ZERO/NEAR-ZERO EMISSIONS
YARD TRACTOR TESTING & DEMONSTRATION GUIDELINES

Port of LONG BEACH
The Green Port

LA THE PORT OF LOS ANGELES

THE PORT OF LONG BEACH & THE PORT OF LOS ANGELES
SEPTEMBER 2017

ZERO/NEAR-ZERO EMISSIONS YARD TRACTOR TESTING & DEMONSTRATION GUIDELINES

THE PORT OF LONG BEACH & THE PORT OF LOS ANGELES

SEPTEMBER 2017

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acronyms and Abbreviations

ARB	Air Resources Board
ANSI	American National Standards Institute
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
CGC	Cornerless Gathering Chassis
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COV	Coefficient of Variation
DC	Direct Current
DOT	US Department of Transportation
DPF	Diesel Particulate Filter
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
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
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

ACRONYMS AND ABBREVIATIONS (CONTINUED)

hp	Horsepower
ICTF	Intermodal Container Transfer Facility
kW	kilowatt
kWh	kilowatt-hour
lb.	Pound
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
OBD	Onboard Diagnostics
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration
PDT	Port Yard tractor
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
RPM	Revolutions Per Minute
SAE	Society of Automotive Engineers
SoCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
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
UC	California Unified Cycle
UCR	University of California-Riverside
UDDS	Urban Dynamometer Driving Schedule
ULSD	Ultra-Low Sulfur Diesel
VAC	Volts Alternating Current
WVU	West Virginia University

INTRODUCTION

The Ports have an interest in establishing guidelines for the technical evaluation, performance testing, and durability of off-road zero and near-zero emissions cargo handling equipment (CHE). CHE are used extensively to move cargo, particularly containerized cargo within marine terminals, intermodal container transfer facilities, and distribution facilities. To that end, this document provides guidance for vehicle design and development for advanced technology zero and near-zero emission CHE designers and manufacturers seeking to partner with the ports in a development, demonstration, and incentive program. This guidance includes:

- Recommended **Vehicle Design & Performance Goals**;
- Recommendations on how to prepare key vehicle specification and testing documentation **Test Plan Development**; and
- What the Ports consider a sufficient level of in-use vehicle testing and demonstration – **In-Use Demonstration**.

At the Ports of Long Beach and Los Angeles, yard tractors are the most common CHE used in on-terminal container movement. According to the 2016 Air Emissions Inventories, there are over 1,800 yard tractors that operate at the Ports, accounting for approximately 52% and 48% of total CHE at the Port of Long Beach and Port of Los Angeles, respectively. Yard tractors, are also known as terminal tractors, utility tractor rigs (UTR), yard trucks, yard goats, or yard hostlers. Throughout this document, the term **yard tractor** will be used to describe and refer to this type of non-road utility vehicle.

This guidance document does not represent a binding obligation on any vehicle manufacturer or port marine terminal. However, this testing and demonstration guidance may, in total or in part, be incorporated into contractual obligations associated with a port-sponsored yard tractor project. The ports also reserve the right to utilize the minimum performance capabilities specified herein as evaluation criteria in future port-sponsored zero and near-zero yard tractor development, demonstration, and incentive programs.

This document is comprised of three primary parts:

- <u>Part A – Applicable Technologies, Regulations, and Minimum Yard Tractor Performance Requirements</u>: Part A sets forth **minimum yard tractor design, regulatory compliance, and performance requirements** for heavy-duty yard tractors operating at the ports.
- <u>Part B – Test Plan Development Guidelines</u>: Part B specifies the essential components of a zero/near-zero **yard tractor test plan**, including guidelines for the preparation of a vehicle technical specification, vehicle performance specification, as well as testing requirements and options;

- Part C – In-Use Demonstration Plan Development Guidelines: Part C specifies the elements of a zero/near-zero **on-terminal demonstration plan** in partnership with a port tenant or intermodal facility and includes recommendations for vehicle acceptance testing and on-terminal testing.

