ultimately has very little impact on the life cycle costs for these vehicles.

5.12 Simplified Life Cycle Cost Analysis

Based on the data and assumptions given above, we can construct a simplified life cycle cost (LCC) model for the LNG and diesel yard hostlers by focusing solely on initial vehicle cost, vehicle purchase incentives, fuel costs and resale value and ignoring all costs which are unknown, insignificant or are not expected to vary significantly between diesel and LNG yard hostlers. Infrastructure costs are discussed separately since they do not apply to individual vehicles but rather to the fleet. 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. LNG yard hostlers is shown in Table 11.

Table 12 - Summary of LCC Parameters for Yard Hostler Business Case

Factor	*Diesel*[65]	*LNG – No Incentives*[66]	*LNG – EPAct NG Incentives*	*LNG – SCAQMD*[67] *(Max. 25 Vehicles)*
Initial Cost of Vehicle	$80,000	$120,000	$120,000	$120,000
Purchase Incentives	$0	$0	$32,000	$40,000

[65] Off-road diesel yard hostler with on-road certified engine purchased or leased in California after January 1, 2007 and used in port applications.
[66] Off-road LNG yard hostler with on-road certified engine purchased or leased in California after January 1, 2007 which are used in port applications but do not qualify for vehicle purchase incentives.
[67] Off-road LNG yard hostler with on-road certified engine purchased or leased in California after January 1, 2007 and used in port applications or distribution centers qualifying for SCAQMD MSRC incentives of $40,000/yard hostler (max. 25 vehicles total for program).

Fuel Cost/Gallon After Tax Credits	$2.60	$0.50	$0.50	$0.50
Gallons/Operating Hour	1.7	3.8	3.8	3.8
Annual Operating Hours	2,000	2,000	2,000	2,000
Annual Fuel Costs	$8,840	$3,800	$3,800	$3,800
Service Life	10 Years	10 Years	10 Years	10 Years
Discount Rate	3%	3%	3%	3%
Present $\text{Value}_{\text{Fuel}}$	$77,669	$33,387	$33,387	$33,387
Resale Value	$5,000	$0	$0	$0
Present $\text{Value}_{\text{Resale}}$	$3,832	$0	$0	$0
LCC	$153,837	$153,387	$121,387	$113,387

According to the model, the life cycle costs for diesel and LNG yard hostlers *without vehicle purchase incentives* are approximately equal. This analysis assumes that vehicle fleet operators will accept payback on the incremental cost of the vehicle over the full service life of the vehicle. In practice, however, vehicle fleet operators typically require a payback on their investments within two to three years. However incentive programs that reduce or eliminate the incremental cost of LNG yard hostlers (such as the SCAQMD MSRC's natural gas yard hostler incentive program and the the 2005 EPAct LNG vehicle tax credits for on-highway yard hostlers) have a major impact on the business case analysis as shown in Table 11. *According to the model, the amount of the incentive provides a corresponding and identical business case advantage for LNG yard hostlers compared to diesel yard hostlers.*

5.12.1 Effect of LNG Refueling Infrastructure Costs

The above model does *not* take into account the amortization of LNG refueling infrastructure costs which would have the general effect of increasing costs for the LNG yard hostler scenario. The impact of LNG refueling infrastructure costs on the LNG yard hostler business case is dependent on the total amount of fuel provided by the infrastructure which is generally proportional to the number of LNG vehicles in the fleet. The more LNG vehicles in the fleet, the easier it is to "spread out" the LNG infrastructure costs and reduce the impact on a per vehicle basis. In addition, there may be arrangements between the LNG refueling infrastructure provider and the fleet operator that affect the LNG fuel cost to the fleet operator.

While LNG refueling infrastructure tax credits can reduce infrastructure expenses somewhat, the relatively small amount of the tax credit ($30,000/property/year) combined with the temporary nature of the tax credit (expiration at the end of 2009) is not expected to have a significant impact on the business case.

5.12.2 Effect of 2010 Emissions Regulations

Note that the simplified LCC model is based on vehicles meeting 2007 on-road heavy-duty engine emissions regulations. The exact impact of 2010 emissions regulations on the market for both diesel and LNG yard hostlers is currently unclear. From an emissions point of view, the

2010 emissions regulations are so stringent that there is likely to be little difference between the emissions of diesel vs. natural gas engines. Other aspects of future 2010 certified natural gas engines which may have direct or indirect impacts on the LNG yard hostler business case are cost, mechanical packaging differences (e.g., volume), cooling requirements, relative fuel consumption and availability of appropriate horsepower levels for the yard hostler application. However it should be noted that there are existing 2007 certified natural gas engines appropriate for the LNG yard hostler application which already meet the 2010 emissions standards.[68]

It is important to note that 2010 on-road diesel engines used in off-road applications such as yard hostlers will also face challenges impacting the business case of diesel vs. LNG yard hostlers. These include the increased cost of 2010 diesel engines and exhaust aftertreatment systems, possible mechanical packaging issues, and other technical issues associated with the use of these systems in the yard hostler application. This report does not attempt to predict the ultimate impact of 2010 emissions regulations on the business case as there are simply too many unknowns at this point.

