

**San Pedro Bay Ports Clean Air Action Plan  
Technology Advancement Program**



*Moving towards zero emissions*



Port of  
**LONG BEACH**  
The Green Port

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... 1

1.0 TECHNOLOGY ADVANCEMENT PROGRAM..... 4

    1.1 Introduction..... 4

    1.2 Technology Advancement Program Objectives..... 5

    1.3 Implementation Process ..... 5

    1.4 Advisory Committee ..... 6

2.0 KEY PROJECTS IN 2015 ..... 7

    2.1 Container Drayage Trucks ..... 7

        2.1.1 International Rectifier Plug-In Hybrid Electric Class 8 Truck Conversion ..... 7

        2.1.2 TransPower Electric Drayage Pre-Commercial Trucks Demonstration..... 9

        2.1.3 U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration .... 13

        2.1.4 TransPower Electric Drayage Infrastructure and Improvement (EDII) Demonstration.. 15

        2.1.5 SCAQMD Zero Emission Cargo Transport (ZECT) II Demonstration ..... 17

3.0 ADDITIONAL PORT-RELATED ADVANCED TECHNOLOGY EFFORTS.....20

    3.1 Zero-Emission Technology Development..... 20

    3.2 2010 CAAP Update Measures OGV-5 & OGV-6 ..... 22

    3.3 Additional Technology Advancement Efforts Tracked by TAP ..... 22

        3.3.1 SCAQMD Efforts ..... 23

            3.3.1.1 SCAQMD Zero Emissions Cargo Transport Project (ZECT I) ..... 23

            3.3.1.2 SCAQMD Catenary Zero-Emission Goods Movement System Demonstration ..... 23

            3.3.1.3 SCAQMD Catenary Zero-Emission Goods Movement System Demonstration ..... 25

        3.3.2 Port Generated Efforts ..... 26

4.0 2015 TAP BUDGET .....27

5.0 TAP PRIORITIES FOR 2016.....30

APPENDIX A: TECHNOLOGY ADVANCEMENT PROGRAM ADVISORY COMMITTEE

APPENDIX B: SUMMARY REPORTS FOR COMPLETED PROJECTS

**LIST OF FIGURES**

Figure 2.1: EDD2 at TTSI.....11  
Figure 2.2: EDD3 at Cal Cartage ..... 12  
Figure 2.3: EDD4 Hauling for NRT ..... 12  
Figure 2.4: US Hybrid Project Test Vehicle..... 14  
Figure 2.5: US Hybrid Project Test Vehicle..... 14  
Figure 2.6: EDII Charging Infrastructure ..... 16  
Figure 3.1: TransPower’s Overhead Catenary Demonstration Vehicle..... 24  
Figure 3.2: Volvo Plug-In Hybrid Urban Delivery Truck..... 25

**LIST OF TABLES**

Table 2.1: IR PHEV Conversion Demonstration Funding Partners..... 8  
Table 2.2: TransPower Electric Drayage Trucks Demonstration Funding Partners ..... 10  
Table 2.3: Status of TransPower EDD Trucks.....11  
Table 2.4: U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration Funding Partners..... 13  
Table 2.5: TransPower Electric Drayage Infrastructure and Improvement (EDII) Demonstration Funding Partners..... 16  
Table 2.6: SCAQMD Zero Emission Cargo Transport (ZECT) II Demonstration ..... 19  
Funding Partners..... 19  
Table 4.1: TAP Funding Investments through December 31, 2015..... 28

**ACRONYMS & ABBREVIATIONS**

AC	Advisory Committee or alternating current
ACTI	Advanced Cleanup Technologies Incorporated
Ah	ampere-hour
AMECS	Advanced Maritime Emissions Control System
APL	Shipping line formerly known as American President Line
APT	Advanced Petroleum Technologies, Inc.
AQIP	Air Quality Improvement Program
BMS	battery management system
CAAP	Clean Air Action Plan
CARB	California Air Resources Board
CCRT	catalyzed continuously regenerating technology
CEC	California Energy Commission
CEMS	continuous emissions monitoring system
CHE	Cargo Handling Equipment
CNG	compressed natural gas
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CRT	continuously regenerating technology
CSF	catalyzed soot filter
DOC	diesel oxidation catalyst
DOE	United States Department of Energy
DPF	diesel particulate filter
DPM	diesel particulate matter
DPM <sub>10</sub>	diesel particulate matter – 10 micron diameter
DPM <sub>2.5</sub>	diesel particulate matter – 2.5 micron diameter
ECA	North American Emissions Control Area
EGR	exhaust gas recirculation
EPA	United States Environmental Protection Agency
GCVW	gross combined vehicle weight
GHG	greenhouse gases
H <sub>2</sub>	hydrogen
HC	harbor craft
HDPF/C	hybrid diesel particulate filter/catalyst
HFO	heavy fuel oil
HHDDT	heavy heavy-duty diesel truck
HP	horsepower
HPDI	high pressure direct injection
HVAC	heating, ventilation and air conditioning
ICE	internal combustion engine
IMO	International Maritime Organization
ISO	International Standards Organization
kW	kilowatt
kWh	kilowatt-hours
LBCT	Long Beach Container Terminal
LNG	liquefied natural gas
MDO	marine diesel oil

ACRONYMS & ABBREVIATIONS (CONT'D.)

MGO	marine gas oil
MOA	Memorandum of Agreement
MW	megawatt
NO	nitric oxide
NO <sub>2</sub>	nitrogen dioxide
NO <sub>x</sub>	oxides of nitrogen
nm	nautical miles
OGV	ocean going vessel
O <sub>2</sub>	oxygen
PAH	polycyclic aromatic hydrocarbon
PHEV	plug-in hybrid electric vehicle
PHL	Pacific Harbor Line
POLA	Port of Los Angeles
POLB	Port of Long Beach
PON	Program Opportunity Notice
PM	particulate matter
PM <sub>10</sub>	particulate matter less than 10 micrometers in diameter
PM <sub>2.5</sub>	particulate matter less than 2.5 micrometers in diameter
RFI	Request for Information
RFP	Request for Proposals
RFQ	Request for Qualifications
RL	railroad locomotives
RTG	rubber tired gantry crane
SCAQMD	South Coast Air Quality Management District
SCR	selective catalytic reduction
SCRT	selective catalytic reduction technology
SFOC	specific fuel oil consumption
SiC	silicon carbide
SoCalGas	Southern California Gas Company
SO <sub>x</sub>	sulfur oxides
SO <sub>2</sub>	sulfur dioxide
SV	slide valve
SwRI	Southwest Research Institute
TAC	toxic air contaminant
TAP	Technology Advancement Program
THC	total hydrocarbon
U.S.	United States
VOC	volatile organic compound
VSR	vessel speed reduction
WiFE	water-in-fuel emulsification
ZEV	zero-emission vehicle

## EXECUTIVE SUMMARY

The Ports of Long Beach and Los Angeles (Ports) comprise one of the world's premier seaport complexes and are recognized as global leaders in environmental stewardship. The Ports also serve as a principal economic engine for Southern California, moving over \$300 billion in trade each year and supporting more than 800,000 jobs in Southern California. The latest economic forecasts indicate that demand for containerized cargo moving through the Southern California region will continue to increase by the year 2035. The Ports recognize that their ability to accommodate the projected growth in trade will depend upon their ability to address adverse environmental impacts that result from such trade.

The Ports' landmark joint Clean Air Action Plan (CAAP)<sup>1</sup> guides the Ports in their commitment to reduce the health risks and air emissions associated with port-related operations, while allowing port development and growth to continue. The CAAP focuses on near-term strategies, targeting significant reductions in diesel particulate matter (DPM), nitrogen oxides (NO<sub>x</sub>), and sulfur oxides (SO<sub>x</sub>). The CAAP also established a health risk reduction goal for 2020 and emissions reduction goals for the years 2014 and 2023.<sup>2</sup> The Ports measure progress towards these goals in their port wide Inventories of Air Emissions (Inventories). The results of the 2015 Inventories for both Ports will be available on their websites by September 2016.

Over the past ten years, the Ports' CAAP has resulted in dramatic strides in reducing air emissions. CAAP programs like the Clean Trucks Program have slashed pollution from heavy-duty trucks. Green leases, voluntary measures and state regulations have curbed emissions from cargo-handling equipment and harbor craft. Vessel speed reduction programs, accelerated shore-power deployment through lease requirements, and low-sulfur fuel regulations have led to significant drops in ship-related air pollution. Overall, between 2005 and 2014, the port-related DPM emissions were reduced by 85 percent, NO<sub>x</sub> emissions were reduced by 51 percent and SO<sub>x</sub> emissions were reduced by 97 percent. Despite this progress, the Ports still have work to do in order to meet the aggressive pollution-reduction goals defined in the 2010 CAAP Update.

In 2007, the Technology Advancement Program (TAP) was developed under the CAAP to ensure that effective air pollution reduction strategies will be commercially available to enable implementation of all CAAP measures. The purpose of the TAP is to identify and demonstrate new technologies or new applications of existing technologies that have a strong potential to reduce air pollution emissions from Port emission sources and meet CAAP goals. The Mission Statement for the TAP is to "accelerate the verification or commercial availability of new, clean technologies through evaluation and demonstration to move towards an emissions free port."

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<sup>1</sup> 2006 San Pedro Bay Ports Clean Air Action Plan: <http://www.polb.com/civica/filebank/blobdload.asp?BlobID=3452>

<sup>2</sup> 2010 San Pedro Bay Ports Clean Air Action Plan Update: <http://www.cleanairactionplan.org/reports/documents.asp>

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The TAP is funded on an annual basis by both Ports. Each Port may allocate up to \$1.5 million annually to worthy projects identified through the program. The Ports maximize the effectiveness of this investment by leveraging the Ports' funding with contributions from stakeholder agencies, including the United States Environmental Protection Agency Region 9 (U.S. EPA Region 9), California Air Resources Board (CARB), and South Coast Air Quality Management District (SCAQMD). Further, a minimum 50 percent co-funding contribution is required by the project applicant for all TAP projects. The TAP implementation process is thoroughly outlined in the TAP Guidelines<sup>3</sup>. The TAP offers grant funding to support the demonstration of advanced technologies that:

- a) Have a high probability of achieving significant reductions in criteria pollutants and CARB-classified air toxic pollutants, specifically, DPM, NO<sub>x</sub>, and SO<sub>x</sub>;
- b) Are seeking CARB verification or certification for the technology; and
- c) Present a strong business case for future successful technology commercialization.

In the simplest terms, the purpose of the TAP is to facilitate the development of additional, effective air pollution reduction strategies for the CAAP "toolbox."

While the TAP primarily focuses on the demonstration of technologies that have a high potential to yield substantial criteria air pollutant reductions, the technologies demonstrated under the TAP often reduce greenhouse gases (GHG) and fine particulate matter (i.e., particle size of 2.5 micron in diameter, or smaller). As a matter of practice, GHG emission reduction potential is considered in the evaluation for each technology proposed for a TAP demonstration.

The TAP serves as the catalyst for identifying, evaluating, and demonstrating new and emerging emission reduction technologies applicable to the port industry. As envisioned by the Ports at the onset of program implementation, successful TAP technologies are intended to be incorporated into CAAP updates as either new control measures, alternatives to existing emission reduction strategies, or as additional mitigation options to support port growth.

The TAP Advisory Committee (AC) consists of agency partners that include the Port of Long Beach (POLB), Port of Los Angeles (POLA), SCAQMD, CARB, and U.S. EPA Region 9. A list of current AC members is included in Appendix A. The AC serves in an advisory capacity to the Ports for screening, evaluating, and recommending projects that merit further development or demonstration. In addition, the AC members provide information as it pertains to co-funding from their agency that could potentially be used to move projects toward implementation. The AC process also serves as the mechanism for member agencies and the Ports to reach consensus on the level of emission reductions achieved by the candidate technologies undergoing evaluation. As an example, in 2015, the Ports focused on the need for test plan guidelines that could be used to evaluate zero emission truck technologies. This effort was coordinated by the Ports with CARB and SCAQMD support, resulting in the publication of the "Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines," which will be used to evaluate upcoming zero emission technologies used in drayage and yard truck applications.

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<sup>3</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2489>



**San Pedro Bay Ports Technology Advancement Program**  
2015 Annual Report

This is the ninth TAP Annual Report under the CAAP. The 2015 TAP Annual Report documents progress with the Ports' efforts to support near-term emerging technology development and demonstration. This Annual Report includes a summary of the five projects that were either selected or continued to be implemented under the TAP during 2015.

These include:

Source Category	TAP Project
Container Drayage Trucks	Infineon/International Rectifier Plug-In Hybrid Electric Class 8 Truck Conversion
	TransPower Electric Drayage Pre-Commercial Trucks Demonstration
	U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration
	TransPower Electric Drayage Infrastructure and Improvement (EDII)
	SCAQMD Zero Emission Cargo Transport (ZECT) II

Each of the projects listed above is discussed in Section 2 of this 2015 Annual Report.



## 1.0 Technology Advancement Program

### 1.1 Introduction

The Ports of Long Beach and Los Angeles (Ports) comprise one of the world's premier seaport complexes and are recognized as global leaders in environmental stewardship. The Ports also serve as a principal economic engine for Southern California, moving \$300 billion in trade each year and supporting more than 800,000 jobs in Southern California. The latest economic forecasts indicate that the demand for containerized cargo moving through the Southern California region will continue to increase by the year 2035. The Ports recognize that their ability to accommodate projected growth in trade will depend upon their ability to address adverse environmental impacts that result from such trade.

While the economic benefits of the Ports are felt throughout the nation, the environmental impacts of trade are more locally concentrated. The Ports are cognizant of the continuing view expressed by local residents, environmental groups, and regulatory agencies that more should be done to address port-related air quality issues. The Ports understand that inconsistent or conflicting environmental measures could have unintended and even counterproductive results.

In 2006, the Ports adopted their landmark joint Clean Air Action Plan (CAAP). The CAAP was updated in 2010 (2010 CAAP Update), and the third update began in late 2015. The CAAP guides the Ports in their commitment to reduce the health risks and air emissions associated with port-related operations, while allowing port development and growth to continue. The CAAP focuses on near-term strategies and targeting significant reductions in diesel particulate matter (DPM), nitrogen oxides (NO<sub>x</sub>), and sulfur oxides (SO<sub>x</sub>). DPM is of particular concern as it is linked to cancer and other serious health effects. NO<sub>x</sub> and SO<sub>x</sub> are contributors to the region's ozone smog and fine particulate matter levels, which are also important health concerns. The CAAP also established a health risk reduction goal for 2020 and emissions reduction goals for the years 2014 and 2023. The Ports measure progress towards these goals in their port wide Inventories of Air Emissions (Inventories). The 2015 Inventories will be available on the Ports' websites by September 2016.

Over the past ten years, the Ports have made dramatic strides in reducing air emissions. CAAP programs have slashed pollution from heavy-duty trucks. Green leases and State regulations have curbed emissions from cargo-handling equipment and harbor craft. Accelerated shore-power deployment through lease requirements and low-sulfur fuel regulations have led to significant drops in ship-related air pollution. In addition, local, state and federal grant funding has supported efforts to implement cleaner technologies at ports. Overall, between 2005 and 2014, the port-related DPM emissions were reduced by 85 percent, NO<sub>x</sub> emissions were reduced by 51 percent and SO<sub>x</sub> emissions were reduced by 97 percent. Despite this progress, the Ports still have work to do in order to meet the aggressive pollution-reduction goals defined in the 2010 CAAP Update and expected to be more challenging in the third update.

This document is the ninth Technology Advancement Program Annual Report under the CAAP.

## 1.2 Technology Advancement Program Objectives

The TAP Mission Statement is to “accelerate the verification or commercial availability of new, clean technologies through evaluation and demonstration to move towards an emissions free port.”

The TAP thus serves as the catalyst for identifying, evaluating, and demonstrating new and emerging emissions reduction technologies applicable to the port industry. These technologies will be incorporated in future updates to the CAAP as either new control measures, alternatives to existing emission reduction strategies, or as additional mitigation options to support port growth.

The emphasis of the TAP is to facilitate testing or distribution of information on emerging technologies that can be used to reduce emissions associated with the five port-related source categories. These source categories include the following:

- Ocean Going Vessels
- Harbor Craft
- Cargo Handling Equipment
- Heavy-Duty Diesel Trucks
- Railroad Locomotives

## 1.3 Implementation Process

There are three primary means by which projects are identified for demonstration in the Technology Advancement Program:

### *Port Generated Projects*

Should the Ports have specific interest in an emissions reduction technology or project, the Ports may elect to develop a project, seek partnerships to demonstrate the technology in port applications, and manage the implementation of the project. The Ports may also seek grant funding from other stakeholders to assist with project implementation.

### *Solicited Proposals*

The Ports enjoy broad authority under the TAP to solicit proposals for a specific technology or for technologies that are applicable to specified source categories. Common methods of soliciting projects include Requests for Information (RFI), Requests for Proposals (RFP), Requests for Qualifications (RFQ), and Program Opportunity Notices (PON).

### *Unsolicited Proposals*

The Ports frequently receive requests to fund various technology advancement projects, either from Port tenants working with technology providers, regulatory agencies conducting research or demonstration projects, or from technology developers/providers directly. When an unsolicited proposal is received by Port staff, it is evaluated using the following criteria:

- Technology Application – *Is the technology applicable to the port industry? Is the application feasible?*
- CARB Verification – *Is the technology developer currently seeking, or are they willing to seek, CARB verification?*
- Matching Funds – *Is the project supported by in-kind or direct capital matching funds?*
- Emission Reductions – *Are the emission reductions consistent with the 2010 CAAP Update goals? Does the technology reduce some emissions without increasing others?*
- Ability to meet the needs of the port industry – *Will the technology perform effectively in the port environment?*
- Uniqueness of the Proposal – *Is the technology new or emerging, at the pre-commercialization stage? Has the technology or demonstration been proposed by multiple vendors?*
- Cost – *Is the cost for the technology reasonable?*
- Industry Support – *Does the project have a committed port-industry partner willing to demonstrate the technology?*

Unsolicited proposals are reviewed by Port staff and the TAP Advisory Committee. During the 2015 calendar year, a number of unsolicited proposals were submitted for TAP consideration and reviewed with the TAP Advisory Committee. Three of these proposals were recommended by the TAP AC and began in 2015. These new projects are discussed below in Section 2.

## **1.4 Advisory Committee**

The TAP Advisory Committee (AC) consists of agency partners that include the Ports, SCAQMD, CARB, and U.S. EPA Region 9. The AC was established by invitation during the first quarter of 2007 and meets every six weeks to deliberate the merits of proposed TAP projects.

The AC serves in an advisory capacity to the Ports for screening, evaluating, and recommending projects to be considered for further development or demonstration. The AC review serves as the mechanism for member agencies and the Ports to discuss the projected emission reductions achieved by the candidate technologies undergoing evaluation.

The stated goal of the TAP program is to accelerate the development, verification, and commercialization of technologies that reduce emissions from any of the five port-related source categories. The Ports seek participation and funding contributions from other agencies for TAP projects. In this context, the AC members identify potential agency co-funding that could support TAP projects, as appropriate.

## 2.0 Key Projects in 2015

This ninth Technology Advancement Program Annual Report includes a summary of the five projects that were implemented or remained active in 2015.

These include:

Source Category	TAP Project
Container Drayage Trucks	Infineon/International Rectifier Plug-In Hybrid Electric Class 8 Truck Conversion
	TransPower Electric Drayage Pre-Commercial Trucks Demonstration
	U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration
	TransPower Electric Drayage Infrastructure and Improvement (EDII)
	SCAQMD Zero Emission Cargo Transport (ZECT) II

Each of the projects listed above is discussed in this section of the 2015 Annual Report. In addition, a summary of all TAP projects completed to date is included in Appendix B.

### 2.1 Container Drayage Trucks

#### *2.1.1 International Rectifier Plug-In Hybrid Electric Class 8 Truck Conversion*

In July 2013, the Ports began their project with International Rectifier to convert a conventional Class 8 drayage truck into a plug-in hybrid electric vehicle (PHEV). The project will include the development and demonstration of the PHEV, which will be placed into drayage operations through Mega Fr8 Ways, Inc. Performance and durability testing will be conducted to validate operation under various payloads and scenarios, which will be incorporated into International Rectifier’s test and demonstration plan.

In December 2014, International Rectifier received funding from the Department of Energy (DOE) to develop an ultra-fast charger (UFC) for use in or near the ports. This new funding will enable International Rectifier to upgrade the battery modules of the same PHEV with a 64kWh on-board ultra-fast-charge system.

***Emission Control Technologies***

International Rectifier (IR) proposes to convert a conventional Class 8 drayage truck to a PHEV with three main sub-systems that will include: a) an all-electric drive, b) a combined diesel-electric drive (hybrid mode) and c) an electrified accessory drive (zero-emissions idling system).

IR upgraded the originally-proposed lithium-polymer batteries to lithium-titanate batteries, which has the advantage of being faster to charge than the former. In addition, lithium-titanate will hold more charge and operate well at lower temperatures.

The PHEV will include a 400 kW motor that will meet the targeted power, torque, and speed for PHEV application. In addition, the PHEV will include a new battery management system (BMS) that will improve battery life under ultrafast charging conditions, to monitor the state of the battery. The BMS provides information such as voltage, temperature of individual cells, battery charge level and the overall condition of the battery. The battery pack within the PHEV will be built from high-energy density 50-volt battery modules designed for heavy-duty applications and will be thermally managed by IR’s liquid cooling technology. Multiple sub-packs will be connected in parallel to form the 64kWh pack.

Statistical analysis shows that if the battery pack is continuously used in the most extreme case, the cycle life of the 64kWh battery is projected to last up to 14 years with approximately 10,000 charge cycles.

***Project Partners & Funding***

The total cost for International Rectifier’s PHEV demonstration is \$731,972 with \$350,000 provided by the Ports (\$175,000 per port) and approximately \$381,972 from International Rectifier as matching funds. Funding contributions are shown below in Table 2.1.