  - ✓ Port-Recommended Design & Performance Goals
  - ✓ Test Plan Development, including
    - Technical Specification
    - Emissions Verification
    - Performance Validation
  - ✓ In-Use Demonstration

PART A: APPLICABLE TECHNOLOGIES, REGULATIONS, & MINIMUM YARD TRACTOR PERFORMANCE REQUIREMENTS

1.0 Applicable Zero/Near-Zero Technologies

This document is applicable to advanced technology heavy-duty yard tractors primarily operating in a port marine terminal or intermodal container facility. These vehicles are by definition non-road trucks and are not registered as motor vehicles under California Vehicle Code Section 4000, et seq.

Yard tractors intended for on-road use – even minimal on-road use – must comply with US Department of Transportation (DOT), US EPA, and California Air Resources Board (CARB) regulations. This document pertains only to non-licensed yard tractors that are not operated on public roadways.

Manufacturers of DOT/EPA-compliant zero and near-zero emission yard tractors should consult the Federal, State, and Port Requirements for on-road container transport vehicles included in the ports' "Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines" for information pertaining to minimum vehicle equipment and safety requirements.

1.1 Zero-Emission Yard Tractors

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

Yard tractors currently undergoing development and demonstration that meet the definition of zero emissions include the following:

- Battery Electric Yard Tractors – a battery electric yard tractor 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. These are also referred to as plug-in electric trucks.
- Fuel Cell Yard Tractors – a fuel-cell electric yard tractor 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 or recharge the vehicle's battery system in a hybrid fuel cell drivetrain system.
- Inductively Charged Electric Yard Tractors – an electric yard tractor 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.

1.2 Near-Zero Emission Yard Tractors

The ports define a "near-zero" emissions yard tractor 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 when tested in accordance with Federal Test Procedures (FTP) under 13 CCR 1956.8. Additionally, total particulate matter (PM) emissions should be no greater than the 2010 EPA standard of 0.01 g/bhp-hr.

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

- <u>Alternative Fuel Yard Tractors</u> – yard tractors equipped with a near-zero engine operating on dedicated alternative fuel. 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.
- <u>Hybrid and Plug-in Hybrid Yard Tractors using Alternative Fuel</u> – yard tractors equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing Alternative Fuels.
- <u>Hybrid and Plug-in Hybrid Trucks using Conventional Fuel</u> – yard tractors equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing conventional fuels or conventional fuels with renewable fuel content. Conventional fuels include motor vehicle fuels that are petroleum derived, such as gasoline and diesel fuels. Conventional fuels with renewable content include, as examples, biodiesel and gasoline ethanol blends such as E85.
- <u>Conventional Fuel Yard Tractors</u> – yard tractors equipped with a near-zero engine operating on dedicated conventional fuel such as low sulfur diesel fuel or synthetic diesel fuel.

2.0. Applicable Requirements & Regulations

Zero-emission and near-zero emission yard tractors participating in a port-sponsored vehicle development, testing, or demonstration project must adhere to the following vehicle requirements and regulations. Any waiver of port-specific requirements 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 another state or federal regulatory agency.

2.1 Federal Requirements:

- US Department of Labor/Occupational Safety and Health Administration (OSHA) – all zero/near-zero vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to OSHA Regulations, Part 1926 Section 1926.601, "Motor Vehicles, Mechanized Equipment, and Marine Operations"
  https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10768

- US Department of Labor/Occupational Safety and Health Administration – all zero/near-zero vehicles participating in a port-sponsored development, demonstration, or incentive project must comply with all applicable requirements pursuant to OSHA Regulations, Part 1910 Section 1910.178, "Powered Industrial Trucks".*https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9828*

2.2 Port Requirements

- Society of Automotive Engineers (SAE) Technical Conformity – all zero/near-zero 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. In addition, electric vehicle supply equipment (EVSE) must be Underwriters Laboratory (UL) listed in accordance with UL Category Code FFTG, DC power, or FFWA, AC power, as applicable. *http://site.ul.com/global/documents/corporate/aboutul/publications/newsletters/electricalconnections/November10.pdf*
- American National Standards Institute (ANSI) – All manufacturers of advanced technology yard tractors should ensure their vehicles comply with the minimum requirements for powered industrial trucks specified in ANSI B56.1-1969 (also see OSHA 1910.178, above).
- International Organization for Standardization (ISO) Technical Conformity - all zero/near-zero yard tractors 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 Yard Tractor Performance Guidelines

