Port of LONG BEACH
The Green Port

THE PORT OF LOS ANGELES


SAN PEDRO BAY PORTS

# Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines

**JULY 2016**

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ARB | Air Resources Board |
| BET | Battery Electric Truck |
| BMS | Battery Management System |
| BS(bs) | Brake Specific |
| Caltrans | California Department of Transportation |
| CARB | California Air Resources Board |
| CAN | Controller Area Network |
| CCR | California Code of Regulations |
| CD | Charge Depletion |
| CE-CERT | University of California-Riverside College of Engineering – Center for Environmental Research and Technology |
| CFR | Code of Federal Regulations |
| CNG | Compressed Natural Gas |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| COV | Coefficient of Variation |
| DC | Direct Current |
| DoD | Depth of Discharge |
| DOT | US Department of Transportation |
| DPF | Diesel Particulate Filter |
| DTP | Drayage Truck Port Cycle |
| DTP-1 | Near Dock Drayage Truck Port Cycle |
| DTP-2 | Local Drayage Truck Port Cycle |
| DTP-3 | Regional Drayage Truck Port Cycle |
| ECM | Engine Control Module |
| ECU | Engine Control Unit |
| EPA | US Environmental Protection Agency |
| EVSE | Electric Vehicle Supply Equipment |
| FCET | Fuel Cell Electric Truck |
| FE | Fuel Economy |
| FHWA | Federal Highway Administration |
| FID | Flame Ionization Detector |
| FMVSA | Federal Motor Vehicle Safety Administration |
| FMVSS | Federal Motor Vehicle Safety Standards |
| FTP | Federal Test Procedure |
| GAWR | Gross Axle Weight Rating |
| g/bhp-hr | Grams per Brake Horsepower Hour |
| GCWR | Gross Combined Weight Rating |

## ACRONYMS AND ABBREVIATIONS (CONTINUED)

| | |
|---|---|
| GHG | Greenhouse Gas |
| g/mi. | Grams per Mile |
| GVW | Gross Vehicle Weight |
| GVWR | Gross Vehicle Weight Rating |
| $H_2$ | Hydrogen |
| HDT | Heavy-Duty Trucks |
| HHDT | Heavy-Heavy Duty Truck |
| hp | Horsepower |
| HUDDS | Heavy Duty Urban dynamometer Drive Schedule |
| HVIP | Hybrid Vehicle Incentive Program (CARB) |
| ICTF | Intermodal Container Transfer Facility |
| kW | kilowatt |
| kWh | kilowatt-hour |
| lb. | Pound |
| LMC | Licensed Motor Carrier |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas (propane) |
| MPG | Miles per Gallon |
| MPGde | Miles per Gallon Diesel Equivalent |
| mph | Miles per Hour |
| MY | Model Year |
| NET | Net Energy Charge |
| NHTSA | National Highway Traffic Safety Administration |
| NMHC | Non-methane Hydrocarbons |
| NOx | Nitrogen Oxides |
| NZET | Near-Zero Emission Truck |
| OBD | Onboard Diagnostics |
| OEM | Original Equipment Manufacturer |
| PDT | Port Drayage Truck |
| PEMS | Portable Emissions Measurement System |
| PM | Particulate Matter |
| POLA | Port of Los Angeles |
| POLB | Port of Long Beach |
| RESS | Rechargeable Energy Storage System |
| RPM | Revolutions Per Minute |
| SAE | Society of Automotive Engineers |
| SoCAB | South Coast Air Basin |
| SCAQMD | South Coast Air Quality Management District |

## ACRONYMS AND ABBREVIATIONS (CONTINUED)

| | |
|---|---|
| SEE | Standard Error Estimate |
| SG | Sustained Grade |
| SOC | State of Charge |
| SOC ini | Initial State of Charge |
| SOC final | Final State of Charge |
| SOC delta | SOC final – SOC ini (difference in SOC over test) |
| THC | Total Hydrocarbons |
| UCR | University of California-Riverside |
| UDDS | Urban Dynamometer Driving Schedule |
| ULSD | Ultra-Low Sulfur Diesel |
| VAC | Volts Alternating Current |
| V2G | Vehicle-to-Grid |
| ZET | Zero Emission Truck |

## INTRODUCTION

Heavy-duty trucks are used extensively to move cargo, particularly containerized cargo, to and from the marine terminals, an activity known as "drayage". Drayage operations include both on-terminal and on-road operations:

- <u>On-Terminal Operations</u> include waiting for terminal entry, transiting the terminal to drop off and/or pick up cargo, and departing the terminals;
- <u>On-Road Operations</u> consists of travel on public roads within the South Coast Air Basin (SoCAB). This also includes travel on public roads within the Port boundaries.

The most common configuration of a drayage truck is the articulated tractor-trailer (truck and semi-trailer) having five axles, including the trailer axles. The most common type of trailer in the study area is the container trailer, built to accommodate standard-sized cargo containers. Additional trailer types include tankers, boxes, and flatbeds. A tractor traveling without an attached trailer is called a "bobtail." A tractor pulling an unloaded container trailer chassis is known simply as a "chassis."

The Ports of Long Beach and Los Angeles, in partnership with the South Coast Air Quality Management District (SCAQMD) and the California Air Resources Board (CARB), have developed the following 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 SoCAB.

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 they pertain 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.

This protocol is intended to serve as *guidance*; it does not represent a binding obligation on any vehicle manufacturer or port motor carrier. However, this testing and demonstration protocol may, in total or in part, be incorporated into contractual obligations associated with a port-sponsored drayage truck development or demonstration project. The ports also reserve the right to utilize the minimum truck performance capabilities specified herein as evaluation criteria in future port-sponsored vehicle development, demonstration, and incentive programs. It is also envisioned that the SCAQMD and CARB may incorporate similar guidelines into their drayage truck development, demonstration, and incentive programs.

This document is comprised of three primary parts:

- Part A – Applicable Technologies, Regulations, and Minimum Drayage Truck Performance Requirements: Part A sets forth minimum vehicle design, regulatory compliance, and performance requirements for class 8 drayage trucks operating at the ports. It is intended to clearly articulate the ports' expectations as it pertains to vehicle design and development, and serves as guidance to zero emission and near-zero emission truck (ZET/NZET) designers and manufacturers seeking to partner with the ports in a future ZET/NZET development, demonstration, and incentive program;
- Part B – Test Plan Development Guidelines: Part B specifies the essential components of a ZET/NZET Test Plan, including guidelines for the preparation of a vehicle technical specification, vehicle performance specification, as well as laboratory and chassis dynamometer testing requirements. A test plan in this or similar format will be a mandatory requirement for ZET/NZET developers or manufacturers seeking to partner with the ports in a future ZET/NZET development, demonstration, and/or incentive program;
- Part C – Demonstration Plan Development Guidelines: Part C specifies the elements of a ZET/NZET On-Road Demonstration Plan. This plan will be prepared and submitted by ZET/NZET developers and manufacturers that intend to demonstrate their drayage truck in on-road testing and revenue service in partnership with a port licensed motor carrier. The guidelines include recommendations for vehicle acceptance testing, on-road testing, and in-service/revenue testing. Note that a demonstration plan in this or similar format will be a mandatory requirement for ZET/NZET developers or manufacturers seeking to partner with the ports in a future ZET/NZET development, demonstration, and/or incentive program.

# PART A: APPLICABLE TECHNOLOGIES, REGULATIONS, & MINIMUM DRAYAGE TRUCK PERFORMANCE REQUIREMENTS

## 1.0 Applicable ZET/NZET Technologies

The testing and demonstration guidelines included in this document are applicable to the development and demonstration of advanced technology on-road class 8 trucks whose primary intended use is on-terminal and on-road container drayage operations. "Class 8" trucks are those with a gross vehicle weight rating (GVWR) greater than 33,000 lbs. (14,969 kg). **While in some cases class 7 trucks are used in port drayage operations, this document only pertains to on-road, class 8 trucks.**

This document is intended to provide uniform testing and demonstration procedures that will allow direct comparison of the technical performance of candidate zero emission and near-zero emission truck technologies. As such, this document is relevant to the following advanced class 8 drayage truck technologies and configurations:

### 1.1 Zero-Emission Drayage Trucks

These vehicles have zero (0) exhaust pipe emissions of criteria and greenhouse gas air pollutants during all phases of port-related drayage operations. Power plant, refinery, or other fuel cycle-generated emissions are not quantified or assigned to the zero emission truck – only direct vehicle emissions are considered.

Drayage trucks currently undergoing development and demonstration that meet the definition of zero emissions include the following:

- Battery Electric Trucks – a battery electric truck (BET) is powered exclusively by electricity from an onboard battery pack. Battery pack recharging is accomplished by plugging into the electric power grid or other off-grid electric power source to recharge the battery pack while the truck is not operating. BET is also referred to as a plug-in electric truck.
- Fuel Cell Trucks – a fuel-cell electric truck (FCET) converts the chemical energy from a fuel source, such as hydrogen, into electricity and then uses the generated electricity to drive an electric motor to propel the truck and in most cases recharge a battery pack used for load buffering and peak power demand.
- Inductively Charged Electric Trucks – an electric vehicle using electromagnetic induction as the power source. Typically, electric power strips have been buried under the road surface and connected to the electrical grid. Pick-up equipment underneath the truck collects power through non-contact magnetic induction that is used either to power the vehicle prime mover or for battery charging.

- Overhead Catenary Electric Trucks – this electric truck configuration utilizes electrified overhead lines, or electric catenary system, as the power source. Pick-up equipment on top of the truck, typically referred to as a pantograph, collects power through direct contact with the electric wires, used primarily to power the vehicle prime mover but also available for in-operation battery recharging.

### 1.2 Near-Zero Emission Drayage Trucks

The Ports define a "near-zero" emissions truck as having exhaust oxides of nitrogen (NOx) emission levels approximately 90% lower than the EPA 2010 heavy-duty emission standards. This equates to NOx emissions less than or equal to 0.02 g/bhp-hr with total particulate matter (PM) emissions no greater than the 2010 EPA standard of 0.01 g/bhp-hr.

For the purpose of the drayage truck test and demonstration guidelines, the ports have expanded the definition of "near-zero" to include the following additional classes of low-emission drayage trucks, as follows:

- Interim Near-Zero Trucks – drayage trucks incorporating low-NOx vehicle technologies with exhaust pipe NOx emissions approximately 75% lower than the EPA 2010 standard;
- Zero-Emissions Mode Capable Trucks – for the purpose of this testing and demonstration plan, hybrid electric drayage trucks that: a) have an all-electric range of at least ten (10) miles); and b) do not exceed EPA 2010 emissions standards at any time when operating outside of Port boundaries, are designated as near-zero emission trucks.

Near-zero truck technologies and configurations include, but are not necessarily limited to, the following:

- Hybrid and Plug-in Hybrid Trucks using Alternative Fuel – class 8 trucks equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing Alternative Fuels. Alternative fuels include, but are not necessarily limited to, compressed and liquefied natural gas (CNG, LNG), including renewable alternative fuels such as biomethane, liquefied petroleum gas (LPG, i.e., propane), ethanol, methanol, dimethyl ether (DME), hydrogen, electricity, and non-petroleum biodiesel fuels.
- Hybrid and Plug-in Hybrid Trucks using Conventional Fuel – class 8 trucks equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing conventional fuels or conventional rules with renewable fuel content. Conventional fuels include gasoline and diesel fuels. Conventional fuels with renewable content include, as examples, biodiesel and gasoline ethanol blends such as E85.

## 2.0 Applicable Requirements & Regulations

As noted above, this protocol is intended to serve as guidance to developers and manufacturers of ZET and NZET drayage trucks intended for operation at the Ports of Long Beach and Los Angeles. However, this testing and demonstration protocol may, in total or in part, be incorporated into contractual obligations associated with a port-sponsored drayage truck development or demonstration project. Any waiver of the following requirements and regulations will be done so at the sole discretion of the Port of Long Beach and Port of Los Angeles. Under no circumstances can the ports waive or modify a rule, requirement, or regulation imposed by a state or federal regulatory agency.

### 2.1 Federal Requirements:

- Federal Motor Carrier Safety Administration (FMVSA) Regulations – all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to US DOT FMVSA Regulations, 49 CFR Parts 300-399.
  *http://www.fmcsa.dot.gov/regulations/title49/b/5/3*

- Federal Highway Administration (FHWA) - all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to US DOT FHWA Vehicle Size Regulations. *http://ops.fhwa.dot.gov/Freight/sw/overview/index.htm*

- National Highway Traffic Safety Administration/Federal Motor Vehicle Safety Standards (FMVSS) - all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to FMVSS Section 105, Hydraulic and Electric Brake Systems, and Section 121 if the vehicle is equipped with air brakes. *http://www.nhtsa.gov/cars/rules/import/fmvss/*

### 2.2 State Requirements

- California Department of Transportation (Caltrans) - all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to Caltrans vehicle size and weight restrictions. *http://www.dot.ca.gov/hq/traffops/engineering/trucks/trucksize/weight.htm*

- California Department of Motor Vehicles/Vehicle Code Section 35550-35558 – All ZET/NZET vehicles must comply with California DMV Code Sections 35550-35558 as it pertains to maximum axle weight ratings and wheel loading. *http://www.leginfo.ca.gov/cgi-bin/displaycode?section=veh&group=35001-36000&file=35550-35558*

- California Highway Patrol (CHP) - all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable motor carrier permit requirements (CHP 362) pursuit to California Vehicle Code Sections §34601(c)(1) and §34601(d).
  *https://www.dmv.ca.gov/pubs/brochures/fast_facts/ffmcp01.htm*

- California Air Resources Board - all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project must adhere to the requirements of the CARB Drayage Truck Regulation (DTR), including participation in the Drayage Truck Registry. *http://www.arb.ca.gov/msprog/onroad/porttruck/porttruck.htm*

**2.3 Port Requirements**

- Ports of Long Beach and Los Angeles Drayage Truck Registry (PDTR) - The Ports' Clean Trucks Programs require all trucks providing drayage services on port property to sign up in the PDTR in order to gain access to the Ports' terminals.

- Maximum Axle Weight Limitations - In addition to the requirements imposed by California DMV Sections 35550-35558; maximum axle weight rating and wheel loading, ZET/NZET trucks converted from an OEM conventional fuel configuration or OEM glider (vehicle without drivetrain) must not exceed the OEM's axle weight ratings as a result of vehicle conversion to a ZET/NZET configuration.

- Society of Automotive Engineers (SAE) Technical Conformity – all ZET/NZET vehicles participating in a port-sponsored development, demonstration, or incentive project that include electric energy storage and/or propulsion components should comply with all applicable requirements pursuant to SAE Vehicle Electrification Standards.
  *http://www.sae.org/standardsdev/vehicleelectrification.htm*

- National Electric Code (NEC) Technical Conformity – Electric vehicle supply equipment, including vehicle recharging infrastructure, located on Port of Long Beach or Port of Los Angeles property must comply with NEC Article 625, including, Sections 625.5; 625.18; 625.19; and 625.22, as applicable.
  *http://site.ul.com/global/documents/corporate/aboutul/publications/newsletters/electricalconnections/November10.pdf*

- International Organization for Standardization (ISO) Technical Conformity - all ZET/NZET vehicles participating in a port-sponsored development and demonstration project that include electric energy storage and/or propulsion components should comply with all applicable requirements pursuant to ISO 43.120 – Electric Road Vehicles.
  *http://www.iso.org/iso/home/store/catalogue_ics/catalogue_ics_browse.htm?ICS1=43&ICS2=120*

## 3.0 Minimum Vehicle Performance Guidelines

To ensure ZET and NZET manufacturers develop vehicles capable of meeting minimum performance standards for drayage trucks operating at the Ports, the following performance specification guidelines have been compiled. These represent the minimum capabilities of a drayage truck operating in typical on-terminal and on-road port operations and are provided to assist in vehicle design.

Note that the minimum performance specifications are applicable to all on-road ZET/NZET trucks intended for container drayage (see Table 3-1 for more information). The Minimum Vehicle Range specification applies to typical short-haul drayage from a marine terminal to a near dock rail yard such as the Intermodal Container Transfer Facility (ICTF). ZET/NZETs intended for local or regional container movements will need to offer range substantially greater than the minimum "short-haul" distance. As such, manufacturers should understand the duty cycle requirements associated with container drayage to facilities such as the ICTF, local rail yards, and distribution centers. Appendix I provides detailed definitions and terminology. Appendix II and Appendix III illustrate laboratory test cycles and on-road drive cycles corresponding to typical container movements; however, manufacturers are cautioned to fully consider all factors that influence vehicle performance.

**Table 3-1: Minimum ZET/NZET Performance Guidelines**

| Minimum Performance Guideline | Performance Metric |
|---|---|
| Design Range | 80 miles with no opportunity charging/refueling assumed |
| | 40 miles with opportunity charging/refueling assumed |
| Freight Load Capacity | 50,000 pounds (loaded container plus chassis) |
| Top Speed | 60 mph at zero grade (0% grade) |
| Gradeability at Vehicle Launch | 15% Grade at 80,000 GCW |
| Gradeability Sustained at 40 mph | 6% grade at 80,000 GCW |

## PART B: TEST PLAN DEVELOPMENT

### 4.0 Vehicle Technical Specification Guidelines

A required element of any ZET/NZET Test Plan developed by a vehicle manufacturer is a detailed technical description of the ZET/NZET configuration as well as a technical specification detailing the vehicle drivetrain design at both the system and subsystem levels.

This section provides guidance as it pertains to the development and documentation of a ZET/NZET vehicle technical specification.

The Ports understand that certain design elements may be considered the proprietary intellectual property of the vehicle designer or manufacturer. As such, the vehicle description may exclude details of hardware or software elements deemed proprietary information and instead present the information at a higher level or more generic manner.

ZET/NZET developers and manufacturers should include the following information, as applicable:

### 4.1. Baseline OEM Vehicle Description

ZET/NZET class 8 semi-tractors that are conversions, retrofits, repowers, or refurbishments of a commercial class 8 semi-tractor should provide information regarding the make, model, year, and top-level specifications of the baseline truck.

### 4.2 ZET/NZET Vehicle Description

The vehicle manufacturer should provide a technical description of the ZET or NZET advanced technology drivetrain architecture and major systems. The manufacturer should identify the ZET/NZET relative to its drivetrain configuration; i.e., battery electric vehicle, parallel hybrid, series hybrid, fuel cell hybrid, as applicable.

*4.2.1 ZET/NZET Mass and Dimensional Properties*
The manufacturer should provide estimates of the ZET/NZET total weight, GVWR, gross axle weight rating (GAWR), and the overall vehicle dimensions.

### 4.3 Drivetrain Components

The vehicle manufacturer should provide a description and technical specifications of drivetrain system components, including but not limited to:

- ICE or Fuel Cell Prime Mover – including rated output power, specific fuel consumption, as applicable.
- Electric Drive Motors – specify motor type (DC, AC induction, reluctance, etc.), rated output power, input voltage, thermal management, etc. as applicable.
- Electric Inverters or Power Conditioning

### 4.4 Energy Storage System(s)

ZET/NZET manufacturers should provide a detailed description of the vehicle energy storage systems, including:

- Battery Pack Description - including battery chemistry, specific energy, specific power and discharge capacity to 80% DoD at the one-hour rate, battery pack voltage, number of battery modules, and an estimate of battery pack cycle life. The manufacturer should describe the battery pack thermal management strategy (active or passive cooling). In addition, ZET/NZET manufacturers should specify the weight of each battery module, and the weight of the battery pack (including removable pack structures). Suppliers should describe how batteries are installed in the vehicle, including details of module connection.
- Other Energy Storage Devices – ZET/NZET manufacturers should provide a technical description of energy storage devices in addition to batteries. This may include energy storage devices such as ultra-capacitors, flywheels, hydraulic assist devices, or other energy storage technologies.
- Battery Management System – the ZET/NZET manufacturer should provide a technical description of the Battery Management System (BMS).
- Conventional or Alternative Fuel Storage Vessels – ZET/NZET manufacturers should provide a technical description of fuel storage vessels for conventional, alternative, and hydrogen fuel vehicles, including but not limited to storage capacity, tank type, pressure ratings, etc. For pressurized fuel systems, ZET/NZET manufacturers should provide expected refueling times at various system fuel pressures and tank fills.