**Table 2.1: IR PHEV Conversion Demonstration Funding Partners**

Project Partners	Contributions
Port of Long Beach	\$175,000
Port of Los Angeles	\$175,000
International Rectifier	\$381,972

***Environmental Benefits***

The PHEV will have three driver selectable modes as follows:

- 1) All-electric drive for zero-emissions operation. The range is designed to allow the PHEV to perform near-dock and short haul drayage routes under electric power only. For longer haul drayage routes, the PHEV will be able to operate within the Ports’ premises under all-electric zero-emissions power, and switch to hybrid-electric power after it leaves the Ports.
  
- 2) Hybrid-electric drive for reduced-emissions operation. For longer haul drayage routes that exceed the all-electric range of the PHEV, the electric drive system will provide supplemental power to the combustion drive system in modes when the diesel engine operates in less-than-optimal efficiency zones to improve fuel economy and to reduce emissions. In this mode, the vehicle is range-limited only by the capacity of the fuel tank.

- 3) Electrified accessory drive. When set in this mode, the PHEV will have a zero-emissions idling system, which will permit drivers to have access to full heating, ventilation and air conditioning (HVAC) and other truck accessories without requiring power from the diesel engine or generator. The PHEV will also have battery regeneration capability.

International Rectifier purchased a 2010 Peterbilt drayage truck with a 2007 CARB-compliant engine. The value of the diesel-electric mode is to reduce the overall fuel used in a drayage route, and thereby reduce overall emissions generated by the vehicle throughout its useful life. Since the diesel engine and its emission system are left in place, the reduced internal combustion engine (ICE) loading by the electric drive system while in hybrid-electric mode will allow the vehicle to remain CARB compliant. Since emissions are typically higher during periods of dynamic loading of the ICE (i.e., acceleration, deceleration, etc.), it is further expected that the rate of emissions will also be reduced when the vehicle is in hybrid-electric mode. This project supports the Ports' efforts in moving toward zero-emission technologies as outlined in the Ports' "Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles."

### ***Project Status***

International Rectifier spent most of 2015 developing the PHEV components and subsystems like their SLIC3™ battery module, battery pack, 400 kW motor, and drivetrain. Modifications and improvements to these components and subsystems have caused a delay in the schedule. Adding to that, changes in the business operations at International Rectifier, with a new parent company, Infineon Technologies, have set them back by approximately one year. Staff continues to monitor the project with Infineon/International Rectifier through their periodic updates that are submitted to the Ports.

#### ***2.1.2 TransPower Electric Drayage Pre-Commercial Trucks Demonstration***

The objective of this TAP project is to develop and demonstrate a zero-emission electric-battery drive system for heavy-duty trucks for drayage service deployment. Under this project, TransPower's ElecTruck™ electric propulsion system is being integrated into seven Navistar International ProStar trucks. This TAP project is a subset of the Zero-Emission Cargo Transport (ZECT) Demonstration that is funded by the California Energy Commission, U.S. Department of Energy, South Coast Air Quality Management District and TransPower. Please see Section 3.3 for more information regarding this larger scale project.

### ***Emission Control Technologies***

The TransPower's ElecTruck™ electric propulsion system offers technological innovations in several key areas, including: 1) power conversion: an advanced "Inverter-Charger Unit" (ICU) that combines the functions of the vehicle inverter, which controls the drive motors, and the battery charger, and regulates recharging of the vehicle battery pack, to facilitate battery recharging; 2) energy storage: high-energy battery modules using lithium-ion cells and an advanced battery management system (BMS) used to monitor each individual battery cell and extend the life of the battery subsystem by enabling the replacement of failing cells; 3) main propulsion: an Automated Manual Transmission (AMT) that delivers torque from electric drive motors to the vehicle's wheels more efficiently than competing transmission technologies; and 4) vehicle control: a proprietary vehicle control system enabling the development of algorithms that will optimize vehicle efficiency, maximize battery life, and protect key components such as batteries and power electronics from excessive temperatures, voltage spikes, or current surges. The TransPower's ElecTruck™ includes a newly redesigned power control and accessory subsystem (PCAS) incorporates most of the truck's control elements into a single integrated structure which greatly facilitates the installation of PCAS



**San Pedro Bay Ports Technology Advancement Program**  
2015 Annual Report

subsystems including the ICUs, Central Control Modules (CCM) and major components of electrically-driven accessory subsystem. In addition, the electric trucks include the latest improved Motor Drive Subsystem (MDS) with the AMT and the Energy Storage Subsystem (ESS) featuring more efficient 300 ampere-hour (Ah) battery cells, consolidated energy storage system with improved access to components, and improved battery management system. The projected vehicle and performance specifications for the TransPower’s electric-battery trucks included the following:

- Vehicle Chassis: Navistar International ProStar Class 8 Chassis
- Drive System: TransPower’s ElecTruck™ electric propulsion system
- Range: 70 to 100 miles at average load of 65,000 total gross vehicle weight rating
- Top Speed: 75 mph at level ground; 28 mph at 6% grade @ 80,000 pounds GCWW
- Capacity: 80,000 pounds maximum gross vehicle weight
- Acceleration: Achieve 30 mph in 16 seconds fully loaded; 60 mph in 70 Seconds fully loaded
- Battery Charging Time: 3 hours with single 70 kW charger (baseline configuration)

***Project Partners & Funding***

The Ports are contributing \$300,000 in co-funding to this project with a total project budget of \$4,443,801. Table 2.2 summarizes the project funding contributions:

**Table 2.2: TransPower Electric Drayage Trucks Demonstration Funding Partners**

Project Partners	Contributions
Port of Long Beach	\$150,000
Port of Los Angeles	\$150,000
TransPower	\$655,000
U. S. Department of Energy	\$1,142,184
California Energy Commission	\$2,296,617

***Environmental Benefits***

Tailpipe criteria air pollutants, toxics air pollutants, and greenhouse gas emissions are completely eliminated in zero-emission trucks. Successful demonstration of zero-emission heavy-duty trucks under this project offers significant potential in reducing/eliminating emissions for trucks in drayage service. The level of emission reductions will be proportional to the extent that these zero-emission electric-battery trucks are deployed in short-haul and medium-haul container drayage service. This project supports the Ports’ efforts in moving toward zero-emission technologies as outlined in the Ports’ “Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles.”



**Project Status**

Four of the seven Electric Drayage Demonstration (EDD) trucks have been completely integrated and placed in service. These include EDD1, EDD2, EDD3, and EDD4. EDD1, featuring the Flux BMS and the larger 700 Ah cells, accumulated about 3,900 zero emission miles operating mainly at SA Recycling carrying metal parts and scrap. EDD1 is currently out of service pending an upgrade with a new and more efficient energy cells and storage module. EDD1 is expected to be returned to service in early 2016. EDD2, EDD3 and EDD4, which include TransPower’s upgraded BMS and the more efficient 300 Ah cells, are in service at various locations within the Ports. Table 2.3 provides a summary of the total accumulated zero emission miles and the current location for each truck (as of December 2015). All three trucks are in daily service driving up to 80 miles per day and carrying containers with maximum capacity of up to 74,500 pounds GCVW. The remaining three trucks (EDD5, EDD6, and EDD&) are expected to be completed and placed in service early 2016.

**Table 2.3: Status of TransPower EDD Trucks**

Electric Truck ID No.	Zero Emission Miles	Operating Location
EDD1	3,330	At TransPower pending upgrade
EDD2	6,067	TTSI
EDD3	2,446	Cal Cartage
EDD4	3,508	National Retail Trucking

**Figure 2.1: EDD2 at TTSI**



Figure 2.2: EDD3 at Cal Cartage



Figure 2.3: EDD4 Hauling for NRT



**2.1.3 U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration**

In September 2015, the Ports awarded \$75,000 to US Hybrid to augment the charging capabilities of two battery-electric trucks being developed and tested under a separate project led by SCAQMD. US Hybrid, which offers comprehensive engineering and integration expertise in powertrain and power conversion systems for medium- and heavy-duty electric, hybrid, and fuel cell vehicles, was selected by SCAQMD to develop and demonstrate two battery-electric zero-emissions Class 8 trucks under the 2012 Department of Energy Zero Emissions Cargo Transport (DOE ZECT) grant. Originally, US Hybrid had planned to charge the trucks using off-board chargers. However, based on feedback from fleet operators and the available electric-vehicle charging infrastructure for heavy-duty trucks at the demonstrator sites, US Hybrid decided to upgrade its electric trucks with on-board chargers. This change will offer simpler charging logistics and cost savings for fleet operators and will make the US Hybrid charging platform compatible with the platform used by other zero-emissions truck manufacturers.

**Emission Control Technologies**

US Hybrid is designing, developing, and integrating two 60 kW 3-phase on-board chargers into two Class 8 battery electric drayage trucks. The proposed 60kW charger is in addition to the existing 6.6 kW Level II on-board charger, giving the truck dual plug capability for fast- or slow-charging.

The goal of this project is to provide a common charging infrastructure to support various demonstration electric trucks, including battery-electric trucks and natural gas plug-in hybrid electric trucks. This upgrade will provide simpler charging logistics for the fleet demonstrators in lieu of bulky off-board chargers. The on-board chargers will be compatible with the charging infrastructure at Total Transportation Services, Inc. (TTSI), where the trucks will recharge.

**Project Partners & Funding**

The Ports are contributing \$75,000 in co-funding to this project with a total project budget of \$150,000. Table 2.4 summarizes the project funding contributions:

**Table 2.4: U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration Funding Partners**

Project Partners	Contributions
Port of Long Beach	\$37,500
Port of Los Angeles	\$37,500
SCAQMD	\$75,000
<b>TOTAL</b>	<b>\$150,000</b>

**Environmental Benefits**

This project supports the TAP’s interest in standardizing charging methods for zero-emission vehicles and equipment.

**Project Status**

US Hybrid completed the testing and integration of the chargers in all three trucks. The full 24-month demonstration of the trucks, which includes ongoing monitoring of the on-board chargers, is expected to begin in 2016.



Figure 2.4: US Hybrid Project Test Vehicle



Figure 2.5: US Hybrid Project Test Vehicle



*2.1.4 TransPower Electric Drayage Infrastructure and Improvement (EDII) Demonstration*

In tandem with the Electric Drayage Pre-Commercial Demonstration (EDPCD) Project (Tasks 1 to 4), TransPower is working with the Port of Long Beach and Los Angeles on the Electric Drayage Infrastructure and Improvement (EDII) Project (Tasks 5 to 8), with partnership from Navistar, Total Transportation Services, Inc. (TTSI), SA Recycling, and CALSTART. The EDII project will build on the successes to date of the EDPCD Project, which as mentioned in Section 2.1.2, has received grant funds from a variety of sources including an earlier TAP grant awarded in 2013.

The EDPCD project gained broader support than originally anticipated, expanding from the initial five to now seven trucks, which created the need for this EDII project. The EDII project will mainly support improved electrical charging at existing sites and improve the advanced battery management system. In addition, this project will also initiate a manufacturing engineering process to reduce the cost of manufacturing components and enable TransPower to develop and implement failure modes and effects analyses and diagnostic capabilities similar to those used by established vehicle manufacturers, which will help improve the overall reliability of the ElecTruck™ system and trucks using it.

The EDII project focuses on four main task areas:

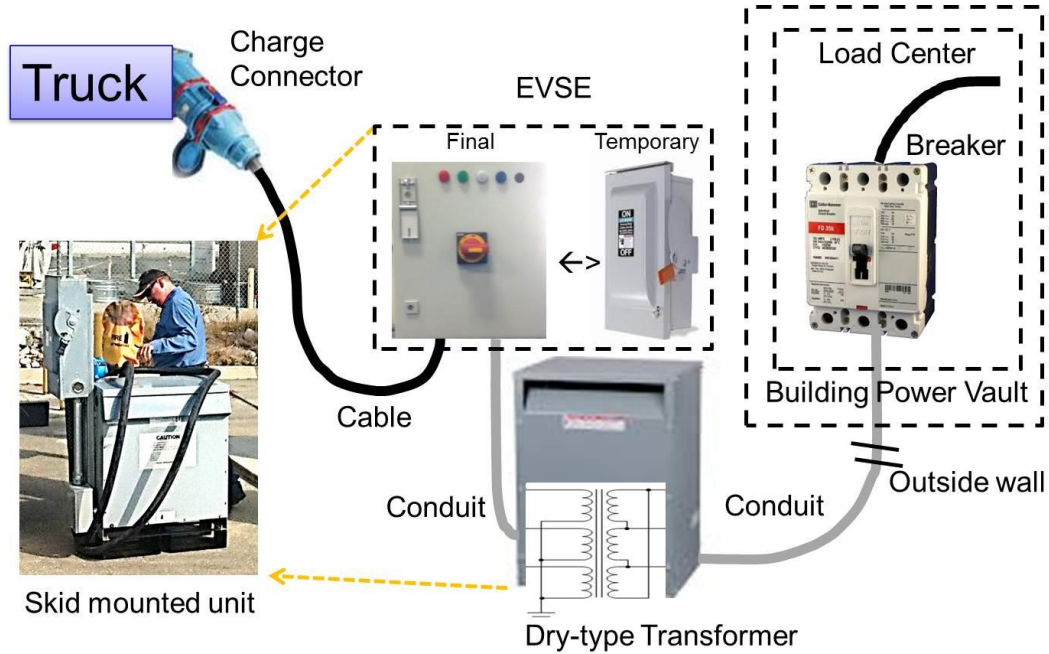
- Upgrade and installation of battery charging infrastructure at fleet operator sites;
- Development and demonstration of a next generation battery management system (BMS);
- Initiation of a manufacturing engineering process to identify and evaluate new manufacturing methods aimed at reducing the costs of manufacturing key ElecTruck™ drive system components and subsystems; and
- Implementation of improved failure analyses and diagnostics capabilities to enhance vehicle reliability.

Ultimately, the result will be a combined EDPCD/EDII project with a total budget of approximately \$5.7 million that is targeted to establish capabilities substantially beyond those targeted by the initial program.

***Emission Control Technologies***

TAP funds are being used to help TransPower cover the cost of installing enhanced electrical charging infrastructure for the seven EDPCD/EDII trucks. The enhancements are expected to achieve important incremental improvements in vehicle battery management. In addition, the project will initiate the manufacturing engineering process that must be undertaken to achieve cost-effective production of future electric trucks, and enhance overall vehicle reliability through improved diagnostics. Successful completion of these new tasks will accelerate commercialization of TransPower's ElecTruck™ electric propulsion system. Figure 2.6 provides a schematic of the EDII charging infrastructure.

Figure 2.6: EDII Charging Infrastructure



**Project Partners & Funding**

The Ports are each contributing \$300,000 in co-funding to this project with a total project budget of \$600,000. Table 2.5 summarizes the project funding contributions:

Table 2.5: TransPower Electric Drayage Infrastructure and Improvement (EDII) Demonstration Funding Partners

Project Partners	Contributions
Port of Long Beach	\$300,000
Port of Los Angeles	\$300,000
TransPower	Match funding provided under TransPower’s EDPCD project, summarized in Section 3.1.2

**Environmental Benefits**

The EDII project supports the seven zero emission trucks from the EDPCD project, which will result in the revenue service of zero emission drayage trucks throughout the Ports. Completion of tasks in the EDII project will include the design, development and deployment of the battery charging infrastructure for these trucks.

**Project Status**

Since 2013, TransPower has expanded their fleet operator partners to now include California Cartage Company, National Retail Trucking (NRT), Knight Transportation, 3-Rivers Trucking, and PASHA (at the Port of Los Angeles terminal).



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

In 2015, TransPower accomplished the design, development, and deployment of the battery charging infrastructure and battery management system required to support the seven electric drayage truck project (Tasks 5 and 6). This effort addresses new needs identified during development and initial testing of the first four electric drayage trucks in 2013-14, including the need for a separate Electric Vehicle Support Equipment (EVSE) console to improve charging safety, and installation of enhanced electrical service at fleet operator sites. Interim charging infrastructure deployed at TTSI and SA Recycling to support the first three trucks was maintained and utilized to enable early experience to be gained with these trucks, in parallel with design and installation of permanent charging infrastructure for all seven trucks. The permanent charging infrastructure will be installed at all participating fleet partner sites.

Task 5 is divided into two main subtasks, 5.1 and 5.2. The principal objectives of Task 5.1 were to complete the design of the EVSE consoles used to support charging of the EDII trucks, develop a bill of material (BOM) listing all key EVSE console components, and place orders for externally sourced items in the EVSE console BOM in preparation for manufacturing of the EVSE consoles at TransPower. Completion of Task 5.1 sets the stage for Task 5.2, whose objectives involves installing the EVSE consoles and other elements of the EDII charging infrastructure at the various sites where the seven EDII trucks are to have their battery packs charged. Task 5.1 was completed in August 2015 and Task 5.2 will be completed in the first quarter of 2016.

Task 6 is to improve the design of TransPower's BMS, a critically important part of TransPower's electric drive system that is responsible for monitoring the ElecTruck™ battery subsystem and balancing the charge among the 224 battery cells used in each truck. This task builds on successes TransPower has already achieved under the EDPCD project, during which several different approaches to battery management have been tested and evaluated. Task 6.1 was completed in August 2015.

The rest of the tasks involving the second part of the next generation BMS (Task 6.2), manufacturing engineering (Tasks 7.1 and 7.2), and improved diagnostics and reliability (Tasks 8.1 and 8.2) are set for completion in 2016.

### *2.1.5 SCAQMD Zero Emission Cargo Transport (ZECT) II Demonstration*

The I-710 and CA-60 highways are major transportation corridors in the Southern California region, which are used daily by heavy-duty drayage trucks that transport the cargo from the Ports to the inland transportation terminals. These terminals, which include store/warehouses, inland-railways, are anywhere from 5 to 50 miles in distance from the Ports. The operation of these drayage vehicles have a significant impact on the air quality in this region and impacts the quality of life in the communities near these corridors and the Ports.

The Zero Emission Cargo Transport II Project follows the SCAQMD's original ZECT project, which is discussed in Section 3.3.1. ZECT II encompasses the development of seven drayage trucks by five different contractors as approved under the U.S. Department of Energy's Zero Emission Cargo Transport Demonstration Funding Opportunity Announcement, which is administered by SCAQMD. The project consists of two components:

- Development and demonstration of zero-emission fuel cell range extended electric drayage trucks; and
- Development and demonstration of hybrid electric drayage trucks for goods movement operations between the Ports near dock rail yards and warehouses.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The purpose of this project is to accelerate deployment of zero emission cargo transport technologies to reduce harmful diesel emissions, petroleum consumption and greenhouse gases in the surrounding communities along the goods movement corridors that are impacted by heavy diesel traffic and the associated air pollution.

### *Emission Control Technologies*

Under the proposed project, five electric drayage trucks will be demonstrated with a range of fuel cell sizes and battery capacities. In addition, plug-in hybrid technologies will be demonstrated on both a natural gas and diesel engine platform. The natural gas platform will also have the potential to connect to a catenary system via a pantograph based on technology developed by Siemens (see Section 3.3.1 for more information on the Siemens project). The diesel platform will employ a retrofit strategy, making the demonstrated technology applicable to the legacy fleet of drayage trucks; including some 10,000-diesel trucks currently serving the Ports.

These advanced technology trucks will operate along major drayage truck corridors including the Terminal Island Freeway, a primary corridor for port cargo travelling between Port of Los Angeles and Port of Long Beach terminals and the ICTF.

The following is a short description of each of the project vehicles and technologies:

Center for Transportation and the Environment (CTE) - Under project management by CTE, BAE Systems will develop a battery electric truck with hydrogen range extender. The power output of the electric drive train is comparable to currently used Class 8 truck engines power output. AC traction motors will be mounted one on each rear drive axle and the electric drive train in the architecture is set up to be fully redundant. The vehicle will operate primarily from the batteries, engaging the fuel cell system only when the batteries reach a specified state of charge. BAE anticipates that the 30 kg of hydrogen (25 kg usable) will provide approximately 112 miles of range between fuel fills.

Transportation Power (TransPower) - TransPower will develop two battery electric trucks with hydrogen fuel cell range extenders. The preliminary technical concept for the proposed fuel cell range extender project is to use TransPower's proven ElecTruck™ drive system as a foundation and add fuel cells provided by Hydrogenics, one of the world's leading suppliers of hydrogen fuel cells. The proposed project will result in the manufacturing and deployment of two demonstration trucks, one with a 30 kW fuel cell and one with a 60 kW fuel cell, enabling a direct comparison of both variants.

U.S. Hybrid - U.S. Hybrid will develop two battery electric trucks with an onboard hydrogen fuel cell generator. The truck will be powered by a lithium-ion battery with an 80 kW hydrogen fuel cell generator in charge sustaining mode, eliminating the need for charging.

Gas Technology Institute (GTI) - Under project management by GTI, contractor BAE Systems will develop one battery electric hybrid truck with CNG range extender and optional catenary capability. The truck will operate in a zero emissions (all-electric) mode and in a conventional hybrid electric mode using CNG.

**San Pedro Bay Ports Technology Advancement Program**  
2015 Annual Report

International Rectifier (IR) - IR will develop one plug-in hybrid-electric truck (PHEV) and an ultra-fast charger (UFC) for use in or near the ports. While International Rectifier is a part of the overall project, no funds from the Ports’ Technology Advancement Program (TAP) are allocated to this contractor since the PHEV development for this project element is also currently funded under a separate TAP grant. Toward the end of 2015, IR was acquired by Infineon Technologies. As of this writing, the disposition of this project is still undetermined.