5.13 Other Cost Considerations

5.13.1 Yard Hostler Refueling Procedures

Depending on the type of refueling procedures used by a particular fleet operator and the local LNG fueling infrastructure permitting requirements, there may be a significant impact on labor costs associated with refueling LNG yard hostlers compared to diesel yard hostlers. Some yard hostler fleet operators (such as LBCT) refuel their yard hostlers using a portable fueling truck that is driven to the area where the yard hostlers are parked. This procedure is sometimes referred to as “wet-hosing”. Other fleet operators require the yard hostler drivers to drive their yard hostlers to a fixed, on-site refueling station at the end of their shift or whenever the vehicle is getting low on fuel. Since most permanent LNG refueling infrastructure is fixed in place, the latter procedure is much more efficient for refueling LNG yard hostlers.

As an example of an “inefficient” refueling scenario that should be avoided, the refueler would go out into the yard to retrieve the LNG yard hostler, drive it to the LNG refueling infrastructure, refuel the vehicle, and drive it back to the yard hostler parking area. Based on a typical “efficient” diesel yard hostler refueling time of five minutes per vehicle, the additional time required to refuel an LNG yard hostler using the aforementioned “inefficient” refueling procedure could be an extra twenty minutes or more per vehicle. Obviously “inefficient” refueling procedures have the potential to increase labor costs dramatically. To avoid this situation, fleet operators should investigate options to optimize their fleet refueling procedures for LNG yard hostlers.

5.13.2 Size of Local Yard Hostler Population

[68] The 2008 Cummins Westport ISL G natural gas engine currently meets 2010 emissions standards without active exhaust aftertreatment (www.cumminswestport.com/products/islg.php).

Given the high cost of permanent LNG refueling infrastructure, it does not generally make financial sense to install this kind of infrastructure for a small number of LNG yard hostlers. The more LNG yard hostlers at a particular location, the easier it is to justify the cost of LNG refueling infrastructure. While there is not a minimum number of vehicles per se, one possible guideline is to have enough LNG consumption in a fleet to require refilling of the bulk LNG storage tank at least once each week. The intent is to prevent LNG evaporation losses from becoming large enough to have a significant impact on LNG fueling costs.

Although ports represent only a small portion of the yard hostler market (< 10%), the highest concentration of yard hostlers is nevertheless found at ports. While the larger markets (e.g., distribution centers) represent a much larger share of the total yard hostler population, the concentration of yard hostlers at individual locations tends to be much lower. Fleet operators with only a small number of yard hostlers at a given location would typically not be the best candidates for changing over their fleet to LNG unless there were other LNG vehicles or existing LNG infrastructure on-site.

5.14 Regulatory Considerations

The following paragraphs provide brief descriptions of current legislation and policies which may have an impact on the market for LNG yard hostlers either directly or indirectly. The individual and combined impact of these policies is difficult to quantify and thus has not been taken into consideration in the simplified LCC analysis. Instead, a high level, qualitative analysis of the potential impact of these factors on the LNG yard hostler market and business case is provided.

5.14.1 San Pedro Bay Ports Clean Air Action Plan

In November, 20006, POLB and POLA jointly released the San Pedro Bay Ports Clean Air Action Plan (CAAP). The CAAP describes the goals and measures that POLB and POLA will take to significantly reduce emissions related to port operations during the five year period ending in 2011.[69] Section 5.3 of the CAAP Technical Report describes CHE control measures. Control Measure SPBP-CHE1, Performance Standards for CHE, specifies that beginning in 2007, all new CHE purchases (including yard hostlers) must meet the cleanest available NOx alternative fuel or diesel fuel engine with PM emissions of 0.01 g/bhp-hr or better. From a practical point of view, this means that new yard hostlers must have either a 2007 on-road natural gas or 2007 on-road diesel engine. Furthermore, by the end of 2010, all yard hostlers must either meet 2007 on-road engine standards or Tier 4 off-road engine standards.

Clearly one of the intents of these measures is to encourage the usage of alternative fuel CHE such as LNG yard hostlers. However the extent to which the control measure actually results in an increased demand for LNG yard hostlers is highly dependent on the incremental cost of the LNG yard hostlers and direct or indirect expenses associated with on-site LNG refueling infrastructure. The CAAP does not currently provide any buy-down or incentive funds for either LNG yard hostlers or on-site LNG refueling infrastructure at the container terminals. Without

[69] *San Pedro Bay Ports Clean Air Action Plan*, Ports of Long Beach and Los Angeles, November 2006.

these financial incentives, it is unlikely that the business case for LNG yard hostlers alone will spur a significant increase in LNG yard hostler usage since the alternative (usage of 2007 on-road diesel engines) is significantly less expensive and does not require changes to refueling infrastructure.