### 4.5 Battery Charger Connections

Vehicle manufacturers should describe the type, size and location of the point of the vehicle charging port or inductive pickup, as applicable.

### 4.6 Recharging/Refueling Infrastructure Requirements

The Electric Vehicle Supply Equipment (EVSE) interface to be provided by the Ports is a 480-volt, 250-ampere, three-phase electric service. ZET/NZET manufacturers whose vehicles include a plug-in recharging capability should ensure their onboard or off-board recharging systems are compatible with the Port's electric service.

## 5.0 Laboratory Testing Guidelines

ZET/NZET vehicles intended to perform port drayage operations are expected to undergo laboratory chassis dynamometer analysis to validate the vehicle's performance capabilities as well as to establish a set of uniform testing criteria that can be used to compare prototype ZET/NZET vehicles. The laboratory testing guidelines included herein were developed in partnership with the University of California at Riverside (UCR) College of Engineering/Center for Environmental Research and Technology (CE-CERT).

The purpose of the laboratory testing effort is to develop a baseline in performance for ZET/NZET vehicles and to gain confidence in these systems to perform, maneuver, and complete expected loaded cycles for port operations. The test cycles were developed specifically for ZET/NZET trucks using empirically derived data; thus, the test cycles simulate port drayage operations with a high degree of accuracy.

### 5.1 Laboratory Chassis Dynamometer Testing

Four test cycles are included in the chassis dynamometer testing:

- Sustained Grade Cycle - The sustained grade test is to ensure that the ZET/NZET prototype vehicles can operate over the Vincent Thomas Bridge with a full load while maintaining observed speed limits.
- Simulated Drayage Truck Port Cycle - The port cycles are to characterize the ZET/NZET while performing typical local and near dock port operations under full load.
- Urban Dynamometer Driving Cycle - The UDDS cycle is desired to make comparisons to heavy-duty diesel vehicles.
- Charge Depleting Cycle - The charge depletion testing is to understand range and other vehicle specific capabilities that can be cross-compared between vehicle tests.

The test cycles were designed to provide safety, performance, vehicle-to-vehicle comparison, and modeling characteristics for ZET/NZET on-road operation. The sustained grade test is to ensure that the vehicles can manage to operate over the Vincent Thomas Bridge with a full load while maintaining observed speed limits with an approach of 50 mph and 0 mph. The port cycles (Phase 1 – 5 in Figure 5-1) are designed to characterize the ZET/NZETs while performing typical local and near dock port operations under loaded conditions. The HUDDS cycle is desired to make comparisons to the certification of HDTs. The system depletion test is to understand the range and other vehicle specific capabilities that can be cross-compared between vehicle tests. Although non-all electric vehicles can perform the system-depleting test, its name is specified as a "charge"-depleting (CD) test.

Table 5-1 shows the list of cycles recommended and a summary description of their significance and Appendix II Part B describes each of the cycles in detail. In order to limit testing to one day, UCR recommends performing each cycle once in the order presented.

Table 5-2 includes a list of important details including accumulated distance and estimated power consumed for the selected test cycles. The total distance traveled prior to the CD test is 50 miles and approximately 163 kWh of energy absorbed based on a final test weight of 75,000 lb.

**Figure 5-1: Drayage Truck Port Cycle Near Dock, Local, and Regional Operations**

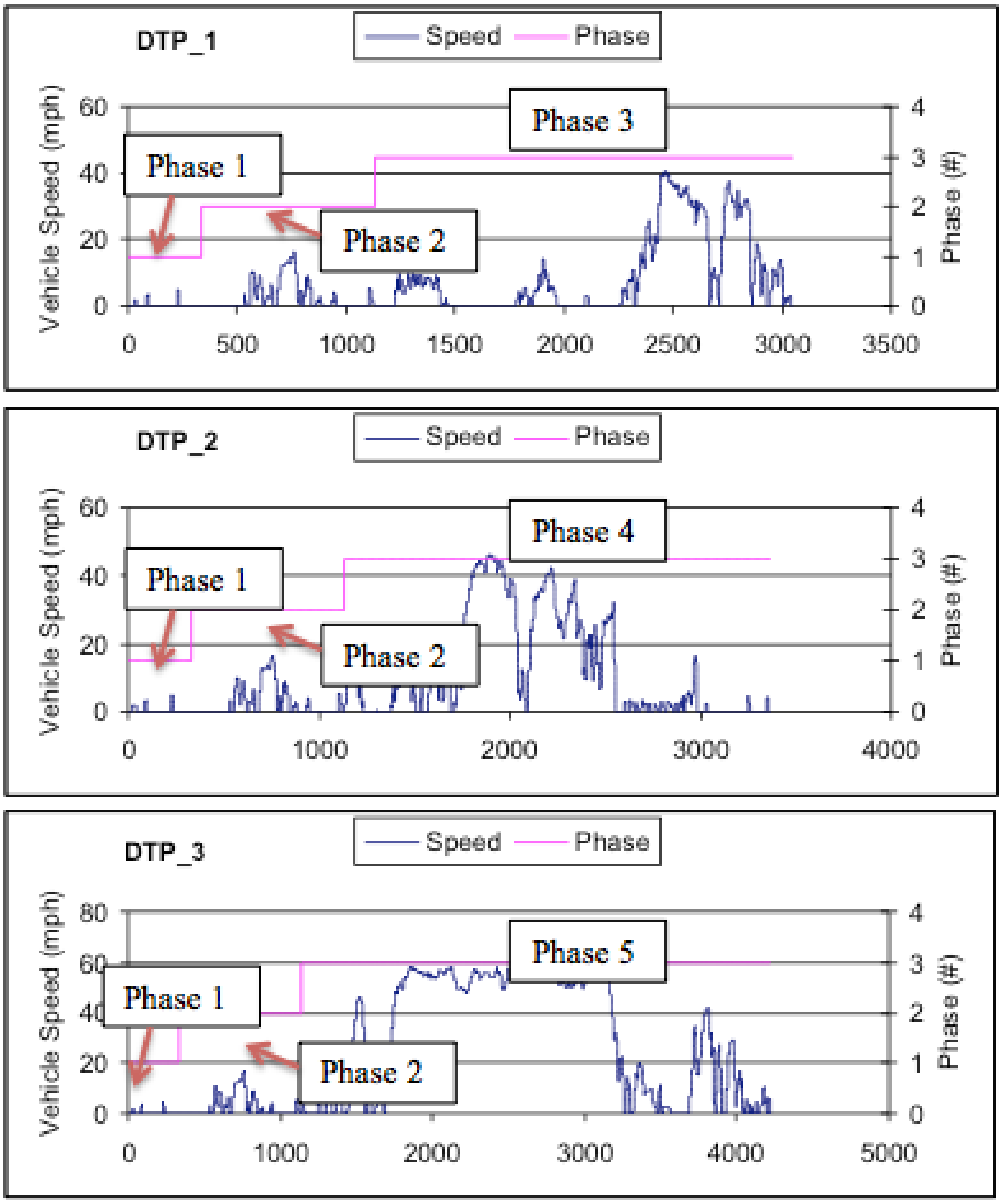


**Table 5-1: Proposed Test Cycles Description**

| Test Order | Test Cycle | Description |
|---|---|---|
| **1** | SG-1 | Simulated Vincent Thomas bridge starting at 50 mph |
| **2** | SG-2 | Simulated Vincent Thomas bridge starting at 0 mph |
| **3** | UDDS | Representative cycle for the engine certification cycle |
| **4** | DPT-Ph1 | Drayage Port Truck (DPT) cycle phase 1 simulating driving within the port and in the queue. |
| **5** | DPT-Ph2 | Phase 2 simulating driving close to the ports at very low speeds |
| **6** | DPT-Ph3 | Phase 3 simulating short high speed transient operation |
| **7** | DPT-Ph4 | Phase 4 simulating longer high speed transient operation |
| **8** | DPT-Ph5 | Phase 5 simulating high speed cruise |
| **9** | **CD** | Charge depleting cycle to drain energy system to manufacturer's recommended minimum charge status or fuel supply. |

**Table 5-2: Proposed Test Cycles Specifications for A Single Day of Testing**

| Test Order | Test Cycle | Test Duration (min) | Average Speed (mph) | Distance (mi) | Accum. Distance (mi) | Est Ave [1] Power (kW) | Accum. Energy (kWh) |
|---|---|---|---|---|---|---|---|
| **1** | SG-1 | 5 | 38 | 3.17 | 3.2 | 200 | **16.7** |
| **2** | SG-2 | 7.6 | 25 | 3.17 | 6.3 | 200 | **42.0** |
| **3** | UDDS | 17.7 | 18.8 | 5.55 | 11.9 | 54 | **57.9** |
| **4** | DPT-Ph1 | 5.58 | 0.29 | 0.027 | 11.9 | 13 | **59.1** |
| **5** | DPT-Ph2 | 13.3 | 2.67 | 0.59 | 12.5 | 22 | **64.0** |
| **6** | DPT-Ph3 | 31.9 | 9.39 | 4.99 | 17.5 | 46 | **88.5** |
| **7** | DPT-Ph4 | 37.1 | 13.1 | 8.10 | 25.6 | 51 | **120** |
| **8** | DPT-Ph5 | 42.1 | 35.1 | 24.63 | 50.2 | 62 | **163** |
| **9** | **CD** | **Varies** | **55** | **Varies** | **Varies** | **Varies** | **Varies** |

Appendix II describes each of the cycles in detail.

### 5.2 Data Collection and Analysis

Data collected during testing includes, but is not limited to load, distance, speed, and weather data from the chassis dynamometer. Data analysis should include, but is not limited to, the following:

- Average and standard deviation for chassis wheel power, distance, speed, and energy
- Electric/hybrid electric vehicle average and standard deviation, temperatures, state of charge (SOC) %, SOC Net kWh, efficiencies, volts, current, power, and ambient conditions
- Total charge time and amount of charge received
- Comparison of SOC Net energy, braking regeneration efficiency, and other energy account details as described in Appendix II.
- Regulated emissions, e.g., NOx, HC, PM…

### 5.3 Reporting

Dynamometer testing reporting should include, at a minimum, a summary of the tests performed, comments during testing, emissions performance, comparisons between chassis and vehicle power measurements, SOC Net energy systems, differences in regeneration power, analysis of expected all-electric range, and a discussion for operation during high power conditions similar to crossing the Vincent Thomas and Gerald Desmond bridges.

# PART C: ON-ROAD DEMONSTRATION PLAN DEVELOPMENT GUIDELINES

## 6.0 Recommended On-Road Demonstration Protocols

This section describes the port-recommended procedures for conducting an on-road demonstration of a class 8 ZET/NZET. Advancement to the on-road demonstration phase assumes that the ZET/NZET vehicle has undergone vehicle laboratory testing in accordance with the guidelines included in Part B, Test Plan Development.

On-Road Demonstration is comprised of three primary phases, as follows:

- <u>Vehicle Acceptance Testing</u> – vehicle acceptance testing is conducted prior to operating the ZET/NZET on public roadways to ensure the vehicle complies with all federal, state, and port requirements and regulations and is suitable for safe port drayage operations. Acceptance testing is typically performed at the vehicle manufacturer facility prior to vehicle delivery and includes participation by the vehicle operator or demonstration partner;
- <u>Controlled On-Road Testing</u> – controlled on-road testing is conducted to ensure the vehicle is capable of meeting the rigors of port drayage operations prior to entering revenue service. Vehicle performance, operability, and initial reliability is measured in controlled on-road conditions simulating on-terminal and on-road drayage operations;
- <u>Revenue Service Demonstration</u> – upon satisfactory completion of acceptance and controlled on-road testing, the ZET/NZET is deployed in port drayage revenue service with a licensed motor carrier (LMC). Evaluation criteria include long-term vehicle efficiency, reliability, maintainability, and durability, as well as programmatic considerations including, but not limited to, vehicle operating costs and lifecycle costs. Driver surveys are typically included during revenue service to gauge driver acceptance.

## 6.1 Vehicle Acceptance Testing

Prior to operating any ZET/NZET on public roadways, it is recommended that the vehicle undergo thorough acceptance testing. This is typically conducted jointly by the vehicle manufacturer and licensed motor carrier who will operate the vehicle during subsequent phases of on-road testing and demonstration.

*6.1.1 Acceptance Testing Parameters*

The following are parameters recommended for inclusion in any ZET/NZET entering an on-road demonstration program. Note that this represents a minimum level of acceptance testing - additional parameters will likely be added based upon the specific technologies and configuration of a prototype ZET/NZET.

- Electrical system audit
- Dimensional requirements audit
- Water test to ensure integrity of electrical drivetrain components at the system and subsystem level, including EVSE
- Function test of OEM semi-tractor systems, subsystems and components not modified during vehicle conversion
- Vehicle top speed
- Acceleration tests
- Brake stop tests
- Gradeability test, including both starting grade and sustained speed at grade
- Airflow tests, if aerodynamic devices have been installed or modified from the OEM configuration
- Air/brake system audit, as applicable
- Vehicle weight
- Individual axle weight
- ZET/NZET energy storage system and subsystem cooling functionality, as applicable
- Body deflection tests, if modified from OEM specifications
- Exterior and Interior lighting
- HVAC functionality
- Speedometer accuracy
- Internal combustion engine performance qualification, including but not limited to charge air cooler performance, air to boil test, loss of coolant, fuel system electrical inputs and engine protection system).
- Transmission performance qualifications

*6.1.2 Documentation and Reporting Guidelines*

The results of ZET/NZET acceptance testing should be documented and may be a required report under a port-sponsored demonstration project. Each test parameter should be listed along with the minimum acceptable performance requirement. A “pass/no-pass” designation can be used for each tested parameter – no-pass parameters should include notation as to the test failure mode and remedial actions planned. Both the vehicle manufacturer and LMC participating in the testing should certify the acceptance testing results, including recommended corrective actions.

## 6.2 Controlled On-Road Testing

Following successful completion of vehicle acceptance testing, the LMC, in coordination with the prototype ZET/NZET manufacturer, will initiate on-road driving trials and performance testing. This is to ensure the ZET/NZET is capable of meeting the rigorous duty cycle requirements of port drayage operations.

### *6.2.1 On-Road Testing Duty Cycles*

The duty cycles associated with on terminal and on-road port drayage operations can be summarized as follows:

- Near Dock Operation **-** This type of operation involves very short cargo moves from two to six miles in length, generally originating at the marine terminal. Cargo moves to the Intermodal Container Transfer Facility (ICTF), which functions as the Union Pacific rail terminal, or nearby container yards are included within this category;
- Local Operation **-** local operation is defined as cargo moves originating or terminating at the ports and having the other end point of the move between six (6) and twenty miles (20) distant from the ports; and
- Regional Operation **-** At distances greater than twenty miles from the ports, large warehouse facilities are common and may be used to transfer goods for interstate delivery. Regional operation is described as cargo moves between 20 and 120 miles in length. This effectively covers drayage operations to the Mexico border to the south, Coachella Valley to the east, and Bakersfield to the north.

To simulate these drayage duty cycles in a realistic and repeatable way, the Ports, in cooperation with CARB and industry participants, have developed on-road test routes, as described below.

### *6.2.2 On-Road Testing of Prototype ZET/NZET*

Vehicles should be conducted with a minimum of two (2) truck configurations:

- ZET/NZET in a bobtail-only configuration;
- ZET/NZET semi-tractor plus trailer simulating a container dray at 80,000 lbs. GCWR.

### *6.2.3 On-Road Test Routes*

The test routes include areas that are within six to eight miles of the Ports for near-dock operations, areas that are between eight to 20 miles of the Ports for local operations, and areas that are between 20 to 120 miles in length for regional operations.

Test routes are selected and repeated for comparison purposes during the controlled truck testing and demonstration. Note that not all prototype ZET/NZET prototypes may complete all three test routes; for example, overhead catenary-powered ZETs may by design be limited to near-dock operations and local container drayage. The three test routes are:

- Near Dock Test Route (short haul): This route is explained in detail in Appendix III. The route begins and ends at the ICTF, includes freeway segments (SR-103, I-710, and I-110) and roadway segments. Both the Gerald Desmond Bridge and Vincent Thomas Bridge are crossed one time each.

- Local Test Route: This route is intended to demonstrate real-world medium distance container movement. The start and endpoint for this route is a marine terminal located at either the Port of Long Beach or Port of Los Angeles. The destination is the Burlington Northern – Santa Fe (BNSF) Hobart Railyard located in the City of Commerce, approximately four (4) miles southeast of downtown Los Angeles. Hobart Railyard is also located within a few miles of major roadways such as I-5, Highway 60, I-10 and the I-710 freeway. The vehicle demonstration partner defines the specific roadways and freeways for this route.

- Regional Test Route: This route simulates long haul container movement in the SoCAB. The vehicle demonstration partner also defines the Regional route. The start and endpoint of this route is a marine terminal located at either the Port of Long Beach or Port of Los Angeles. The destination is user-defined distribution center located in Mira Loma, Riverside, or Moreno Valley.

See Appendix III for additional Test Route information.

### *6.2.4 On-Road Testing Parameters*

On-road ZET/NZET testing should be conducted on an instrumented vehicle equipped with a data acquisition system. Note that the data collected during on-road testing will be specific to the ZET/NZET technology and drivetrain configuration. Parameters recommended for data logging include, but are not necessarily limited to, the following:

- Record data from the various OEM electronic control units (ECU) via the SAE J1939 vehicle CAN bus or external data logger, as applicable to the prototype ZET/NZET;
- Record data from the battery management system, motor controllers, ECU, and other equipment via the CAN bus or external data logger, as applicable;
- Record data from the various analog sensors (rotational speed, temperature, flow, pressure, voltage, and miscellaneous sensors) from the ECU via the CAN bus or external instrumentation/data logger;
- Determine speed, altitude, grade, and acceleration from a GPS unit;

From the stand-alone data acquisition equipment, the following information should be derived and documented:

- Fuel consumption (gal/hour or lbs./hour), as applicable;
- ICE output torque and reference torque, if applicable;
- Output power;
- System voltage, current consumption, and energy use;
- Power and energy used for traction, accessory drive, and for the 12V truck system, as applicable;
- Propulsion motor(s) output power, speed, and current;
- System efficiency of each motor system;
- Vehicle speed, position, grade, acceleration.

In addition to quantitative data acquisition, data collection should also include, but is not limited to, environmental and traffic conditions, documentation of vehicle system, subsystem, or component failures, vehicle planned and unplanned maintenance requirements, and qualitative observations of vehicle performance, including driver observations.

#### *6.2.5 Documentation and Reporting Guidelines*

All instrumented data, vehicle failures, and qualitative observations from each drive cycle should be recorded and documented.

### 6.3 Revenue Service Demonstration

Following successful completion of Controlled On-Road Testing, one or more prototype ZET/NZET vehicles will enter the revenue service demonstration phase. The revenue service demonstration is conducted by the LMC in coordination with the vehicle manufacturer or vendor. The following sections describe the minimum expectations as they pertain to the in-revenue service vehicle demonstration.