***Project Partners & Funding***

The Ports are contributing \$1,133,979 in co-funding to this project with a total project budget of \$19,984,820. Table 2.6 summarizes the project funding contributions:

**Table 2.6: SCAQMD Zero Emission Cargo Transport (ZECT) II Demonstration  
Funding Partners**

Project Partners	Contributions
US Department of Energy	\$9,725,000
OEMs	\$3,075,841
SCAQMD	\$2,400,000
California Energy Commission	\$2,400,000
L.A. Department of Water and Power	\$1,000,000
Port of Long Beach	\$566,990
Port of Los Angeles	\$566,990
Southern California Gas Company	\$250,000

***Environmental Benefits***

The battery-electric trucks equipped with fuel cell range extenders will have zero emissions. The hybrid-electric trucks will operate at near-zero emission levels. This project supports the Ports’ efforts in moving toward zero-emission technologies as outlined in the Ports’ “Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles.”

***Project Status***

The project is divided into four budget periods. Each budget period is one year and at the end of the year each contractor will be evaluated by the US DOE and SCAQMD on their completion of tasks within that period of time and a go or no-go decision will be made to proceed on a per-contractor/truck basis. The decision will include a determination that each contractor will be able to move on to the next budget period or if they will need to complete requirements of the previous period prior to authorization to proceed into the next period.

Currently, the project is still in contracting phase, which is expected to be finalized by first quarter 2016.

### 3.0 ADDITIONAL PORT-RELATED ADVANCED TECHNOLOGY EFFORTS

The TAP tracks other related efforts that support the overall TAP goals and mission. Currently, there are two major Port initiatives underway that synergistically support the TAP mission. These include the Zero-Emission Technology Development Program and the implementation of the 2010 CAAP Update Measures OGV-5 and OGV-6.

#### 3.1 Zero-Emission Technology Development

The mission statement for the Ports' TAP is *"...to accelerate the verification or commercial availability of new, clean technologies, through evaluation and demonstration, to move towards an emissions-free port."* As summarized above in Section 2, the TAP is currently evaluating and demonstrating technologies that could eventually lead to deployment of zero-emission technologies for sources in port-related operations. Some of those technologies represent interim or transitional technologies that help to significantly reduce air emissions, but are not yet emissions-free (for example, the CNG hybrid drayage truck being developed under the SCAQMD ZECT II project). Nonetheless, the deployment of these technologies in the near term will help ports reduce air emissions and associated health risks while continuing to strive for full deployment of zero-emission technologies in the appropriate areas of port goods movement for the future. The Ports continue to work with the Los Angeles County Metropolitan Transportation Authority's Countywide Zero-Emission Trucks Collaborative to "promote consistency among public agencies in working to catalyze the development and deployment of zero-emission trucks in Los Angeles County." This Collaborative includes both Ports, Caltrans, Southern California Association of Governments, and the SCAQMD.

In 2015, the Ports committed to updating the CAAP with new strategies to move the Ports closer toward zero emissions. Development of the updated CAAP is expected to continue through 2016. This CAAP update is anticipated to remain consistent with the "Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles<sup>4</sup>," which lays out the Ports' goals for zero emission technology implementation. In addition, the Ports continued to implement the following TAP projects:

- International Rectifier's demonstration to test their hybrid electric technology with zero-emissions option on Class 8 trucks. Please visit Section 2.2.1 for more information on their Plug-In Hybrid Electric Class 8 Truck Conversion Demonstration.
- TransPower's two separate demonstration projects to test their battery-electric technology on Class 8 trucks. Please visit Section 2.2.2 for more information on their Electric Drayage Pre-Commercial.

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<sup>4</sup> Download the Roadmap at: <http://www.cleanairactionplan.org/reports/default.asp>

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

Also in 2015, the TAP AC recommended, and the ports subsequently approved, three new TAP projects that support the zero emission technology development priority at the ports. These new projects are:

- U.S. Hybrid's design and development project to develop an on-board charger for zero emission drayage trucks. This project supports the SCAQMD's 2012 Zero Emission Cargo Transport (ZECT I) project. Please visit Section 2.2.3 for more information on this charger development project.
- TransPower's Electric Drayage Infrastructure and Improvement (EDII) project, which is a second TAP project that supports charging infrastructure development for zero emission truck and yard tractor technologies.
- SCAQMD's 2014 project under a grant from the US DOE for the second Zero Emission Cargo Transport (ZECT II) project that will design and demonstrate several zero emission and zero-mile hybrid heavy-duty truck technologies.

In addition, the Ports, in collaboration with the South Coast Air Quality Management District and the California Air Resources Board, continued the effort to develop guidelines for the technical evaluation, performance testing, and durability validation of electric, hybrid-electric, and other advanced technology trucks intended to dray shipping containers from port marine terminals to destinations within the South Coast Air Basin. The intent of this testing and demonstration protocol is to provide a consistent set of guidelines to advanced technology truck manufacturers and licensed motor carrier demonstration partners regarding port requirements and expectations as it pertains to vehicle performance, operability, and durability. Without such consistency, it is difficult to compare technologies and/or verify that zero or "near-zero" emission trucks meet the minimum performance standards required for drayage truck operations within the port environment. The protocol is anticipated to be completed in early 2016.

Also, the Port of Los Angeles published a draft of its Zero Emission White Paper (White Paper) in September 2015. The White Paper<sup>5</sup> was developed to assist the Port in moving toward the adoption of zero emission technologies utilized for the purpose of moving cargo on and off Port terminals to a final destination. The White Paper contains information on various types of zero-emission and near-zero-emission technologies, the status of those technologies, proposed testing plans for future demonstrations, infrastructure planning, and a business case study. The paper concluded with a series of specific recommendations, including a goal of assisting in the purchase and demonstration of up to 200 zero-emissions vehicles at Port terminals by the year 2020.

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<sup>5</sup> To view the Zero Emissions White Paper, visit:  
[https://www.portoflosangeles.org/pdf/Zero\\_Emmissions\\_White\\_Paper\\_DRAFT.pdf](https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf)

### **3.2 2010 CAAP Update Measures OGV-5 & OGV-6**

Ships (ocean-going vessels or OGVs) remain San Pedro Bay's largest contributor to air pollution. As indicated by the Ports' respective 2014 Emissions Inventories, OGVs account for approximately 52 percent of the port-related diesel particulate matter, 54 percent of NO<sub>x</sub> emissions, and almost all of SO<sub>x</sub> emissions. As such, the 2010 CAAP Update called for a two-pronged approach to clean up the San Pedro Bay shipping fleet: (1) attract newly built ships that meet the most up-to-date, strictest environmental standards, and (2) reduce emissions in the legacy fleet through retrofit technologies or operational changes. The CAAP identifies these efforts as control measures OGV-5 and OGV-6, respectively.

Both Ports have adopted voluntary incentive programs to attract ships with the cleanest engines, specifically engines meeting the IMO NO<sub>x</sub> Tier II and Tier III standards, which produce 15% fewer NO<sub>x</sub> emissions and 85% fewer NO<sub>x</sub> emissions respectively, or the equivalent reductions through emission-reduction technologies.

In 2015, the Port of Los Angeles paid \$446,000 in incentives to shipping companies following the protocol established by the International Association of Harbors and Ports, Environmental Ship Index Incentive Program, and the Port of Long Beach paid \$450,000 in incentives to shipping companies who participated in the Green Ship Incentive Program. Overall, 19% of the San Pedro Bay fleet met the Tier II engine standard in 2015, up from 3% in 2012, when these programs launched.

Additionally, the Ports have been working with the shipping industry to identify promising emission-reduction technologies for TAP demonstrations. The Ports will continue to monitor emission-reduction technologies for ships in hopes of identifying promising technologies ready for demonstration in a real-world port environment.

### **3.3 Additional Technology Advancement Efforts Tracked by TAP**

In addition to the above major initiatives, there are a number of other technology development efforts being tracked by the TAP. These projects include projects being led by SCAQMD, as well as projects generated by the Ports for a targeted purpose.

### *3.3.1 SCAQMD Efforts*

#### *3.3.1.1 SCAQMD Zero Emissions Cargo Transport Project (ZECT I)*

SCAQMD contracted with U.S. DOE on behalf of the Southern California Zero-Emission Freight Movement Regional Collaborative to develop and demonstrate zero emission Class 8 drayage trucks in real world drayage service. DOE awarded the SCAQMD \$4.17 million for the demonstration, which is referred to as the Zero Emission Cargo Transport I project (ZECT I). ZECT I originally included four vendors: Balqon, Vision, TransPower, and US Hybrid. During 2015, Balqon and Vision withdrew from the project and SCAQMD received approval from US DOE to reprogram the funds to TransPower and US Hybrid to add natural gas fueled plug-in hybrid electric vehicles (PHEVs) to the project. TransPower will build two compressed natural gas (CNG) PHEVs using a small (3.7 liter) CNG engine to provide extended range up to 200 miles with 30-40 all-electric range (AER) miles. US Hybrid will convert three liquefied natural gas (LNG) drayage trucks operated by TTSI with their PHEV system with capabilities to provide 30-40 AER miles and 150-200 mile range per charge. To recap, the current list of equipment for this program (11 in total) includes:

- TransPower – four (4) battery electric trucks and two (2) CNG plug-in hybrid trucks
- US Hybrid – two (2) battery electric trucks and three (3) LNG plug-in hybrid trucks

As of December 2015, TransPower completed the four battery electric trucks and these are operating in demonstration service. US Hybrid completed one of the two battery electric trucks with the second truck to be completed by early 2016. Both trucks will be placed in service by Q2 2016. The contract modifications to add the plug-in hybrid demonstration vehicles were fully executed in December 2015 and work on these trucks will begin in 2016.

#### *3.3.1.2 SCAQMD Catenary Zero-Emission Goods Movement System Demonstration*

SCAQMD has an ongoing project with Siemens Industry Inc. (Siemens) to develop and demonstrate an overhead catenary system (OCS) using their eHighway wayside power technology for heavy-duty trucks. The demonstration involves one mile of catenary power lines in both directions along Alameda Street in the City of Carson with four catenary accessible trucks from Volvo, TransPower and BAE/Kenworth. The trucks will demonstrate a variety of architectures such as diesel hybrid, CNG hybrid and battery electric. The hybrid drive system will extend the operating range of the truck beyond the all-electric range of the catenary system, enabling the truck to perform regional drayage operations and bridge gaps in catenary infrastructure as it is deployed on a regional level. The Siemens' pantograph system will allow for seamless connection and detachment from the catenary power source. When entering the catenary system corridor, the pantograph system will verify the presence of catenary lines and allow the driver to raise the pantograph from within the cab of the truck. Upon leaving the catenary lane, the pantograph will automatically retract and the truck will switch to on-board power systems.



The infrastructure portion of the project is in the construction phase with completion scheduled for the second quarter of 2016. Both trucks – one battery electric and one CNG hybrid - being developed by TransPower were completed in 2015; the Volvo diesel hybrid truck will be completed in mid-2016; and the BAE/Kenworth CNG hybrid truck is scheduled for completion in 2017. In October 2015, one of TransPower's trucks was successfully tested at an off-the-street OCS test track in Carson to validate the truck's ability to operate on battery and catenary power.

**Figure 3.1: TransPower's Overhead Catenary Demonstration Vehicle**





*3.3.1.3 SCAQMD Catenary Zero-Emission Goods Movement System Demonstration*

The SCAQMD and Volvo Technology of America, Inc. partnered to develop and demonstrate a Class 8 plug-in hybrid-electric drayage truck. The truck features a Mack chassis at 60,000 gross combined weight (GCW) with a proprietary hybrid driveline, a new energy optimized battery, external charging interface and newly developed energy management and control systems suitable for port drayage application. By utilizing plug-in hybrid technology, fully zero-emission electric mode is possible for limited distances at low speeds, such as in a predetermined zero emission geofence. The integration of a plug-in hybrid powertrain with downsized engine (11L in lieu of 13L), along with several improvements to vehicle efficiency are expected to result in approximately 30% improvement in fuel economy. The total project cost was approximately \$2.4 million.

The project was completed in July 2015 with a final demonstration of the concept vehicle on a simulated drayage route around Volvo's North American headquarters in Greensboro, NC. The route included all traffic conditions typical of drayage operation in Southern California as well as geo-fences defined to showcase the zero emission capabilities of the truck. The test vehicle successfully completed four consecutive trips with 44,000 lb. GCW, covering approximately two miles per trip in the Zero Emission geo-fence. The test route was nine miles in total.

Volvo's future work will focus on improving their analytical tools to better capture engine and exhaust after-treatment component behavior under start-stop or low speed conditions. Volvo believes this will help identify robust strategies to control the complex plug-in hybrid energy management algorithms necessary to maximize the air quality and energy benefits of the plug-in hybrid electric vehicle technology in drayage and other local and regional hauling applications.

**Figure 3.2: Volvo Plug-In Hybrid Urban Delivery Truck**



### *3.3.2 Port Generated Efforts*

In May 2015, the Port of Los Angeles closed out a grant under CARB's AB 118 Air Quality Improvement Advanced Technology Demonstration Projects: Zero-Emission Off-Road Equipment Program with TransPower's Electric Yard Tractor Demonstration (EYTD) Project. For this project, TransPower integrated their electric drive technology into two off-road yard tractors, which supports the Ports' goal of developing zero emission technologies. The two electric yard tractors were completely integrated and used in service by SA Recycling, TTSI, and Dole fruit dock in the Port of San Diego. The grant demonstration is complete; however, both tractors continue to operate on a limited basis at APM Terminal and Pasha in the Port of Los Angeles. In addition to the two yard tractors developed for the port environment, TransPower developed a yard tractor for Ikea. The Ikea tractor has operated over 15,000 miles and runs 40-80 miles in a typical full service day.

- The Port of Long Beach has partnered with SCAQMD to demonstrate the feasibility and emissions reduction capability of Advanced Cleanup Technologies, Inc.'s (ACTI) barge-based, 'direct-connect' Advanced Maritime Emissions Control System (AMECS). During Phase I, ACTI designed and developed the barge system and successfully completed proof-of-concept testing. ACTI has conducted demonstration testing on over 20 container vessels during phase 1 to assess both the effectiveness of the direct-connect system and its associated capture efficiency, as well as the emissions reduction capability of the system. The AMECS received approval from the CARB as an alternative to shore-to-ship power for container vessels on October 17, 2015. As a result, the Mediterranean Shipping Company (MSC) utilized the AMECS on 11 of its container vessel calls in 2015 to address its shorepower requirements. Phase 2 of the demonstration involves full-scale emissions testing on vessels (RoRo, tankers, bulk, etc.) that are not otherwise regulated under CARB's Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port (At-Berth Regulation), at which time ACTI will again request CARB review of the data and consideration of this system as an approved alternative compliance option under the regulation for those vessel types.
  
- The Port of Los Angeles contracted with TraPac, Inc. (TraPac) to demonstrate the Mobile Emissions Treatment System (METS-1), which is a barge-mounted emission control system developed by Clean Air Engineering-Maritime, Inc. (CAE-M). This system is designed to reduce ocean going vessel at-berth auxiliary engine emissions. It is anticipated that the overall emissions reduction will be at least 81% for DPM, SO<sub>x</sub>, and NO<sub>x</sub>. The system consists of two sub-systems: (1) a hood/transfer line/crane assembly designed to capture greater than 90% of the at-berth auxiliary engine exhaust, and 2) a Tri-Mer Corporation emissions treatment unit designed to achieve greater than 90% reduction in captured DPM and NO<sub>x</sub>. The Tri-Mer unit is a fourth generation design composed of a cloud chamber scrubber and a selective catalytic reduction unit to reduce the DPM and NO<sub>x</sub> emissions, respectively. The overall emissions reduction is anticipated to be at least 81%, Phase I measured the capture efficiency of the hood/transfer/crane assembly (emissions capture device) at the Pasha terminal. Phase II demonstrated a fully integrated system with the emissions capture device coupled with the emissions treatment unit on a mobile barge at the TraPac terminal. As of December 2014, 14 vessels were tested. On June 25, 2015, CARB issued Executive Order AB-15-01, approving the METS-1 as an approved alternative technology under the At-Berth Regulation. Since approval of the METS-1, five vessels have utilized the system to achieve shore power equivalency at the Port of Los Angeles.

#### 4.0 2015 TAP BUDGET

The TAP is supported by both Ports at an annual level of up to \$1,500,000 from each Port (up to \$3 million total). Additional funding is contributed on an ad-hoc basis by participating agencies, including but not limited to the SCAQMD, CARB, U.S. EPA, and California Energy Commission (CEC). Project co-funding is also contributed by the project proponent as either cash or in-kind contribution, or a combination of both.

The Ports and agency stakeholder investments for all past and current TAP projects approved to date are shown in Table 4.1. Three new projects were approved and funded by the TAP in 2015. Contributions from participating agencies other than the Ports are typically made on a project-by-project basis. In addition to the funding amounts reflected in Table 4.1, TAP contractors are required to provide a minimum of 50 percent co-funding in the form of cash and/or in-kind contributions to each project. Required match contributions are not included in Table 4.1, but are noted within each project summary in Section 2 and Appendix B.

San Pedro Bay Ports Technology Advancement Program  
2015 Annual Report

**Table 4.1: TAP Funding Investments through December 31, 2015**

Project Category	Status	POLB	POLA	AQMD	CARB	US EPA/ USDOE	CEC	Total Port & Agency Stakeholder
<b>Ocean Going Vessels</b>								
APL Singapore Slide Valve/WiFE	2009	\$22,500	\$22,500		\$783,628			\$828,628
ACTI AMECS Emissions Testing	2008	\$149,527	\$149,527	\$55,000				\$354,054
Bluefield Holdings Krystallon OGV Scrubber	2013	\$825,000	\$825,000					\$1,650,000
OGV Slide Valve Low-Load Emissions Evaluation	2013	\$108,000	\$108,000					\$216,000
<b>Harbor Craft</b>								
Foss Maritime Hybrid Tugboat	2010	\$500,000	\$889,920*		\$1,000,000			\$2,389,920
<b>Cargo Handling Equipment</b>								
LNG Yard Tractor	2007	\$350,000				\$75,000**		\$425,000
Balqon Electric Terminal Tractor	2009		\$263,500	\$263,500				\$527,000
Vycon RTG REGEN Flywheel	2007	\$11,500	\$11,500	\$8,000				\$31,000
Balqon Lithium Battery Upgrade	2011		\$400,000					\$400,000
Hybrid Yard Tractor	2010	\$300,000*	\$300,000*			\$300,000**		\$900,000
LBCT Eco-Crane	2011	\$42,467.50	\$42,467.50			\$130,130		\$215,065
Capacity Plug-In Hybrid Tractor	2010	\$29,500*	\$32,000*					\$61,500
APT Emulsified Biodiesel	2011	\$44,000	\$44,000					\$88,000
<i>RYPOS Diesel Emission Control (L2+)</i>	2012	<i>\$32,334.21</i>	<i>\$32,334.21</i>					<i>\$64,668.42</i>
Hybrid Yard Tractor Development & Demonstration – Beta Test	2011	\$13,000*	\$13,000*					\$26,000
RYPOS Adv. L3+ DPF - RTG Cranes	2014	\$36,130	\$36,130					\$72,260
<b>Container Drayage Trucks</b>								
<i>Vision Motor Corp. Hydrogen Fuel Cell Plug-In Hybrid Electric Truck</i>	2012	<i>\$95,625</i>	<i>\$95,625</i>					<i>\$191,250</i>
Westport ISX LNG Engine	2010	\$250,000	\$250,000	\$1,250,000			\$500,000	\$2,250,000
SoCalGas CNG Drayage Truck	2010	\$111,577.50	\$111,577.50	\$421,250				\$644,405
International Rectifier Plug-In Hybrid Electric Class 8 Truck Conversion	ongoing	\$175,000	\$175,000					\$350,000
TransPower Pre-Commercial Electric Drayage Truck Demonstration	ongoing	\$150,000	\$150,000			\$1,142,184	\$2,296,617	\$2,596,617
<b>U.S. Hybrid On-Board Charger for Zero Emission Cargo Transport Demonstration</b>	ongoing	<b>\$37,500</b>	<b>\$37,500</b>	<b>\$75,000</b>				<b>\$150,000</b>
<b>TransPower Electric Drayage Infrastructure and Improvement (EDII)</b>	ongoing	<b>\$300,000</b>	<b>\$300,000</b>					<b>\$600,000</b>
<b>SCAQMD Zero Emission Cargo Transport (ZECT) II</b>	ongoing	<b>\$566,990</b>	<b>\$566,990</b>	<b>\$2,400,000</b>		<b>\$9,725,000</b>	<b>\$2,400,000</b>	<b>\$5,933,980</b>

**Table 4.1: TAP Funding Investments through December 31, 2015 (cont'd)**

Project Category	Status	POLB	POLA	AQMD	CARB	US EPA/ USDOE	CEC	Total Port & Agency Stakeholder
<b>Locomotives</b>								
Johnson Matthey DPF Locomotive Demonstration	<b>2014</b>	\$75,000	\$75,000		\$346,178			\$496,178
<b>Research Projects</b>								
Heavy-Duty Drayage Truck Duty Cycle Characterization	<b>2011</b>	\$12,681*	\$13,000*					\$25,681
Development of Drayage Truck Chassis Dynamometer Test Cycle	<b>2011</b>	\$12,000*	\$11,466*					\$23,466
AQMD HDV In-Use Emissions Testing Program	<b>ongoing</b>	\$153,276	\$153,276	\$1,701,156				\$2,007,708
Total Investment		\$4,403,608.21	\$5,109,313.21	\$6,173,906	\$2,129,806	\$11,372,314	\$5,196,617	\$34,385,564.42
Total TAP Investment		\$4,036,427.21	\$3,849,927.21					
<b>Total Ports' TAP Investment</b>		<b>\$7,886,354.42</b>						

\*This funding amount is a non-TAP, Port funding contribution to the project.

\*\*Denotes EPA-grant funding contribution from the U.S. EPA West Coast Collaborative (pre-dating the TAP).

*Italics* denotes projects that were modified during implementation in a manner that changed the original budget. See Section 2 or Appendix B for more information.