5.14.2 CARB Cargo Handling Equipment Regulations

In December 2006, CARB adopted regulations for mobile CHE at ports and intermodal rail yards.[70] The purpose of the regulations is to reduce PM and other criteria pollutant emissions from diesel CHE operating at ports and intermodal rail yards in California. The regulations require that all yard hostlers purchased after January 1, 2007 and operated in California ports or intermodal rail yards include either an on-road certified engine meeting the emissions requirements of the year it was purchased, or meet Tier 4 off-road emissions standards. The regulations also require that yard hostler fleet operators begin phasing out an increasing percentage of their older (pre-2007) yard hostlers according to a compliance schedule commencing in 2008. Yard hostler fleet operators can comply with the regulations by using alternative fuels such as LNG but this is not required. Therefore by themselves, the CARB regulations are not expected to spur a significant increase in LNG yard hostler demand.

5.14.3 California Low Carbon Fuel Standard

In January 2007, Governor Schwarzenegger issued Executive Order S-1-07, the Low Carbon Fuel Standard (LCFS), calling for a 10% or greater reduction in the carbon intensity of California's transportation fuels by 2020.[71] The goal of the LCFS is to reduce the GHG emissions associated with the transportation sector in California. It is assumed that the LCFS will eventually lead to state regulations and enforcement mechanisms that encourage the use of lower carbon fuels, including LNG, relative to higher carbon fossil fuels such as diesel. To the extent that these regulations improve the business case for LNG yard hostlers (e.g., through relatively higher costs for diesel fuel compared to LNG), the LCFS may indirectly increase the demand for LNG yard hostlers in the long-term. Since the state's implementation of the LCFS has not been defined yet, the short-term effect on the demand for LNG yard hostlers is unclear at this time.

5.14.4 California Assembly Bill 1007 – Alternative Fuels Plan

In September 2005, the California state legislature adopted Assembly Bill 1007 (AB 1007), the Alternative Fuels Plan.[72] AB 1007 requires the California Energy Commission (CEC) in coordination with CARB and other state agencies to develop a plan to increase the use of alternative transportation fuels in 2012, 2017 and 2022. The CEC subsequently expanded the scope of the Alternative Fuels Plan to include off-road vehicles involved with goods movement

[70] *Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards,* California Air Resources Board, December 2006, www.arb.co.gov/regact/cargo2005/revfro.pdf.
[71] Executive Order S-1-07, *Low Carbon Fuel Standard,* Governor Schwarzenegger, January 18, 2007, www.energy.ca.gov/low_carbon_fuel_standard.
[72] AB 1007, *Alternative Fuels Plan*, Pavley, September 29, 2005.

at ports.[73] Early drafts of the State Alternative Fuels Plan includes recommendations for state financial incentives to address the incremental cost of heavy-duty natural gas vehicles and capital costs associated with installation of natural gas refueling infrastructure.[74] Perhaps more than any other policy, the State Alternative Fuels Plan shows the greatest promise for spurring the usage of LNG yard hostlers by addressing the financial obstacles associated with vehicle incremental costs and LNG refueling infrastructure.

5.14.5 California Assembly Bill 118 – Alternative Fuels and Vehicle Technologies Bill

In October 2007, the California state legislature adopted Assembly Bill 118 (AB 118), the Alternative Fuels and Vehicle Technologies Bill.[75] AB 118 authorizes $200M in combined annual funding for the CEC and CARB to support clean vehicles and fuels in California through 2015; total funding will therefore be $1.5 billion. The primary goals of the bill are to help reduce GHG emissions, smog and reduce California's dependence on oil. While AB 118 does not specifically allocate money for individual projects, there are no restrictions that would prevent the funds from being used to support projects involving LNG yard hostlers. Given the large amounts of funding available and the focus on reducing port emissions in California, it is not unreasonable to expect that some of the AB 118 funding could be allocated to port projects involving CHE such as alternative fuel (e.g., LNG) yard hostlers. In fact, given the reductions in CO_2 emissions (CO_2 is one of the primary GHGs contributing to climate change) and oil consumption associated with LNG yard hostlers compared to the vehicles they replace, LNG yard hostlers may be considered a good candidate for AB 118 funding. In general, the availability of AB 118 funding could have a positive impact on the demand for LNG yard hostlers, however the magnitude of that impact is impossible to quantify at this time.

5.14.6 California Proposition 1B

In November 2006, the people of California approved Proposition 1B, the Highway Safety, Traffic Reduction, Air Quality and Port Security Bond Act of 2006.[76] Proposition 1B includes $1 billion in funding for projects to reduce emissions associated with goods movement through California ports. Proposition 1B is similar to AB 118 in that it does not specifically allocate money for individual projects, however the availability of funding could have a positive impact on the demand for LNG yard hostlers.