#### *6.3.1 Demonstration period*

ZET/NZET testing in revenue service should encompass a 12-month period of continuous service and include a minimum of 150 revenue trips. The 12-month demonstration period may include vehicle out-of-service time due to regularly scheduled maintenance. In the event the demonstration vehicle is removed from service due to unplanned maintenance or a failure mode, the demonstration period should be extended such that a minimum of 12 months of operational service is accrued with a minimum of 150 container drays.

### *6.3.2 Demonstration Data Collection Parameters*

The LMC operating the ZET/NZET in revenue service should record, at a minimum, basic operating data, including but not limited to:

- Fuel economy
- Range per kWh, if applicable
- Planned vehicle maintenance, recording component(s) replacement
- Unplanned vehicle maintenance, recording corrective actions and component(s) replacement
- Failure modes
- Random anomalies not resulting in failure
- Incidents, including collisions or other incidents that may impact vehicle performance or operability
- Driver surveys regarding vehicle operability
- Mechanic surveys regarding vehicle maintenance

### *6.3.3 Documentation and Reporting Guidelines*

The data collection parameters described above should be documented to assist the vehicle manufacturer in refining the prototype ZET/NZET. Additionally, if the in-service demonstration is conducted as an element of a Port-sponsored project, data collected during the in-service demonstration phase will be a required element of a project Final Report.

## Appendix I: Definitions & Terminology

**Alternative Fuel –** Motor vehicle fuels other than Conventional Fuels. For the purpose of this document, alternative fuels include, but are not necessarily limited to, compressed and liquefied natural gas (CNG, LNG), liquefied petroleum gas (LPG, i.e., propane), ethanol, methanol, dimethyl ether (DME), hydrogen, electricity, and non-petroleum biodiesel fuels.

**Battery** - a device that stores chemical energy and releases electrical energy.

**Battery electric Truck -** A battery electric truck (BET) is powered exclusively by electricity from an onboard battery pack. Battery pack recharging is accomplished by plugging into the electric power grid or other off-grid electric power source to recharge the battery pack while the truck is not operating. BET is also referred to as a plug-in electric truck.

**Battery Rated Ampere-Hour Capacity -** Manufacturer-rated capacity of a battery in Ampere-hours obtained from a battery discharged at the manufacturer's recommended discharge rate (C/1 – C/6) such that a specified minimum cut-off terminal voltage is reached.

**Bobtail Tractor –** An informal term for a semi-truck tractor operating without a trailer or container chassis.

**Certification** – Certification is associated with the emission standards of a heavy-duty truck regulation. The certification standards are an engine dynamometer test stand test for all regulated pollutants except for greenhouse gases that are evaluated on a chassis dynamometer.

**Controller Area Network (CAN) –** CAN bus is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer.

**Charging Station** - An electric vehicle charging station, also called EV charging station, electric recharging point, charging point, charge point and EVSE (Electric Vehicle Supply Equipment), is an element in an infrastructure that supplies electric energy for the recharging of plug-in electric vehicles, including all-electric vehicles and plug-in hybrids.

**Chassis Dynamometer** – The engine is mounted in the chassis of a vehicle/truck and tested by applying resistance and load at a roller/wheel interface.

**Chassis Dynamometer Testing -** Used to simulate driving on a road inside a laboratory under controlled conditions. The vehicle is driven on rollers, while a dynamometer simulates the inertia of the vehicle as well as the drag and friction on the vehicle. Because an entire vehicle is tested instead of just an engine, and a driver controls the vehicle instead of a computer, the use of a chassis dynamometer allows the assessment of "real world" emissions.

**Class 8 Truck (Semi-Tractor) –** A semi-tractor with a gross vehicle weight rating (GVWR) greater than 33,000 lbs. (14,969 kg).

**Coast-down Procedure** – This is a test where a vehicle is accelerated to a given speed and then allowed to coast with the engine ungeared until the vehicle stops. This can be performed over the road to evaluate how the resistant forces acting on the vehicle at certain speed and road conditions impact its ability to move forward. On the dynamometer, a coast-down test is performed to determine if the road load coefficients at a given speed are correctly simulating the forces that would actually be working on the vehicle over the road.

**Conductive Charging –** Conductive charging is a method for connecting the electric power supply network to the EV for the purpose of transferring energy to charge the battery and operate other vehicle electrical systems, establishing a reliable equipment grounding path, and exchanging control information between the EV and the supply equipment.

**Container (shipping) -** A shipping container is a container with strength suitable to withstand shipment, storage, and handling. Shipping containers range from large reusable steel boxes used for intermodal shipments to corrugated boxes. In the context of international shipping trade, a container designed to be moved from one mode of transport to another without unloading and reloading.

**Conventional Fuel –** Motor vehicle fuels that are petroleum derived, including gasoline and diesel fuels.

**Data Logger -** A data logger (also referred to as “datalogger” or “data recorder”) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer). They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

**Drayage Truck –** In intermodal freight transport, drayage is the transport of containerized cargo by specialized trucking companies between ocean ports or rail ramps and shipping docks. For the purpose of this document, a “drayage truck” is a class 8 semi-tractor used to perform container drayage.

**Drive Cycle -** Drive cycles are typically represented by a graph that plots vehicle speed against time. Data for defining a drive cycle can be collected using various technologies, such as a dedicated on-board data logger, telematics or downloading data from the vehicle CAN bus (controller area network).

**Duty Cycle** – A vehicle’s duty cycle provides information on how much a vehicle is used. Typical duty cycle information includes: hours/shifts per day; days per week (or other measurement cycle); total miles per measurement cycle; typical (average) load profile; and peak load profile.

**Dynamometer** - Tools are designed to measure torque and rotational speed (rpm) from which the power produced by an engine can be calculated from the product of torque ($\tau$) and angular velocity ($\omega$) values or force ($F$) and linear velocity ($v$). These dynamometers can be steady state or transient designed where transient types are needed for the proposed test cycles in this guidance document.

**Electric Vehicle Supply Equipment (EVSE) –** See charging station.

**Engine Dynamometer** – An engine removed from the vehicle is tested on a stand where the torque and speed are directly measured from the crankshaft for break power.

**Final Test Weight** – Test weight used in the determination of the ABC road load coefficients. This test weight is the sum of the tractor weight and fixed trailer + payload weight of 52,500 lbs. and inertial weight of the number of tires.

**Flywheel** - A device that stores rotational kinetic energy and releases that kinetic energy.

**Fuel Cell Trucks** – A fuel-cell electric truck (FCET) converts the chemical energy from a fuel source, such as hydrogen, into electricity and then uses the generated electricity to drive an electric motor to propel the truck and in most cases recharge a battery pack used for load buffering and peak power demand.

**Gerald Desmond Bridge -** The Gerald Desmond Bridge is on a major trade corridor, carrying 15 percent of all containerized cargo imported to the United States. The Bridge connects Terminal Island, the heart of the port complex, with the Long Beach Freeway (I-710) as well as downtown Long Beach. The new Gerald Desmond Bridge, which is currently under construction, will be one of the tallest cable-stayed bridges in the United States and the first of its kind in California. The total bridge length will be 2,000 ft (610 m) long, with roadway grades of five (5) percent in both directions.

**Greenhouse Gases** - According to the federal register 2015 the regulated/reported greenhouse gases associated with HDT testing are, $CO_2$, $N_2O$, and CH4.

**Gross Axle Weight Rating -** The gross axle weight rating (GAWR) is the maximum distributed weight that may be supported by an axle of a road vehicle. Typically, GAWR is followed by either the letters FR or RR, which indicate front axle rating (FR) or rear axle rating (RR), respectively.

**Gross Combined Weight Rating -** The Gross Combination Weight Rating (GCWR) is the sum of all GVWRs for each unit in a combination-unit motor vehicle. For single-unit trucks, there is no difference between the GVWR and the GCWR. For combination trucks (truck tractors pulling a single semi-trailer, truck tractors pulling double or triple trailers, trucks pulling trailers, and trucks pulling other motor vehicles), the GCWR is the total of the GVWRs of all units in the combination.

**Gross Vehicle Weight Rating (GVWR) –** The gross vehicle weight rating (GVWR), or gross vehicle mass (GVM) is the maximum operating weight/mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.

**Hybrid** - In this document a hybrid is defined as a system that recovers energy during deceleration. Common energy storage systems are batteries, capacitors, or hydraulic fluids. Electric drive fossil fuel generator systems are not hybrids if an energy storage system is not employed.

**Hybrid Drivetrain -** A hybrid drivetrain uses two or more power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine, energy storage system, and one or more electric motors.

**Hybrid and Plug-in Hybrid Trucks using Alternative Fuel** – This definition is for Class 8 trucks equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing Alternative Fuels. Alternative fuels include, but are not necessarily limited to, compressed and liquefied natural gas (CNG, LNG), liquefied petroleum gas (LPG, i.e., propane), ethanol, methanol, dimethyl ether (DME), hydrogen, electricity, and non-petroleum biodiesel fuels.

**Hybrid and Plug-in Hybrid Trucks using Conventional Fuel** – This definition is for Class 8 trucks equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing Conventional Fuels. Conventional fuels include motor vehicle fuels that are petroleum derived, such as gasoline and diesel fuels.

**Hybrid Vehicle Incentive Program (HVIP) –** The California Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP) is a streamlined program to help speed the early market introduction of clean, low-carbon hybrid and electric trucks and buses. HVIP offsets a portion of the incremental cost of these vehicles in the early market years when production volumes are still low.

**Inductive Charging –** Also known as "wireless charging", uses an electromagnetic field to transfer energy between two objects. This is usually done with a charging station. Energy is sent through an inductive coupling to an electrical device, which can then use that energy to charge batteries or run the device.

**Kilowatt-Hour –** The kilowatt-hour (kWh) is a unit of energy equal to 1,000 watt-hours. If the energy is being transmitted or used at a constant rate (power) over a period of time, the total energy in kilowatt-hours is the product of the power in kilowatts and the time in hours.

**Local Operation -** Local operation is defined as cargo moves originating or terminating at the ports and having the other end point of the move between six (6) and twenty miles (20) distant from the ports.

**Long Haul –** See regional operation.

**Medium Haul –** See local operation.

**Near Dock Operation -** This type of operation involves very short cargo moves from two to six miles in length, generally originating at the marine terminal. Cargo moves to the Intermodal Container Transfer Facility (ICTF), which functions as the Union Pacific rail terminal, or nearby container yards are included within this category.

**Near-Zero Emission Truck (NZET) –** In the context of the Ports' drayage truck test and demonstration guidelines, a "near-zero" emission truck is defined as having exhaust pipe $NO_x$ emission levels approximately 90% lower than the EPA 2010 heavy-duty emission standards. This equates to oxides of nitrogen emissions less than or equal to 0.02 g/bhp-hr. Additionally, "near-zero" also includes interim low-NOx vehicle technologies equal to or less than 0.05 g/bhp-hr or hybrid trucks that operate in a zero-emissions mode within Port boundaries.

**Net Energy Change (NEC)** - The net change in energy level of a RESS expressed in Joules (watt-seconds).

**Off-Grid –** The term off-grid refers to not being connected to a grid, mainly used in terms of not being connected to the main or national electrical grid. In electricity, off-grid can be stand-alone systems or mini-grids typically to provide a smaller community or industrial complex with electricity.

**Overhead Catenary Electric Trucks** – This electric truck configuration utilizes electrified overhead lines, or electric catenary system, as the power source. Pick-up equipment on top of the truck, typically referred to as a pantograph, collects power through direct contact with the electric wires, used primarily to power the vehicle prime mover but also available for in-operation battery recharging.

**Inductively-Charged Electric Vehicle –** An electric vehicle using electromagnetic induction. Typically, electric power strips are buried under the road surface and connected to the electrical grid. Pick-up equipment underneath the vehicle then collects power through non-contact magnetic induction, which is used either to power the vehicle prime mover or for battery charging.

**Minimum Energy** - The minimum energy is defined as the lowest energy state, as designed by the manufacturer of the ZET/NZET system. This minimum energy will be the designed lower threshold for the testing program where the energy storage systems may have some remaining capacity based on reliability and longevity needs of the technology.

**Opportunity Charging -** Opportunity charging is the act of charging a battery during break time, lunchtime, or any opportunity that presents itself during the workday.

**Parallel Hybrid Drivetrain –** In a parallel hybrid vehicle, the electric motor(s) and the internal combustion engine are installed such that they can power the vehicle either individually or together. Typically, the internal combustion engine, the electric motor, and the gearbox are coupled by automatically controlled clutches. For electric driving, the clutch between the internal combustion engine is open while the clutch to the gearbox is engaged. While in combustion mode, the engine and motor run at the same speed.

**Passive (Battery) Cooling –** An electric vehicle battery pack thermal management strategy that uses ambient air as the primary battery temperature control mechanism to keep vehicle batteries within their recommended operating temperature range.

**Payload Weight** - The weight carried by a HDT such as goods contained within a trailer.

**Plug-in Electric Vehicle –** For the purpose of this document, a plug-in electric vehicle (PEV) is a class 8-semi tractor that can be recharged from an external source of electricity, such as EVSE, and the electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEVs include all electric or battery electric vehicles (BEVs), as well as plug-in hybrid vehicles (PHEVs).

**Propulsion Energy** - Energy that is derived from the vehicle's consumable fuel and/or RESS to drive the wheels. If an energy source is supplying energy only to vehicle accessories (e.g., a 12-volt battery on a conventional vehicle), it is not acting as a source of propulsion energy.

**Rechargeable Energy Storage System (RESS)** - A component, or system of components, that stores energy and for the delivery of power and which is rechargeable.

**Regeneration –** In a battery-powered electric vehicle, regeneration is the conversion of the vehicle's kinetic energy into chemical energy stored in the battery, where it can be used later to drive the vehicle. It is braking because it also serves to slow the vehicle. It is regenerative because the energy is recaptured in the battery where it can be used again.

**Regenerative Energy** - Deceleration of the HDT caused by operating an electric motor-generator system. This act returns energy to the vehicle propulsion system and provides charge to the RESS or to operate on-board accessories.

**Regional Operation -** At distances greater than twenty miles from the ports, large warehouse facilities are common and may be used to transfer goods for interstate delivery. Regional operation is described as cargo moves between 20 and 120 miles in length. This effectively covers drayage operations to the Mexico border to the south, Coachella Valley to the east, and Bakersfield to the north.

**Regulated Emissions** – According to federal regulations the following species are to be quantified for regulated emissions for vehicle testing. These include THC, NMHC, $CH_4$, CO, $CO_2$, $NO_x$, and PM.

**Revenue Service –** In the context of this document, defined as when a drayage truck is in operation and generating income for the operator.

**Road Load Coefficients –** The road load coefficients, or ABC coefficients, are the parameters used by the dynamometer to simulate the forces working against the vehicle motion as it would be operated over a typical road surface. The coefficients are a function of the vehicle speed and are designed to represent rolling resistance, air and wind resistance that are dependent on the size and shape of the vehicle, and a gradient resistance representative of the steepness of the roadway.

**Series Hybrid Drivetrain –** A series- or serial-hybrid vehicle is driven by the electric motor(s) with no mechanical connection to the internal combustion engine (ICE) or direct energy conversion prime mover, such as a fuel cell. The ICE or fuel cell is tuned for running a generator when the battery pack energy supply is insufficient to meet vehicle energy demands.

**Short Haul –** See near dock operation.

**State of Charge (SOC) –** State of charge (SOC) is the equivalent of a fuel gauge for the battery pack in a battery electric vehicle (BEV), hybrid vehicle (HEV), or plug-in hybrid electric vehicle (PHEV). The units of SOC are percentage points (0% = empty; 100% = full). An alternate form of the same measure is the depth of discharge (DoD), the inverse of SOC (100% = empty; 0% = full). SOC is normally used when discussing the current state of a battery in use, while DoD is most often seen when discussing the lifetime of the battery after repeated use.

**SOC initial** - The SOC at the beginning of a test run. The initial SOC is typical stable and can be taken at the beginning of the test.

**SOC final** - The final state of charge at the end of a test run. Sometimes the SOC continues to recover while the vehicle sits. It is recommended that the SOC final be taken as the start point of the next test. If the SOC final is the last test, the final SOC should be taken from the typical soak time that should be between 5 and 20 minutes depending on the application.

**Sustained Grade (SG) Cycle –** A chassis dynamometer test cycle developed by the University of California/CE-CERT to simulate a heavy-duty truck crossing the Vincent Thomas Bridge. The SG-1 cycle simulates an approach speed of 50 mph, increasing load until the vehicle speed is reduced to 30 mph. The SG-2 cycle simulates approaching the bridge at zero (0) mph (simulated standstill traffic conditions) and accelerating to 20 mph under full load conditions. Each cycle is 400 seconds in duration and represents approximately 250 horsepower of sustained power for a simulated distance of three (3) miles.

**Test Cycle –** See Drive Cycle, above.

**Total Fuel Energy** - The total energy content of the fuel, in British Thermal Units (Btu) or kWh, consumed during a test as determined by carbon balance or other standard.

**Tractor weight** – The weight of the tractor without the trailer and payload goods. This weight may vary between ZET/NZET/HDTs.

**Trailer weight** – The tare weight of a tractor-trailer.

**Unregulated but Reported Emissions** - According to federal regulations the following species are to be reported (not regulated) for vehicle testing. These include ($NH_3$, and $N_2O$)

**Unregulated Emissions –** In addition to the regulated and unregulated but reported emissions, there are several pollutants measured by researchers to help characterize the health and environmental impacts of HDT emissions. These include, but are not limited to, toxics (formaldehyde, acetaldehyde, benzene, toluene, ethyl benzene, xylenes, butadiene, and polycyclic aromatic hydrocarbons (PAHs)), particle size distribution, particle number, PM composition (elemental, organic, and sulfate PM), and other species.

**Vehicle-to-Grid** - Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles, such as battery electric vehicles (BEVs) and plug-in hybrids (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate.

**Vincent Thomas Bridge -** The Vincent Thomas Bridge is a 1,500-foot (460 m)-long suspension bridge, crossing the Los Angeles Harbor linking San Pedro with Terminal Island. It has an approach grade of approximately 5.5% and maximum grade of approximately 6%.

**Ultra-Capacitor** - A device that stores energy electrostatically and releases electrical energy.

**Ultra-Capacitor SOC** - The actual measured energy content of a capacitor and expressed as a percentage of the capacitor's maximum rated voltage squared ($V^2$).

**Zero Emission Truck -** These vehicles have zero (0) exhaust pipe emissions of criteria and greenhouse gas air pollutants during all phases of port-related drayage operations. Power plant, refinery, or other fuel cycle-generated emissions are not quantified or assigned to the zero emission truck – only direct vehicle emissions are considered. This would include Battery Electric Trucks, Fuel Cell Trucks, Inductively Charged Electric Trucks, and Overhead Catenary Electric Trucks.

**Zero-Emissions Mode Capable Trucks** – For the purpose of this testing and demonstration plan, hybrid electric drayage trucks that: a) operate in a zero-emissions mode at all times when within Port boundaries; and b) do not exceed EPA 2010 heavy-duty emissions standards of 0.02 g/bhp-hr $NO_x$ and 0.01 g/bhp-hr PM at any time when operating outside of Port boundaries, are designated as near-zero emission trucks.

## Appendix II: Laboratory Testing Protocol

### Purpose

The purpose of this document is to provide a uniform set of test protocols/guidelines for the evaluation of ZET/NZET using chassis dynamometers. The chassis dynamometer will allow the vehicle's performance capabilities to be validated as well as establish a set of uniform testing criteria that can be used to compare prototype ZET/NZET vehicles. The testing will utilize driving test cycles designed to simulate port operations and certification-like cycles. The test cycles were developed specifically for heavy-duty trucks (HDTs) using empirically derived data; thus, the test cycles simulate port drayage operations with a high degree of accuracy. The information provided through this laboratory testing effort will develop a performance baseline for ZET/NZET vehicles and to provide confidence in these systems to perform, maneuver, and complete expected loaded cycles for port operations.