## 5.0 TAP PRIORITIES FOR 2016

The TAP Priorities for 2016 will continue to support the Zero-Emission Technology Development Program and the implementation of 2010 CAAP Update ship measure OGV-6.

In addition, the TAP will continue to support the identification, development and demonstration, and, ultimately, CARB verification of lower emitting technologies applicable to all source categories and focus areas identified in the CAAP. Therefore, the TAP funding priorities for 2016 will be based on the technology needs identified in the 2010 CAAP Update to improve air quality at the Ports and protect the health of residents of the South Coast Air Basin. The technical and programmatic TAP priorities for 2016 are summarized below.

### *2016 Technical Priorities*

For 2016, the Ports will continue the effort to identify and develop TAP technologies for the key source categories that contribute to port emissions. This includes targeting emission reductions from ocean-going vessels, locomotives, on-road and off-road trucks with continued focus on zero or near-zero emission technologies.

### *2016 Programmatic/Policy Priorities*

For 2016, a number of program enhancements continue to be pursued, including:

- Working to identify opportunities to further integrate port operators and other stakeholders into the technology review process, with the goal of facilitating acceptance into port operations following demonstration. This will support both the zero-emission technology and OGV-6 efforts;
- Facilitating “matching” potential fleets with technology companies to reduce the difficulty some companies encounter when trying to find a project partner;
- Increasing coordination and the level of communication with other domestic and world ports as it relates to air quality improvement technologies and the potential for inclusion in the CAAP;
- Partnering with the TAP Advisory Committee member agencies, other agency stakeholders, and project proponents in an effort to leverage TAP funding and maximize the effectiveness of the TAP;
- Ensuring that port equipment operators are aware of grant program eligibility, and when appropriate, facilitate application to such programs, which include, but are not limited to, the U.S. EPA Emerging Technologies Program, CARB’s AB 118 Air Quality Investment Program, and SCAQMD’s Carl Moyer Program.



APPENDIX A

TECHNOLOGY ADVANCEMENT PROGRAM ADVISORY COMMITTEE MEMBERSHIP

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## Appendix B

### Summary Reports for Past Projects

The following Technology Advancement Program projects are concluded or completed:

1. ACTI Advanced Maritime Emission Control System (AMECS) Project (2008)
2. APL Singapore Slide Valve & Water-In-Fuel Emulsion Demonstration Program (2009)
3. Alternative Petroleum Technologies' Emulsified Biodiesel (2011)
4. Balqon E-30 Electric Terminal Tractor Development & Demonstration Project (2009)
5. Balqon Lithium-Ion Battery Demonstration (2011)
6. Bluefield Holdings Krystallon Ocean Going Vessel Scrubber (2013)
7. Capacity Plug-In Hybrid Electric Terminal Tractor (2010)
8. Characterization of Drayage Truck Duty-Cycles (2011)
9. Development of a Drayage Truck Chassis Dynamometer Test Cycle (2011)
10. Foss Maritime Green Assist™ Hybrid Tugboat (2010)
11. Hybrid Yard Tractor Development & Demonstration (2010)
12. Hybrid Yard Tractor Development & Demonstration – Beta Test (2011)
13. Johnson Matthey Locomotive DPF Demonstration (2014)
14. Liquefied Natural Gas Yard Tractor Demonstration (2007)
15. Long Beach Container Terminal Eco-Crane™ (2011)
16. OGV Slide Valve Low-Load Emissions Evaluation (2013)
17. RYPOS Advanced Diesel Particulate Filter for Cargo Handling Equipment (2012)
18. RYPOS Advanced Level 3+ Diesel Particulate Filter RTG Crane Demonstration (2014)
19. SoCalGas CNG Drayage Truck Demonstration (2010)
20. SCAQMD HDV In-Use Emissions Testing Program (2013)
21. Vision Motor Corp. Hydrogen Fuel Cell Hybrid Electric Trucks (Zero-TT and Tyrano) (2012)
22. VYCON REGEN® System for Rubber-Tired Gantry Cranes Testing & Verification (2007)
23. Westport GX LNG Engine Development (2010)

Summaries of the Final Reports submitted for these projects are included herein.

## ACTI Advanced Maritime Emission Control System

### Technology Manufacturer

Advanced Cleanup Technologies, Inc. (ACTI)

### Co-Participants

Port of Long Beach, Port of Los Angeles, South Coast Air Quality Management District, Metropolitan Stevedore Company, Engine Fuel & Emissions Engineering, Inc., Professional Environmental Services

### Background

Advanced Cleanup Technologies, Inc. (ACTI) is a professional full service firm specializing in environmental emergency response, hazardous waste cleanup, and air pollution control technology. ACTI developed the Advanced Maritime Emissions Control System, or AMECS, as an alternative pollution control method for ocean-going vessels that are not configured to use shore power, also known as “cold ironing,” while at berth.

### Project Objective

To investigate the technical and commercial feasibility of reducing emissions from ocean-going vessels not configured to use shore power while at berth. The goal was to demonstrate pollution reduction efficiencies equal to cold ironing for nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), and particulate matter (PM).

### Technology Demonstration

The AMECS design tested during the demonstration used a shroud lifted over the vessel exhaust stack by means of a specially designed crane and deployment arm. The shroud was then lowered over the stack and then cinched to provide a soft attachment between the shroud and the ship's stack.

A seal closes the open area between the perimeters of the bonnet and ship's stack to limit the amount of air entering the bonnet as well as to prevent exhaust gases from escaping. The exhaust gases from the ship's auxiliary engines and the boilers are routed through a flexible duct to an Emission Treatment System (ETS) located on the dock adjacent to the vessel's berth. The ETS uses multiple exhaust gas treatment technologies to remove both gaseous and particulate pollution:



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The **Pre-Conditioning Chamber**, which uses a counter-flow spray system to remove PM and water soluble organic gases. The spray water is treated with sodium hydroxide to simultaneously remove sulfur oxide pollution. The water spray also cools the exhaust gas, allowing smaller particles to coalesce such that they are more efficiently captured in subsequent phases of exhaust gas treatment;

**Cloud Chamber Scrubbers** remove the remaining exhaust PM. Three separate units generate a fog of very fine water droplets with a high electrical charge. The charged water droplets attract and capture multiple PM particles. The PM laden water is circulated through filters where the PM is removed. The three cloud chambers are identical except for the polarity of the charge imparted to the water droplets. Sodium hydroxide is also injected into the water streams of the cloud chambers to remove any remaining sulfur oxides;

**Selective Catalytic Reduction (SCR) Reactor** removes NO<sub>x</sub> emissions. Liquid urea is injected into the hot gas stream ahead of the SCR where it is converted to ammonia. The ammonia reacts with the NO<sub>x</sub> while passing through the catalyst to form nitrogen and water vapor, which are then vented to atmosphere. The SCR Reactor is designed to remove at least 99% of the NO<sub>x</sub> emitted by the vessel while at berth;

The **Continuous Emissions Monitoring System (CEMS)** is used to measure exhaust gas pollution levels both into and out of the ETS. This system is used to gauge pollutant removal efficiency, as well as control the injection rates of sodium hydroxide and urea used during exhaust treatment.

### Status

The TAP-sponsored AMECS demonstration and testing project was completed as of July 2008. The Final Report documenting the test protocols and measured emission reduction efficiency levels was prepared by TIAX LLC on behalf of ACTI and submitted to the Ports and South Coast AQMD for review and comment. The demonstration results were also provided to and underwent an independent evaluation by the California Air Resources Board (CARB). As a result of their evaluation, CARB submitted a letter on December 15, 2008, stating their concurrence with the AMECS emissions efficiency testing results.

### Results

The AMECS was demonstrated at Metropolitan Stevedore/Port of Long Beach on multiple vessels with varying exhaust stack configurations. During the demonstration period, two full-scale emission reduction efficiency tests were conducted, the results of which were independently verified by two testing laboratories.

### Benefits

During emissions testing, NO<sub>x</sub> and PM emissions were reduced by 99% and 95.5%, respectively. In addition, sulfur oxides (SO<sub>x</sub>) were reduced by 99%, and volatile organic compound (VOC) emissions were reduced by greater than 97 percent.

### Project Costs

The total project cost was \$603,211. Funding included \$149,527 from each Port's TAP budget and a \$55,000 contribution from the South Coast AQMD.

### 2015 Update

Further demonstration of this technology was necessary to determine how it functions in day-to-day operations, including evaluation of costs, durability, integration into operations, etc. SCAQMD coordinated with ACTI in 2012/2013 on a land-based AMECS demonstration at Metropolitan Stevedore's facility on Pier F, which was funded by a grant from U.S. EPA. All emissions testing related to this demonstration was completed in September 2013, per ACTI's agreement with U.S. EPA.

To ensure continuity from the land-based demonstration, SCAQMD took the lead on managing the next phase of the project, working in partnership with ACTI, to conduct further demonstration of the AMECS technology. ACTI's third-generation design is barge-based, instead of the previous design, which was fixed permanently to the wharf. Also, the new system connects to each exhaust stack separately – a “direct connect” system – rather than the previous “sock on a stack” bonnet design that fit over all the exhaust stacks at once. ACTI will test at least 25 vessels (up to 36 total) for a minimum of 1,000 hours, which is expected to take at least six months. For this follow-on project phase, the Port contracted directly with SCAQMD, which then contracted separately with ACTI.

On October 17, 2015, ACTI received CARB approval for its barge-based emissions control system to be used on container vessels as an alternative compliance option for the CARB Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port, otherwise known as the Shore Power Regulation. The At-Berth Regulation includes a provision that allows alternative technologies to be used if they achieve emissions control efficiencies similar to those achieved using on-shore grid based electrical power. In order to use the equivalency option, particulate matter and nitrogen oxides control efficiencies for the alternative technology must be determined by testing as specified in the At-Berth Regulation. CARB staff reviewed ACTI's AMECS testing results and approved compliance with the requirements of the At-Berth Regulation. AMECS can now be used as an alternative technology to grid-based shore power for container vessels only. For specific approval conditions, refer to the approval documents at this link: <http://www.arb.ca.gov/ports/shorepower/shorepower.htm>

Updated: December, 2015





## APL Singapore Slide Valve & Water-In-Fuel Emulsion Demonstration Project

**Technology Manufacturer**  
MAN B&W Diesel  
Sea to Sky Pollution Solutions

**Co-Participants**  
Port of Long Beach, Port of Los Angeles, University of California-Riverside CE-CERT, Bay Area AQMD, Ventura County APCD, San Luis Obispo County APCD, Santa Barbara County APCD, California Air Resources Board, U.S. EPA Region 9



### Background

The Technology Advancement Program completed participation in a demonstration of emission reduction technologies aboard the container ship *APL Singapore*. Two emission control technologies were demonstrated - the use of slide valves in the vessel's main engines, and water-emulsified bunker fuel using an innovative onboard water in fuel emulsifier.

### Project Objective

To investigate the technical feasibility, engineering requirements, and potential for replication in other ocean going-vessels (OGVs), the San Pedro Bay Ports partnered with the U.S. EPA, CARB, and a number of air districts to demonstrate two retrofit technologies that have the potential to significantly reduce both particulate matter and oxides of nitrogen (NO<sub>x</sub>) emissions. The primary objectives of the demonstration project were to:

- Evaluate the particulate matter (PM) emission reduction effectiveness of retrofitting OGV main engines with an improved injector design known as a slide valve;
- Demonstrate demand-based onboard water in fuel emulsification system and measure the NO<sub>x</sub> reduction effectiveness of varying the water content.

### Technology Demonstration

**Slide Valve Injectors** – Slide valves installed on the APL Singapore's main engine differ from conventional valves in their spray patterns and are designed to reduce dripping of fuel from the injector during the combustion process. Particulate matter is a product of incomplete combustion and unburned fuel. Optimization of the fuel injection system was expected to result in a reduction in fuel consumption and a reduction of PM emissions on the order of 10% to 25%. The slide valve technology was provided by MAN B&W Diesel (MAN).

**Water-in-Fuel Emulsification (WiFE)** – WiFE is the process of introducing water into fuel prior to injection into the combustion cylinder. The fuel-water emulsion technology was provided by Sea to Sky Pollution Solutions. A fuel homogenizer was installed in the APL Singapore’s engine room to produce the emulsification. Fuel and water are carried by separate lines into a mixing chamber called a “homogenizer/emulsifier” which is essentially a large funnel. Inside the funnel is a rotor that spins with a very small clearance next to the funnel’s walls. The spinning rotor draws in the fuel and water, mixes them together and squeezes the mixture out of the funnel with water present in the fuel as tiny droplets. The water droplets, as small as one micron (0.000001 meter in diameter) are fully contained within the fuel.

The fuel/water mixture is immediately injected and atomized within the engine’s combustion chamber. The heat inside the combustion chamber causes the water droplets to vaporize into steam – this requires energy from the combustion process and results in lower peak combustion temperatures. The lower combustion temperatures reduce NO<sub>x</sub> formation.

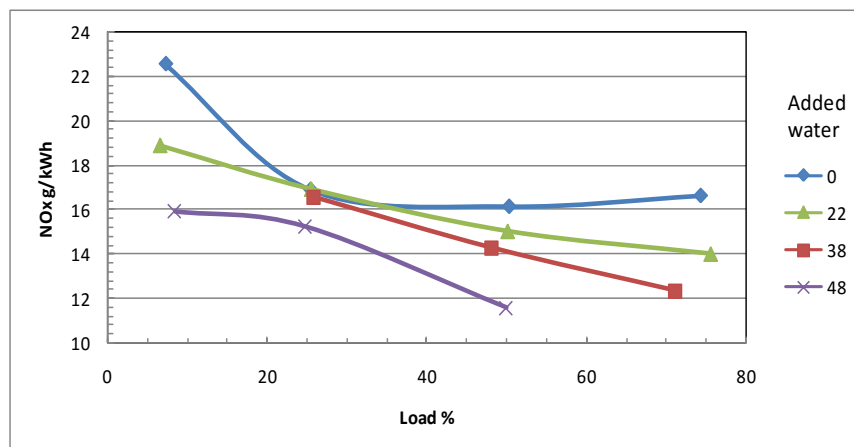
### Status

The first emissions tests were conducted during a 15-day transpacific voyage from Kaohsiung Taiwan to the San Pedro harbor. Testing was conducted in parallel by University of California-Riverside and MAN B&W. A second test protocol was performed in spring 2008, also conducted by the University of California-Riverside in cooperation with engine manufacturer MAN B&W Diesel.

### Results

Project test conditions resulted in an evaluation that indicated the benefits of slide valves appear to be limited. Emissions testing data were inconclusive and a clear determination of the technology benefits could not be made. Due to the importance of reducing emissions from OGVs, additional study was conducted in 2012 to gain more data and experience with slide valves as a potential emission reduction strategy.

Testing of the WiFE system aboard the APL Singapore yielded the results shown below in the figure below. As shown, water concentrations as high as 48% were successfully demonstrated, yielding NO<sub>x</sub> reductions on the order of 30%<sup>6</sup>.



<sup>6</sup> Measurement uncertainty ranges from 3% to 15% for these results.

### Project Costs

Seven funding partners contributed approximately \$1.3 million toward this demonstration and evaluation project. The San Pedro Bay Ports, the Bay Area, Ventura County, San Luis Obispo County, and Santa Barbara County Air Pollution Control Districts contributed funds towards the emissions testing element of the project. The San Pedro Bay Ports contributed \$45,000 in TAP funding toward emissions testing.

### Looking Forward

This project demonstrated the potential for NO<sub>x</sub> reductions that can be achieved through OGV retrofit using commercially available emulsification technology. The Ports conducted a follow-up study in 2012 to evaluate the potential for OGV engine emission reductions from the use of slide valves. For more information, please see Page B-39 of this Appendix to learn more about the OGV Slide Valve Low-Load Emissions Evaluation.

Updated: April, 2014



## Alternative Petroleum Technologies Emulsified Biodiesel Fuel Demonstration

**Technology Manufacturer**  
Alternative Petroleum Technologies, Inc.

**Co-Participants**  
Port of Long Beach, Port of Los Angeles, West Basin Container Terminal (Ports America)

### Background

The use of biodiesel fuel blends as a method to reduce diesel particulate matter (DPM) and greenhouse gas (GHG) emissions from diesel engines has been studied extensively. The results consistently show that while biodiesel fuels produced from renewable sources have the potential to effectively reduce hydrocarbon, carbon monoxide (CO), and DPM emissions, there is often a corresponding increase in oxides of nitrogen (NO<sub>x</sub>) emissions on the order of 2 percent or greater. Given the serious nonattainment status for ozone in the South Coast Air Basin, any air pollution reduction strategy that increases NO<sub>x</sub> emissions, a principal ozone precursor, is not recommended by state and local air quality regulatory agencies.



### Project Objective

Under the TAP, Alternative Petroleum Technologies, Inc. (APT) set out to demonstrate that their soy-derived, emulsified fuel technology could mitigate the NO<sub>x</sub> emissions increase that is historically associated with the use of traditional biodiesel fuels. The TAP project consisted of both laboratory-based emissions testing and an in-use, field demonstration of the fuel in standard cargo handling activities at the West Basin Container Terminal.

### Technology Demonstration

To demonstrate the viability and effectiveness of the emulsified biodiesel fuel in cargo handling equipment, APT performed a two-phased demonstration that consisted of an evaluation of the emulsified fuel with and without a diesel oxidation catalyst (DOC) in a laboratory setting and a real-time demonstration of the fuel in yard equipment at a port terminal.

The first phase of the project was conducted at Olson EcoLogic Engine Testing Laboratories. Emissions testing was conducted on a 2004 Cummins QSM 11C engine certified to Tier 2 standards, since it is representative of the engines installed in the top handler units featured in the field evaluations. The QSM 11 C is rated at 330hp at 2100 rpm. The engine was tested according to the non-road transient cycle, a standardized engine dynamometer transient driving schedule.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

In the second project phase, a field trial was conducted at Ports America, which operated three 2008 model year top handlers in regular container movement operation for a period of five months. Three primary activities constituted the in-use demonstration phase:

1. Operation of three top-handler units on regular B20 biodiesel fuel;
2. Operation of three top-handler units on emulsified B20 biodiesel fuel;
3. Operation of one top-handler unit on emulsified B20 biodiesel fuel with a DOC.

### Status

The APT demonstration project was completed in August 2011 and the final report is available on the TAP website<sup>7</sup>.

### Results

The APT demonstration successfully proved that APT's emulsified B-20 blend mitigated an increase in NO<sub>x</sub> emissions, while also providing additional reductions in PM when coupled with a verified diesel emissions control system. This provides port drayage operators an alternative fuel selection for their existing fleet of container yard equipment.

### Benefits

The testing demonstrated that a 6 percent water emulsion effectively mitigated the NO<sub>x</sub> increase associated with the regular B20 biodiesel fuel. The inclusion of a DOC after-treatment unit showed a beneficial effect on the total PM emission reduction by 40 percent in comparison to a 29 percent reduction with the fuel as a stand-alone emissions control strategy. Additionally, there were no perceptible operational differences in the dedicated top handlers during the demonstration.

### Project Costs

Funding for the emulsified biodiesel demonstration was provided by POLB and POLA, each contributing \$44,000, for a total of \$88,000 in TAP funding for this project. APT committed matching funds in the amount of \$88,000 towards the demonstration project as well as committed to pursue CARB Level 2 verification for both their emulsified diesel fuel and their fuel in combination with currently verified diesel exhaust after-treatment systems.

### Commercialization and Applications

APT plans to leverage the findings of this TAP demonstration by pursuing their plans for CARB verification of the emulsified biodiesel fuel. This would enable future sales and marketing of the APT biodiesel blend fuel to existing cargo handling equipment fleet operators in the state of California.

Updated: May, 2013

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<sup>7</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2533>



# Balqon E-30 Electric Terminal Tractor Development & Demonstration Project

**Technology Manufacturer**  
Balqon Corporation

**Co-Participants**  
Port of Los Angeles  
South Coast Air Quality Management District (SCAQMD)



### Background

The Balqon E-30 Electric Terminal Tractor was built as a demonstration vehicle, co-funded by the Port of Los Angeles and SCAQMD, and designed specifically for drayage operations. Developed by the Balqon Corporation as a Port of Los Angeles initiative, the prototype E-30 all-electric terminal tractor successfully completed cargo terminal tests during 2008.

### Project Objective

Fleets of hundreds of yard tractors, powered mainly by diesel and propane fuel, move thousands of containers each day between the Port’s docks and terminal backland. The objective of the E-30 Electric Terminal Tractor demonstration project was to prove the performance capabilities and commercial feasibility and practicality of using zero-emission electric terminal tractors to perform this function.

### Technology Description

Designed specifically for short-haul or drayage operations, this heavy-duty terminal tractor demonstrated the capability to pull a 60,000 pound cargo container at a top speed of 45 mph, and has a range between 30 to 60 miles per battery charge. The battery charger was designed to charge up to four electric trucks simultaneously in four hours. Key design goals for the Balqon E-30 electric terminal tractor are highlighted below:

<b>Vehicle Performance</b>	Maximum speed 45 mph; unloaded grade 10%, loaded 5%; Max GCWR 125,000 lbs; Range: unloaded 150 miles; fully loaded range 90 miles
<b>Vehicle Dimensions (inches)</b>	Overall – 210” X 96” X 120”; wheelbase 135”; fifth wheel height 46”; front wheel overhang 44”, rear wheel overhang 31”
<b>Electric Motor</b>	300 hp rated 230 volt AC electric motor connected to flux vector variable frequency controller; 300% peak load rating
<b>Traction Controller</b>	Proprietary flux vector motor controller 240 KW liquid cooled; integrated CAN BUS and self-diagnostic system
<b>Traction Battery</b>	280 kW-hr lead acid battery pack, 336 Volt; battery management system monitors battery cell performance
<b>Battery Charger</b>	100 KW multi-vehicle fast charger; 4 charging ports standard; priority smart charge algorithm based on vehicle state of charge

**Benefits**

The Balqon E-30 is a zero emission electric vehicle using electric motors for motive power and batteries for energy storage; thus, tailpipe emissions for this low-speed electric terminal tractor are zero.