5.14.7 Port of Los Angeles Resolution No. 6164

In February 2003, the Board of Harbor Commissioners of the Port of Los Angeles adopted resolution number 6164. This resolution requires that all new leases with port tenants shall require that any new yard hostlers purchased by the tenant be powered by alternative fuels provided that such yard hostlers are commercially available. It would appear, however, that this

[73] Docket 06-AFP-1, Committee Scoping Notice for Alternative Fuels Plan, California Energy Commission, April 28, 2006, www.energy.ca.gov/ab1007/notices/2006-04-28_cmte_scoping_order.pdf.
[74] *Draft State Alternative Fuels Plan*, California Energy Commission and California Air Resources Board, October, 2007, http://cacx.org/2007publications/CEC-600-2007-011/CEC-600-2007-011-ctd.pdf.
[75] AB 118, *Alternative Fuels and Vehicle Technologies Bill*, Nunez, October, 2007.
[76] Proposition 1B, *Highway Safety, Traffic Reduction, Air Quality and Port Security Bond Act of 2006*, November 6, 2007, www.sos.ca.gov/elections/vig_06/general_06/pdf/proposition_1b/entire_prop1b.pdf.

resolution has never been enforced despite the availability of LNG yard hostlers from yard hostler OEMs. It is therefore not considered a factor in the current market demand for LNG yard hostlers.

6 Project Findings and Recommendations

This project marks one of the first times that LNG yard hostlers have undergone a formal and rigorous evaluation in a demanding marine terminal environment.[77] Given the prototype nature of the hardware and the lack of industry experience with this type of LNG equipment, it is not surprising that there were some occasional difficulties, particularly during the start-up phase of the project. Overall, however, the equipment performed well and clearly met the requirements of the application. This section summarizes the main technical and business case findings of the project and provides recommendations to address the major issues identified.

6.1 Findings

LNG yard hostlers exhibit comparable performance to diesel yard hostlers in port applications. Throughout the eight-month demonstration project, the LNG yard hostlers consistently performed the same tasks as diesel yard hostlers. There were occasional issues with the on-vehicle LNG fueling system that affected vehicle performance, although it is assumed that many of these were attributable to hardware problems encountered during the start-up phase of the project as well as vehicle manufacturer inexperience with LNG fueling systems. Overall, however, the LNG yard hostlers are clearly capable of meeting the performance requirements for the application.

The LNG yard hostlers were received positively by operators. Based on driver surveys, 97% of the drivers found the LNG yard hostlers to have the same or better performance than traditional diesel yard hostlers with 67% rating them as superior in general. Steering, ride comfort and interior/exterior noise levels were the features of the LNG yard hostlers most consistently rated better than the diesel yard hostlers. Of these, interior and exterior noise levels are most directly related to the operation of the LNG engine.

The LNG yard hostlers were received positively by mechanics. Based on mechanic surveys, 100% of the mechanics rated the maintainability of the LNG yard hostlers similar to traditional diesel yard hostlers. However problems with LNG pressure regulation and leaks were noted by most of the mechanics during the start-up phase of the project.

LNG yard hostler product maturity is currently below that of diesel yard hostlers. To date, only a small number of LNG yard hostlers have been manufactured. Westport Innovations identified problems with the LNG fuel delivery system and implemented a major fueling system

[77] In parallel with the LNG yard hostler evaluation at LBCT at POLB, an SES-funded demonstration of two LNG yard hostlers was performed at Yusen Terminals Inc. (YTI) at POLA. While the YTI/POLA demonstration did include operator feedback and emissions testing, most of the evaluation was considerably less formal than the LBCT/POLB evaluation with the exception of emissions testing.

upgrade towards the end of the project. As a result of this upgrade, no further low fuel pressure fault codes were recorded by the on-vehicle diagnostics systems. Unfortunately there was insufficient data after the upgrade to draw firm conclusions regarding its effectiveness. However it is reasonable to expect that fixes for these and other issues will be incorporated into future products by the manufacturer as experience is gained with fielded vehicles.

Measured NOx emissions of MY 2005 LNG yard hostlers were 21% higher than MY 2005 diesel yard hostlers with on-road engines. Emissions measurements were performed on a heavy-duty chassis dynamometer using a modified steady-state emissions testing protocol. The higher NOx emissions of the LNG yard hostlers were unexpected and the root cause remains unclear at this time. It should be noted, however, that NOx emissions during idling were 88% lower for the LNG yard hostlers compared to the diesel yard hostlers, especially since yard hostlers typically spend 50% or more of the time idling.

Measured PM emissions of MY 2005 LNG yard hostlers were assumed to be virtually zero. While LNG yard hostler PM emissions testing was not performed as part of this project, earlier LNG yard hostler emissions testing at POLA using an identical LNG engine configuration indicated PM emissions of 0.008 g/whp-hr, well below the current EPA standard of 0.01 g/bhp-hr. Extremely low PM emissions are typical for natural gas engines so this result is not surprising.