This document is designed to be a standalone document to provide guidance to vehicle developers and testing facilities for the setup, testing, reporting, and validation to be performed on all ZET/NZET vehicles intended for port drayage operation.

### Approach

Regulated emissions from HDTs are certified on engine dynamometers. Carbon dioxide, greenhouse gases and fuel economy regulations will be certified on chassis dynamometers starting in 2018.[1] As such, this chassis performance and emissions guidance document represents a blend of chassis requirements (per 40 Code of Federal Regulations (CFR) Part 1066) and engine dynamometer requirements (per 40 CFR Part 1065).

The user of this guide is expected to understand the 40 CFR Part 1066 and Part 1065 reference methods. This document describes deviations to the standard methods in order to accommodate testing ZET/NZETs in <u>one full day</u> of testing, which includes the following sections:

- **Section 1 – Chassis Laboratory Setup**: Describes vehicle chassis dynamometer setup and verifications. This section would be needed for ZETs and NZETs.

[1] The Air Resources Board is developing Interim Medium- and Hybrid Heavy-Duty Vehicle Hybrid Technology Emission Test Procedures as part of its Innovative Technology Regulation (www.arb.ca.gov/msprog/itr/itr.htm). These procedures are intended to ensure a minimum $CO_2$ emission decrease and no NOx increase from a hybrid truck or bus relative to its non-hybrid counterpart. While the ports' Drayage Truck Testing and Demonstration Guidelines are specific to drayage trucks at the demonstration phase, and ARB's Innovative Technology Regulation would apply at the early commercialization stage (i.e., when a heavy-duty engine or vehicle is certified by ARB. Please contact Mr. Joe Calavita of ARB at 916-445-4586 or jcalavit@arb.ca.gov for more information regarding development of ARB's test procedures.

- **Section 2 – Chassis Testing**: Describes testing and validation for the vehicle performance without emissions measurements. This section would be needed for ZETs and NZETs.
- **Section 3 – Emissions Testing:** Describes the emissions testing and validation aspect of the testing that includes selected topics in 40 CFR Part 1065. This section is only needed for NZETs.

**Section 4 – Reporting:** Describes the data to report, recommended formats to use, and recommended validation reports to provide. The purpose in this section is to report specific data and show that testing was performed properly. The reporting section references Appendix II - Part B "Reporting Format and Data Submission", and Appendix II – Part C, "Electric Vehicle Calculations" worksheets.

Additional explanatory information, calculation methods, reporting templates, and reference material are also included in the document. This information is included in Parts A-G, as follows:

- Part A – Road Load Determination
- Part B – Test Cycles
- Part C – Reporting Formats and Data Submission Forms
- Part D – Electric Vehicle Calculations
- Part E – Quick Start Guide
- Part F – GHG Regulation Standards and References; and
- Part G – Vehicle Inspection Reporting Example

This guidance document provides detailed explanation and justification for the recommended testing approach. For convenience, Part D provides a quick start guide for a step-by-step setup testing of ZET/NZET vehicles for a quick summary reference.

**General Testing Scope**

This guidance document is designed for drayage operations performed at the port HDTs. There are two classes of vehicles operating at the ports that fit the category. These are vehicles governed for speeds slower than 30 mph (i.e., yard tractors) and those that can reach speeds of up freeway speeds (55 mph or higher). This document is designed around the freeway capable trucks. Slight modifications would be required during the road load determination sections to accommodate testing of vehicles governed to 30 mph.

<u>Zero Emission Vehicles</u>

The vehicles that meet the category as ZET will not need to perform emissions measurement and thus only Section 1, 2 and 4 of this document should be followed. The following vehicles fit into this category:

- Battery Electric Trucks

- Fuel Cell Trucks
- Overhead Catenary Electric Trucks or Inductively Charged Trucks

Near-Zero Emission Vehicles

While not universal, most regulatory agencies define a "near-zero" emissions truck as having exhaust pipe emission levels on the order of 90% lower than the EPA 2010 heavy-duty $NO_x$ emission standard of 0.20 g/bhp-hr, or less than or equal to 0.02 g/bhp-hr as measured on the federal test procedure (FTP) during engine dynamometer testing. Total particulate matter (PM) emissions would not exceed the 2010 EPA standard of 0.01 g/bhp-hr. The Heavy-duty Urban Dynamometer Driving Schedule (HUDDS) is the chassis approximation of the FTP engine certification test cycle, thus the HUDDS will be performed to evaluate the NZET's emissions as part of this testing.

For the purpose of the drayage truck test and demonstration guidelines, the ports have expanded the definition of "near-zero" to include several classes of low-emission drayage trucks. The NZET will need to follow Sections 1, 2, 3, and 4 of this guidance document. These vehicles include, but are not limited to:

- Interim Near-Zero Trucks
- Zero-Emissions Mode Capable Trucks
- Hybrid and Plug-in Hybrid Trucks using Alternative Fuel
- Hybrid and Plug-in Hybrid Trucks using Conventional Fuel

**Section 1: Chassis Laboratory Setup**

Dynamometers are essential equipment for the accurate measurement of emission factors. These very useful tools are designed to measure torque and rotational speed (rpm) from which the power produced by an engine can be calculated from the product of torque ($\tau$) and angular velocity ($\omega$) values or force ($F$) and linear velocity ($v$). Dynamometers come in various configurations. A dynamometer directly coupled to an engine is known as an engine dyno. An engine dynamometer measures power and torque directly from the engine's crankshaft (or flywheel) and does not need to account for power losses in the drive train, such as the gearbox, transmission or differential as the engine values are directly measured. An engine dynamometer can either be a power absorbing or motoring type. The power absorbing-type is limited to steady-state cycles while a dynamometer with a motoring design can test either steady state or transient cycles.

A dynamometer that measures torque and power delivered by the power train at the wheels of a vehicle without removing the engine from the vehicle is a chassis dynamometer. With a chassis dynamometer, the vehicle operates with its wheels on rollers, where the output power from the engine is measured. While engine dynamometers provide the most accurate results of an engine operation, a chassis dynamometer is often the most practical approach as it measures the power and torque of an engine without removing the engine, thus saving time and money. The main issue with the chassis dynamometer is that the measured power and torque at the wheels is less than the values at the engine flywheel (e.g. brake horsepower), due to the frictional and mechanical losses in the various components. For example, drive train transmission, gearbox, and tire friction are all factors that need to be considered. The rear wheel brake horsepower is generally estimated to be 15-25 percent less than the brake horsepower due to frictional losses. Fortunately, many current engines have an Electronic Control Module (ECM) that is calibrated by the engine manufacturer to report brake power, enabling measurement of power both at the wheels and at the flywheel.

HDTs are generally certified by having their engines tested on an engine dynamometer prior to being installed on a vehicle chassis. More recently, regulatory agencies have moved from this type of engine dynamometer testing to measurements based on emissions during actual work cycles. Although these new in-use regulations require vehicle compliance on-road, performing on-road tests is difficult and not reproducible. Chassis dynamometers are used for certification of light duty vehicles and are a common tool for research on in-use HDTs. More recently chassis dynamometers are being used to certify greenhouse gases for HDTs that will start being enforced in 2018.

### 1.1 Specifications

The chassis dynamometer should be capable of mimicking the transient inertial load, aerodynamic drag, and rolling resistance associated with normal operations of HDTs. The transient inertial load shall be simulated using appropriately sized flywheels or electronically controlled power absorbers. The driver shall be provided a visual display of the desired and actual vehicle speed to allow the driver to operate the vehicle on the prescribed cycle. 40 CFR Part 1066 Subpart C provides dynamometer specifications that should be met by the facility utilized for chassis laboratory testing. These specifications include verifications, linearity, torque and speed calibrations, and dynamometer performance specifications such as parasitic losses, inertia verification, and acceleration verifications. It is assumed the selected test laboratory has performed these verifications and keeps good records for their validation.

Selected verifications should be provided as part of the reporting process as listed in **Part C – Reporting Format and Data Submission**.

### 1.2 Vehicle Preparation

Test vehicles should be inspected with a standard checklist to insure the vehicle is in typical operating condition and that it is safe to drive and testable on a chassis dynamometer. The checklist should include information on the vehicle and engine identity, its hours of operation/mileage, its weight capacity, and the condition of the vehicle including fluid levels, brakes, and tires. An example of a typical checklist for conventional vehicles is provided in **Part G – Vehicle Inspection Report Example**. Some modification may be needed for the ZET/NZET vehicles.

### 1.3 Test Weight

Chassis testing requires the estimation of vehicle weight that may include the tractor, trailer, and payload weights. According to estimates from South Coast Air Quality Management District and previous drayage HDT testing, the average vocational vehicle weight is listed in Table 1-1. For this guidance document, the goods movement HDT will be utilized where a targeted test weight of 69,500 lbs., as listed in Table 1-1, is recommended. Since some advanced vehicles may have heavier tractor weights, the total test weight will be adjusted for any additional weight of the tractor in comparison to the conventional tractor. The conventional tractor weight is approximately 17,000 lbs. (non-sleeper style) where the trailer plus payload weight is 52,500 lbs. as listed in Table 1-2.

Note for chassis dynamometer testing one must also add weight to simulate rotational inertial forces of the tires and axels as per 40 CFR § 1066.310(b). As such for a Class 8 ZET/NZET the total mass per tire contact is 125 lbs./tire (56.7 kg/tire). For a Class 8 heavy duty tractor-trailer utilized in port service, the trailer will be assumed to have 8 tires and the tractor will have a range of tires where standard is 10 (assuming dual axels and double tires per axel). At 18 contact wheels, this adds 125 lbs. * 18 or 2,250 lbs. to the total weight for a final test weight of 71,750 if the tractor weighed 17,000 lbs., see Table 1-2. Some advanced ZET/NZETs may employ low rolling resistant tires or utilize tractors with single axels or combinations of both. As such, the total tire contract added force will vary by ZET/NZET configuration and will need to be determined as detailed in **Part E**, Table E-1.

Table 1-1: Conventional Test Vehicle Weight Selections (By Vocation)

| Vehicle Weights (lbs.) | | | |
|---|---|---|---|
| Transit | School Bus | Refuse | Goods Movement |
| 34,500 [1] | 20,000 [2] | 56,000 [3] | 69,500 [4] |

[1] Typical weight of an average transit bus with passengers estimated at 150 lb. The weight accounted here is the sum of the vehicle weight with passengers.

[2] A school bus with a capacity of 64 passengers at 100 lb. The weight accounted here is the sum of the vehicle weight with school kids.

[3] Typically loaded heavy-duty goods movement truck and refuse hauler in the SC AQMD district. Tractor weight is estimated at 17,000 lbs. where the payload capacity is estimated at 52,500 lb.

Table 1-2: Class 8 Heavy Duty Drayage Port Test Weight Details

| Test Weight (lbs.) | | | | |
|---|---|---|---|---|
| Conventional HDT [1] | Payload +Trailer | Rolling Loads (18 Tires) | Test Weight | Final [2] Test Weight |
| 17,000 | 52,500 | 2,250 | 69,500 | 71,750 |

[1] Adv. vehicle empty weight is the weight of the advanced ZET or NZET that may be higher than a standard conventional vehicle of 17,000 lb. The payload weight is the weight of the trailer and its payload.

[2] The final test weight is the HDT weight plus payload + trailer weight (i.e. the weight utilized for the load determination of the chassis dyno) and the weight due to 18 tires contacting the road surface.

1.4 Road Load Coefficients

One of the most important steps in testing a vehicle on a chassis dynamometer is the proper determination of the vehicle's road load forces. Road load forces are a generalized set of equations that define the forces required to move a vehicle over a length of road. The road load forces are reduced to three coefficients, aerodynamic resistance (A), drivetrain resistance (B), and rolling resistance (C). These coefficients are normally referred to as the vehicle's ABCs. The determination of these coefficients is usually achieved by coasting a vehicle from high to low speeds while recording the time while the vehicle slows. These data are analyzed and plotted with load on the y-axis and speed on the x-axis where the coefficients of the best-fit polynomial (second order type) are the ABCs of the road load coefficients.

For light duty vehicles (LDV), the coast down coefficients are provided for each vehicle make/model by the manufacturer, thus, making LDV testing straightforward and reproducible. For HDTs the road load force coefficients are not available by the manufacturer so the coefficients need to be determined prior to testing for each tractor/weight/trailer configuration. There are two primary methods for determining the ABC coefficients for HDTs, 1) coast down the vehicle on-road, or 2) calculate the coefficients using the principles of vehicle dynamics. The EPA and ARB recommend the use of the first method as per 40 CFR Part 1066 Subpart D as part of the federal greenhouse gas regulations. The coast down method requires the following details:

1. Minimum of 16 valid coast down runs (8 in each direction).
2. Not recommended to perform on days for which winds are forecast to exceed 6.0 mph.
3. If road grade is greater than 0.02% over the length of the test surface, you must compensate for grade with recommended formulas
4. Operate from 70 mph down to 15 mph on a single stretch of road (split is allowed, but not recommended). No turn movement is allowed as this will add additional forces affecting the coast results.
5. Measure wind speed, direction at the time and location for the testing using specified measurement tools (calibrations 24 hr. prior to testing). Specify distance from station to

the vehicle centerline (2.5 – 3 vehicle widths), just above midpoint of the vehicle, and 50 feet from trees and 25 feet from bushes.

6. Correct for the wind measurement based on GPS location where the station is at the midpoint of the coast down area.
7. All valid coast down run times in each direction must be within 2.0 standard deviations of the mean of the valid coast down run times (from the specified maximum speed down to 15 mph)

The on-road coast down method requires long stretches of road to coast a vehicle from up to 70 mph to 15 mph which for a loaded HDT can take up to 9 miles with minimal grade, controlled ambient conditions, high and low speeds access, and minimal vehicle traffic. This is very difficult in many cities and usually requires the use of test tracks or dedicated roadways. EPA has found that significant effort is needed to perform these on-road coast-down tests where their approach is to rent Air Force runways in Arizona and in Michigan, for example. Thus, to minimize testing costs and to consolidate HDT preparation into a half day an alternate approach is recommended.

The 2$^{nd}$ approach is to determine the ABC coefficients using the principles of vehicle dynamics. For this approach the road load coefficients are calculated based on a standard formula that incorporates a measured vehicle frontal area (per SAE J1263 measurement recommendations), a tire rolling resistance, and a coefficient of drag ($C_d$). These parameters are used to calculate the A, B, C coefficient, where the details of these calculations and assumptions are provided in Part A.

1.5 Road Load Validation

The road load coefficients should be verified by performing a coast down validation procedure on the dynamometer. For the dynamometer coast downs, the vehicle should be accelerated to a given constant speed and then it should be allowed to coast down to a point where the vehicle is nearly stopped. The coast downs should cover a speed range starting from approximate 65 mph going down to 5 mph. The vehicle is coasted down with the engine ungeared. The times for the vehicle to coast down should be broken down into 10 mph speed bins that can be compared to theoretical predictions for each speed bin. For each speed bin, the coast downs should be within 5% of the expected theoretical values. Use good engineering judgment to adjust ABCs to achieve proper coast down acceptance as described in Part C - Dynamometer Coefficient and Coast down Evaluation report.

## 1.6 Test cycles

Three main cycles are considered as part of this testing, 1) a sustained grade cycle, 2) simulated drayage truck port cycles, and 3) the HUDDS cycle. In addition to standardized test cycles UCR also recommends performing a system depleting cycle to evaluate the full range of the vehicle's power system. The test cycles were designed to provide safety. The sustained grade test is to ensure that the vehicles can manage to operate over both the Vincent Thomas and Gerald Desmond bridges with a full load while maintaining observed speed limits with an approach of 50 mph and 0 mph. The port cycles (Phase 1 – 5 in Figure 1-1) are designed to characterize the ZET/NZETs while performing typical local and near dock port operations under loaded conditions. The HUDDS cycle is desired to make comparisons to the certification of HDTs. The system depletion test is to understand the range and other vehicle specific capabilities that can be cross-compared between vehicle tests. Although the system-depleting test may be performed by non-all electric vehicles, its name is specified as a charge-depleting (CD) test. Table 1-3 provides the list of recommended cycles and a summary description of their significance and Part B describes each of the cycles in detail. In order to limit testing to one day, UCR recommends performing each cycle once in the order presented in Table 1-3.

Table 1-4 includes a list of important details including accumulated distance and estimated power consumed for the selected test cycles. The total distance traveled prior to the CD test is 50 miles and approximately 163 kWh of energy absorbed based on a final test weight of 75,000 lb.