On a “kilowatt-hour of energy” cost basis, the Balqon electric truck is projected to cost approximately 20 cents per mile to operate. A typical class 8 diesel truck could cost anywhere from four to nine times as much, depending on the cost of diesel fuel and truck duty cycle.

**Status**

Following the completion of cargo terminal tests during 2008, the Harbor Department purchased 14 electric terminal tractors from Balqon as part of the “Green Terminal” program. Once these trucks have been demonstrated as a viable alternative to conventional tractors, the Port plans to deploy them at the terminals. The Green Terminal program also included the production of one on-road electric truck. In total, the Port of Los Angeles invested approximately \$5 million to purchase the electric drayage trucks.

**Project Costs**

The development and demonstration of the Balqon electric terminal tractor was co-funded by the Port of Los Angeles and SCAQMD at a total cost of \$527,000.

Project Partners	Contributions
Port of Los Angeles	\$263,500
South Coast AQMD	\$263,500



**Next Steps**

A follow-on study was conducted to evaluate the capability of new lithium-ion battery technology for use in the Balqon electric demonstration units. This project is summarized on page B-13.

In 2015, the Port of Los Angeles worked with terminals and Balqon to finalize three-party agreements to demonstrate this technology at two container terminals.

Updated: December, 2015.

## Balqon Lithium-Ion Battery Demonstration

**Technology Manufacturer**  
Balqon Corporation

**Co-Participants**  
Port of Los Angeles



### Background

The Balqon Lithium-Ion Battery Demonstration project was a follow-on project to the Balqon Electric Terminal Tractor Demonstration TAP project completed in 2008 (see page B-11). During this earlier project, the Port of Los Angeles TAP and the SCAQMD partnered to demonstrate a Class 8 electric truck for port drayage operations.

### Project Objective

The objective of this follow-on project was to evaluate and demonstrate a lithium-ion battery as a technological upgrade to the lead-acid battery pack used in the previous TAP demonstration. The advanced technology lithium-ion batteries were anticipated to provide more than double the vehicle range, without adding additional weight.

Lithium-ion batteries have several important advantages over competing battery technologies. Primarily, lithium is a highly reactive element with very high energy density. The electrodes are composed of lightweight lithium and carbon, offering a much lighter weight compared to other rechargeable batteries of a similar size. Lithium-ion batteries retain their charge longer than other battery chemistries, and exhibit no “memory effect” – some high energy density battery chemistries, such as nickel cadmium, can become degraded if recharged before the battery has been fully discharged. Lithium-ion batteries can be recharged without completely discharging with no battery degradation, and can withstand literally hundreds of charge/discharge cycles, increasing battery lifespan.

### Technology Demonstration

Under this demonstration, one electric drayage truck, the Balqon Nautilus Model XE-30, was converted from lead acid battery to lithium battery technology. This zero emission all-electric drayage truck was designed to transport containers in terminal or on-road and carry loads up to 100,000 lb. with a range of 100 miles on a single charge.



The lithium battery cells were assembled into the battery packs at Balqon’s Harbor City, California facility and fitted with a proprietary battery management system (BMS) specifically designed for lithium-ion battery chemistry and characteristics. This TAP project also supported development of new charging algorithms to allow fast charge the lithium-ion batteries using the existing Balqon fast charger. Vehicle range tests were conducted using both dynamometer and field test

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

protocols. Installation of lithium batteries was expected to increase range by a factor greater than two as compared to the lead acid battery-equipped vehicle. It was anticipated that unloaded range would increase to 180 miles on single charge. Range at a loaded weight of 60,000 pounds at 45 miles per hour during short haul drayage was expected to exceed 100 miles on a single charge.

### Results

In June 2009, Balqon completed assembly of a Nautilus E30 all-electric tractor retrofitted with lithium ion battery packs. A one-day demonstration of the Nautilus E30 confirmed a range of over 150 miles on a single charge with unloaded conditions at 80% depth of discharge. The new lithium-ion battery packs included Balqon's BMS, which allows batteries to be fast charged and self-equalize during idle operation. It is noteworthy that the lead-acid battery system provided 30 to 50 mile range under comparable test conditions.

### Status

As of late 2010, Balqon had not yet initiated the full-scale vehicle range testing (either on the dynamometer or in the field) and the Balqon TAP agreement expired. Due to project constraints, results were not quantified, however initial testing did indicate a range of greater than 150 miles. It was anticipated that that testing would be complete in 2011. Unfortunately, retrofit of the E20 terminal tractor and the demonstration testing with the lithium-ion batteries and new BMS was never completed, the last project payment was forfeited and POLA closed out the project in 2011.

Since close out of the TAP project, Balqon upgraded the Port's Nautilus E30 tractor with additional lithium-ion battery capacity and completed a preliminary demonstration, which included several round-trips from a near dock rail yard to Port terminals. The next step will be for the Port and Balqon to work with a local drayage operator to test the truck in actual land-bridge operations for an entire year.

### Benefits

Zero-emission drayage trucks provide significant environmental benefits. However, operational concerns regarding range and charging times limit the applicability of zero-emission technology for the dray industry. Completion of this advanced battery demonstration project supports the long-term goal of increasing the use of zero-emission electric truck technologies in the drayage truck sector.

### Project Costs

The total project cost was \$940,000. The Port of Los Angeles, under TAP, contributed \$400,000. Balqon Corporation provided the two vehicles as well as additional in-kind engineering and test resources; the Balqon contribution was valued in excess of \$540,000.

### Commercialization and Applications

In July 2009, Balqon announced the release of lithium-ion batteries as an alternative to lead acid traction batteries for its entire product line of Class 8 yard tractors and drayage vehicles

Updated: May, 2013.



## Bluefield Holdings/Krystallon Ocean Going Vessel Scrubber Demonstration Project

**Technology Manufacturer**  
Bluefield Holdings/Krystallon

**Co-Participants**  
Port of Long Beach and Port of Los Angeles, California Air Resources Board, APL



### Background

Bluefield Holdings completed demonstration of a Krystallon sea water scrubber to reduce auxiliary engine emissions aboard the container ship *APL England*. The seawater is used to “scrub” or filter particulate contaminants from the ship exhaust stream before the exhaust is emitted to the atmosphere.

### Project Objective

The primary focus of this project was to demonstrate the reduction of emissions of sulfur oxides (SO<sub>x</sub>) from an Ocean Going Vessel using an exhaust gas cleaning device to meet the International Maritime Organization (IMO) fuel sulfur limits in Emission Control Areas (ECA) and further to reduce particulate matter (PM), and volatile organic compound (VOC) emissions. The project also demonstrated the removal of particulate waste from the washwater and maintained the pH of the washwater within the IMO guidelines prior to discharge overboard.



### Technology Demonstration

For this TAP project, Bluefield Holdings installed, demonstrated, and quantified the emission reduction capabilities of a seven (7) megawatt (MW) Krystallon SC 500 scrubber on the *APL England*, an APL C-11 class container ship. This was the first SC 500 type scrubber built by Krystallon to be commissioned and installed on an OGV. The Krystallon scrubber was configured to treat the combined emissions from three auxiliary engines. The demonstration plan included operating the scrubber within 200 nautical miles (nm) from shore all the way

to the berth. Heavy fuel oil (HFO), compliant with IMO regulations at the time of the evaluation, was used in all engines from 200 nautical miles (nm) to 24 nm; distillate fuel compliant with CARB regulation was used within 24 nm of the California coast.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The real-time continuous emissions monitoring system (CEMS) was included as a component of the scrubber system. The CEMS data compared favorably with the emissions measured by the third-party testing contractor. The CEMS allows the project team to track emissions from the scrubber. The continuous monitoring equipment functions whenever the scrubber is operating. Average and instantaneous measurements are made for: carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), nitric oxide (NO), sulfur dioxide (SO<sub>2</sub>) and water.



A wastewater monitoring system installed on the APL England contains sensors on the intake and discharge lines to measure the following: temperature, turbidity, PAH at intake and outlet; Wastewater supply pressure to the scrubber; temperature, PAH, pH and turbidity downstream of the treatment plant; temperature at wastewater discharge; differential pressure across the water treatment plant; and exhaust gas pressure at the scrubber inlet and outlet.

In addition to the CEMS, a third party contractor collected and analyzed discreet emission samples, including DPM, while at berth. This testing included engine operation emission results while the engines were using both residual fuel oil and marine distillate fuels. Sampling and testing of emissions and treated wastewater took place at berth in the US and while underway between Taiwan and mainland China.

### Environmental Benefits

Both emissions and discharges from the scrubber were tested using U.S. EPA standard test methods and supplemented by an onboard CEMS. With the scrubber running HFO fuel, sulfur reductions were in the range of 98 to 99 percent and PM reductions ranged from 56 to 70 percent. There were only minimal reductions of NO<sub>x</sub> (2 to 5 percent) when operating on HFO. When the scrubber ran marine gas oil (MGO) fuel, sulfur reductions ranged from 95 to 97 percent and PM reductions ranged from 68 to 75 percent<sup>8</sup>. There were only minimal reductions of NO<sub>x</sub> (2 to 8 percent) when operating on MGO.

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<sup>8</sup> Since there is less PM in MGO, the scrubber can remove a higher percentage of PM in MGO than in HFO.

### Status

The APL England completed its four-call requirement in August 2012. The draft final report documenting the results of the scrubber's performance throughout the demonstration, and emissions reduction efficiency levels, was submitted to the Ports for review in late 2012. Based on this review, additional testing of the discharge water was requested to alleviate concerns with metal particles (zinc and copper) found in the discharge water during the demonstration<sup>9</sup>. Additional samples taken from the scrubber discharge water in February 2013 measured copper as non-detectable and zinc at 16.7 µg/L, far below the water quality criteria of 90 µg/L. The revised draft final report was submitted in May 2013 and accepted by the Ports.

The approved final report is available at

<http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2565>.

### Project Partners & Funding

The TAP funding contributions were used to partially offset the costs associated with the scrubber equipment, as well as scrubber installation, testing, and reporting. Total TAP funding applied to the seawater scrubber demonstration was \$1.65 million (\$825,000 dollars per port) and Bluefield/Krystallon contributed \$1.75 million.

### Looking Forward

This project demonstrated the potential for PM and SO<sub>x</sub> reductions that can be achieved through OGV retrofit using commercially available scrubbing technology. The Ports are open to consideration of additional research to further evaluate the potential for OGV engine emission reductions from scrubbers on main engines to comply with IMO ECA regulations.

Updated: April, 2014



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<sup>9</sup> Upon inspection of the scrubber, it was found that one of the brass nozzles fell down into the scrubber and deteriorated causing metal particles (i.e., zinc, copper) were found in the discharge water. The nozzles were subsequently replaced with ceramic nozzles.

## Capacity Plug-In Hybrid Electric Terminal Tractor

**Technology Manufacturer**  
Capacity of Texas, Inc.

**Co-Participants**  
Port of Long Beach, Port of Los Angeles  
Ports America, Total Terminals, Inc., and Yusen Terminals, Inc.

### Background

Terminal tractors are essential to the daily operations of a port terminal. However, they also consume large volumes of diesel fuel and generate significant levels of harmful diesel emissions within the ports they serve. The development and deployment of low-emission, high-efficiency terminal tractors are high priorities for the Ports under the Clean Air Action Plan.

In response to the need for environmentally friendly yard hostlers, Capacity of Texas, Inc. developed a Pluggable Hybrid Electric Terminal Tractor (PHETT™). The Port of Long Beach, in conjunction with Capacity, Ports America, and Total Terminals, Inc. (TTI) conducted a three-week trial of the PHETT™ from June 8 to June 25, 2009. Results from this trial are available for download from the TAP website<sup>10</sup>.

A follow-on trial test to evaluate improvements made to the PHETT™ following the initial trial was conducted from December 8 to December 29, 2009 at the Port of Los Angeles' Yusen Terminals, Inc. (YTI). The final report for this trial is available for download from the TAP website<sup>11</sup> as well.

### Project Objective

The purpose of the demonstrations was to evaluate the performance and emissions of the PHETT™. In order to characterize the PHETT™ duty cycle and measure its load factor, the vehicle was equipped with a multi-channelled data logging system. The PHETT™ fuel economy was evaluated using the data collected by the data logger and supplemented with information provided by Capacity and site demonstration partners. In addition, surveys were developed and distributed to operators and maintenance personnel to assess the overall capability of the PHETT™.



<sup>10</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2416>

<sup>11</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2517>

### Technology Description

The PHETT™ is a diesel-electric plug-in hybrid terminal tractor that uses a small diesel generator and a large lead-acid battery pack to provide power for vehicle operation. As a plug-in hybrid, the PHETT™ offers a modest all-electric range and higher overall efficiency, which can significantly reduce fuel consumption and emissions compared to a conventional diesel-fueled terminal tractor.

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

According to Capacity, this diesel-electric hybrid terminal tractor is a “charge sustaining series hybrid that utilizes a constant and efficient rate generator to supply power, reducing fuel consumption by as much as 60 percent and audible decibel by 30 percent.

Three electrical inverters are used to supply the vehicle subsystems with power. The inverters convert the DC voltage of the battery pack into alternating current (AC) voltage that is better suited to operate the numerous AC electrical motors in the PHETT™.

Additionally, several systems on the vehicle use a 12VDC auxiliary power supply including the safety light, radios, and cabin HVAC fan. Capacity estimates a fixed power draw of 500 watts, assumed to be constant while the vehicle is in use.

### Project Costs

TAP funding in the amount of \$29,500 was allocated to the Port of Long Beach PHETT™ demonstration and testing project. The Port of Los Angeles also conducted a follow-on study at Yusen Terminal, Inc. (YTI) with non-TAP funding in the amount of \$32,000. Additional in-kind contributions were provided by Capacity, Ports America, TTI and YTI; however, the equivalent dollar values of these additional contributions were not quantified.

### Results

The load factor for the PHETT™ was determined by measuring the diesel generator output over the entire operating time of the PHETT™. During the demonstration at TTI, the PHETT's™ load factor was evaluated as 0.58, equivalent to an average engine load of 23.3 hp. The PHETT™ was estimated to achieve a 77% reduction in NO<sub>x</sub> emissions, and an 82% reduction in PM emissions compared, to the baseline diesel fleet (2002 levels). The emission rates of the PHETT™ were also found to be lower compared to a 2009 diesel yard tractor. Due to a lack of fueling logs, fuel economy improvements were difficult to verify; however, fuel improvements were estimated to be in the range of 28% to 60% over the baseline fleet.

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

During the demonstration of the “beta” unit at YTI, the PHETT’s™ load factor was determined to be 0.54, equivalent to an average engine load of 21.7 hp. The beta PHETT™ was estimated to achieve a 44% reduction in NO<sub>x</sub> emissions, and a 56% reduction in PM emissions compared to a 2009 diesel yard tractor at 43% load (CARB’s approved load factor for yard tractors). However, the emission rates of the PHETT™ were similar to those of a 2009 MY diesel yard tractor at actual load (18%). Fuel consumption measurements showed a 34% improvement over the baseline fleet. Information gathered from the operators and maintenance personnel at both Ports indicated no significant problems with the PHETT™ and comparable performance to diesel yard tractors.

Following this demonstration, Capacity has marketed the PHETT in various applications throughout the U.S. and internationally. However, because the PHETT utilizes a Tier 4-interim generator drive engine (genset), it does not meet the requirements for port yard tractors in California under CARB’s Cargo Handling Equipment regulation, which requires engines meeting Tier 4 final off-road or 2007 on-road emissions standards. Capacity has since focused their efforts on the development of a zero-emissions terminal tractor, the zero-emission terminal tractor, powered by plug-in electric/hydrogen fuel cell technology.

Updated: May, 2013





## Characterization of Drayage Truck Duty-Cycles

**Technology Manufacturer**  
Not applicable

**Co-Participants**  
Port of Long Beach; Port of Los Angeles;  
TIAX, LLC

### Background

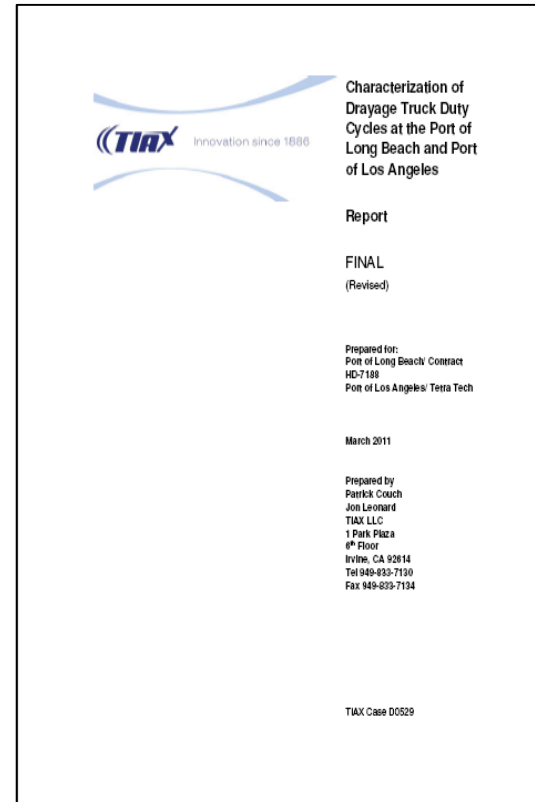
Currently, there are approximately 11,000 heavy-duty diesel drayage trucks in service at the Port of Long Beach and Port of Los Angeles. According to the Ports' 2010 emissions inventories, the drayage truck fleet is the second largest source of NO<sub>x</sub> emissions and the fourth largest source of DPM emissions at the Ports. Even with increasingly stringent emissions standards promulgated by regulatory agencies, the drayage truck source category must continue to be as clean as possible. The introduction of zero-emission, hybrid-electric or other advanced heavy-duty truck technologies into the drayage fleet has the potential to provide significant emission reductions for this source category.

### Project Objective

The Ports initiated the Drayage Truck Duty-Cycle Characterization project in order to provide drayage truck equipment manufacturers with a thorough understanding of typical duty cycles associated with drayage service. The goal of this project was to collect detailed duty cycle information for drayage truck operations in near-dock, local, and regional operation. This duty cycle information, and raw data collected for the study, is now available online<sup>12</sup> for equipment manufacturers to help accelerate and improve the development of advanced drayage truck technologies.

### Benefits

While this project did not result in direct emission reduction benefits, it is anticipated that a wide variety of clean heavy-duty drayage truck technology developers would benefit from this duty-cycle characterization project.



<sup>12</sup><http://www.cleanairactionplan.org/programs/tap/techdemos.asp>

### Results

For this project, vehicle operational data for multiple trucks were collected over a period of several weeks in the later part of 2010. Project trucks were equipped with data loggers and produced data in each of three operating regions: near-dock, local, and regional operation. The characterization of port drayage truck operation resulting from this project was used to develop a composite duty-cycle that will be used in upcoming drayage truck emissions evaluations. In addition, the duty-cycle will be distributed to engine and vehicle original equipment manufacturers with technology targeted to the drayage market.

Data from this study was used to develop a chassis dynamometer test schedule for drayage trucks serving the Ports in 2011. More information on the “Development of a Drayage Truck Chassis Dynamometer Test Cycle” project may be found in the body of this report.

### Project Costs

The Ports initiated this project to fulfill the need for drayage truck operational profiles that ports are uniquely positioned to support. The Ports contracted with Tetra Tech and their subcontractor TIAX, LLC, an internationally recognized expert in the field of duty-cycle characterization and development. The Ports funded the study to support future TAP efforts to support technologies that reduce emissions from heavy-duty trucks.

The combined TAP funding from both Ports was \$25,681.

Updated: May, 2013



## Development of a Drayage Truck Chassis Dynamometer Test Cycle

**Technology Manufacturer**  
Not applicable

**Co-Participants**  
Port of Long Beach, Port of Los Angeles,  
TIAX, LLC

### Background

In early 2011, the Port of Long Beach and Port of Los Angeles released a report authored by TIAX, LLC that characterized the duty cycle of on-road, Class 8 drayage trucks at the Ports. The report included statistics based on over 1,000 truck trips collected over a four-week period in late 2010. Based on these statistics, TIAX, LLC identified five modes of operation and an “average” trip associated with each mode. The statistics and trip data from this earlier work provided important information on the real-world operation of drayage trucks in the South Coast Air Basin.

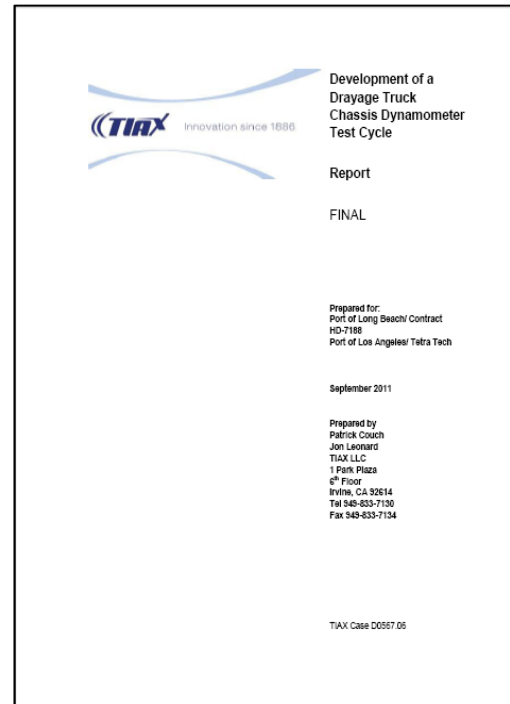
### Project Objective

As a follow-up to the earlier “Heavy-Duty Drayage Truck Duty-Cycle Characterization” project, this study encompassed the development of a detailed driving schedule suitable for use when testing heavy-duty vehicles on a chassis dynamometer that is based on the modes of operation and trip data previously identified in the earlier study.