Yard tractor activities in marine terminals generally fall into three main categories: ship work, rail work, and dock work. Ship work involves the loading and unloading of containers onto and from container vessels. Rail work comprises loading and unloading containers to and from cargo trains, while dock work consists of moving containers within a terminal yard, such as the consolidation of containers. In-use data obtained from a marine terminal at the Port of Long Beach suggests rail work imposes the most strenuous loads on yard tractors.

To assist in vehicle design, the minimum capabilities, or performance metrics, of a yard tractor operating in typical marine terminal or near dock rail yard operations are provided in Table 3-1.

Note that the minimum performance metrics identified in Table 3-1, below, are applicable to non-road zero/near-zero yard tractors.). Yard tractors configured for both on-road and non-road use should, at a minimum, meet the vehicle performance specifications for short-haul drayage as specified in the ports' "Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines".

Table 3-1: Minimum Zero/Near-Zero Yard Tractor Performance Guidelines

Minimum Performance Guideline	Performance Metric
Design Duty Cycle	One (1) 8-hour shift with no opportunity charging/refueling assumed Two (2) 8-hour shifts with opportunity charging/refueling assumed
Freight Load Capacity	70,000 pounds (loaded container plus simple chassis or CGC)
Top Speed[1]	25 mph at zero grade (0% grade)
Gradeability at Vehicle Launch	20% grade at 81,000 GCW
Gradeability Sustained at 10 mph	15% grade at 81,000 GCW

For the purpose of these Guidelines, a yard tractor "shift" is defined as an eight (8) hour operational period comprised of 25% rail work, 70% ship work, and 5% yard work. Table 3-2 lists the minimum requirements for the number of container movements (pulls per shift, duration, loads, and average speeds associated with the design duty cycle for an 8-hour shift). Note that "load" includes the weight of the container plus either a simple chassis or cornerless gathering chassis:

Table 3-2: Design Duty Cycle – 8-hour Shift Minimum Requirements

Number of Container Movements (pulls per shift)	Duration (sec.)	Load (lbs.)	Average Speed (mph)
84	60	45,000	9
30	45	50,000	8
6	120	30,000	15

[1] Top speed for zero/near-zero emission yard tractors is typically governed as an energy conservation strategy.

In addition, zero/near-zero yard tractor manufacturers should strive to develop commercialized vehicles that offer the following performance attributes and capabilities comparable to diesel yard tractors:

- **Reliability** – Zero/near-zero yard tractor operational availability or Mean Time Between Failures (MTBF) is comparable to a diesel yard tractor. It is understood that prototype or preproduction advanced technology yard tractors may experience higher failure rates;
- **Durability** – Zero/near-zero yard tractor useful service life is comparable to a diesel yard tractor;
- **Maintainability** - Zero/near-zero yard tractor advanced technology drivetrain does not impose additional maintenance requirements or accessibility issues as compared to a diesel yard tractor;
- **Serviceability** - Zero/near-zero yard tractor advanced technology drivetrain does not impede serviceability of the yard tractor chassis or non-driveline systems;
- **Operability** - Zero/near-zero yard tractor operator experience is equal to or more favorable than a diesel yard tractor.

PART B: TEST PLAN DEVELOPMENT

4.0 Yard Tractor Technical Specification Guidelines

Any zero/near-zero yard tractor Test Plan developed by a vehicle developer/manufacturer must include a detailed technical description of the zero/near-zero vehicle configuration and a technical specification detailing the vehicle drivetrain design at both the system and subsystem levels.

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 in a more generic manner.

The Technical Specification of a Zero/Near-Zero Yard Tractor Test Plan should include the following information identified in Sections 4.1 through 4.7, as applicable:

4.1 Baseline OEM Vehicle Description

Zero/near-zero yard tractors that are OEM, conversions, retrofits, repowers, or refurbishments of a commercial conventional yard tractor should provide information regarding the make, model, year, and top-level specifications of the baseline OEM truck.