Figure 1-1: Drayage Truck Port Cycle Near Dock, Local, and Regional Operations

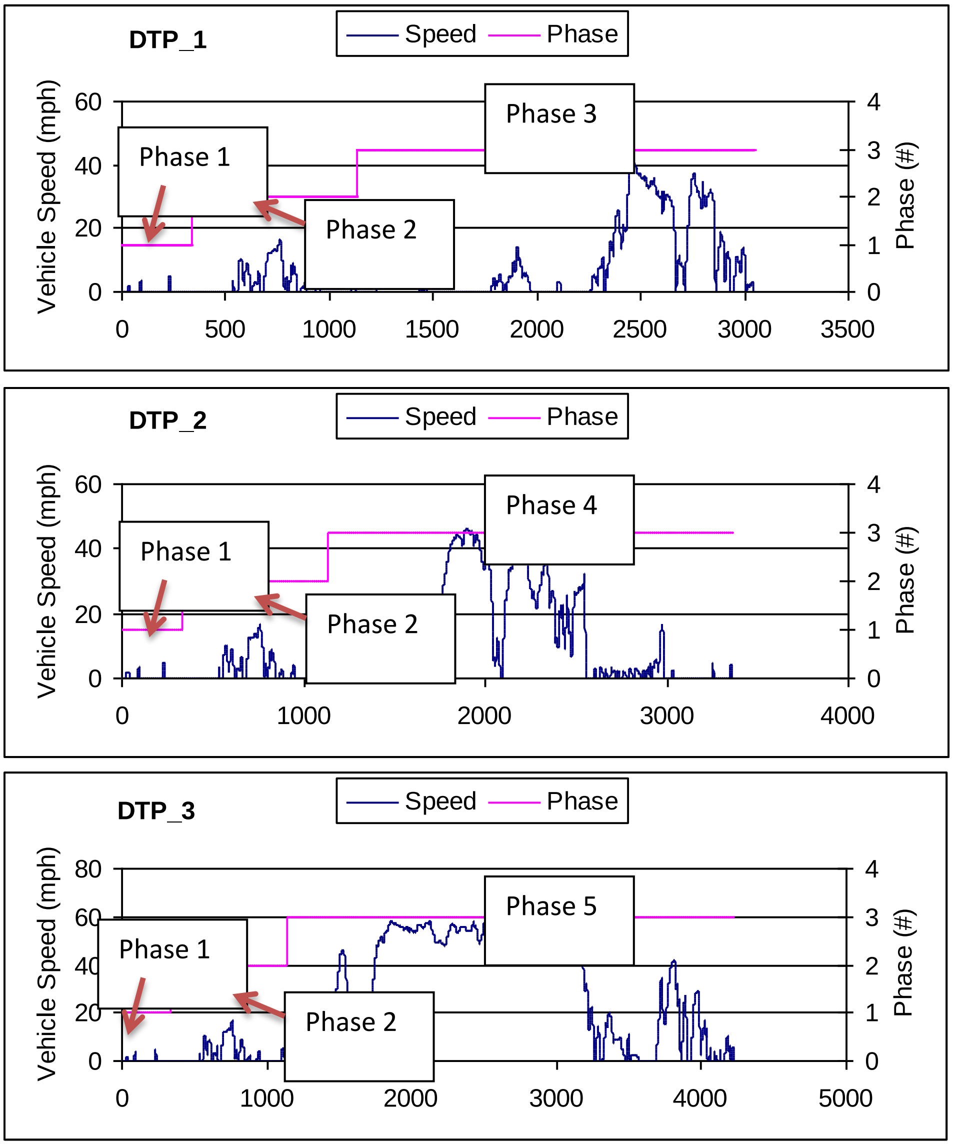


Table 1-1: Proposed Test Cycles Description

| Test Order | Test Cycle | Description |
|---|---|---|
| **1** | SG-1 | Simulated Vincent Thomas bridge starting at 50 mph |
| **2** | SG-2 | Simulated Vincent Thomas bridge starting at 0 mph |
| **3** | UDDS | Representative cycle for the engine certification cycle |
| **4** | DPT-Ph1 | Drayage Port Truck (DPT) cycle phase 1 simulating driving within the port and in the queue. |
| **5** | DPT-Ph2 | Phase 2 simulating driving close to the ports at very low speeds |
| **6** | DPT-Ph3 | Phase 3 simulating short high speed transient operation |
| **7** | DPT-Ph4 | Phase 4 simulating longer high speed transient operation |
| **8** | DPT-Ph5 | Phase 5 simulating high speed cruise |
| **9** | **CD** | Charge depleting cycle to drain energy system to manufacturer's recommended minimum charge status or fuel supply. |

Table 1-2: Proposed Test Cycles Specifications for A Single Day of Testing

| Test Order | Test Cycle | Test Duration (min) | Average Speed (mph) | Distance (mi) | Accum. Distance (mi) | Est. Ave [1] Power (kW) | Accum. Energy (kWh) |
|---|---|---|---|---|---|---|---|
| **1** | SG-1 | 5 | 38 | 3.17 | 3.2 | 200 | **16.7** |
| **2** | SG-2 | 7.6 | 25 | 3.17 | 6.3 | 200 | **42.0** |
| **3** | UDDS | 17.7 | 18.8 | 5.55 | 11.9 | 54 | **57.9** |
| **4** | DPT-Ph1 | 5.58 | 0.29 | 0.027 | 11.9 | 13 | **59.1** |
| **5** | DPT-Ph2 | 13.3 | 2.67 | 0.59 | 12.5 | 22 | **64.0** |
| **6** | DPT-Ph3 | 31.9 | 9.39 | 4.99 | 17.5 | 46 | **88.5** |
| **7** | DPT-Ph4 | 37.1 | 13.1 | 8.10 | 25.6 | 51 | **120** |
| **8** | DPT-Ph5 | 42.1 | 35.1 | 24.63 | 50.2 | 62 | **163** |
| **9** | **CD** | **Varies** | **55** | **Varies** | **Varies** | **Varies** | **Varies** |

[1] Estimated power based on payload capacity of 65,000 lbs. and a final test weight of 75,000 lbs. (truck weight 17,000 lbs.) and a standard frontal area while testing an electric vehicle. Values may vary slightly for each vehicle and will depend on the vehicles energy efficiency and road load coefficients. Test cycles represent full or partial cycles to reduce test time. Full cycle comparison is completed by combining phases of the individual cycles.

## Section 2: Chassis Testing

This section discusses soak times, testing conditions (accessory status such as the air conditioner, air brakes, etc.), and other details needed to control the proper operating of a HDT on a chassis dynamometer.

### 2.1 General ZET and NZETs

The HDT should be tied down to the chassis dynamometer using standard operating procedure to ensure the vehicle is securely stabilized on the dynamometer in a manner that allows the dynamometer to operate on the drive wheel without impedance. This procedure would typically involve chains or other straps to tie the vehicle down from multiple directions and some type of chocks to prevent the non-drive wheels from moving.

For all chassis testing, the vehicle will be operated under normal in-use service conditions with the exception of the following (see Part E for step-by-step procedures):

- AC will be off.
- ABS and vehicle traction related systems may be disabled if they cause improper operation on a chassis dynamometer.
- Air brakes and systems will function normally.
- HDT cooling systems, fans, and details shall be in the normal automatic setting as used during in-service testing.
- Forced cooling will be provided by the test laboratory to simulate a vehicle moving at on road speeds. A cooling fan of sufficient size (~1 hp) and a close location (within 2 feet) will be used for all the simulated testing.
- Soak times between tests will be 20 minute between selected test cycles to accommodate NZET testing and possible ZET needs (such as during the SG-1 and 2 tests).
- Cold starts will not be performed for any of the tests.

### 2.2 ZET Testing

Typically, preconditioning and vehicle warm up is needed to stabilize the emissions control and engine combustion systems. For electric vehicles and other ZETs, pre-conditioning is not needed and may actually impact the vehicles range estimation. As such, no preconditioning for ZETs is recommended.

The electrical demand and regeneration power shall be monitored both by the vehicle CAN system and independently by the test laboratory. For the vehicle CAN system, the current, voltage, and real-time power shall be recorded and reported on a second by second and integrated basis. The power shall be reported where both propulsion (power supplied from the batteries to the wheels) and regeneration (power supplied from the wheels to the batteries) is reported and uniquely identified. The power shall be monitored at a location that is closest to the batteries where the total ZET power includes both power for propulsion and accessory loads.

For the independent laboratory measurement, a suitable power meter with high accuracy (< 1% on power) shall be used. The power meter shall be installed at a location closest to the batteries to quantify the propulsion/regeneration power and accessory loads of the ZET. The voltage, current and power shall be measured at a sufficient frequency to be representative of electric vehicle testing. The following instruments may be required: a DC wideband Ampere-hour meter with an integration period of less than 0.05 seconds if an integration technique is used; an instrument to measure a capacitor's voltage; an instrument to measure an electromechanical flywheel's rotational speed; an AC Watt-hour meter to measure AC Recharge energy; and a voltmeter and ammeter.

The state of charge (SOC) of the vehicle is typically a vehicle specific calculation that will vary by manufacturer. As such, the vehicle SOC should be measured from the vehicle CAN system continuously (at a rate of 1Hz or greater) and recorded throughout the entire test. In addition, any indication of SOC from the driver dashboard shall be manually logged. These results should be in agreement and reported as part of the final data set.

### 2.3 NZET Testing

Since NZET technologies may incorporate additional energy storage devices, these hybrid systems need to be monitored closely to accurately determine their final state of charge. The hybrid analysis approach includes accounting for the energy needed to return the system to the initial state of charge. Procedures for this should follow the recommended practices of SAE J2711. SAE J2711 provides the calculation methods for determining total energy used and recovered by energy storage systems (batteries, flywheels, capacitors or other) when hybrids are employed.

The recorded data should be time integrated against the emission measurement data at the beginning and end of the test to coincide with the emission measurement portion of the chassis test. Provided the SOC is measured, time sequenced and integrated in accordance with the procedures in this document, only the beginning and ending SOC values are necessary in the final test report.

## 2.4 Test Matrix

The testing approach for ZET/NZET is to perform selected tests back to back while allowing some soak or vehicle reconditioning between other tests. Table 2-1 shows the recommended testing approach where there are soaks between the heavily loaded SG-1 and SG-2 cycles, HUDDS cycle, and Phase 3, 4 and 5 of the port drayage cycle.

Table 2-1: Proposed Test Cycles Description

| Test ID | Test Type | Description |
|---|---|---|
| **1** | SG-1 | **Simulated Vincent Thomas bridge starting at 50 mph** |
| - | soak | Allow ZET/NZET technology to stabilize |
| **2** | SG-2 | **Simulated Vincent Thomas bridge starting at 0 mph** |
| **-** | soak | Allow ZET/NZET technology to stabilize |
| **3a** | UDDS | **Representative cycle for the engine certification cycle** |
| **-** | soak | Allow ZET/NZET technology to stabilize |
| **4a** | DPT-Ph1 | **Drayage Port Truck (DPT) cycle phase 1 simulating driving within the port and in the queue.** |
| **4b** | DPT-Ph2 | **Phase 2 simulating driving close to the ports at very low speeds** |
| **4c** | DPT-Ph3 | **Phase 3 simulating short high speed transient operation** |
| **-** | soak | Allow ZET/NZET technology to stabilize |
| **5** | DPT-Ph4 | **Phase 4 simulating longer high speed transient operation** |
| **-** | soak | Allow ZET/NZET technology to stabilize |
| **6** | DPT-Ph5 | **Phase 5 simulating high speed cruise** |
| **-** | soak | Allow ZET/NZET technology to stabilize |
| **7** | **CD** | **Charge depleting cycle to drain energy system to manufacturer's recommended minimum SOC or fuel supply.** |

**Section 3: Emissions Testing**

The NZET is expected to have lower emissions than the regulated standards. The regulated species included are total hydrocarbons (THC), methane (CH4), non-methane hydrocarbons (NMHC), oxides of nitrogen ($NO_2$ and $NO_x$), carbon monoxide (CO), carbon dioxide ($CO_2$), particulate matter (PM), and fuel economy, as listed in Table 3-1. The recommended reductions range from a 75% reduction in $NO_x$ and no reduction for CO, see Table 3-1. Additionally, it is expected the NZET will have improved fuel economy where a reduction in $CO_2$ and fuel consumption is expected. The basis for the emissions comparison will utilize the HUDDS test cycle and fuel economy will utilize a combination of all the cycles. EPA also recommends the measurement of some non-regulated but reported emissions sources such as nitrous oxide ($N_20$) and ammonia ($NH_3$), see Table 3-2. Although their regulation is not mandatory it is suggested that these species be measured if there is good engineering judgment to expect their emissions to be present. Other non-regulated pollutants such as toxics and detailed PM analysis are not recommended unless there is reason to believe the NZET may contribute to these un-regulated species. The test laboratory should use good engineering judgment to decide on the measurement of these non-regulated species.

Table 3-1: List of Regulated Species and Recommendations For NZET (g/bhp-hr)

| Species [1] | Standard [2] | NZET Recommendation |
|---|---|---|
| **NMHC** | 0.14 | 0.07 (50% reduction) |
| **NOx** | 0.20 | 0.05 or 0.02 (75% or 90% reduction) |
| **CO** | 15.5 | 15.5 (no reduction) |
| **PM** | 0.01 | 0.003 (70% reduction) |
| **$CH_4$** | 0.05 [2] | 0.05 g/bhp-hr |
| **$CO_2$** | Varies [3] | 2027 std. or better [3] |

[1] NMHC, $CH_4$, NOx, CO and PM are regulated on 1065 specifications and $CO_2$ is regulated under 1066 specifications as a pollutant. The $CO_2$ regulation begins in 2018 and is fully enforced by 2027 as part of the federal guidelines for fuel standards and greenhouse gas emissions and is thus presented here as a reference point for figure requirements.
[2] The standard is based on FTP testing and the NZET is based on HUDDS testing.
[3] The federal guidelines for GHG emissions vary by tractor, vocation, and other details see Part F – GHG Regulatory Standards and References. Validated on HUDDS test cycle.

Table 3-2: List of Non-Regulated Species to Report, But Not Regulated

| Species [1] | Expected CAP [1] | NZET Recommendation |
|---|---|---|
| **$N_2O$** | 0.05 g/bhp-hr | - report if available |
| **$NH_3$** | <10 ppmv raw [3] | - report if available |

[1] The measurement method for $N_20$ is specified in 40 CFR Part 1065 and the CAP limits in the proposed Federal Register for GHG emissions except for $NH_3$. $NH_3$ is a precursor for PM formation during secondary atmospheric conditions. At some point in the future, EPA may elect to regulate these pollutants based on the data reported. Currently, there is a CAP standard that is adopted herein as guide to their current regulated limit based on FTP and SET engine test cycles.

[2] Alternative fueled (i.e. Natural Gas) vehicles can emit significant amounts of $NH_3$ in addition to SCR equipped diesels. Although $NH_3$ is not regulated, there is a SCR diesel slip limit recommendation in the Federal Register (FR). Thus, it is expected advanced systems should measure less than 10-ppm raw exhaust concentration as per recommendations of the FR.

## 3.1 Measurements

All emissions measurement, calibration, and verification methodologies are provided in 40 CFR Part 1065. 1065 delineates equipment specifications, measurement principles, calibrations intervals, and verification requirements. It is expected the testing facility follows the equipment specifications and details of 1065 with the following details highlighted.

Because the NZET will be a low emitting vehicle (significantly lower than the 2010 certification standards), high accuracy measurement systems are recommended. As such, emission from the vehicle exhaust should be measured from a recognized and validated emissions laboratory. Portable emissions measurement systems (PEMS) are not sufficiently accurate for these measurements. Typically, these validated laboratories incorporate constant volume sampling systems (CVS) and laboratory grade analyzers. The tunnel inlet should be filtered for PM with a HEPA filter to aid in lowering detection limits. Tunnel flow volume shall be set at the minimum level possible for vehicles such that a carbon balance for fuel efficiency and a hydrocarbon balance for tunnel integrity can be performed accurately and the lowest possible detection limits can be determined. Fuel consumed should be determined by carbon balance from the analytical instruments, and the number of dynamometer roll revolutions shall be used to determine the distance traveled during the driving cycles. Particulate matter should be measured gravimetrically using Teflo membrane filters at a filter temperature of 47 ± 5 ºC in addition to many other details as specified in 40 CFR Part 1065. Filters shall be conditioned to temperature and humidity conditions and measured with a precision microbalance all as specified in 40 CFR Part 1065.

The fuel type may vary between NZETs. For the purposes of minimizing costs, nominal fuel properties should be reported. These would include ultra low sulfur diesel fuel, natural gas (LNG or CNG), and other possible fuels such as ethanol, hydrogen, etc. Fuel analysis is not necessary unless the fuel properties may cause the emissions to vary significantly. The test laboratory shall provide good engineering judgment to determine if fuel analysis is needed for the selected NZET.

### 3.2 Verifications and Calibration

It is expected that the test facility utilizes and follows the recommendations of 40 CFR Part 1065 for the calibration and verification of testing. For this guidance document it is expected that the test facility provide a minimum level of reported 1065 verifications such as analyzer drift, linearity, and other conditional details as found during emissions testing. These are specified in **Part C – Reporting Format and Data Submission**.

## Section 4: Reporting

Data reporting will typically involve the combination of files representing different data streams. These include: 1) chassis dynamometer load and speed information, 2) electric power meter systems, 3) vehicle CAN network system, 4) emissions measurements for NZETs and 5) hand logs on test observations. The chassis data includes dynamometer roll speed and power absorbed, acceleration, and frictional torque/force/hp measurements. The electric power measurements include current, voltage, and integrated power with a laboratories precision power meter. The vehicle CAN network provides information from the engine control unit (ECU) on vehicle performance and battery performance CAN channels. The hand logs can include information available to the driver that included the odometer, state of charge (SOC), and any warning indicator lights available to the driver.

### 4.1 ZET Reporting

The ZET data reporting will include chassis and vehicle CAN results as listed, but not necessarily limited to those in Table 4-1 and Table 4-2.

Table 4-1: Data to Be Collected On The ZET CAN System

| Vehicle Data | |
|---|---|
| **Bulk battery (voltage, current, and temperature)** | Wheel speed, motor RPM |
| **Power plus direction (propulsion and regeneration)** | Alarms or faults |
| **Reported SOC/ Net Energy Change (NEC)** | Accessory load, battery rating specified at final SOC |

Table 4-2: Data to Be Collected On The ZET/NZET Chassis System

| **Chassis Data** | |
|---|---|
| **Wheel speed (mph)** | Power (absorbed, motored) |
| **Ambient conditions (Rh, wind speed, direction, temperature, dew point)** | Roller force (absorbed, motored) |
| **Coast down results (ABC)** | Hp @ 50 mph |

## 4.2 Vehicle CAN Power

The vehicle CAN power calculations can be performed based on the product of measured DC current and DC voltage. The vehicle CAN current measurements usually include direction where propulsion current is energy from the battery and regen current is energy to the batteries (regeneration). The power should be provided by the CAN system or calculated by the following formula:

$$\textit{Vehicle CAN Power}_i = \sum Current_i * Voltage_i$$

Where:

| | |
|---|---|
| *Vehicle CAN Power* | is the instantaneous vehicle CAN power consumption at time *i*, where propulsion power is the current consumed by the vehicle and regen power is current recovered (regenerated) by the vehicle. |
| $Current_i$ | is the instantaneous vehicle CAN current usage at time *i* |
| $Voltage_i$ | is the instantaneous vehicle CAN voltage at time *i* |

## 4.3 Vehicle CAN SOC

The vehicle SOC represents the vehicle status and is a relative parameter and is dependent on each manufacturer's claims for range and usage and thus may vary by manufacturer due to their utility of the battery systems. Thus, SOC is a generally calculated value, but is still a reasonable metric for the status of the vehicle and when re-charging is needed. The SOC is typically provided by the vehicle using two methods. One method is the measurement of SOC from the vehicle CAN reporting system and the other is utilizing the display of SOC to the driver. In general, both the ECM-reported value and the visual display are in agreement, suggesting that the SOC-reported data represents the overall status of the vehicle. The real-time energy accumulation should be calculated including the propulsion and net chassis dynamometer energy and the net electric energy measured during testing. The chassis net energy is the sum of the absorbed and motored energy measured/calculated by the chassis dynamometer and the vehicle net energy is measured by the laboratory's power meter and vehicle CAN system.

4.4 NZET Reporting

The NZET data reporting will include emissions data in addition to the chassis and vehicle CAN results. Due to slight differences in the energy storage of the NZET, the list of reported details should include, but not be limited to, those presented in Tables 4-2, 4-3, and 4-4.

The emissions to measure and report are HC, $NO_2$, $CH_4$, NMHC, $NO_x$, CO, PM, and $CO_2$. Additional measurements of $N_2O$ and $NH_3$ may be measured if available at the test facility and where appropriate depending on the utilized NZET technology. Fuel economy will be measured using CAN channels and via the carbon balance method with corrections for energy storage as per SAE standards. All emissions data will be reported on a g/hr, g/bhp-hr, g/mi, and g/kg fuel basis.

Table 4-3: Emissions Data to Be Collected and Reported

| Required | Recommended |
|---|---|
| **THC, $CH_4$, and NMHC** | $N_2O$ for selected NZET with selected catalysts and fuels |
| **NOx and $NO_2$** | $NH_3$ for selected NZET fuel systems |
| **PM, CO, and $CO_2$** | Real-time PM, PM fines, and other for some NZETs without DPFs |

Table 4-4: Data to Be Collected On The NZET CAN System

| Vehicle Data | |
|---|---|
| **Bulk battery (voltage, current, and temperature) if applicable** | Wheel speed, motor RPM |
| **Power including direction (propulsion and regeneration)** | Alarms or faults |
| **Reported SOC** | Accessory load |
| **Fuel consumption, Boost Pressure, Other related fuel details for alt. fuels** | Engine loads (actual, friction, and reference torque) |
| **Intake and Coolant Temperature** | Engine RPM and % Load |

4.5 Additional Resources

This section includes useful links and references to other literature and contacts for specific experts in the field of advanced vehicle chassis testing.

4.5.1 Advanced vehicle testing references:

- SAE J1711 Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid- Electric and Conventional Heavy-Duty Vehicles, issued September 2002, IBR approved for § 1066.501(a).
- SAE J2711 Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles, revised June 2010, IBR approved for § 1066.501(a). HD hybrid testing group for heavy-duty vehicles.
- SAE J1634 SAE Recommended Practice establishes uniform procedures for testing battery electric vehicles (BEV's) that are capable of being operated on public and private roads. This document deals with electric vehicles, but references other SAE standards SAE J2711 and SAE J1711 and SAE J4252.