### Status/Results

The Port of Long Beach and Port of Los Angeles initiated this project to fulfill the need for drayage truck operational profiles that the Ports are uniquely positioned to support. The Ports contracted with Tetra Tech and their subcontractor TIAX, LLC, an internationally recognized expert in the field of duty-cycle characterization and development. The Ports funded the study to support future TAP and outside agency efforts to evaluate technologies that reduce emissions from heavy-duty trucks.

The chassis dynamometer test cycle was developed to provide the Port of Long Beach and Port of Los Angeles with a tool to compare the emissions performance from various drayage truck technologies. While this cycle was developed using actual in-use vehicle data and methods similar to those used to develop the widely used heavy heavy-duty diesel duty truck (HHDDT) test cycle used by test labs nationwide, this new drayage truck cycle has not yet benefitted from validation on a chassis dynamometer.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The final report is available in the public domain for all interested parties to utilize. The final report can be accessed at the Ports' Clean Air Action Plan website at <http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2526>.

The SCAQMD is emissions testing several heavy-duty vehicles, including diesel and liquefied natural gas drayage trucks, as part of their HDV In-Use Emissions Testing Program. The Ports provided the test cycle developed in this project for use in SCAQMD's multi-vehicle testing program. The drayage truck cycle will be used to assess drayage truck emissions and will also be used to compare the results of the drayage truck test cycle to other existing cycles.

### Benefits

The successful completion of this study resulted in a test cycle that reflects typical port drayage truck operation. Use of this cycle in emission testing programs and engine/vehicle system design projects will help ensure that emission reduction efforts of agencies and technology developers will result in information or products that are relevant to port operation or can meet rigorous port duty cycles.

### Project Costs

The Ports shared the cost of this study. The Port of Long Beach contributed \$12,000 and the Port of Los Angeles contributed \$11,466.

Updated: May, 2013





## Foss Maritime Green Assist™ Hybrid Tugboat

### Technology Manufacturer

Foss Maritime  
Aspin Kemp & Associates  
XeroPoint

### Co-Participants

Port of Long Beach, Port of Los Angeles, South Coast Air Quality Management District, California Air Resources Board



### Background

Foss Maritime achieved several significant milestones in the development of the World's first diesel electric hybrid tugboat. Christened the *Carolyn Dorothy*, the FOSS Green Assist™ hybrid tug was unveiled on January 23, 2009 and began working in the harbor immediately, even though some systems were still being commissioned. All system commissioning was complete on March 1, 2009, at which point the *Carolyn Dorothy* became a full working member of the Foss Maritime tug fleet. Since this time, the hybrid tug demonstrated performance comparable to a conventional Dolphin Class tugboat.

### Technology Demonstration

The Green Assist™ hybrid tug was built by Seattle-based Foss Maritime in partnership with Aspin Kemp & Associates and their affiliate XeroPoint, which developed the unique hybrid power management system. At the heart of the Foss Green Assist™ project is the Dolphin class tug currently operated by Foss at the Ports of Long Beach and Los Angeles. The conventional diesel-fueled tugs are powered by Caterpillar main engines producing a total of 5,080 bhp and a bollard pull of 60 tons. Externally, the *Carolyn Dorothy* is quite similar in appearance to its conventionally powered forebears. The only noticeable evidence of its unique power plant is a pair of smaller exhaust stacks.

The tug's diesel-battery-electric propulsion system comprises two fully azimuthing propulsion units powered by batteries, diesel generators and/or two diesel main engines. A modified engine room accommodates two battery packs, producing the equivalent of 670 horsepower, and two 335 horsepower diesel powered generators. The main engines are substantially smaller and less powerful than those in the existing Dolphin class tugs.

An essential feature is the power management system required to produce seamless transition from one power source to another, depending on the tug's duties and the power demand. In its various modes of operation, the new tug employs battery power idling and no-wake low speed maneuvering and a combination of battery and generators for transiting. When full power is required, the diesel main engines start automatically and are coupled by clutches to the drive system in addition to the electric motors. Surplus power generated at any stage is used to recharge the battery packs.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

Although the main engines in the new tug are smaller than those of existing vessels, the same total horsepower and the same 60 tons bollard pull is available. The Green Assist™ Tug has four distinct modes of operation:

**STOP** - When the tug is docked at the pier. Main engines are off-line; power is provided by batteries for hotel loads (lighting, HVAC, etc.) and can be recharged by shore power;

**IDLE** - When the vessel is not secured to a pier but is stopped at sea. Main engines are off-line. Batteries provide power for hotel loads and station keeping. A generator automatically starts up and comes on line to recharge batteries;

**TRANSIT** - Continuous slow and fast transit 6-8 knots. One generator for the slower “harbor – speed” transit of approximately 6 knots. The second generator automatically starts when the throttle setting calls for a faster speed transit of about 8 knots. Batteries provide “ride-through” power until the second generator is online. The generators also are providing hotel loads and are recharging the batteries while simultaneously providing the propulsive power.

**ASSIST** - Full power ship-assist requirements. Both main engines, generator sets and batteries provide full power.

Based on the operating profile of the conventional Dolphin tugs currently operating in the Ports, it is estimated that the hybrid will spend at least 75 percent of its operating hours in the operating modes without main engines. Only batteries and generators are used during idle or low speed/low load operation, but the vessel is able to access full power on demand.

### Results

Foss completed development of the project test plan in September 2009, and formed a Technical Working Group (TWG) with Foss, POLB, POLA, CARB, EPA, SCAQMD, and the Pacific Merchant Shipping Association in the fall of 2009. In late 2009, the UC Riverside College of Engineering – Center for Environmental Research and Technology (CE-CERT) began test equipment acquisition and software code upgrades to prepare for test plan implementation. Full system and emissions testing was conducted in early 2010. This project’s final report is available for download from the TAP website<sup>13</sup>.

### Benefits

The hybrid tugboat achieved emission reductions that exceed original targets (to reduce both NO<sub>x</sub> and PM by approximately 44%) when compared with the Dolphin tugs currently operating in the San Pedro Bay. The *Carolyn Dorothy* reduced PM, NO<sub>x</sub> and CO<sub>2</sub> emissions by 73%, 51% and 27%, respectively<sup>14</sup>. Based on this evaluation, fuel consumption is reduced by approximately 20 to 30 percent.

The measured emission levels of the *Carolyn Dorothy* are cleaner than the U.S. EPA’s Tier 2 emissions standard for marine engines. Along with less pollution, the Green Assist™ tug offers improved fuel economy and requires significantly less maintenance. It is also quieter than its Dolphin sister tugs when operating on batteries that can be recharged using environmentally friendly shore power.

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<sup>13</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2501>

<sup>14</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2502>

### Project Costs

The overall cost for the design, development and commissioning of the *Carolyn Dorothy* was over \$8 million. The Port of Long Beach provided \$500,000 in TAP funding, and the Port of Los Angeles provided \$889,920 in non-TAP funding to support this project. Additional in-kind support was provided by CARB and SCAQMD. Remaining costs were covered by Foss Maritime.

### Commercialization and Applications

The Port of Long Beach and the Port of Los Angeles teamed with Foss to implement the “Tugboat Hybridization Project”. This \$2.3 million project is funded in part by a \$1 million grant from CARB’s AB 118 Air Quality Investment Program. The tugboat *Campbell Foss* was retrofitted with hybrid technology, followed by an in-service evaluation for emissions reductions and fuel savings. The tugboat has been incorporated into Foss’ operations.

Updated: April, 2011



## Hybrid Yard Tractor Development & Demonstration

**Technology Manufacturer**  
US Hybrid

**Co-Participants**

Port of Los Angeles, Port of Long Beach, CALSTART, U.S. Environmental Protection Agency, Kalmar Industries, Long Beach Container Terminal (LBCT)

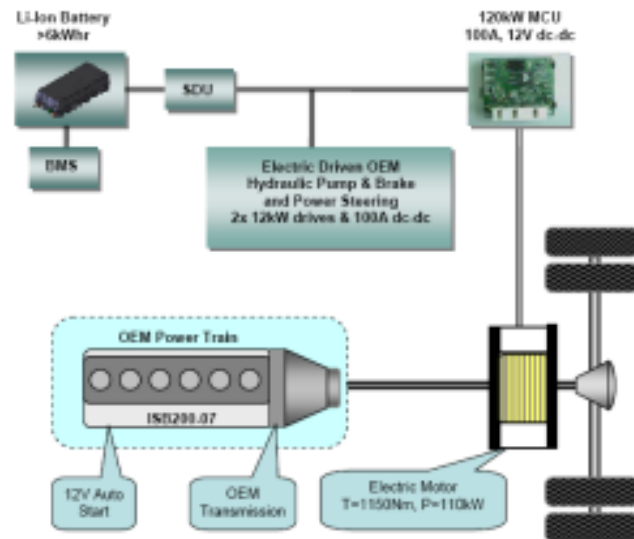
**Background**

The TAP investigated the feasibility and commercial viability of using advanced technology drive systems in cargo handling equipment. The TAP, in partnership with the U.S. EPA’s West Coast Collaborative, worked together to develop and test hybrid technology yard tractors for use at container terminals.

Yard hostlers (also known as yard tractors, terminal tractors, or utility tractor rigs) are common at port terminals, rail yards, and distribution centers. Their function is to move containers around the facility. At a port, containers are loaded off a ship onto a bobtail rig that is pulled by the yard hostler to an intermodal point or to a storage facility. Yard hostlers often sit idling as they wait in queues to pick up or drop off their loads.

**Project Objective**

The Ports of Long Beach and Los Angeles partnered with CALSTART, a non-profit company that focuses on advancing cleaner technologies, to manage the demonstration of three (3) diesel-hybrid yard hostlers at the Long Beach Container Terminal (LBCT). The U.S. EPA also provided grant funds for the design and development of the hybrid drive system. Vehicle emissions and performance were evaluated relative to diesel yard hostlers, and a business case/lifecycle cost-benefit assessment was performed to determine the financial viability for large-scale use of hybrid yard hostlers in marine terminals.



**Technology Description**

US Hybrid was selected as the hybrid drive system supplier through a competitive bid process. US Hybrid designed and developed a diesel-electric parallel hybrid, post-transmission configuration system that was integrated into a Kalmar Industries Ottawa 4x2 terminal tractor.

### Benefits

The three hybrid yard hostlers underwent six months of operation and in-use testing at LBCT and were able to perform all the tasks required of yard hostlers in real-world port operations, and were well accepted by drivers and maintenance staff. Fuel economy and emissions benefits were evaluated, but a difference discovered in the mechanical specifications of the vehicles limited comparability. Based on all the evaluations and analyses conducted, the hybrid system is estimated to provide a 12% to 18% improvement in fuel economy. Further development of the hybrid system is underway in an effort to improve fuel economy and emissions reductions. A follow-up study was conducted entitled “Hybrid Yard Tractor Development and Demonstration – Beta Test”, which is summarized on page B-28. The lifecycle cost assessment for large-scale use of hybrid yard hostlers showed that incentives of approximately \$18,000 per vehicle would be needed to ensure payback of the hybrid system. The final report for this project is available for download from the TAP website<sup>15</sup>.

### Project Costs

The project was valued at \$1.2 million. The Ports contributed \$300,000 each and the U.S. EPA contributed \$300,000 through a West Coast Collaborative grant. LBCT and other project suppliers provided in-kind labor contributions estimated at \$300,000. CALSTART provided technical project management assistance.

Updated: April, 2011



<sup>15</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2516>



## Hybrid Yard Tractor Development & Demonstration – Beta Test

**Technology Manufacturer**  
US Hybrid

**Co-Participants**  
Port of Long Beach, Port of Los Angeles, Long Beach Container Terminal

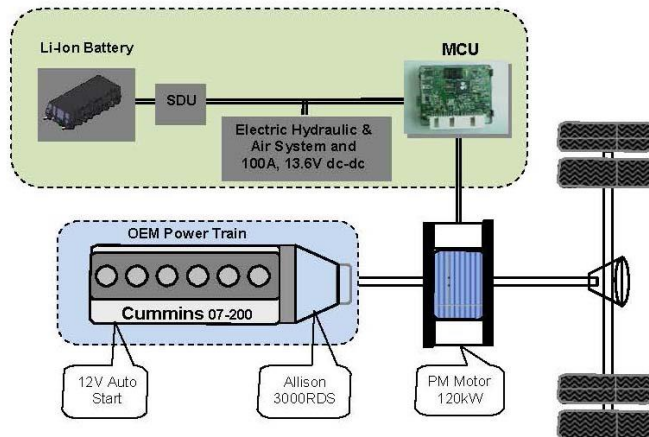
### Background

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

For the majority of the demonstration period, LBCT had use of only one US Hybrid yard hostler. Ship service provided the greatest amount of vehicle operation and fuel consumption data possible, relative to the other two service types, therefore LBCT elected to use the US Hybrid yard hostler in ship service. Late in the demonstration, a second US Hybrid unit was made available to LBCT and this unit was placed into rail service.

### Project Objective

As a follow-on Hybrid Yard Tractor Development & Demonstration Project<sup>16</sup> conducted in 2010, the Port of Long Beach, Port of Los Angeles, US Hybrid and Long Beach Container Terminal assessed the potential in-use fuel economy performance of newly modified hybrid yard hostlers from February to June 2011 under a new project, Hybrid Yard Tractor Development & Demonstration – Beta Test.



<sup>16</sup> Final Report entitled “Hybrid Yard Hostler Demonstration and Commercialization Project” available for download at: <http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2516>



### Technology Demonstration

The hybrid yard hostlers demonstrated consist of standard Kalmar Ottawa yard hostlers fitted with a parallel hybrid-electric power trains. Following the initial demonstration of the hybrid yard hostlers in 2010, US Hybrid made modifications to the hybrid system to improve fuel economy from the previous demonstration. In particular, US Hybrid altered the battery management algorithm, hybrid control algorithm, idle management strategy, and increased the capacity of the traction battery. These modifications resulted in a Generation 1.1 configuration. Near the end of the current demonstration, US Hybrid provided a second unit to LBCT that incorporated several additional modifications, including changes to the transmission control algorithm, electric motor, and motor control unit. This configuration is referred to as Generation 2.0.

### Status and Results

The results of the analysis support the following conclusions:

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

Following the completion of the project, the hybrid systems were removed and the vehicles returned to their original state by Kalmar. Further demonstration of the hybrid drive technology in yard hostlers continues in a separate parallel project conducted by the New York Power Authority and the Port Authority of New York/New Jersey. Three of the newer generation hybrid yard hostlers have been operating in day-to-day terminal operations at New York Container Terminal since 2010. Similar to the project conducted at LBCT, the hybrid vehicles' in-use performance and fuel economy is being assessed. In addition, chassis dynamometer emissions testing will be conducted. The TAP will continue to monitor the progress of the project.



### Project Costs

The total cost of the supplemental demonstration was \$26,000 which was split evenly between the two Ports (or \$13,000/port).

Updated: April, 2011

## Johnson Matthey Locomotive DPF Demonstration

### Technology Manufacturer

Johnson Matthey

### Co-Participants

Port of Long Beach, Port of Los Angeles, Union Pacific Railroad, South Coast Air Quality Management District, California Air Resources Board

### Background

The Ports, in conjunction with CARB, SCAQMD, Union Pacific Railroad and Johnson Matthey partnered to demonstrate and evaluate the effectiveness of a Johnson Matthey diesel particulate filter (DPF) as an aftertreatment device on a Union Pacific Railroad Switcher Locomotive equipped with three (3) Tier 3 700 horsepower (hp) gensets (total 2,100 hp).

### Project Objective

The purpose of the demonstration was to determine whether the installation of the Johnson Matthey system would allow the Tier 3 engines to meet Tier 4 PM emission standards, and to quantify additional reductions in carbon monoxide and hydrocarbon emissions. This project was also designed to demonstrate the transferability of Johnson Matthey's DPF technology, which is typically used in on-road heavy-duty vehicle applications, to an off-road locomotive application.

### Technology Demonstration

The Johnson Matthey Switcher Locomotive DPF System consists of multiple DPF, diesel oxidation catalyst (DOC), and catalyzed soot filter (CSF) components and was expected to achieve greater than 85 percent PM reduction in order to allow Tier 3 engines to meet federal Tier 4 locomotive engine emission standards for PM. The Catalyzed Continuously Regenerating Technology (CCRT™) system is a modified version of Johnson Matthey's Continuously Regenerating Technology (CRT™) used in on-road applications, with the addition of a specialized coating to the filter. The coating enhances the passive regeneration potential of the system at lower temperatures. According to Johnson Matthey, lower DPF regeneration temperatures are important in a switcher locomotive application because locomotive engines, with the significant amount of time spent at idle, have a temperature profile that is too low for other types of DPFs. Additionally, the system is designed with a feature to minimize back pressure that helps to increase the service life between filter cleanings.

The design modifications made to the locomotive CCRT™ (L- CCRT™) for this project consisted of multiple DOC and CSF pairs. The sizing of the system and the choice of specific DOC and CSF depended on the exhaust characteristics of the engine. Johnson Matthey conducted baseline testing on a 2007 model year, QSK19 engine at Southwest Research Institute (SwRI) and gathered useful data on the engine out temperature, exhaust flow, and emissions. From this testing, an alpha system was designed and installed on one of the three genset engines of Union Pacific switcher UPY-2737. This earlier test served as a precursor to the following CARB AQIP demonstration, in which Union Pacific switcher UPY-2755 was fitted with three DOC and CSF pairs (one for each genset).

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The demonstration required 3,000 engine hours of operation in order to determine the durability of the Johnson Matthey system against the shock and vibrational forces experienced during standard switcher locomotive operation. TAP project funding was allocated to cover emissions testing throughout the project and support the technology verification effort.

### Results

Design and installation of the Johnson Matthey system took place in early 2011. After successful installation, the zero-hour emissions testing showed the Johnson Matthey system achieved Tier 4 PM emission levels. The retrofitted switcher was placed into Union Pacific's revenue service in July 2011 to fulfill the engine-hour durability testing requirement per the CARB AQIP agreement. Upon completion of the first 1,500 hours, the switcher was sent to SwRI to undergo the second round of emissions testing. Results from the 1,500 hour summary report demonstrated that the Johnson Matthey system performed well, averaging below Tier 4 levels at a PM output of 0.01 g/bhp-hr, well below the Tier 4 PM emission limit for the switcher duty cycle (0.030 g/bhp-hr). The switcher experienced minor mechanical problems (not related to the DPF) that resulted in unfavorable utilization during the latter half of 2012. The switcher was repaired in order to accumulate the 3,000 hours needed for CARB verification.

UPY-2755 accrued 3,000 hours of durability usage in March 2013 and was transferred to the SWRI testing facility to undergo final testing and data analysis. Results showed that the DPF performed at an average PM output of 0.021 g/bhp-hr, which is under the Tier 4 threshold of 0.030 g/bhp-hr, while achieving CO and HC emission reductions of 99% and 90%, respectively. The on-board data logger showed that the back pressure did not increase during the period from 0 to 3000 durability hours, which is a sign of system health. Meanwhile, the system was regenerating during the entire period and did not produce a significant amount of ash. Final test results indicated low back pressure across all three engines and despite the unrelated engine mechanical issues; the DPF was able to stay below the required emissions standard. The locomotive will continue to use the L-CCRT™ and the data logger to collect data after the project term. The project demonstration concluded on December 2, 2013 and Johnson Matthey submitted the final project report, which is available on the CAAP website. The CARB verification portion of the project was completed in February 2014 with CARB's approval of the L-CCRT™, retrofitted onto a NREC 3GS21 locomotive model, with a PM emission level of 0.02 g/bhp-hr.

### Benefits

The benefits of the L-CCRT were verified by CARB with a PM emission level of 0.02g/bhp-hr. This verification is only for the use of the L-CCRT DPF on the NREC three-engine genset switcher locomotive, or locomotive model 3GS21. Test results also demonstrated a reduction in CO and HC of 99% and 90%.

### Project Costs

The total budget for this project was \$692,356, of which Johnson Matthey committed \$146,246 in cash match funding (21 percent total). Half of the project costs were covered by a fiscal year (FY) 2011-2012 CARB Air Quality Improvement Program (AQIP) grant in the amount of \$346,178 to support the durability demonstration effort. TAP funding in the amount of \$150,000 (\$75,000 per Port) was committed to the project to cover emissions testing and verification costs.

**Commercialization and Applications**

CARB verified the L- CCRT™ for retrofit for an NREC 3G521 locomotive with a PM emission level of 0.02g/bhp-hr. Johnson Matthey intends to commercialize the L-CCRT™ for use on switch locomotive applications in California and elsewhere in the US.

Updated: June, 2015





## Liquefied Natural Gas (LNG) Yard Tractor Project

### Technology Manufacturer

Kalmar Industries  
Cummins Engine Company

### Co-Participants

Port of Long Beach, U.S. EPA Region 9, Long Beach Container Terminal, CALSTART

### Background

Yard tractors, also referred to as yard hostlers, terminal tractors, and yard goats, are heavy-duty off-road truck tractors designed for moving cargo containers within port container terminals and other off-road areas. These vehicles are the most common type of cargo handling equipment (CHE) used at container terminals at the Ports. According to emission inventories compiled by the Ports of Long Beach and Los Angeles, yard tractors emit approximately 64% of the particulate matter (PM) and 59% of the nitrogen oxides (NO<sub>x</sub>) emissions for all cargo handling equipment. Further, yard tractors are the single largest landside source of PM and NO<sub>x</sub> emissions at the Ports.

### Project Objective

To investigate the technical and commercial feasibility of reducing emissions from yard tractors, the Port of Long Beach, in partnership with the U.S. EPA, funded the demonstration of yard tractors equipped with low-emission liquefied natural gas (LNG) engines.

### Technology Demonstration

The project was divided into three phases. The first phase focused on development of LNG yard tractor specifications, procurement, and installation of temporary LNG refueling.