Measured CO_2 emissions of MY 2005 LNG yard hostlers were 18% lower than MY 2005 diesel yard hostlers with on-road engines. As one of the primary GHGs contributing to climate change, CO_2 emissions are coming under increasing scrutiny at the ports. Emissions measurements were performed on a heavy-duty chassis dynamometer using a modified steady-state emissions testing protocol. It should be noted, however, that CO_2 emissions during idling were 34% higher for the LNG yard hostlers compared to the diesel yard hostlers. This is of interest because yard hostlers typically spend 50% or more of their time idling.

In the absence of vehicle purchase incentives, life cycle cost estimates for LNG yard hostlers are about the same as diesel yard hostlers excluding LNG refueling infrastructure costs. Where vehicle purchase incentives are available, LNG yard hostlers have a life cycle cost advantage equal to the amount of the incentives. A simplified life cycle cost analysis was performed taking into account initial vehicle cost, vehicle purchase incentives, fuel cost and resale value for LNG yard hostlers compared to off-road diesel yard hostlers with a 2007 on-road engine. In the absence of vehicle purchase incentives, the results indicate similar costs over a typical ten-year service life for yard hostlers in port applications. While life cycle costs for diesel and LNG yard hostlers are similar without vehicle purchase incentives, fleets generally make shorter term payback decisions and are often unwilling to wait more than two to three years to see a payback on their investment. Where purchase incentives are available, however, the LNG yard hostlers have a life cycle cost advantage equal to the amount of the purchase incentives. The analysis does not include LNG refueling infrastructure costs estimated at a minimum of $700K per fleet. The cost of LNG refueling infrastructure may be significantly reduced, however, by local infrastructure incentive programs such as the SCAQMD Alternative Fuel Infrastructure Funding Program. In addition to the capital equipment and installation costs of LNG refueling infrastructure, the potential impact on labor costs associated with LNG vehicle refueling may be very significant depending on individual fleet refueling procedures.

More incentive programs are necessary to stimulate demand for LNG yard hostlers. Off-road LNG yard hostlers do not qualify for federal natural gas vehicle tax credits under the Energy Policy Act of 2005. On-road LNG yard hostlers do qualify for these incentives (up to $32,000 per vehicle) but are not typically used in port applications. California's Carl Moyer Program does not appear to provide significant funding for LNG yard hostlers relative to the incremental cost of such vehicles. Local incentive programs, such as the SCAQMD Incentives for the Purchase of Heavy Duty Natural Gas Off-Road Cargo Handling Equipment (Yard Tractors & Hostlers), provide strong incentives for purchasing LNG yard hostlers but funding is limited.

In the absence of specific alternative fuel vehicle purchase incentives, the CHE measures in the San Pedro Bay Ports Clean Air Action Plan (CAAP) are insufficient to stimulate any significant near-term demand for LNG yard hostlers. Without incentive funding for LNG refueling infrastructure and incremental vehicle costs, it is more cost effective for POLB and POLA yard hostler fleet operators to meet the performance-based requirements for yard hostlers by purchasing diesel yard hostlers with 2007 on-road certified engines than switching to LNG yard hostlers. Given the assumed higher cost and complexity of engines meeting 2010 on-road emissions standards, however, the ultimate effect of these measures on the long-term demand for LNG yard hostlers is unclear at this time.

In the absence of specific alternative fuel vehicle purchase incentives, the CARB CHE regulations are unlikely to stimulate any significant near-term demand for LNG yard hostlers. Without incentive funding for LNG refueling infrastructure and incremental vehicle costs, it is more cost effective for California yard hostler fleet operators to meet the CARB requirements for yard hostlers by purchasing diesel yard hostlers with 2007 on-road certified engines than switching to LNG yard hostlers. Given the assumed higher cost and complexity of engines meeting 2010 on-road emissions standards, however, the ultimate effect of these regulations on the long-term demand for LNG yard hostlers is unclear at this time.

California state policies currently under development and other state funding sources for clean vehicles may eventually have a positive impact on the business case for LNG yard hostlers. The State Alternative Fuels Plan currently being developed by the CEC and CARB as directed by AB 1007 includes recommendations for state financial incentives to address the incremental cost of heavy-duty natural gas vehicles and capital costs associated with installation of natural gas refueling infrastructure. In addition, AB 118 and Proposition 1B contain significant amounts of funding that may be used to offset costs associated with the introduction of clean technologies into goods movement at California ports. Other California policies such as the Low Carbon Fuel Standard (LCFS) may also contribute to an increased demand for LNG yard hostlers in the longer term.