4.2 Yard Tractor Description

The test plan should include a technical description of the zero-or near-zero advanced technology drivetrain architecture and major systems; i.e., battery electric vehicle, parallel hybrid, series hybrid, fuel cell hybrid, as applicable.

4.3 Mass and Dimensional Properties

The manufacturer should provide estimates of the zero/near-zero yard tractor's weight, gross combined weight rating (GCWR), gross axle weight rating (GAWR), and overall vehicle dimensions.

4.4 Drivetrain Components

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

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

4.5 Energy Storage System(s)

Zero/near-zero yard tractor manufacturers should provide a detailed technical description of the vehicle energy storage systems, including:

- **Battery Pack Description** - including 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), and identify the weight of each battery module, 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** – 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** – A technical description of the Battery Management System (BMS).
- **Conventional or Alternative Fuel Storage Vessels** – 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, zero/near-zero manufacturers should provide expected refueling times at various fuel pressures and tank fills.

4.6 Battery Charger Connections

Yard tractor designs that include a plug-in capability should describe the type, size, and location of the vehicle charging port, as applicable.

4.7 Recharging Infrastructure (EVSE) Interface

The EVSE interface to be provided by the Ports is a 480-volt, 250-ampere, three-phase electric service. Zero/near-zero vehicles that include a plug-in recharging capability should ensure the onboard or off-board recharging systems are compatible with the Port's electric service.

5.0 Yard Tractor Testing Guidelines

Zero/near-zero yard tractors intended to operate in a marine terminal or near dock intermodal facility are expected to undergo verification analysis to validate the vehicle's performance and zero/near-zero emissions capabilities.

Yard tractors subject to these Guidelines are non-road vehicles. As such, they operate in a limited access, regulated facility alongside other professional operators and do not interact with the general motoring public. Thus, there is a lower level of risk as compared to prototype vehicles that operate on public roadways. A yard tractor failure within the confines of a marine terminal or intermodal yard does not pose the same level of liability or traffic disruption as a drayage truck breakdown on public roads. As a result, the testing guidelines for an advanced technology yard tractor are designed to afford greater flexibility while still achieving the Ports' goal of verification and validation of a prototype vehicle design and performance capabilities.

5.1 Emissions Verification

The Ports are pursuing advanced technology yard tractors as a strategy to reduce criteria air pollutants and Greenhouse Gas (GHG) emissions, specifically NOx and PM, in accordance with the joint Ports' Clean Air Action Plan (CAAP). Thus, verification that port and other public agency-sponsored yard tractors are achieving air pollutant reductions is a key element of yard tractor testing and demonstration. The following sections provide guidance to conduct emissions testing and verification for zero and near-zero yard tractor prototype vehicles.

5.1.1 Zero-Emission Yard Tractor Emissions Verification

Zero-emission yard tractors, those that have zero tailpipe emissions, are not required to undergo any additional emissions testing or verification. These types of yard tractors include plug-in battery-electric vehicles, hydrogen fuel cell-powered yard tractors, or electric yard tractors that use wireless or inductive charging.

5.1.2 Near-Zero Emission Yard Tractor Emissions Verification

The Ports' have defined "near-zero" emission levels to be less than or equal to the CARB Optional NOx standard of 0.02 g/bhp-hr with PM levels at or below the EPA 2010 standard of 0.01 g/bhp-hr when evaluated under the heavy-duty FTP test cycle[2]. This equates to a NOx emissions rate 90% lower than the 2010 EPA on-road heavy-duty engine standard.

Advanced technology yard tractors that are equipped with an on-road engine that is certified by CARB to the Port-defined near-zero emission levels are not required to undergo any additional emissions testing or verification.

5.1.3 Near-Zero Emission Yard Tractor Emissions Verification – Testing Requirements

Advanced technology yard tractor designs may be capable of demonstrating equivalency with the Ports' near-zero emissions definition, even if equipped with an engine certified above the CARB Optional NOx standard. An example is a battery-dominant hybrid-electric drivetrain configuration that utilizes a small displacement engine as a range extender.