Phase 2 included operation of the LNG yard tractors at a marine terminal for a period of eight months. Demonstration commenced in June 2006 and was completed in January 2007. During this time, data were collected on the performance of the LNG yard tractors compared to a group of baseline diesel vehicles. Emissions testing was also conducted at the conclusion of the second phase.

The third phase of the project was the development of a business case assessment to determine the cost-effectiveness and return on investment of using LNG equipment as opposed to diesel.



The project team consisted of the Port of Long Beach, U.S. EPA Region 9, Sound Energy Solutions, CALSTART, and Long Beach Container Terminal (LBCT). LBCT volunteered to test the LNG yard tractors in their container terminal operations during the eight-month evaluation period.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

A total of three LNG yard tractors were deployed for performance testing and evaluation. Specifications for the LNG yard tractors were based on the Ottawa Commando 50 4x2 off-road terminal tractor performance specifications.

The LNG engine specified for the demonstration was the model year 2005 Cummins C Gas Plus 8.3 liter natural gas engine, rated at 250 hp and certified to the CARB on-road Optional NO<sub>x</sub> standard.

Eight diesel yard tractors were selected from LBCT's fleet to serve as the baseline yard tractor group for comparative purposes. The baseline vehicles were equipped with various off-road diesel engines, ranging from model year 2001 to 2003 Cummins 8.3 liter 6CT engines rated at 205-215 hp and certified at Tier 1 or Tier 2, to model year 2005 Cummins 5.9 liter ISB engines certified to the on-road emissions standard. All baseline diesel engines were equipped with diesel oxidation catalysts and closed crankcase ventilation to reduce particulate matter emissions. Data was collected on the baseline yard tractor group in parallel with the LNG tractors under similar operating conditions.

### Results

Data collection was performed for quantitative parameters, such as fuel consumption and exhaust emissions, as well as qualitative attributes, such as operator perceptions of vehicle drivability. With respect to fuel economy, the LNG yard tractors used approximately 30% more fuel, on a diesel equivalent gallon basis, as compared to the average for baseline diesel vehicles. This result is consistent with expectations for the relative efficiency of a spark-ignited natural gas engine compared to a compression-ignited diesel engine.

Operator acceptance was assessed via surveys given to all LNG yard tractor drivers. Drivers were asked to rate the LNG yard tractor as "better", "same", or "worse" in key performance areas compared to a typical diesel tractor. The areas covered by the survey included maneuverability, pulling power, acceleration, shifting, steering, in-cab visibility, ride comfort, etc.

Based on the driver surveys, 97% of the drivers found the LNG yard tractors to have the same or better performance compared to the diesel tractors; 67% of the drivers rated the LNG tractors as having superior performance in general.

### Benefits

During emissions testing, the lowest NO<sub>x</sub> and PM emissions were produced by the 2005 on-road diesel engine-equipped tractor and the 2005 LNG tractor, respectively. NO<sub>x</sub> emissions from the LNG yard tractor were approximately 21% higher than NO<sub>x</sub> emissions from the on-road diesel engine equipped with a diesel oxidation catalyst and closed crankcase ventilation system.

### Project Costs

The total project cost was \$425,000. Funding included \$350,000 from the Port of Long Beach TAP Program and a \$75,000 contribution from U.S. EPA Region 9.

### Commercialization and Applications

Original Equipment Manufacturer yard tractor chassis manufacturers now offer LNG yard tractors equipped with the Cummins Westport ISL G natural gas engine. This 8.9 liter heavy-duty on-road engine is certified at the 2010 0.2 g/bhp-hr NO<sub>x</sub> emission standard.

Updated: April, 2011

## Long Beach Container Terminal EcoCrane™

### Technology Manufacturer

R.J. Corman EcoPower Hybrid Systems, Inc., formerly Railpower Technologies, Inc.

### Co-Participants

Port of Long Beach, Port of Los Angeles, Long Beach Container Terminal

### Background

This project involved the demonstration of a rubber tired gantry crane (RTG) equipped with an advanced energy capture and battery storage system. The system, called EcoCrane™, was developed by R.J. Corman EcoPower Hybrid Systems, Inc., formerly Railpower Technologies, Inc. The project was sponsored by the Port of Long Beach (POLB) and Port of Los Angeles (POLA) under the joint Technology Advancement Program (TAP).

### Project Objective

A conventional diesel-electric RTG uses a diesel-fueled engine to generate electricity that powers electric motors used in container lifting as well as the motive power to move the RTG along the container stack. An RTG diesel genset used in port operations has a diesel engine rated, on average, at greater than 600 horsepower.

In the EcoCrane™ configuration, the diesel genset is equipped with a much smaller diesel engine – less than half of the rated horsepower of a conventional RTG. The reduced engine size and ability to turn the engine off during idling results in significantly lower fuel consumption and exhaust emissions. In addition, the smaller engine used in the EcoCrane™ genset is rated by the U.S.EPA at Tier 3, representing the current state-of-the-art diesel engines for off-road applications. This enables the EcoCrane™ to achieve substantial emission reductions as compared to a conventional RTG.



**Technology Demonstration**

During operation of a conventional diesel genset RTG, electric motors are used to lift the container and reposition the RTG along the container stack. Once in the proper position, the RTG lowers the container at a controlled rate. In a conventional RTG, the energy available when a container is lowered is wasted. In contrast, a hybrid RTG configuration captures the energy associated with lowering a container and stores in an energy storage system.

The EcoCrane™ uses a regenerative braking energy capture and storage system, similar to a hybrid-electric automobile. When a container is lowered using the EcoCrane, the motor used to lift the container is “reversed”; the motor becomes a generator, and the electricity produced as the container is lowered is directed to a bank of batteries - the electric energy storage system. The energy stored in the batteries can then be used to augment the EcoCrane’s™ electric motor during the crane’s subsequent lift.

Because batteries provide a portion of the energy used by the EcoCrane™ during container lifting, the amount of energy required from the diesel genset is substantially reduced. In the EcoCrane™ hybrid electric configuration, the reduction in power required from the diesel genset is greater than 50 percent. This means that the existing diesel genset can operate at a much lower load factor. The EcoCrane™ hybrid RTG is equipped with a 134 kW (180 brake horsepower (bhp)) Tier 3 John Deere diesel engine. This engine replaced a Cummins KTA-19 diesel engine rated at approximately 507 bhp at an engine speed of 1,800 RPM. Therefore, the EcoCrane™ diesel engine is approximately 65 percent smaller than the conventional RTG diesel engine in terms of rated power. A comparison of the EcoCrane™ diesel engine as compared to the original RTG diesel engine is shown below.

**EcoCrane™ Diesel Genset Engine as Compared to RTG Diesel Genset Engine**

	Conventional RTG Cummins KTA-19	EcoCrane™ RTG Tier 3 John Deere
Rated Horsepower (bhp)	507	180
Fuel Consumption (1,800 RPM)	27.3 gallons per hour	9.1 gallons per hour
NOx + Hydrocarbon Emissions Standard	4.8 g/bhp-hr	3.0 g/bhp-hr

**Status**

The experience gained from the LBCT project resulted in EcoPower Hybrid Systems modifying the original EcoCrane design and developing a second-generation EcoCrane™ hybrid RTG system. The new design is equipped with alternating current (AC) motors and eliminates the high power inverter. Control, power electronics, and hardware have also been improved. In addition, the new EcoCrane™ configuration is equipped with a dual battery pack with a total capacity of 440 amp-hours (Ah), compared to the LBCT EcoCrane™ battery capacity of 180Ah. This new battery configuration was designed to adapt to the voltage and energy requirements of existing RTG drive systems.

### Results and Benefits

The LBCT EcoCrane™ project demonstrated the application of hybrid-electric technology to cargo handling equipment in a marine terminal environment. Significant reductions in criteria air pollutant emissions, as well as reductions in fuel consumption and greenhouse gases, are being achieved by the EcoCrane™ as compared to a conventional diesel-electric RTG. Specifically, NO<sub>x</sub> plus hydrocarbon emissions of the Tier 3 John Deere engine are approximately 38 percent lower than RTG original equipment engine. Fuel consumption of the smaller John Deere engine is also significantly lower than a conventionally-equipped RTG.

### Project Costs

The cost of the demonstration project was \$169,870, with LBCT providing a fifty-percent cost share. The balance of funds, \$84,935, was provided by the TAP.

### Commercialization and Applications

Ports America demonstrated the next generation of EcoCrane™ at the Port of Los Angeles' West Basin Container Terminal. The new design reduced greenhouse gases on the order of 70 percent and more important, received verification for diesel particulate matter reductions of 85 percent.

Updated: May, 2012





## OGV Slide Valve Low-Load Emissions Evaluation

**Technology Manufacturer**  
MAN Diesel & Turbo A/S

**Co-Participants**  
MAN Diesel & Turbo A/S  
Mitsui Engineering & Shipbuilding Co, LTD  
Starcrest Consulting Group, LLC

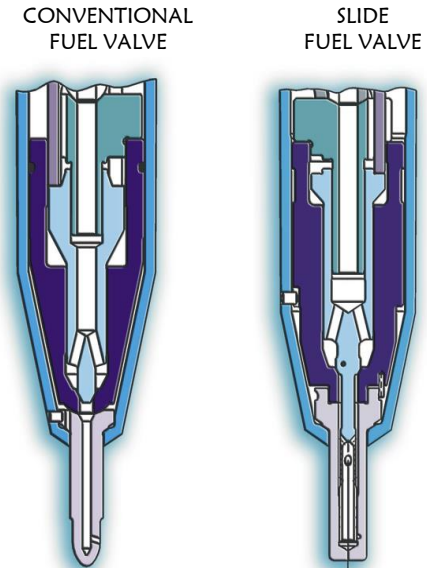
### Background

In 2008, the Port of Los Angeles and the Port of Long Beach participated in a demonstration of slide-type fuel valves to quantify their effectiveness as an emissions reduction retrofit technology for ocean-going vessels (OGVs) equipped with Tier 0 and Tier 1 two-stroke diesel main engines<sup>17</sup>.

The demonstration was conducted aboard the *APL Singapore*. This new type of OGV main engine fuel valve is designed to improve combustion properties by eliminating sac volume (i.e., fuel drips) at the valve nozzle. The elimination of the sac volume results in lower fuel oil consumption. In addition, slide valve nozzles incorporate an optimized spray pattern designed to improve the combustion process - this is intended to reduce overall emissions, including hydrocarbon, NO<sub>x</sub> and particulate matter. The visible smoke level is also greatly reduced as a result of the improved combustion.

The manufacturer, MAN Diesel & Turbo A/S (MDT), had previously published data suggesting slide valves offered a potential for a 30% reduction in NO<sub>x</sub> emissions and 25% reduction in DPM emissions when the technology is optimized in new engines.

The results from the 2008 *APL Singapore* slide valve retrofit demonstration, although ultimately inconclusive, seemed to suggest that the use of slide valves as an OGV main engine retrofit technology might not provide the level of emission reductions originally anticipated. In addition to the APL data, new information provided by the manufacturer also indicated that potential benefits from slide valves could be eroded as engine load is reduced. Ships complying with the vessel speed reduction (VSR) program, which has upwards of 95% participation in San Pedro Bay, generally have main engine loads below 25%, which is the lowest load point at which slide valves had been previously tested. Discussions with MDT determined that there had been no low-load engine tests for slide valve emission reductions conducted specifically on large slow-speed, two-stroke propulsion engines below 25% load and, therefore, no data to determine whether the slide valve benefit is appropriate at these lower loads.



<sup>17</sup> New Tier 2 vessels already incorporate slide valves and therefore no additional reduction is applicable to their use.



## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

The emission reduction benefits associated with slide valves is currently being applied in both port's emissions inventories for all vessel main engine loads. Due to the high participation levels of vessels complying with the VSR program, the Port of Los Angeles (POLA) and Port of Long Beach (POLB) sponsored additional emissions testing to determine what, if any, benefit results from MAN slide valves, especially at engine loads below 25 percent. Over 41% of all 2012 vessel arrivals to both ports are made by vessels with MAN slide valve equipped propulsion engines. This testing was conducted in support of the San Pedro Bay Ports Clean Air Action Plan OGV Measure Number 6 (OGV6) and is intended to improve the annual emissions inventories.

### Project Objective

The ports, with support from their project partners, developed a comprehensive test plan to quantify emissions from OGV fuel valves as a function of fuel valve nozzle design and engine load. Three fuel valve nozzle designs underwent performance and emissions testing:

- Slide-valve (SV) nozzle C26 – this is standard equipment on new slow-speed marine diesel engines manufactured by MDT and its licensees;
- Conventional C3 nozzle – this is the fuel valve design used on Tier 0 and Tier 1 MDT marine diesel engines;
- Conventional C11 nozzle – this is a “low-NOx” conventional fuel valve, equipped with a nozzle that delivers a fuel spray pattern designed to minimize NOx emissions.

### Technology Demonstration

The MAN 6S70MC-C7 marine diesel engine was selected as the test bed for the low-load emissions testing. This six-cylinder, slow-speed two-stroke marine engine was selected based on call activity data from both ports over the past several years and is the most representative propulsion engine available for testing in the fleet of vessels that has called at both ports.

Three test cycles consisting of the following load profiles were specified for each fuel valve configuration:

- Test Cycle #1: Engine load of E3 while temperature is stable;
- Test Cycle #2: Engine load of 15% while temperature is stable;
- Test Cycle #3: Engine load of 10% while temperature is stable.

Testing methods specified in the test plan were consistent with methods outlined in Chapter 5 of the IMO MARPOL Annex VI, NOx Technical Code 2008 (2009 Edition), and ISO8178. Tests were conducted for particulate matter, soot, and gaseous emissions. In the photos below, an MDT Technician Prepares Particulate Filters in Preparation for Sampling in Accordance with ISO 8178.



## Results

Results from the Mitsui Engineering & Shipbuilding, Co., LTD., Gaseous Measurements and MDT Particulate Measurements of Fuel-Valve Tests on 6S70MC-C7 at Tamano Works, Japan are summarized as follows:

- Slide valves (SV C26) emit the same level or more NO<sub>x</sub> (g/kW-hr basis) at low loads compared to the two conventional fuel valve configurations;
- The conventional C11 fuel valve was found to emit ~15% less NO<sub>x</sub> (g/kW-hr basis) at low loads than the SV C26 and C11 fuel valves;
- Below loads of 75%, slide valves emitted more NO<sub>x</sub> (g/kW-hr basis) than the two conventional fuel valve configurations and the C11 emitted the least NO<sub>x</sub> of all three fuel valve configurations;
- SV C26 nozzles were confirmed to emit less diesel particulate matter (DPM) at low loads compared to the two conventional fuel valve configurations. At low loads, SV emits up to 50% less DPM than conventional C3 and C11 fuel valves and up to 65% less DPM for cylinder-lubrication-corrected particulate-emission results;
- SV C26 nozzles emit over 90% less total hydrocarbons compared to the two conventional fuel valve configurations.

## Project Costs

The Port of Long Beach and Port of Los Angeles each contributed \$108,000 in TAP funding for the OGV Low Load fuel valve test program.

## Looking Forward

The results of the MAN slide valve low-load testing were documented in a Final Report approved by both Ports in August 2013. The Ports, along with the Emissions Inventory Technical Working Group, will evaluate the testing results to determine the appropriate emissions accounting for slide valve-equipped OGV calls in future Port emissions inventories.

Updated: April, 2014



# RYPOS Advanced Diesel Particulate Filter for Cargo Handling Equipment

**Technology Manufacturer**  
RYPOS, Inc.

**Co-Participants**  
Port of Long Beach, Port of Los Angeles

## Background

Although rubber tired gantry (RTG) cranes account for roughly 5% to 6% of cargo handling equipment at the Ports of Long Beach and Los Angeles, RTG cranes have been a significant contributor to port emissions.

## Project Objective

To investigate the technical and commercial feasibility of reducing emissions from RTG cranes and other cargo handling equipment equipped with an active diesel particulate filter.

## Technology Demonstration

RYPOS ActiveDPF/C™ system consists of the filter housing, flow control, electrical control circuit, and filter cartridges. The electrical control circuitry automatically monitors and controls the regeneration of the filter cartridges.

The diesel particulate filter cartridge is composed of sintered metal fibers that are shaped into filter elements and then incorporated into filter cartridges. These sintered metal fiber cartridges are capable of capturing the very fine carbon particles present in the exhaust stream, with high efficiency and high holding capacity. The diesel oxidation catalyst filter cartridge reduces CO, NO<sub>2</sub>, and hydrocarbon emissions, and can act as a sound absorption device, replacing the muffler while occupying the same space.

The operation of the RYPOS ActiveDPF/C™ is controlled by a microprocessor. The controller monitors the filters and, as required, an electric current is passed through a filter element, which then acts as a heating element. A dedicated power source provides the required electrical current to heat each filter element individually to the temperature required to burn soot, reducing the maximum amount of electrical energy required. This regeneration strategy is designed to keep the back pressure below a pre-set level. The average power consumption required for regeneration is less than one percent of the rated power of the engine.

The proposed project demonstration consisted of installing the system on a RTG crane, a top handler and a side handler.

### Results

In early 2012, RYPOS prepared and submitted to the California Air Resources Board an in-use operation test plan for review. During that time, tests conducted on the filter prompted a reevaluation of voltage needed for optimum regeneration as well as filter design and sizing. With much of their time focused on obtaining Level 3 verification for the RTG crane application, RYPOS determined that it was unable to move forward on developing the Active DPF/C™ system for top and side handler application. As a result, RYPOS has completed their obligations under the TAP and the project is considered complete.

### Benefits

In August 2011, the RYPOS ActiveDPF/C™ was verified by CARB to reduce particulate matter in the RTG crane application at CARB Level 2-plus verification (50%, but actual test results showed 83% effectiveness). RYPOS will continue to modify the system to achieve Level 3 verification for CHE.

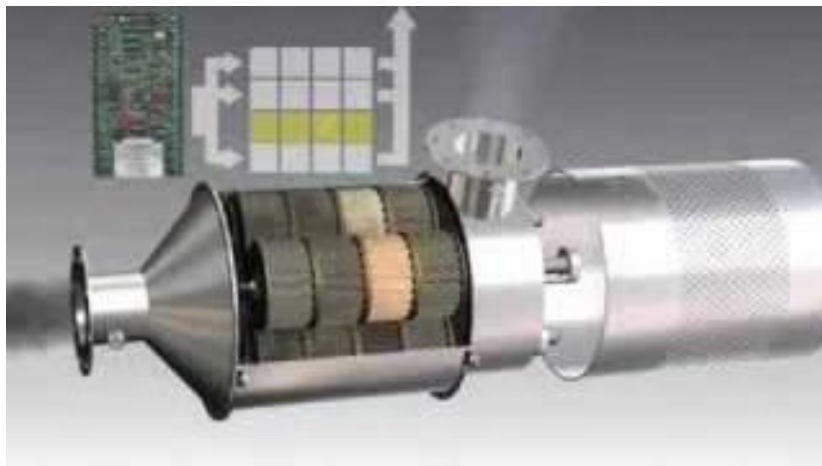
### Project Costs

The total project cost was \$322,140. Funding included \$64,668 from the Port of Long Beach TAP Program and a \$64,688 contribution from the Port of Los Angeles TAP Program.

### Commercialization and Applications

RYPOS achieved Level 3 verification (at least 85% PM reduction) of the Active DPF/C™ system for RTG cranes as part of a follow-on project. This was accomplished by adjusting the software that dictates how often regeneration occurs on an RTG crane at TraPac at the Port of Los Angeles. A final report for this Level 3 system is available on the TAP website.

Updated: June, 2015.



## RYPOS Advanced Level 3+ Diesel Particulate Filter RTG Crane Demonstration

**Technology Manufacturer**  
RYPOS, Inc.

**Co-Participants**  
Port of Long Beach, Port of Los Angeles

### Background

Since 2009, RYPOS Inc. (RYPOS) initiated a number of different project demonstrations in an effort to evaluate the effectiveness of their Hybrid Diesel Particulate Filter/Catalyst (HDPF/C™) system in various port equipment applications. These projects include:

- Installation of the HDPF/C™ system on an RTG crane at International Transportation Service, Inc. at the Port of Long Beach in 2009;
- Installation of the HDPF/C™ system on a top handler and a side handler at Seaside Transportation Services, LLC (STS) at the Port of Los Angeles in 2010; and
- Installation of the HDPF/C™ system on an RTG crane at STS terminal in early 2011.

In August 2011, the RYPOS ActiveDPF/C™ was verified by CARB to reduce particulate matter in the RTG crane application at CARB Level 2-plus verification (50 percent, but actual test results showed 83 percent reduction effectiveness).

### Project Objective

In 2013, RYPOS initiated a new project under the TAP to achieve verification for a reengineered RYPOS ActiveDPF/C3+™ in RTG crane applications at CARB Level 3 (i.e., 85 percent reduction effectiveness).

### Technology Demonstration

The system was installed on a RTG located at the TraPac terminal in the POLA where durability hours were accumulated and source testing was conducted.

The RYPOS HDPF/C™ was originally designed as a passive/active-regeneration diesel particulate filter estimated to reduce particulate matter emissions by more than 85 percent. The system incorporated a microprocessor-controlled, electric heating element to regenerate and burn off accumulated DPM captured by the filter without additional action by the equipment operator. A diesel oxidation catalyst (DOC) attached to the outlet of the particulate filter was used to remove the soluble organic fraction of particulate matter while also reducing hydrocarbon, carbon monoxide, and nitrogen dioxide emissions.

RYPOS redesigned and upgraded the HDPF/C™ for RTG cranes with an all-electric charged, active regeneration filter—the ActiveDPF/C™. The ActiveDPF/C™ is designed to regenerate at any exhaust temperature and is not affected by idle operation.



### Results

RYPOS received CARB verification for Level 3-plus<sup>18</sup> for RTG crane applications on February 13, 2014, thus completing this TAP project. The project's final report is posted on the TAP website.