6.2 Recommendations

Develop a standard yard hostler duty cycle to measure emissions. There is currently no standard yard hostler duty cycle for chassis-level emissions testing. Emissions certification for off-road heavy-duty engines is currently performed at the engine-level using a steady-state emissions testing protocol. Emissions certification for on-road heavy-duty engines is also performed at the engine-level using a transient duty cycle developed for on-road heavy-duty vehicles. Neither of these engine-level emissions testing protocols use a duty cycle that is indicative of real-world yard hostler driving profiles. Measuring yard hostler emissions levels on a heavy-duty chassis dynamometer using a standard yard hostler duty cycle would provide absolute emissions levels similar to in-use operation and allow for relative comparisons of emissions between different types of yard hostlers.

Measure LNG vs. diesel yard hostler emissions using yard hostlers with current engines certified to meet (or exceed) the most recent heavy-duty engine emissions standards. The 2007 on-road and Tier 3 off-road heavy-duty engine emissions standards currently in effect are much more stringent than the 2002 on-road and Tier 2 off-road standards in effect when this project began. In addition, there is a natural gas engine certified to EPA 2010 emissions standards that is currently being engineered into a model year 2008 yard hostler by a major yard hostler OEM.[78] Emissions testing should be performed with the most recent model engines to provide comparisons between currently available heavy-duty natural gas and diesel engines.

Evaluate the in-use performance of new LNG yard hostlers when they become available to determine whether the performance issues noted in this project (e.g., LNG fuel pressure regulation problems) have been adequately resolved by the manufacturer. Westport Innovations performed a major LNG fuel delivery system upgrade to the LNG yard hostlers towards the end of the project but the subsequent performance testing was insufficient to confirm that the upgrade addressed all the performance problems noted during the earlier phase of the project.

Update the business case analysis based on actual costs for new LNG yard hostlers when they become available. The present LNG yard hostler business case analysis is based on estimated costs and other assumptions that may not be accurate for new LNG yard hostlers with engines certified to 2007/2010 emissions standards. Many of these costs will not be accurately determined until manufacturers receive orders for new LNG yard hostlers and integrate 2007/2010 certified natural gas engines and LNG fuel delivery systems into vehicles.

Investigate methods of streamlining the LNG refueling infrastructure permitting process at POLB. The LNG permitting process for approval of temporary LNG refueling infrastructure at LBCT for this project was lengthy and resource-intensive. The process should be investigated in cooperation with LBFD and recommendations made for streamlining the process so that LNG refueling permitting does not become perceived as an obstacle for potential adopters of LNG-fueled CHE at POLB.

[78] Capacity of Texas, the second largest yard hostler OEM, plans to offer an LNG yard hostler with the 2008 Cummins Westport ISL G natural gas engine certified to EPA 2010 emissions standards in model year 2008.

Optimize vehicle refueling procedures for LNG yard hostler fleets. Fixed LNG refueling infrastructure may require changes to vehicle refueling procedures at some container terminals in order to minimize labor costs associated with refueling.

Consider port-based incentives to help address the incremental cost of LNG yard hostlers. The incremental cost of LNG yard hostlers is currently a significant barrier to adoption of the technology by more fleets. In the absence of specific incentives from the ports or other entities, the business case is marginal and it is unlikely that there will be a significant near-term demand for LNG yard hostlers. POLB and POLA should consider including port-based incentives for alternative fuel CHE incremental costs in future revisions to the CAAP.

Consider port-based incentives to help address the capital costs of LNG refueling infrastructure. The capital costs associated with LNG refueling infrastructure are another significant barrier to adoption of the technology by more fleets. (In some cases LNG fuel providers will install LNG refueling infrastructure at their own expense in exchange for a long term contract with a large fleet customer. However discussions with LNG fuel providers indicate that this is likely to result in an increased LNG fuel price to the customer.) In the absence of specific incentives from the ports or other entities, it will be difficult for fleets to justify switching from diesel to LNG yard hostlers. POLB and POLA should consider including port-based incentives for alternative fuel refueling infrastructure capital costs in future revisions to the CAAP.

Consider port-based incentives to help address the incremental costs of technologies and fuels that reduce both criteria pollutant emissions and GHGs. Given the increasing importance of GHG reductions together with criteria emissions reductions, the ports should establish funding criteria that takes both considerations into account. LNG technology is one example that can potentially provide benefits in both areas simultaneously. POLB and POLA should consider including port-based incentives for adoption of technologies that reduce both criteria pollutant emissions and GHGs in future revisions to the CAAP.

Advocate for regional, state and federal policy changes to provide funding for incremental costs of alternative fueled CHE and associated refueling infrastructure costs. POLB and POLA have considerable political influence which could be used to encourage regional, state and federal agencies to make funds available for alternative fueled CHE and the associated refueling infrastructure. In some cases this may require changes to existing funding policies and requirements, e.g., to provide LNG vehicle tax credits for off-road vehicles.