4.5.2 Emissions (part 1065 and part 1066):

- 40 CFR Part 1065 (emissions testing as it pertains to regulated emissions not including CO2). Engine test stand basis.
- *http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr1065_main_02.tpl*
- 40 CFR Part 1066 (chassis greenhouse gas (GHG) testing as it pertains to fuel economy and $CO_2$ emissions). Chassis testing basis.
- *http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5;node=40%3A33.0.1.1.15*

4.5.3 Chassis setup, ABCs, and verifications:

- SAE J1100 Motor Vehicle Dimensions. Standardized method for determining frontal area of a vehicle.
- SAE J4252 specifications and information on tire drag.
- *http://www.epa.gov/smartway/forpartners/performance.htm.*
- SAE J1263. Road load measurement and dynamometer simulation using coast-down techniques. SAE Recommended Practice, 1991 (SAE, Warrendale, Pennsylvania). Referenced in 1066.310.
- SAE J2263, Road Load Measurement Using Onboard Anemometry and Coast-down Techniques, revised December 2008, IBR approved for § § 1066.301(b), 1066.305, and 1066.310(b). Referenced in 1066.310. This guidance document does not recommend these procedures in order to reduce testing effort to one day.
- SAE J2264 Chassis Dynamometer Simulation of Road Load Using Coast down Techniques and Referenced by 1066.315 "Dynamometer road-load settings and 1066.1010 Incorporation by reference.
- SAE J2951, Drive Quality Evaluation for Chassis Dynamometer Testing, revised January 2014, IBR approved for § 1066.425(j).
- 40 CFR Part 1066 Subpart C Dynamometer Specifications: Coast-down verifications and acceptance testing. Pass/fail is 1% where in this document it was widened to 5% to allow one day testing.

- 40 CFR Part 1066 Subpart D Coast-downs: Load determination methods and procedures.
- *http://www.epa.gov/otaq/climate/gem.htm:* Link to the GEM model for determining aerodynamic improvements categories and reductions.

4.5.4 Contact information:

- UCR, Dr. Kent Johnson, (951) 781 5786, kjohnson@cert.ucr.edu
- EPA, Daniel McBryde (734) 214-4328, mcbryde.dan@epa.gov
- ARB, Dr. Tao Huai (916) 324-2981, thuai@arb.ca.gov

## Part A – Road Load Determination

Road load coefficients vary with speed and the square of the speed where a properly configured dynamometer is needed to simulate the loads from 0 to 70 mph. For example, at 65 mph the aerodynamic term accounts for 53% of the resisting force, rolling resistance 32%, driveline losses 6% and auxiliary loads at 9%. The method for determining coast down coefficients was published and evaluated as part of a study submitted to the South Coast Air Quality Management District[2]. Typical coast down procedures assume that vehicle loading force is a function of vehicle speed, drag coefficient, frontal area and tire rolling resistance coefficient and takes the form of equation 1:

$$M\frac{dV}{dt} = \frac{1}{2}\rho A C_D V^2 + \mu M g cos(\theta) + Mgsin(\theta) \qquad \text{(Equation 1)}$$

Where:
M = mass of vehicle in lb. (tractor + payload + trailer+ 125lb/tire)
ρ = density of air in $kg/m^3$.
A = frontal area of vehicle in square feet, see Figure A-1 below
$C_D$ = aerodynamic drag coefficient (unit less).
V = speed vehicle is traveling in mph.
μ = tire rolling resistance coefficient (unit less).
g = acceleration due to gravity = 32.1740 $ft./sec^2$.
θ = angle of inclination of the road grade in degrees (this becomes zero).

Assuming that the vehicle loading is characteristic of this equation, speed-time data collected during the coast down test can be used with static measurements (ZET/NZET mass, air density, frontal area, and grade) to solve for drag coefficient ($C_d$) and tire rolling resistance coefficient (μ). The frontal area is measured based on the method described in Figure A-1 below. However, experience performing in-use coast downs is complex and requires grades of less than 0.5% over miles of distance, average wind speeds < 10 mph ± 2.3 mph gusts and < 5 mph cross wind[3]. As such, performing in-use coast downs in CA where grade and wind are unpredictable are unreliable where a calculated approach is more consistent and appropriate. Additionally, vehicles equipped with automatic transmissions have shown that on-road loading is also affected by the characteristics of the vehicle transmission, especially when reverse pumping losses at low speed begin to dominate.

[2] Draft Test Plan Re: SCAQMD RFP#P2011-6, "In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines", October 2011.

[3] EPA Final rulemaking to establish greenhouse gas emissions standards and fuel efficiency standards for medium and heavy duty engines and vehicles, Office of Transportation and Air Quality, August 2011 (Page 3-7) and J1263 coast down procedure for fuel economy measurements

UCR's and others recommend a road load determination method that uses a characteristic coast down equation, with a measured vehicle frontal area (per SAE J1263 measurement recommendations), a tire rolling resistance μ, and a coefficient of drag (Cd) as listed in Table A-1. If low rolling resistant tires are used, then the fuel savings can be employed with a slightly improved coefficient as listed. Similarly, if an aerodynamic tractor design is utilized (i.e., a certified SmartWay design) then a lower drag coefficient can be selected. Table A-1 lists the coefficients to use based on different ZET/NZET configurations. Once the coefficients are selected, then they can be used in the above equation to calculate coast down times to be used for calculating the A, B, C coefficients in Equation 2 for the dynamometer operation parameters. From these equations, calculate the coast down times based on the coefficients in Table A-1 as shown in Table A-2 (65,000 lb., □std, $C_D$std and table A-1). From Table A-2, one can plot the force (lb.) vs. average speed bin to get the ABC coefficients for the chassis dynamometer (see Figure A-2). These are the coefficients to enter into the chassis dynamometer then validate via the details of Part C. Repeat process until validation criteria are met. Typically, one or two iterations are needed to meet the validation criteria.

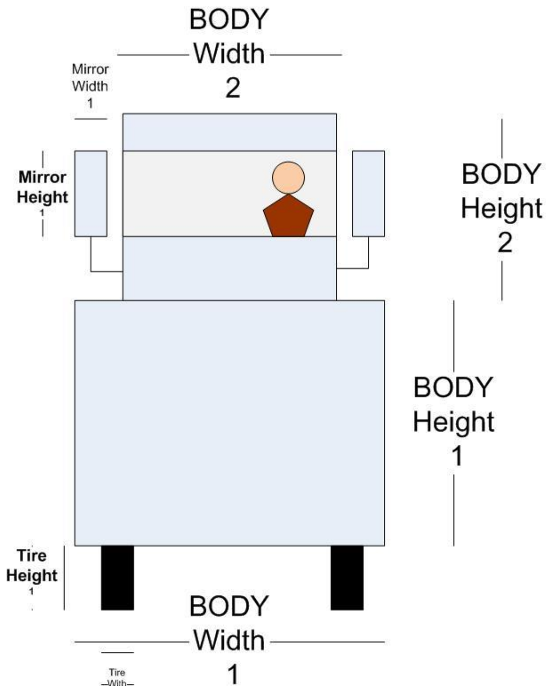
Table A-1 Constants and Parameters for Class 8 HDTs

| Variable | Value | Description |
|---|---|---|
| **θ** | 0 | no grade in these tests |
| **ρ** | 1.202 | standard air density kg/m$^3$ |
| **$\mu_{std}$** | 0.00710 | standard tires |
| **$\mu_{adv}$** | 0.00696 | low rolling resistant tires |
| **$C_{D\_std}$** | 0.750 | for non-SmartWay tractor |
| **$C_{D\_adv}$** | 0.712 | for SmartWay tractor |
| **g** | 9.806 | nominal value m/sec$^2$ |
| **M** | Varies | mass: final test weight kg |

[1] The tire rolling resistance, μ, for low rolling resistant tires shows a 1-2% savings (ref SmartWay). As such, utilize 0.00686 for low rolling resistant tires. If the tractor utilizes the certified SmartWay tractor type then coefficient of drag can be reduced by up to 10% (5% fuel savings) depending on the technology. Use $C_D$_adv for SmartWay tractors and $C_D$_std for non-SmartWay tractors. For reference, other vocations show higher Cd's, such as the $C_D = 0.79$ for buses and 0.80 for refuse trucks. Nominal value of gravity is used in this document where actual value can be found by following 40 CFR 1065.630 or at *http://www.ngs.noaa.gov*

$$\frac{dV}{dt} = \frac{1}{2}\frac{\rho A C_D V^2}{M} + \mu g cos(\theta) + g sin(\theta) \quad \text{(Equation 2)}$$

Figure A-1 Vehicle Frontal Area Dimensions Method



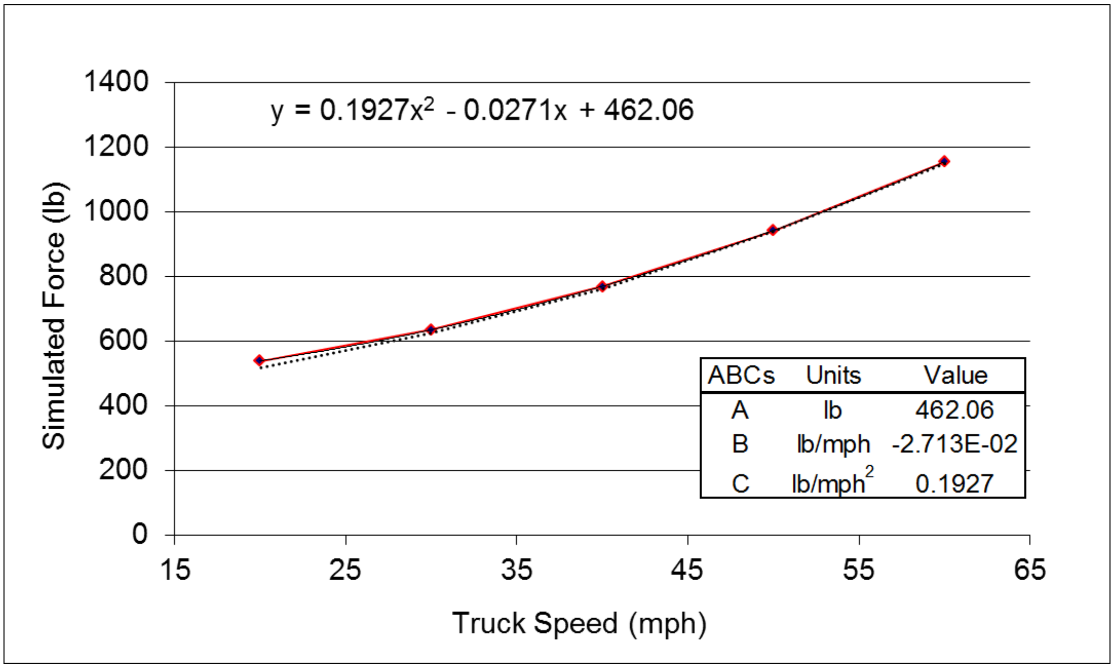

Using Equation 2 (solution for $\frac{dV}{dt}$ or deceleration), one can calculate the deceleration for each average speed bin (60, 50, … down to 20 mph); see Table A-2. From the deceleration time, one can calculate the desired time that is the target for the coast down simulation on the chassis dynamometer. Using the final test weight (M), the total simulated force can be calculated using Equation 1 at each speed bin, see values Table A-2. Plot the simulated force (lb.) on the y-axis vs. truck speed (mph) on the x-axis. Using a best-fit polynomial of order two, calculate the polynomial coefficients A ($0^{th}$ order term), B ($1^{st}$ order term), and C ($2^{nd}$ order term), see Figure A-2. Enter these ABCs into your chassis dynamometer and verify the coast down times match your desired coast down times to within 5%. Repeat as needed and report the final ABCs and verification coast down times in Part C.

The calculation approach is consistent and has proven very reliable for chassis testing HDT and has been used for years by UCR and others. For detailed evaluation of aerodynamic modifications and body styles, UCR recommends investing the time to perform in-use coast downs where sufficient program resources will be needed as per 40 CFR Part 1066, SAE J2263, and J1263.

Table A-2: Desired Coast Down Times for a Class 8 Truck with Standard Components

| Data Point | Ave. Speed (mph) | Calc time (sec) | Decel (mph/sec) | Decel (ft/sec2) | Decel (g) | Force (lb) |
|---|---|---|---|---|---|---|
| 65-55 | 60 | 25.67 | 0.38054 | 0.57 | 0.018 | 1154 |
| 55-45 | 50 | 31.44 | 0.31806 | 0.47 | 0.014 | 942 |
| 45-35 | 40 | 38.51 | 0.25965 | 0.38 | 0.012 | 769 |
| 35-25 | 30 | 46.68 | 0.21422 | 0.31 | 0.01 | 635 |
| 25-15 | 20 | 55.02 | 0.18177 | 0.27 | 0.008 | 539 |

Figure A-2 Resulting ABCs based on Table A-2 results



## Part B – Test Cycles

Four main cycles are considered as part of this testing, 1) the sustained grade cycle, 2) the simulated drayage truck port cycle, 3) the urban dynamometer driving cycle, and 4) a charge depleting cycle. Each of these cycles provides an important metric for the safety, performance, and modeling characteristics for electric heavy-duty trucks (eHDT) on-road. The sustained grade test is to ensure that the eHDT's can manage to operate over the bridge safely while maintaining observed speed limits. The port cycles are to characterize the eHDT while performing typical port operations. The HUDDS cycle is desired to relate to the large database of HDT testing results, and the charge depletion testing is to understand range and other vehicle specific capabilities that can be cross-compared between vehicle tests. Additionally, these repeatable cycles provide comparability between different electric vehicle systems to evaluate benefits and dis-benefits for different design approaches.

Sustained Grade (SG) Cycles

Crossing the Vincent Thomas Bridge is unique to operation in the port of Los Angeles and part of normal port activity. This bridge has a steep approach grade so it is important to learn that the new vehicle technologies can cross the bridge with a full load (GVW = 80,000 lb.). The bridge is the 4$^{th}$ longest suspension bridge in the world at 6,060 feet long and is relatively high mid span (365 ft.) to clear vessels in the navigation channel. The maximum grade of the bridge is estimated at 7%. Both high speed and low speed approaches are comment when traveling across the bridge due to traffic conditions.

Two sustained grade (SG) test cycles were created to evaluate the performance of the electric eHDT while crossing the bridge. SG-1 cycle simulates approaching the bridge at 50 mph and increasing load until the vehicle reduced to 30 mph. SG-2 cycle simulates approaching the bridge at 0 mph (standstill traffic) and accelerating up to 20 mph under full load conditions. Each cycle is 400 seconds (< 10 minutes) long and represents approximately 250 hp of sustained power representing about 3 miles of distance traveled.

Figure B-1 Vincent Thomas Bridge Crossed Regularly During Port Activity

Drayage Truck Port (DTP) Cycle

TIAX, the Port of Long Beach and the Port of Los Angeles developed the port cycle. Over 1,000 Class 8 drayage trucks at these ports were data logged for trips over a four-week period in 2010. Five modes were identified based on several driving behaviors: average speed, maximum speed, energy per mile, distance, and number of stops. These behaviors are associated with different driving conditions such as queuing or on-dock movement, near-dock, local or regional movement, and highway movements (see Table A-1 for the phases). The data were compiled and analyzed to generate a best-fit trip (combination of phases). The best-fit trip data were then additionally filtered (eliminating accelerations over 6 mph/s) to allow operation on a chassis dynamometer.

The final driving schedule is called the drayage port truck (DPT) cycle and is represented by 3 modes where each mode has three phases to best represent near dock, local, and regional driving as shown in Table B-1, B-2 and Figure B-2. The near-dock (DTP-1) cycle is composed of phase 1, 2, and 3a from Table A-1. This gives the complete near-dock cycle listed in Table A-2. Similarly, for the Local and Regional cycles (DPT-2 and DPT-3) the main difference is phase 3, which changes to 4 and 5 respectively. Phase 1 and 2 remain the same for all three cycles where creep and low speed transient are considered common for all the port cycles. For this testing it is recommended to perform phase 1 through 5 individually and to calculate the weighted emissions from the combined phases for an overall weighing impact. They will be performed in order from 1, 2, 3, 4, and 5.

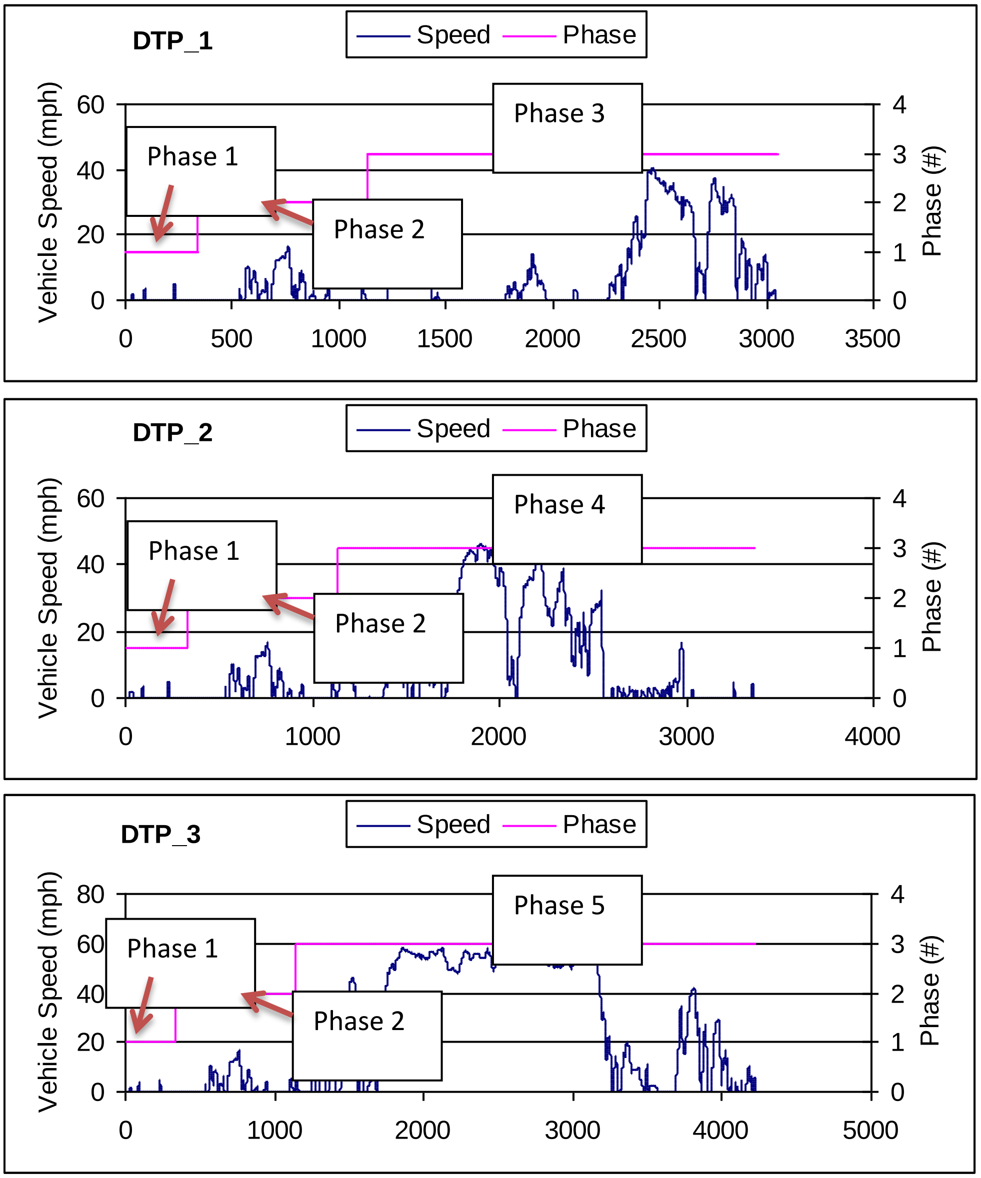
Table B-1: Drayage Truck Port Cycle by Phases

| Description | Phase # | Distance mi | Ave Speed mph | Max Speed mph | Cycle length |
|---|---|---|---|---|---|
| **Creep** | 1 | 0.0274 | 0.295 | 4.80 | 335 |
| **low speed transient** | 2 | 0.592 | 2.67 | 16.8 | 798 |
| **short high speed transient** | 3 | 4.99 | 9.39 | 40.6 | 1913 |
| **Long high speed transient** | 4 | 8.09 | 13.07 | 46.4 | 2229 |
| **High speed cruise** | 5 | 24.6 | 35.04 | 59.3 | 2528 |