### Benefits

In September 2013, the RYPOS ActiveDPF/C3+™ was verified by CARB to reduce particulate matter in the RTG crane application at CARB Level 3-plus verification (85 percent PM reduction, while limiting NO2 emissions to 20 percent).

### Project Costs

The TAP supported the RYPOS verification effort with project co-funding in the amount of \$36,130 per port. TAP funding was matched by RYPOS in the amount of \$72,260, for a total project cost of \$144,520.

### Commercialization and Applications

The RYPOS ActiveDPF/C3+™ achieved CARB verification and is available for use in California. The project final report is available on the TAP website.

Updated: June, 2015.



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<sup>18</sup> See Verification DE-13-002-01: <http://www.arb.ca.gov/diesel/verdev/companies/rypos/de1300201.pdf>

## SoCalGas CNG Drayage Truck Demonstration

### Technology Manufacturer

Cummins Westport

Autocar LLC

### Co-Participants

Port of Long Beach, Port of Los Angeles, SoCalGas Company, California Cartage Company, South Coast Air Quality Management District



### Background

The Ports are committed to reducing air pollution from drayage operations as exemplified by their respective Clean Truck Programs and research into zero-emission container movement. The TAP is also supporting the Ports' transition to low emission drayage operations by demonstrating technologies that have high potential to be both commercially viable and significantly reduce pollution from container drayage.

### Project Objective

Under the TAP, the Ports embarked upon a collaborative effort with Southern California Gas Company (SoCalGas) and their partners, California Cartage Company and Autocar LLC, to develop and demonstrate the nation's first drayage trucks powered by compressed natural gas (CNG). Four trucks were delivered June 2008 and used to move containers between the Ports and nearby freight consolidation yards.

### Technology Demonstration

The trucks were manufactured by Autocar LLC and are powered by the Cummins Westport ISL G engine. The Cummins Westport ISL G is currently the cleanest heavy-duty internal combustion engine commercially available, with certified NO<sub>x</sub> levels one-half that of U.S. EPA's stringent 2010 on-road heavy-duty emissions standard.

To demonstrate the viability of the ISL G CNG engine in port drayage operations, California Cartage Company (CCC), the largest trucking company operating at the Ports, operated the four CNG-powered trucks in regular revenue drayage operations for a one-year demonstration period. This period covered calendar year 2009. During this period, the trucks underwent continuous monitoring to assess performance capabilities, operability, driver impressions, and vehicle reliability.

### Status

The CNG trucks operated throughout 2009. Initially, the trucks were used exclusively in local drayage service around the Ports in an effort to familiarize the drivers with the new vehicles and to build confidence in the local, public CNG infrastructure. In early May 2009, CCC's management decided they had the comfort level with the TAP-funded CNG truck to begin running it on longer inland routes. Beginning on May 4, 2009, the TAP-funded CNG truck began running one inland route from CCC to Ontario each morning. The truck ran local routes each afternoon. The CNG truck continued running this single daily inland route for most of May 2009 through September 2009. After September, the CNG truck was returned to in-service operation until reclaimed by SCG for further research purposes in 2010.

### Results

The SoCalGas demonstration proved the feasibility and capability of using CNG fuel in commercially available heavy-duty engines for port drayage operations. This provides port drayage operators an additional low emission technology choice when replacing or upgrading their fleet vehicles. This project's final report is available for download on the TAP website<sup>19</sup>.

### Benefits

The certified NO<sub>x</sub> emission levels of the Cummins Westport ISL G engine are about 90 percent below a model year 2007 diesel drayage truck. The use of "low carbon content" natural gas will also help California achieve its goals under its Low-Carbon Fuel Standard and reduce greenhouse gas emissions by approximately 20 percent as compared to diesel fuel.

### Project Costs

The combined TAP funding from both Ports was \$223,155, which was applied to the capital purchase cost of one demonstration vehicle. The remaining three demonstration trucks were purchased by SoCalGas. The SCAQMD co-funded the construction of a temporary CNG refueling station to support the demonstration trucks' daily refueling needs. The SCAQMD also contributed \$421,250 towards the purchase of capital equipment for the temporary refueling station.



### Commercialization and Applications

The Cummins Westport ISL G engine is commercially available today, and an increasing number of heavy-duty truck chassis manufacturers are offering vehicles equipped with the ISL G in a compressed natural gas configuration. The 8.9L engine is marketed as meeting 2010 U.S. EPA and CARB emission standards. In addition, the relatively low cost of CNG, as compared to diesel fuel, makes this engine an attractive option for port drayage operators.

Updated: April, 2011.

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<sup>19</sup><http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2471>

## SCAQMD HDV In-Use Emissions Testing Program

### Lead Program Sponsor

South Coast Air Quality Management District (SCAQMD), West Virginia University, University of California, Riverside and California Air Resources Board (CARB)

### Co-Participants

Port of Long Beach, Port of Los Angeles

### Background

The Ports joined an existing SCAQMD research program<sup>20</sup> to conduct in-use emissions testing for class 8 diesel- and LNG-fueled trucks, and if needed, to evaluate emission-reduction potential of retrofit technology on existing and new on-road heavy-duty engines. The original project scope was budgeted at a total \$1,701,156. The University of California, Riverside (UCR) and West Virginia University (WVU) were selected by competitive bid to conduct this emissions testing program jointly with SCAQMD. The TAP funding for this project covered program enhancements to include emissions testing of additional drayage trucks utilizing a newly developed port drive test cycle<sup>21</sup> specifically derived from in-use drayage operation. The TAP provided \$306,552 in co-funding to test six additional heavy-duty drayage vehicles using the Ports' drive test cycle, bringing the total project budget to \$2,007,708.

### Project Objective

The objectives of the project included: in-use emissions testing of heavy-duty natural gas and diesel vehicles to verify emissions standards and the emission-reduction potential of engine or aftertreatment technology to reduce regulated emissions over time; measurement of ammonia and formaldehyde emissions from heavy-duty vehicles; the effectiveness of oxidation catalysts or alternative technologies to reduce these emissions; the assessment of the emission-reduction potential of exhaust gas recirculation (EGR) to reduce PM and NO<sub>x</sub> emissions from diesel engines; and the impact of using water in-lieu of urea or no reductant for SCR technology. To achieve these objectives, the project included on-road heavy-duty vehicles used in transit, school bus, refuse, and goods movement applications and powered by engines fueled with natural gas, propane, diesel, and combination of diesel and natural gas fuels.

### Technology Description

The vehicles were tested across 66 different test configurations. The engines were categorized into eight groups including natural gas engines with three-way catalysts, high pressure direct injection (HPDI) engines with EGR and DPF with or without SCR technology, propane and diesel school bus engines, propane engines certified at or below 0.2 g NO<sub>x</sub>, diesel engines certified at 1.2 g NO<sub>x</sub>, diesel engines certified above 0.2 g NO<sub>x</sub> without SCR technology, and diesel engines certified at or below 0.2 g NO<sub>x</sub> with SCR technology. In addition, WVU utilized its Transportable Emissions Measurement System (TEMS) and Horiba Portable Emissions Measurement System (PEMS) to measure in-use emissions from a U.S. EPA 2010 compliant heavy-

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<sup>20</sup> On December 3, 2010, the SCAQMD Board awarded contracts to the University of California, Riverside (UCR) and West Virginia University (WVU) to conduct in-use emissions testing, and if needed, to evaluate emission-reduction potential of retrofit technology on existing and new on-road heavy-duty engines.

<sup>21</sup> See Section 2.5.4 for more information on this new cycle.

## San Pedro Bay Ports Technology Advancement Program 2015 Annual Report

duty diesel truck loaded to approximately 70,000 pounds, while driven from Morgantown WV to Riverside CA. WVU continuously tracked all not-to-exceed events, and measured total and non-methane hydrocarbon, NO<sub>x</sub>, CO, CO<sub>2</sub>, NO<sub>2</sub>, nitric oxide, nitrous oxide, PM, and ammonia emissions.

### Benefits

The project supports the effort to better characterize in-use emissions from port drayage truck operation. While this project did not result in actual emission reductions per se, the knowledge base gained from this comprehensive effort will provide the Ports, SCAQMD and other industry stakeholders with a much better understanding of the in-use emissions that result from implementation of advanced alternative fuel and aftertreatment technologies that could potentially be used to further reduce PM emissions from on-road heavy-duty vehicles.

### Status

An MOA between the Ports and SCAQMD was implemented in early 2012 to facilitate Port co-funding of this project and increase the scope to include port-related testing. Project vehicle testing began in late 2011. Emissions testing for the following 24 project vehicles was completed as part of this project:

- Three natural gas-fueled drayage vehicles ( one CNG & two LNG)
- One LNG-fueled refuse vehicle
- One CNG-fueled transit bus
- Four High Performance Direct Injection natural gas vehicles (dual-fuel LNG & diesel)
- Two school buses (one propane and one diesel)
- One propane-fueled drayage truck
- Eight diesel-fueled drayage trucks
- Four diesel fueled refuse vehicles

Nine of the test vehicles were evaluated by WVU, eleven were evaluated by UCR, and four were evaluated by both contractors to review the correlation of results between the two laboratories. All testing was completed and the final reports from each contractor (WVU and UCR) are available from SCAQMD staff.



### Project Costs

The Ports contributed \$306,552 in co-funding to this project for the additional port-specific testing, bringing the total project budget to \$2,007,708. CARB also provided an in-kind services contribution to support the project, which included quantification of criteria pollutant emissions using a portable emission measurement system, collection and analysis of exhaust gases for N<sub>2</sub>O emissions, data analysis, and interpretation of emissions test results and measurements.

In general, emissions testing results indicated that while emissions were within expected limits, the in-use testing results were significantly higher than original certification level of the project truck engines. Also, natural gas trucks were found to emit less NO<sub>x</sub> as compared to diesel trucks since the SCR units on the diesel engines were not performing at optimal efficiency when at temperatures below 250 degrees centigrade. When the SCR units were not operational, diesel engine emissions were found to be as much as ten times higher than from natural gas engines.

The PM emissions from all technology vehicle types were close to the detection limits of the measurement system (i.e., very low). Diesel vehicles employing high-EGR strategy resulted in frequent DPF regeneration events which contributed to momentary high PM mass emissions. Whereas, the PM emissions from the soot free combustion of natural gas were similar in magnitude to DPF-equipped diesel. It should also be noted that natural gas engines equipped with three-way catalysts were able to achieve low PM emissions without the use of a DPF. Another significant result of this test program was that ammonia emissions were found to be significant for the natural gas-fueled vehicles.

### Looking Forward

SCAQMD is moving forward on a follow-on study to explore two key results from this study:

- WVU will investigate emission controls to improve the control of ammonia emissions from natural gas engines.
- In-use vehicle testing will be conducted to evaluate real-world emissions; this will involve on-road testing during regular truck operation.

The results of this follow-on study should improve the emissions control effectiveness of natural gas engine controls and contribute to a better understanding of the truck fleets' real-world emissions and how much needs to be done to address minimize in-use fleet emissions. It is hoped that study results will be available by the end of 2015.

Updated: December, 2014

## Vision Motor Corp. Hydrogen Fuel Cell Plug-In Hybrid Electric Trucks

**Technology Manufacturer**  
Vision Motor Corp.

**Co-Participants**  
Port of Long Beach, Port of Los Angeles

### Background

Zero-emission vehicles (ZEVs) provide significant environmental benefits. Tailpipe emissions are completely eliminated, and even on a lifecycle basis (i.e., including the fuel cycle emissions of hydrogen versus petroleum diesel fuel production and distribution), the ZEVs are cleaner than conventional alternatives. This project was designed to support the joint Port effort to increase the use of zero-emission technology in port equipment. This effort is detailed in the “Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles.”

### Project Objective

To demonstrate a zero emission hydrogen fuel cell/hybrid-electric drive system in short-haul drayage and terminal container movement operations.

### Proposed Technology Demonstration

The project scope includes the design, development and demonstration of two vehicle types: 1) the Tyrano™ class 8 on-road truck equipped with Vision’s proprietary hydrogen (H<sub>2</sub>) fuel cell/hybrid electric drive system; and 2) the Zero-TT off-road terminal tractor equipped with a similar zero-emission hybrid drive system. During the demonstration, each vehicle will undergo performance testing to validate maximum speed and maximum daily operating range under various payloads and conditions.

The Class 8 truck design is based on a battery electric drive system that incorporates a hydrogen fuel cell range extender. The design specifications include an estimated 8-hour shift with a range of 200 miles, a governed maximum highway speed of 65 miles per hour, and ability to haul an 80,000 pound payload.

The Zero-TT is designed to be equipped with a similar battery electric drive system with a hydrogen fuel range extender. The design specifications include an estimated 8-hour shift with a range of 100 miles and the ability to haul a 130,000 pound maximum container.

### Results

Both projects fell significantly behind schedule, and Vision was unable to begin the demonstrations within the contractual time period. The contract expired at the end of 2012; at that time, there were no results to report from the TAP testing period. Vision continues to develop the vehicles and conduct mini-demonstrations with its private partners.

### Benefits

Vision was unable to provide proof of environmental benefits conforming to the TAP test plans during the project demonstration period. However, Vision continues to test these vehicles and refine the technology.

### Project Costs

The original project budget was \$999,211 with \$425,000 in TAP funding and \$574,211 from Vision in matching funds. TAP funding in the amount of \$191,250 was spent on the project prior to contract expiration.

### Commercialization and Applications

At this time, these zero-emission vehicles are considered emerging technologies in the demonstration phase with no immediate plans for CARB verification or commercialization. Any future demonstrations of these technologies will be completed outside the scope of the TAP; Port staff will follow any progress made to provide status updates of the technology to interested terminal operators and partners

Updated: December, 2013.



## Vycon REGEN® System for Rubber-Tired Gantry Cranes

**Technology Manufacturer**  
VYCON Energy

**Co-Participants**  
Port of Los Angeles, Port of Long Beach, South Coast Air Quality Management District, California Air Resources Board, ITS, Evergreen and VYCON



### Background

The VYCON REGEN® system supports the goal of clean air and a healthier environment through the reduction of air pollution from port equipment. Specifically for this project, a rubber tire gantry (RTG) crane operating at each Port was retrofit with the VYCON system.

### Project Objective

Two marine terminals, ITS in the Port of Long Beach and Evergreen in the Port of Los Angeles, installed VYCON's REGEN system onto one of the terminals' rubber tire gantry (RTG) cranes.

### Technology Description

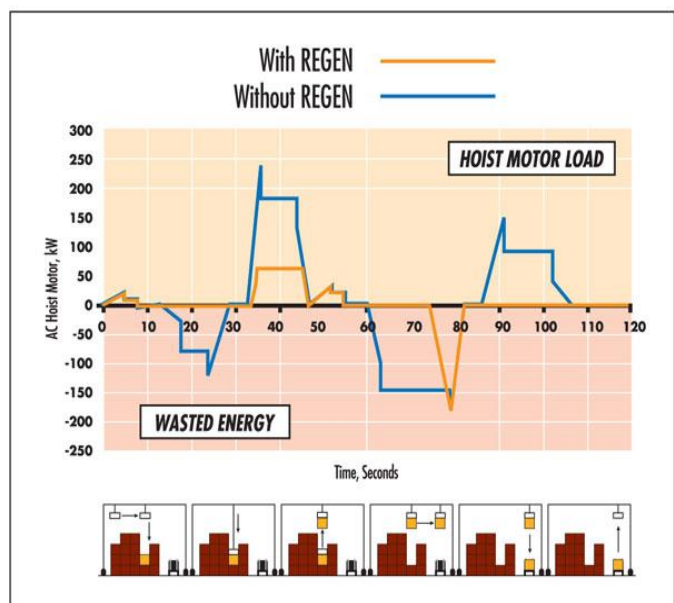
VYCON's REGEN system is an energy storage system that is also capable of supplying the stored energy on demand.

The REGEN system is re-charged each time the AC motor in the hoist regenerates power (i.e., on the down cycle). This stored energy is then quickly released back to the AC motors during the "up" cycle, resulting in increased efficiency during each lift cycle. The transitions are seamless and instantaneous. This conserves energy, increases fuel efficiency, and reduces emissions as well as operating costs. The REGEN System can be retrofitted onto in-use cranes or installed at the factory as part of a new crane.

### Results

The primary TAP role in this project was to co-fund emissions testing in support of CARB verification. This work was completed and VYCON received its Level 1 CARB verification in October, 2007.

### Typical Load Profile vs. Load Profile with REGEN





### Benefits

VYCON's REGEN system is verified to reduce particulate matter (PM) emissions by a minimum of 25 percent and is estimated to reduce oxides of nitrogen (NO<sub>x</sub>) emissions by 30 percent. Emissions of carbon dioxide (CO<sub>2</sub>) are estimated to be reduced by about 30 percent, resulting from the associated reduction in diesel fuel consumption up to 35 percent.

### Project Costs

The TAP supported the VYCON verification effort by co-funding emissions testing of the project equipment. Each Port committed \$11,500 for a total cost of \$23,000.

### Commercialization and Applications

The VYCON flywheel regeneration system already has a number of applications. In addition to the Level 1 RTG crane application, VYCON's REGEN system is also used in rail, uninterruptable power supply and wind power applications

Updated: April, 2010.





## Westport GX LNG Engine Development

### Technology Manufacturer

Westport Innovations  
Kenworth Truck Company

### Co-Participants

Port of Los Angeles, Port of Long Beach, South Coast Air Quality Management District, California Energy Commission

### Background

Westport Innovations (Westport), developer of the High Pressure/Direct Injection (HPDI) liquefied natural gas (LNG) fuel system technology, developed an LNG 15-liter heavy-duty truck engine that was certified to the 2010 on-road NO<sub>x</sub> emission standard of 0.2 grams per brake horsepower-hour (g/bhp-hr).

The 400- and 450-horsepower rated heavy-duty engines are based on the 15-liter Cummins ISX diesel engine platform and are designed to satisfy the performance requirements of class 8 tractors that provide drayage service at the Ports.

### Project Objective

The GX LNG heavy-duty engine development project had three primary objectives:

1. Development and certification of a 2007 LNG high-pressure direct-injection engine to 0.6 g/bhp-hr NO<sub>x</sub> by early 2008;
2. Establish the manufacturing capacity to produce LNG trucks in a high volume truck production facility;
3. Certification of a 0.2 g/bhp-hr NO<sub>x</sub> (2010 standard) compliant truck by early 2010 for deployment in mid-2010.

### Technology Demonstration

Westport's HPDI technology facilitates the use of natural gas as an engine fuel while retaining typical diesel engine combustion, power, and torque. The technology differs from other natural gas engines through the absence of spark plugs. A patented injector delivers a small amount of diesel fuel (approximately 6% by energy content) and high pressure natural gas directly to the engine combustion chamber, where the diesel fuel acts as the ignition source.

LNG fuel for the Westport GX engine is stored in the LNG tank mounted to the chassis of the vehicle. The liquid natural gas is drawn from the tank using a proprietary LNG pump that is powered by an engine-driven hydraulic pump. The LNG is then vaporized using excess heat from the engine's coolant system.



Simultaneously, a diesel fuel pump draws and pressurizes diesel fuel from its storage tank. Both the natural gas and diesel are then routed to a fuel conditioning module, where both fuels are pressure regulated, filtered, and sent to the fuel injector nozzles.

HPDI relies on late-cycle high pressure injection of natural gas into the combustion chamber. The natural gas is injected at the end of the compression stroke, similar to the diesel fuel in a diesel engine. Natural gas has a higher ignition temperature compared to diesel, so a diesel pilot injection is used to initiate combustion.

The benefits of the high pressure direct injection cycle include horsepower and torque output similar to a conventional diesel engine and fuel cost savings due to the high substitution of lower cost LNG as compared to diesel.

With the low emissions profile of natural gas and the high efficiency of the diesel combustion cycle, HPDI technology combines high energy efficiency with low emissions. The HPDI system extends beyond the fuel injection equipment, and is developed as a fully integrated system including fuel system management electronics, LNG tanks, and vehicle installation.

### **Results**

The Westport GX demonstrated emission levels during certification testing at or below 0.2 g/bhp-hr NO<sub>x</sub> in mid-2009. Westport worked closely with the U.S. EPA to finalize the deterioration rate for the engine. While this resulted in a slight delay in achieving final certification, the Westport GX heavy-duty LNG engine was granted a CARB Executive Order at the 0.2 g/bhp-hr NO<sub>x</sub> certification level on July 6, 2010.

### **Benefits**

The Westport GX LNG engine will accelerate NO<sub>x</sub> emission reductions by achieving the final 2010 standard in early 2010. Diesel engines of a comparable displacement are not expected to meet the 2010 standard initially – engine manufacturers will instead use credits generated from family emission level (FEL) engines to offset the higher emissions of their large displacement on-road engines. Westport estimates emission reductions of at least 0.45 tons of NO<sub>x</sub> per year per truck above the equivalent model year diesel truck, until the 0.2 standard is phased in for diesel engines. The LNG heavy-duty truck also emits 15 to 20 percent less greenhouse gases compared to diesel engines.

### **Project Costs**

The total project cost for development and certification of Westport GX natural gas engine is estimated at \$9,894,027. Westport contributed \$7,144,027 of the project development cost (in-kind) and secured additional funding in the amount of \$500,000 from Clean Energy, a provider of LNG fuel, to assist with integration of the engine and related fuel system. The California Energy Commission (CEC) provided \$500,000 under the PIER program. Kenworth Truck Company was a key partner in the project and will provide in-kind contributions to assist with the future deployment of GX-equipped LNG trucks. The SCAQMD contributed \$1.25 million, and the Ports of Long Beach and Los Angeles contributed \$250,000 in TAP funding.

### **Commercialization and Applications**

This large displacement, low emission natural gas engine is commercially available and can be used in port drayage, as well as other heavy-duty vehicle applications. For 2012, the engine is certified by CARB to have lower NO<sub>x</sub> emissions than the comparably sized diesel engine.

Updated: April, 2011