6.3 Additional Comments

This report has pointed out at least two major concerns associated with LNG yard hostlers in port applications. First, a 2005 diesel yard hostler with an on-road engine had lower NOx emissions than a 2005 LNG yard hostler with an on-road natural gas engine during steady-state emissions testing on a chassis dynamometer. The higher NOx emissions of the LNG yard hostlers were unexpected and the root cause remains unclear at this time. Since no comparison of NOx emissions between current model year LNG and diesel yard hostlers with on-road engines has been performed, no conclusions can be drawn regarding their relative emissions under similar conditions. Nevertheless this is obviously an area of potential concern and additional testing is recommended.

Second, in the absence of purchase incentives, the business case for LNG yard hostlers is extremely marginal. Where significant vehicle purchase incentives have been available, they have created a corresponding demand for LNG yard hostlers. However when those incentives were no longer available, market demand has dried up. In order to stimulate the near-term demand for LNG yard hostlers, further vehicle purchase incentives will be necessary as well as incentives that can be applied to the cost of LNG refueling infrastructure. Without such incentives, it is unlikely that there will be significant near-term demand for LNG yard hostlers in port applications. In the longer-term, there are numerous factors that may affect the demand for LNG yard hostlers, including future emissions regulations and emerging funding opportunities for alternative fueled vehicles, however the overall effect is difficult to predict at this time.

Despite these issues, there are additional benefits of LNG yard hostlers that may become increasingly important in the future and should not be overlooked. Some of these benefits are discussed briefly below.

LNG usage increases energy security by decreasing U.S. reliance on foreign oil. With world petroleum reserves declining and oil consumption in developing nations like China and India on the rise, oil prices are expected to continue increasing as world oil supplies shrink. Potential disruptions in the supply of oil due to geopolitical instability and/or sharp increases in the price of oil can have serious impacts on the U.S. economy. The substitution of alternative fuels such as LNG for petroleum-based fuels reduces U.S. dependence on foreign oil and makes the U.S. economy less vulnerable to oil supply disruptions and/or price fluctuations. While there are many possible options for alternative fuels in transportation, LNG is currently one of the most common, especially for heavy-duty vehicles such as yard hostlers.

LNG can be made from renewable sources. LNG is normally produced by liquefying natural gas found in oil and natural gas fields. While the natural gas feedstock for LNG is technically a fossil fuel, biogas and landfill gas derived from renewable sources are also potential feedstocks for LNG after appropriate processing (i.e. removal of most of the non-methane components of the gas such as CO_2, H_2S, H_2O and various contaminants). Renewable LNG (sometimes referred to as liquefied biomethane) has the dual advantages of both increasing energy security and having a net zero or even causing a total net reduction in GHG emissions.[79] It should be noted, of course, that biodiesel can also be made from renewable sources. However liquefied biomethane has the advantage of being made primarily from waste products whereas biodiesel is made primarily from agricultural products.

LNG yard hostlers have lower CO_2 emissions than diesel yard hostlers. Testing indicated that CO_2 emissions of MY 2005 LNG yard hostlers were 18% lower than MY 2005 diesel yard hostlers with on-road engines.[80] CO_2 is one of the primary GHGs believed to be responsible for

[79] Rutledge, Brad, *California Biogas Industry Assessment White Paper*, April, 2005, www.calstart.org/info/publications/California_Biogas_Industry_Assessment_White_Paper.pdf.
[80] However it should be noted that neither the MY 2005 diesel on-road or MY 2005 LNG engines have been optimized by the manufacturer for CO_2 emissions reductions.

climate change. While GHGs are not currently considered a criteria pollutant, their contribution to climate change has brought them to the attention of regulators. Should GHG emissions become regulated or incentives for GHG emissions reductions be made available at some point in the future, LNG yard hostlers are likely to have an advantage over diesel yard hostlers in this respect.

Appendix A LNG Driver Survey Data

LNG Driver Survey

Dates of Operation: ________________________

Equipment ID: ________________________

Operator (circle one): Driver Mechanic

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

15. Any problems with methane detection system (e.g. false alarms, shutdowns)? Yes No
    If yes, explain. ____

Comments: ____

____

____

Summary of LNG Driver Survey Data by Month

Month: June, 2006

Number of Driver Surveys Filled Out: 4

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	50%	50%	
2. Pulling power w/ full container		100%	
3. Acceleration w/ no container	50%	25%	25%
4. Smoothness of shifting	50%	50%	
5. Steering	100%		
6. In-cab visibility	50%	50%	
7. Ride comfort	75%	25%	
8. In-cab controls	50%	50%	
9. Braking	75%	25%	
10. Interior noise level	100%		
11. Exterior noise level	100%		
12. HVAC system	50%	50%	
13. Cab entry and exit		25%	75%
14. Overall vehicle rating	50%	50%	
15. Methane detection system problems?	No (100%)		