Table B-2: Drayage Truck Port Cycle by Mode and Phases

| Description | Distance mi | Ave Speed mph | Max Speed Mph | Mode 1 | Mode 2 | Mode 3 |
|---|---|---|---|---|---|---|
| **Near-dock PDT1** | 5.61 | 6.6 | 40.6 | Creep | Low Speed Transient | Short High Speed Transient |
| **Local PDT2** | 8.71 | 9.3 | 46.4 | Creep | Low Speed Transient | Long High Speed Transient |
| **Regional PDT3** | 27.3 | 23.2 | 59.3 | Creep | Low Speed Transient | High Speed Cruise |

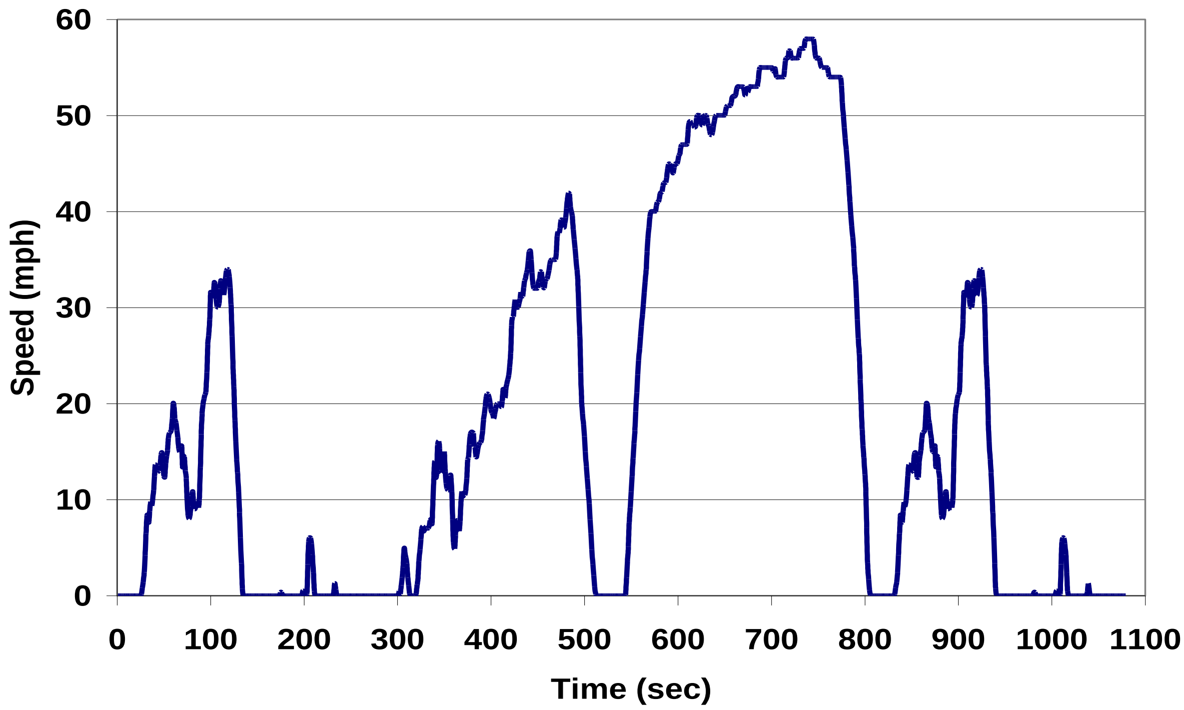
Figure B-2: Drayage Truck Port Cycle Near Dock, Local, and Regional Operations



Urban Dynamometer Driving Schedule (UDDS) Description

The Federal heavy-duty vehicle Urban Dynamometer Driving Schedule (UDDS) is a cycle commonly used to collect emissions data on engines already in heavy, heavy-duty diesel (HHD) trucks. This cycle covers a distance of 5.55 miles with an average speed of 18.8 mph, sample time of 1061 seconds, and maximum speed of 58 mph. The speed/time trace for the HUDDS is provided below in Figures B-3.

Figure B-3: Speed/Time Trace for A 1x HUDDS Cycle for The Chassis Dynamometer




Charge Depletion Cycle (CD)

The charge depletion test incorporates the same simulated test weight of a loaded tractor cruising at 55 mph until the energy storage systems are reduced to the minimum energy as defined by the manufacturer. This test will be performed at the end of each day to characterize the true range of the system and compare this range between other vehicles tested.

## Part C – Reporting Format and Data Submission

Part C covers expected data reporting formats for the chassis testing. Each report should be prepared with the laboratory's name clearly referenced. This includes verifications of the chassis setup, performance tests, and emissions results. The following three main reports are expected:

1. Dynamometer Coefficients and Coast down Evaluation (1 per vehicle)
2. Advanced Vehicle Energy Recovery Assessment (1 per test)
3. Emissions Test Validation (1 per test)

**The dynamometer coefficient and coast down evaluation** report should include test date, operator, vehicle make and model, vehicle weight, payload plus trailer weight, and final test weight, see Attachment 1 in this Part. Additionally, this report will have the actual ABC coefficients used, with validation of their coast down evaluation in units of absolute time difference and percent difference from the calculated values, see Attachment 1 in this Part for details.

**The advanced vehicle energy recovery assessment** report should include energy calculation details average voltage, current, accessory loads, SOC ini, SOC final, SOC delta, etc. The purpose of this report is to capture all the necessary information to characterize the starting and engine energy storage system for a complete analysis of the total energy utilized during testing. This report will include verification of proper placement of the facility's power meter system in comparison to the vehicles CAN based power measurement system.

**The emissions validation** report should include typical routine emission laboratory checks such as THC hang-up, leak checks, proportionality checks, dilution ratio checks, filter face temperatures and analyzer drift specifications relative to the 2010 standards. These verifications are important for measurement of emissions below current standards where measurement error may become significant. Additional reporting to document proper operational conditions, such as temperatures (dilution air, coolant, combustion air), ambient conditions, (barometric pressure, temperature, and dew point temperature) should be included as listed in Attachment 3 in this Part.

## Part C - Attachment 1

UCR | College of Engineering- Center for Environmental Research & Technology

# Dynamometer Coefficients and Coast Down Evaluation

| Test Information | | | |
|---|---|---|---|
| Coast Down Date: | 6/11/2015 | Parasitic File: | 20150611_v |
| Operator: | Eddie | Customer: | |

| Basic Information | | | | |
|---|---|---|---|---|
| Vehicle ID: | 2015_005 | Vehicle Wt: [3] | 15,000 | lb |
| Vehicle Make/Year: | | Payload Wt: [3] | 50,000 | lb |
| Engine Model: | | | | |
| Engine Family: | | Final Test Wt: [3] | 65,000 | lb |

| Horsepower Evaluation | | | |
|---|---|---|---|
| Percent Dif | Calculated HP @ 50 | Observed HP @ 50 | Pass/Fail Criteria |
| -1.6% | 67.83 | 66.78 | Pass |

| Calculated Dyno Road Load Coefficients[2] | | | |
|---|---|---|---|
| | A (lb) | B (lb/mph) | C (lb/mph^2) |
| Calculated | 234.3 | 3.31E-03 | 0.110 |

**Coast Down Parameters**

| Start Speed (mph) | End Speed (mph) | Avg Speed (mph) | Calculated Time (sec) | Force (lbf) | Observed Time (sec) | Force (lbf) |
|---|---|---|---|---|---|---|
| 65 | 55 | 60 | 23.89 | 432.0 | 23.74 | 429.3 |
| 55 | 45 | 50 | 29.57 | 341.0 | 30.08 | 346.9 |
| 45 | 35 | 40 | 36.69 | 277.0 | 37.03 | 279.5 |
| 35 | 25 | 30 | 45.16 | 222.2 | 46.15 | 227.1 |
| 25 | 15 | 20 | 54.06 | 186.5 | 54.98 | 189.7 |

**Coast Down Evaluation (Observed v. Calculated)**

| Start Speed (mph) | End Speed (mph) | Avg Speed (mph) | Abs Time (sec) Difference | Percent Difference | Abs Force (lbf) Difference | Percent Difference |
|---|---|---|---|---|---|---|
| 65 | 55 | 60 | 0.15 | 0.63% | 2.71 | 0.63% |
| 55 | 45 | 50 | 0.51 | 1.70% | 5.881 | 1.72% |
| 45 | 35 | 40 | 0.34 | 0.92% | 2.567 | 0.93% |
| 35 | 25 | 30 | 0.99 | 2.15% | 4.87 | 2.19% |
| 25 | 15 | 20 | 0.92 | 1.67% | 3.175 | 1.70% |

**General Notes**

1) Tires were not low rolling resistance. So no coast down credit for this.
2) Standard frontal area calculation method utilized for Coast Down ABC determination, with a measured vehicle frontal area per SAE J1263 measurement recommendations, a tire rolling resistance of 0.007, and a Cd 0.75 for class 8 Truck.
3) Vehicle weight is the empty weight of the vehicle, payload weight is the program related average payload desired for the the vehicle (such as trailer + goods or passenger weight). Final weight is the sum of the two weights and the weight used for the chassis dyno.

**Part C - Attachment 2 (one per test)**

UCR | College of Engineering- Center for Environmental Research & Technology

# Advanced Vehicle Energy Assessment

| Basic Information | | | |
|---|---|---|---|
| Test ID: | 201503100850 | Customer: | |
| Test Date: | 3/10/2015 | Cycle: | UDDS_x2 & |

**Energy Storage System**

| Reference | System Checks | Value | Ref | % of Ref | Criteria | Pass/Fail |
|---|---|---|---|---|---|---|
| | | | | | | |

**PSU System Checks**

| Reference | System Checks | Value | Ref | % of Ref | Criteria | Pass/Fail |
|---|---|---|---|---|---|---|
| | | | | | | |

**Other System Values**

| System Checks | Value | System Checks | Value |
|---|---|---|---|
| | | | |

**Power Validatoin**

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

**General Notes**

1) Reference value of 15 ppm is based on typical concentration that would be seen in the CVS at the HC standard of 0.15 g/bhp-hr.
2) Determined via dilution factor calculation under 1066.610-2 with selected data removal based on 1065.1001 tolerances and 1066 exclusions.
3) Cell temperature is the outside air temperature.
4) Oil temperature and charge coolant temperature were not available.

## Part C - Attachment 3 (one per test)

UCR | College of Engineering- Center for Environmental Research & Technology

# Emissions Test Validation Report

| Basic Information | | | |
|---|---|---|---|
| Test ID: | 201503100850 | Customer: | |
| Test Date: | 3/10/2015 | Cycle: | UDDS_x2 & |

**CVS System Checks**

| Reference | System Checks | Value | Ref | % of Ref | Criteria | Pass/Fail |
|---|---|---|---|---|---|---|
| 1065.520(f) | Dilute HC Hangup (ppm)[1] | 0.08 | 15.00 | 0.5% | <2% | pass |
| 1065.520(f) | Ambient Bag HC Hangup (ppm)[1] | 0.08 | 15.00 | 0.5% | <2% | pass |
| 1065.345 | Gaseous Sample Leak Check (mol/sec) | 6E-07 | 4E-05 | N/A | <0.5% | pass |
| 1065.545(b) | Bag Proportionality Check | 0.32% | N/A | N/A | <2% | pass |
| 1065.140(e)(2) | CVS Minimum Dilution Ratio | 2.681 | N/A | N/A | >2 | pass |
| 1065.110(b)(2)(iii)(b) | CVS Dilution Factor (carbon balance) | 13.27 | N/A | N/A | 20>DF>7 | pass |
| 1065.140(e)(3) | CVS Residence Time Check (sec) | 0.787 | N/A | N/A | >.5 | pass |
| 1065.140(c)(2) | Tunnel Pressure Differential (kPa) | 0.654 | N/A | N/A | <1.2 | pass |

**PSU System Checks**

| Reference | System Checks | Value | Ref | % of Ref | Criteria | Pass/Fail |
|---|---|---|---|---|---|---|
| 1065.546 | PM Filter Minimum Dilution Ratio[2] | 5.695 | N/A | N/A | 7>DF>5 | pass |
| 1065.140(e)(4) | Filter Temperature (°C) | 51.62 | N/A | N/A | 42>T>52 | pass |
| 1065.345 | PM Sample Leak Check (mol/sec) | 3.E-07 | 4E-05 | N/A | <0.5% | pass |
| 1065.140(e)(3) | PM Residence Time Check (sec) | 1.942 | N/A | N/A | 1<s<5 | pass |
| 1065.140(e)(4) | Filter Face Velocity (3.8 cm stain area) | 97.99 | N/A | N/A | ≤100 | pass |

**Other System Values**

| System Checks | Value | System Checks | Value |
|---|---|---|---|
| Cell Temperature[3] (°C): | 15.10 | Coolant Temperature (°C): | 125.88 |
| Oil Temperature[4] (°C): | n/a | Dilution Air Temperture (°C): | 15.10 |
| Coolant Temperature (°C): | 192.7 | Secondary Dilution Air Temperature (°C): | 23.65 |
| Charge Coolant Temperature (°C): | n/a | Combustion Intake Air Temperature (°C): | 15.10 |
| Barometer (mmHg): | 734.8 | Combustion Intake Air Humidity: | 52% |
| | | Combustion Dew Point (°C): | 6.723 |

**Instrument Verification**

| Compound | % Dif, Rel to Standard/ Uncorrected Value | Pass/Fail 4% Criteria | Compound | % Dif, Rel to Standard/ Uncorrected Value | Pass/Fail 4% Criteria |
|---|---|---|---|---|---|
| THC | 0.01% | Pass | CO | 0.00% | Pass |
| CH4 | - | - | CO2 | -0.41% | Pass |
| NOx | 0.09% | Pass | | | |

**General Notes**

1) Reference value of 15 ppm is based on typical concentration that would be seen in the CVS at the HC standard of 0.15 g/bhp-hr.
2) Determined via dilution factor calculation under 1066.610-2 with selected data removal based on 1065.1001 tolerances and 1066 exclusions.
3) Cell temperature is the outside air temperature.
4) Oil temperature and charge coolant temperature were not available.

## Part D – Electric Vehicle Calculations

The analysis includes time synchronization and calculations for power and energy from various systems. This section describes some of the details of the calculations used in this report.

**Vehicle CAN power:** The vehicle CAN power calculations can be performed based on the product of measured DC current and DC voltage. The vehicle CAN current measurements usually include direction where propulsion current is energy from the battery and regen current is energy to the batteries (regeneration). The power should be provided by the CAN system or calculated by the following formula:

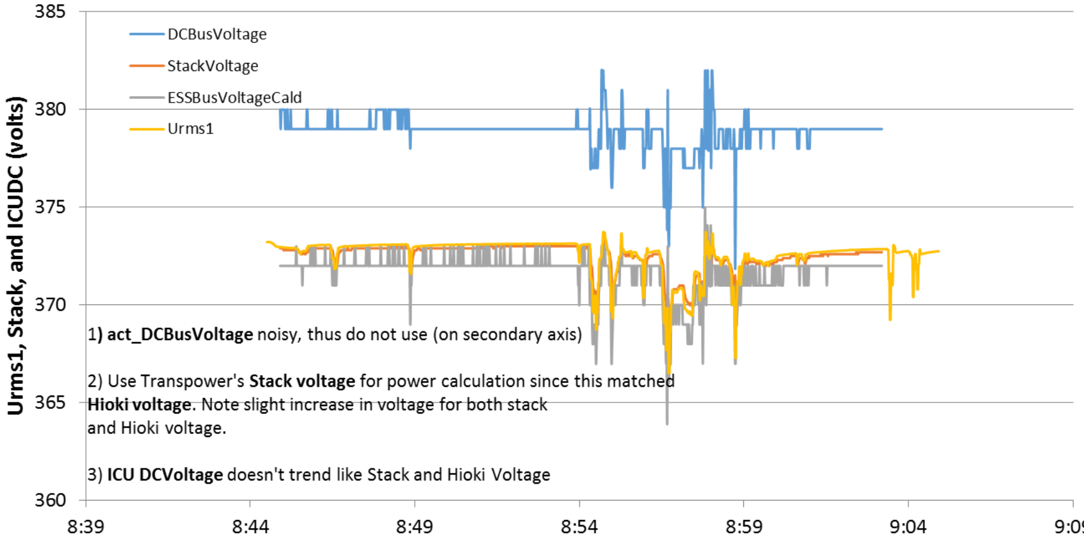
$$\text{Vehicle CAN Power}_i = \sum Current_i * Voltage_i$$

Where:

| | |
|---|---|
| *Vehicle CAN Power* | is the instantaneous vehicle CAN power consumption at time *i*, where propulsion power is the current consumed by the vehicle and regen power is current recovered (regenerated) by the vehicle. |
| *Current* | is the instantaneous vehicle CAN current usage at time *i* |
| *Voltage$_i$* | is the instantaneous vehicle CAN voltage at time *i* |

During previous testing of an electric vehicle, several buss voltages and currents were provided as shown in Figure D-1. It is expected that the testing laboratory will work with the ZET/NZET for the proper voltage, current measurement and power system to represent the total power (propulsion/regeneration plus accessory loads).

Figure D-1 Voltage Measurement Utilized on the CAN Electric Vehicle System



**Vehicle CAN State of Charge**: The vehicle SOC represents the vehicle status and is a relative parameter and is dependent on each manufacturer's claims for range and usage and thus may vary by manufacturer due to their utility of the battery systems. Thus, SOC is generally a calculated value, but is still a reasonable metric for the status of the vehicle and when re-charging is needed. The SOC is typically provided by the vehicle using two methods. One method is the measurement of SOC from the vehicle CAN reporting system and the other is utilizing the display of SOC to the driver. In general, both the ECM-reported value and the visual display are in agreement, suggesting that the SOC-reported data represents the overall status of the vehicle.

The real-time energy accumulation should be calculated including the propulsion and net chassis dynamometer energy and the net electric energy measured during testing. The chassis net energy is the sum of the absorbed and motored energy measured/calculated by the chassis dynamometer and the vehicle net energy is measured by the laboratory's power meter and vehicle CAN system.

## Part E – Quick Start Guide

This summary is a quickstep guide to chassis testing. For the ZET vehicles only E-1 and E-2 are needed. For the NZET vehicles Table E-1, E-3 and E-4 should be used.