Month: July, 2006

Number of Driver Surveys Filled Out: 5

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	80%	20%	
2. Pulling power w/ full container		100%	
3. Acceleration w/ no container	20%	40%	40%
4. Smoothness of shifting	40%	40%	20%
5. Steering	100%		
6. In-cab visibility	40%	60%	
7. Ride comfort	100%		
8. In-cab controls	40%	60%	
9. Braking	80%	20%	
10. Interior noise level	100%		
11. Exterior noise level	100%		
12. HVAC system	40%	40%	20%
13. Cab entry and exit	20%	20%	60%
14. Overall vehicle rating	80%	20%	
15. Methane detection system problems?	No (100%)		

Month: August, 2006

Number of Driver Surveys Filled Out: 6

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	50%	50%	
2. Pulling power w/ full container	33%	67%	
3. Acceleration w/ no container	33%	50%	17%
4. Smoothness of shifting	33%	67%	
5. Steering	83%	17%	
6. In-cab visibility	50%	50%	
7. Ride comfort	83%	17%	
8. In-cab controls	50%	50%	
9. Braking	33%	67%	
10. Interior noise level	83%	17%	
11. Exterior noise level	67%	33%	
12. HVAC system	67%	33%	
13. Cab entry and exit	33%	17%	50%
14. Overall vehicle rating	50%	50%	
15. Methane detection system problems?	No (100%)		

Month: September, 2006

Number of Driver Surveys Filled Out: 4

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	50%	50%	
2. Pulling power w/ full container	50%	50%	
3. Acceleration w/ no container	50%	50%	
4. Smoothness of shifting	75%	25%	
5. Steering	75%	25%	
6. In-cab visibility	50%	50%	
7. Ride comfort	100%		
8. In-cab controls	50%	50%	
9. Braking	75%	25%	
10. Interior noise level	100%		
11. Exterior noise level	100%		
12. HVAC system	50%	50%	
13. Cab entry and exit	75%		25%
14. Overall vehicle rating	100%		
15. Methane detection system problems?	No (100%)		

Month: October, 2006

Number of Driver Surveys Filled Out: 4

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	25%	50%	25%
2. Pulling power w/ full container	25%	25%	50%
3. Acceleration w/ no container	25%	75%	
4. Smoothness of shifting	25%	75%	
5. Steering	50%	50%	
6. In-cab visibility	100%		
7. Ride comfort	75%	25%	
8. In-cab controls	100%		
9. Braking	50%	50%	
10. Interior noise level	75%	25%	
11. Exterior noise level	50%	50%	
12. HVAC system	25%	75%	
13. Cab entry and exit		25%	75%
14. Overall vehicle rating	75%		25%
15. Methane detection system problems?	No (100%)		

Month: November, 2006

Number of Driver Surveys Filled Out: 2

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability		100%	
2. Pulling power w/ full container		50%	50%
3. Acceleration w/ no container		100%	
4. Smoothness of shifting		100%	
5. Steering	50%		50%
6. In-cab visibility		100%	
7. Ride comfort		100%	
8. In-cab controls		100%	
9. Braking		100%	
10. Interior noise level	50%	50%	
11. Exterior noise level	50%	50%	
12. HVAC system		100%	
13. Cab entry and exit		100%	
14. Overall vehicle rating	50%	50%	
15. Methane detection system problems?	No (100%)		

Month: December, 2006

Number of Driver Surveys Filled Out: 4

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability	100%		
2. Pulling power w/ full container	50%	50%	
3. Acceleration w/ no container	25%	25%	50%
4. Smoothness of shifting	75%	25%	
5. Steering	100%		
6. In-cab visibility		100%	
7. Ride comfort	75%	25%	
8. In-cab controls		100%	
9. Braking	50%	50%	
10. Interior noise level	75%	25%	
11. Exterior noise level	75%	25%	
12. HVAC system	50%	50%	
13. Cab entry and exit	25%	50%	25%
14. Overall vehicle rating	75%	25%	
15. Methane detection system problems?	No (100%)		

Month: January, 2007

Number of Driver Surveys Filled Out: 1

LNG Yard Hostler Performance Characteristic	*Better*	*Same*	*Worse*
1. Maneuverability		100%	
2. Pulling power w/ full container		100%	
3. Acceleration w/ no container		100%	
4. Smoothness of shifting		100%	
5. Steering	100%		
6. In-cab visibility		100%	
7. Ride comfort		100%	
8. In-cab controls		100%	
9. Braking		100%	
10. Interior noise level	100%		
11. Exterior noise level	100%		
12. HVAC system		100%	
13. Cab entry and exit			100%
14. Overall vehicle rating		100%	
15. Methane detection system problems?	No (100%)		

Appendix B LNG Mechanic Survey

Mechanic: ____________________

Date: ____________________

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

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

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Please rate the following issues related to LNG 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. LNG 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. Manufacturer Support:	1	2	3	4	5

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

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7. Additional Comments:

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Appendix C LNG Bulk Fuel Deliveries

Delivery Date	*Gallons of LNG*
6/12/06	1594
7/19/06	2558
8/9/06	1746
9/11/06	2186
10/9/06	1685
11/21/06	2332
Dec. 2006	None
Jan. 2007	None