Table E-1: Vehicle Inspection and Dynamometer Setup ZET and NZET

| Item | Description |
|---|---|
| **1** | Secure vehicle and record vehicle related information (Part C-Attachment 1); disable any regeneration devices that would prevent the ZET/NZET from coasting under natural conditions. |
| **2** | Obtain tractor weight from supplier or weigh on a scale - record on Part C – Attachment 1 |
| **3** | Count the number of tires contacting the ground and add 8 for the assumed trailer. Multiply this by 125 lb./tire for total weight. Add this weight to the tractor weight above. Then add the payload+trailer weight of 52500 lb. for a total weight.<br><br>Test Weight = Tractor Weight + 52,500 lb. + (No. Tractor Tires+8)*125lb<br><br>For example a 17,000 lb. tractor with 52,500 lb. trailer + payload with 10 tractor wheels would be [Test Weight = 17,000+52,500+(10+8)*125 = **71,750 lb.**] |
| **4** | Calculate frontal area, select the coast down coefficients, and report these with the test weights as listed in Part A. Note the coast down coefficients should be reported in the footnote. |
| **5** | Calculate the simulated coast down times as described in Part A and as shown in Table A-2. Record these as the desired target times in Chassis report listed in Part C. |
| **5** | Calculate the ABCs from the polynomial force vs. speed curve shown in Figure A-2 Part A. Enter these values into the chassis dynamometer |
| **5** | With the test ZET/NZET on the chassis dyno and the dynamometer warmed up following standard practices, perform a coast down validation test. This involves the following:<br>*1.* Bring vehicle up to top speed = 70 mph<br>*2.* Record the coast down time from each of the speed bins listed in Table A-2 Part A.<br>*3.* Compare these times with the desired time (Table A-2)<br>*4.* If the difference is more than 5% for any bin adjust the ABCs to match coefficients to match the coast times (Use good engineering judgment)<br>*5.* Once the targeted values are achieved within 5% the report these values in Part C. |
| | The test ZET/NZET is ready for chassis testing |

Table E-2: Chassis Testing ZET

| Item | Description |
|---|---|
| 1 | Warm up chassis dynamometer and needed instrumentation and perform startup checks and validations. Verify no active faults on test vehicle via the CAN system and/or OBD if available. Report this as listed in Part C |
| 2 | Disable the AC and enable all other accessories enabled |
| 3 | Ensure the vehicle is at a full SOC prior to starting the tests and record the final state in Part C |
| 4 | The overall test generally consists of prescribed sequences of fueling, parking, and driving at specified test conditions. An exhaust emission test generally consists of measuring emissions and other parameters while a vehicle follows the drive schedules specified in the standard-setting part. |
| 5 | (1) Transient cycles. Transient test cycles are typically specified in the standard-setting part as a second-by-second sequence of vehicle speed commands. Operate a vehicle over a transient cycle such that the speed follows the target values. Proportionally sample emissions and other parameters and calculate emission rates as specified in subpart G of this part to calculate emissions. The standard-setting part may specify three types of transient testing based on the approach to starting the measurement, as follows: |
| | (i) A cold-start transient cycle where you start to measure emissions just before starting an engine that has not been warmed up. |
| | (ii) A hot-start transient cycle where you start to measure emissions just before starting a warmed-up engine. |
| | (iii) A hot-running transient cycle where you start to measure emissions after an engine is started, warmed up, and running. |
| | (2) Cruise cycles. Cruise test cycles are typically specified in the standard-setting part as a discrete operating point that has a single speed command. |
| | (i) Start a cruise cycle as a hot-running test, where you start to measure emissions after the engine is started and warmed up and the vehicle is running at the target test speed. |
| | (ii) Sample emissions and other parameters for the cruise cycle in the same manner as a transient cycle, with the exception that the reference speed value is constant. Record instantaneous and mean speed values over the cycle. |

Table E-3: Chassis Testing NZET

| Item | Description |
|---|---|
| **1** | Warm up chassis dynamometer and needed instrumentation and perform startup checks and validations. Verify no active faults on test vehicle via the CAN system and/or OBD if available. Report this as listed in Part C |
| **2** | Disable the AC and enable all other accessories enabled |
| **3** | Ensure the vehicle is at a full SOC prior to starting the tests and that the fuel systems are prepared and record the SOC and fuel levels in Part C |

Table E-4: Emissions testing NZET

| Item | Description |
|---|---|
| **1** | Warm up chassis dynamometer and needed instrumentation and perform startup checks and validations. Verify not active faults on test vehicle. |
| **2** | Prepare the fuel for the test including documenting the type of fuel either by analysis or utilizing good engineering judgment. |

## Part F – GHG Regulatory Standards and References

The references to the GHG standards listed in Table I-7 from the Federal Register are based on vehicle chassis testing (Tractors, Trailers, Vocational Diesel, and Vocational Gasoline) and engine testing (Diesel Engines; see the Federal Register.) The chassis GHG test cycles are the ARB transient cycle, 55 mph cruise with grade, 65 mph cruise with grade, and an idle test. The engine tests (boxed in section) are evaluated on the FTP and SET engine test cycles.

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TABLE I–7—PROPOSED FINAL (MY 2027) NUMERIC STANDARDS BY REGULATORY SUBCATEGORY

| Regulatory subcategory | $CO_2$ grams per ton-mile (for engines $CO_2$ grams per brake horsepower-hour) | Fuel consumption gallon per 1,000 ton-mile (for engines gallons per 100 brake horsepower-hour) |
|---|---|---|
| Tractors:. | | |
| Class 7 Low Roof Day Cab | 87 | 8.5462 |
| Class 7 Mid Roof Day Cab | 96 | 9.4303 |
| Class 7 High Roof Day Cab | 96 | 9.4303 |
| Class 8 Low Roof Day Cab | 70 | 6.8762 |
| Class 8 Mid Roof Day Cab | 76 | 7.4656 |
| Class 8 High Roof Day Cab | 76 | 7.4656 |
| Class 8 Low Roof Sleeper Cab | 62 | 6.0904 |
| Class 8 Mid Roof Sleeper Cab | 69 | 6.7780 |
| Class 8 High Roof Sleeper Cab | 67 | 6.5815 |
| Trailers: | | |
| Long Dry Box Trailer | 77 | 7.5639 |
| Short Dry Box Trailer | 140 | 13.7525 |
| Long Refrigerated Box Trailer | 80 | 7.8585 |
| Short Refrigerated Box Trailer | 144 | 14.1454 |
| Vocational Diesel: | | |
| LHD Urban | 272 | 26.7191 |
| LHD Multi-Purpose | 280 | 27.5049 |
| LHD Regional | 292 | 28.6837 |
| MHD Urban | 172 | 16.8959 |
| MHD Multi-Purpose | 174 | 17.0923 |
| MHD Regional | 170 | 16.6994 |
| HHD Urban | 182 | 17.8782 |
| HHD Multi-Purpose | 183 | 17.9764 |
| HHD Regional | 174 | 17.0923 |
| Vocational Gasoline: | | |
| LHD Urban | 299 | 33.6446 |
| LHD Multi-Purpose | 308 | 34.6574 |
| LHD Regional | 321 | 36.1202 |
| MHD Urban | 189 | 21.2670 |
| MHD Multi-Purpose | 191 | 21.4921 |
| MHD Regional | 187 | 21.0420 |
| HHD Urban | 196 | 22.0547 |
| HHD Multi-Purpose | 198 | 22.2797 |
| HHD Regional | 188 | 21.1545 |
| Diesel Engines: | | |
| LHD Vocational | 553 | 5.4322 |
| MHD Vocational | 553 | 5.4322 |
| HHD Vocational | 533 | 5.2358 |
| MHD Tractor | 466 | 4.5776 |
| HHD Tractor | 441 | 4.3320 |

## Part G – Vehicle Inspection Report Example

Veh. No.:________________ VIN:____________________________________________

| | |
|---|---|
| ARRIVAL DATE: | ARRIVAL TIME: |
| AGENCY RELEASE SIGNATURE: | |
| DELIVERED BY: | |

| | |
|---|---|
| DEPARTURE DATE: | DEPARTURE TIME: |
| ENGINEER RELEASE SIGNATURE: | |
| RETURNED TO: | |

**Retest?** ☐Yes ☐No. If Yes, reason for retest:_______________________________________ ______

### Engine Compartment

**REMARKS**

| | | |
|---|---|---|
| OIL LEVEL: | ☐ FULL ☐ LOW | |
| COOLANT LEVEL: | ☐ FULL ☐ LOW | |
| POWER STEERING FLUID: | ☐ FULL ☐ LOW | |
| CONDITION OF BELTS: | ☐ GOOD ☐ WORN | |
| CONDITION OF AIR FILTER: | ☐ CLEAN ☐ DIRTY | |
| VISIBLE EXHAUST LEAKS: | ☐ YES ☐ NO | |
| VISIBLE FLUID LEAKS: | ☐ YES ☐ NO | |
| ENGINE APPEARANCE: | ☐ CLEAN ☐ GREASY | |

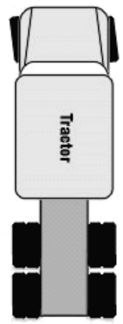
### Equipment

| | | |
|---|---|---|
| SERVICE BRAKES: | ☐ GOOD ☐ POOR ☐ TOUCHY | |
| PARKING BRAKES: | ☐ GOOD ☐ POOR | |
| POWER DIVIDER: | ☐ GOOD ☐ DEFECTIVE ☐ NOT EQUIPPED | |
| TRANSMISSION: | ☐ NORMAL ☐ HARD SHIFTS ☐ NOISY | |
| LUG NUT COVERS: | ☐ YES ☐ NO NUMBER MISSING: | |
| TIRE CONDITION: | FRONT | REAR |
| | ☐ GOOD ☐ WORN | ☐ GOOD ☐ WORN |
| REMARKS: | | |

### Vehicle Interior

| | | |
|---|---|---|
| UPHOLSTERY: | ☐ CLEAN ☐ DIRTY ☐ STAINED ☐ DAMAGED | REMARKS: |
| CARPET: | ☐ CLEAN ☐ DIRTY ☐ STAINED ☐ DAMAGED | REMARKS: |
| GENERAL APPEARANCE: | ☐ CLEAN ☐ DIRTY | REMARKS: |
| GAUGES AND CONTROLS: | ☐ OPERATE PROPERLY ☐ DEFECTIVE | REMARKS: |

**Vehicle Exterior** (mark the location and describe any dents, scratches, damaged lights, mirrors etc. when the vehicle was received by UCR):




1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________
12. ____________________
13. ____________________
14. ____________________
15. ____________________
16. ____________________
17. ____________________
18. ____________________

**Was this vehicle damaged while in test lab custody?** ☐ Yes No If Yes, explain:____________

____________________________________________

____________________________________________

____________________

**General Remarks**

____________________________________________

____________________________________________

____________________________________________

## Appendix III: Near-Dock, Local, and Regional Drayage On-Road Test Routes

The on-road test routes include areas that are within six to eight miles of the Ports for near-dock operations, areas that are between eight to 20 miles of the Ports for local operations, and areas that are between 20 to 120 miles in length for regional operations.

Test routes are selected and repeated for comparison purposes during the controlled truck testing and demonstration. Note that not all ZET/NZET prototypes may complete all three test routes; for example, overhead catenary-powered ZETs may, by design, limit operations to near-dock and local container drayage.

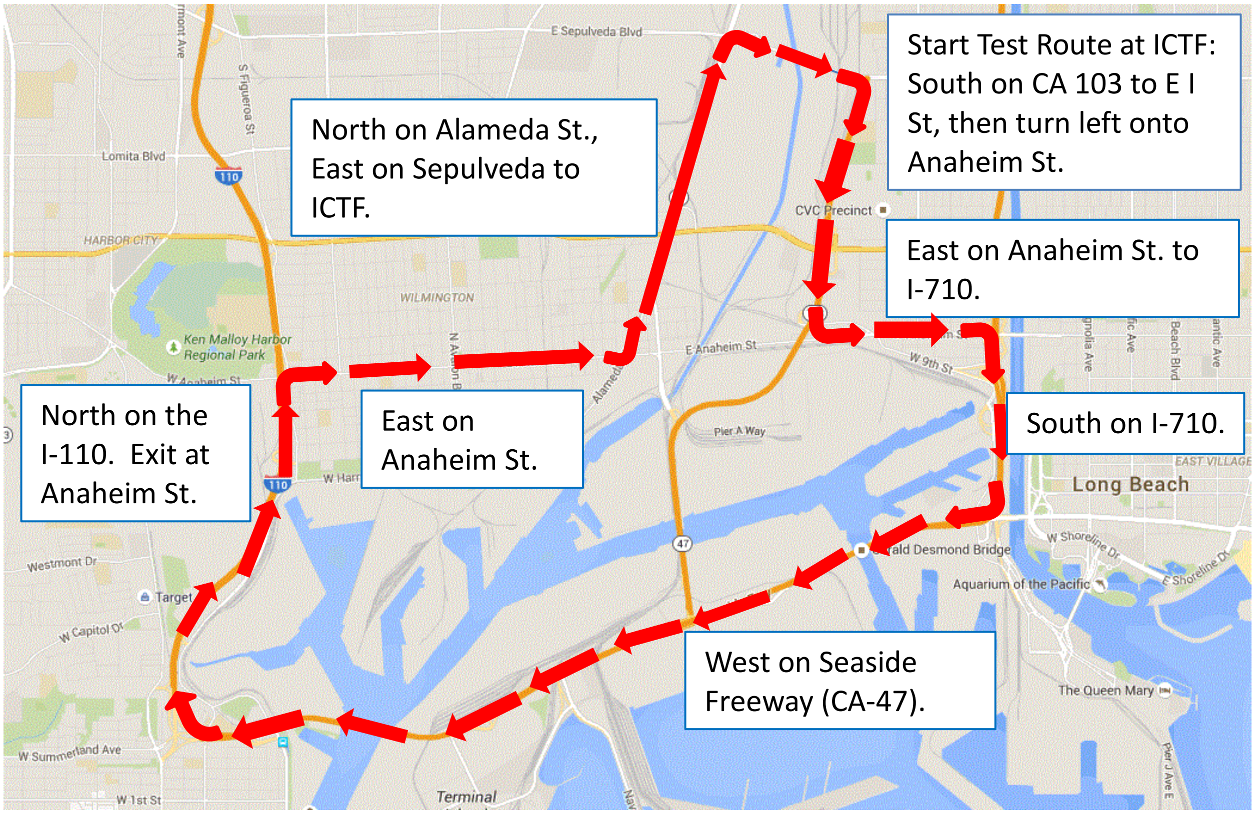
A. Near Dock Test Route (short haul): This route begins and ends at the ICTF, includes freeway segments (SR-103, I-710, and I-110) and roadway segments. Both the Gerald Desmond Bridge and Vincent Thomas Bridge are crossed one time each.

Route Details:

1. Begin at the ICTF. Take CA-103 South to East I Street; turn left onto Anaheim St.
2. Proceed East on Anaheim St. to the I-710.
3. Take the ramp to the South I-710; continue on the I-710 to the West Seaside Freeway (CA-47).
4. Continue on CA-47 to the North I-110.
5. Exit at Anaheim St. and proceed East on Anaheim Street.
6. Turn left onto Alameda St. and proceed North to Sepulveda Ave.
7. Turn right onto Sepulveda Ave. and return to ICTF.

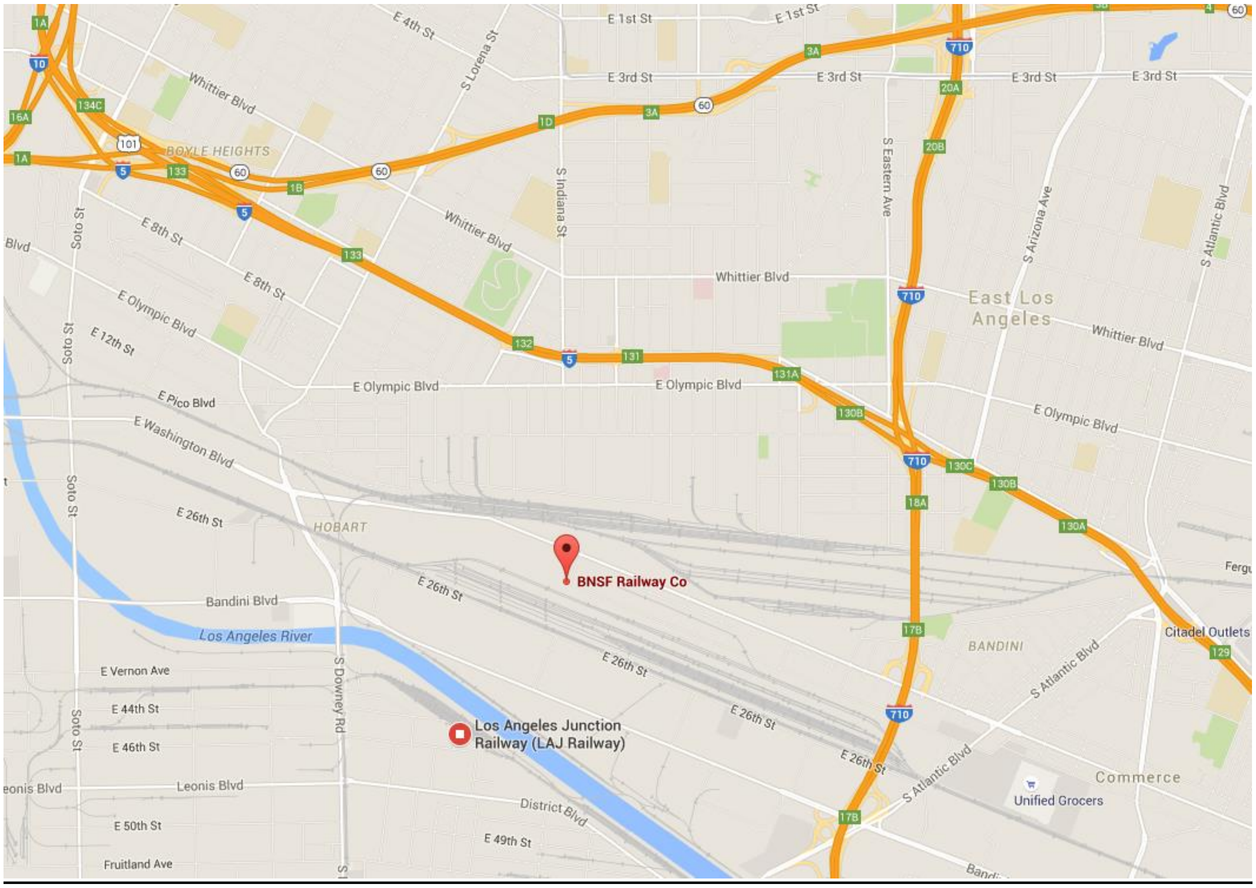
This route is mapped as follows in Figure A-1, below:

Figure A-1: Simulated Near-Dock Container Dray Test Route



<u>B. Local Test Route</u>: This route is intended to demonstrate real-world medium distance container movement. The start/endpoint for this route is a marine terminal located at either the Port of Long Beach or Port of Los Angeles. The destination is the BNSF Hobart Railyard located in the City of Commerce, approximately four (4) miles southeast of downtown Los Angeles. See Figure B-1. Hobart Railyard is also located within a few miles of major roadways such as I-5, Highway 60, I-10 and the I-710 freeway. **The vehicle demonstrator defines the specific roadways and freeways for this route.**

Figure B-1: Simulated Local Container Dray Destination




<u>C. Regional Test Route</u>: This route simulates long haul container movement in the SoCAB. The vehicle demonstrator also defines the Regional route. The start/endpoint of this route is a marine terminal located at either the Port of Long Beach or Port of Los Angeles. The destination is user-defined distribution center located in Mira Loma, Riverside, or Moreno Valley.