In cases where a manufacturer of an advanced technology yard tractor seeks near-zero emissions status, but does not meet the engine certification requirements delineated above in Section 5.1.2, near-zero emissions equivalency can be demonstrated in one of the following ways:

a) If the prototype yard tractor is equipped with an engine that is certified by CARB under a different test cycle, including but not limited to the California Unified Cycle (UC), the manufacturer can seek documentation from CARB attesting that the proposed engine meets emissions levels equivalent to the Optional NOx standards. An example is a hybrid-electric yard tractor that incorporates an on-road engine certified under the UC in units of "grams per mile" as opposed to "g/bhp-hr".
b) The prototype yard tractor undergoes chassis dynamometer emissions testing at a CARB-recognized testing laboratory. The test cycles to be used for yard tractor emissions testing are described in Section 5.3, "Yard Tractor Performance Validation".

[2] The FTP (Federal Test Procedure) heavy-duty transient cycle is used for regulatory emission testing of heavy-duty on-road engines [CFR Part 86 and Part 1065]. The FTP transient test is based on the UDDS chassis dynamometer driving cycle.

The Ports recognize that prototype zero and near-zero yard tractor designs are most likely not capable of attaining vehicle speeds required for testing under the heavy-duty FTP test cycle. The chassis dynamometer test cycles discussed in Section 5.3 are designed to accurately replicate an in-use yard tractor duty cycle and thus do not require yard tractor operation at a speed higher than approximately 25 miles per hour. As a result, the emission levels measured under the FTP cycle cannot be directly compared to emissions measured under the yard tractor test cycle.

In the interim, prototype yard tractor emissions test results will be evaluated by the Ports, with assistance from CARB and the emissions laboratory conducting the testing to determine near zero equivalency on a case-by-case basis.

5.2 Performance Validation

Advanced Technology yard tractor manufacturers seeking to partner with the Ports in a yard tractor demonstration project or port-sponsored incentive program should subject their pre-commercial yard tractors to independent performance testing. The Ports strongly recommend prototype vehicles undergo **chassis dynamometer testing** at a CARB-certified laboratory using the Ports' Yard Tractor Duty Cycle.

The Ports, in partnership with the US EPA, funded CALSTART to manage development of these test cycles to provide emissions, performance, safety, vehicle-to-vehicle comparisons, and modeling characteristics for zero/near-zero yard tractors.

Port-recommended chassis dynamometer testing includes two yard tractor-specific transient test cycles and one steady-state test cycle. West Virginia University – Center for Alternative Fuels, Engines, and Emissions (WVU) developed the two transient test cycles based on data acquired from data logged yard tractors operating under in-use conditions at the Port of Long Beach. Inclusion of a steady-state test cycle in yard tractor emissions and performance testing was recommended by the University of California-Riverside, Center for Environmental Research and Technology (UCR CE-CERT). UCR has successfully employed this chassis dynamometer testing protocol for battery-electric yard tractors, and there are no known limitations for applying this test protocol to ICE, hybrid, or any other advanced technology yard tractor drivetrain configuration.

5.2.1 Chassis Dynamometer Testing – Transient Test Cycles

The transient test cycles developed by WVU include one cycle representing a medium-heavy load and a second cycle representing a heavy-heavy load. The gross combined vehicle weights (GCVW) corresponding to medium–heavy and heavy-heavy loads are as follows:

- Average weight for medium-heavy duty category: 11,888 kg. (26,209 lbs.)
- Average weight for heavy-heavy duty category: 32,837 kg. (72,393 lbs.)

Each transient test cycle is 1200 seconds in duration, the first 300 seconds representing rail work activity and the last 900 seconds representing ship work activity. The Driving Schedule, represented as yard tractor speed as a function of time for the medium-heavy and heavy-heavy test cycles are shown below in Figures 5-1 and 5-2, respectively:

Figure 5-1: Medium-Heavy Load Driving Schedule

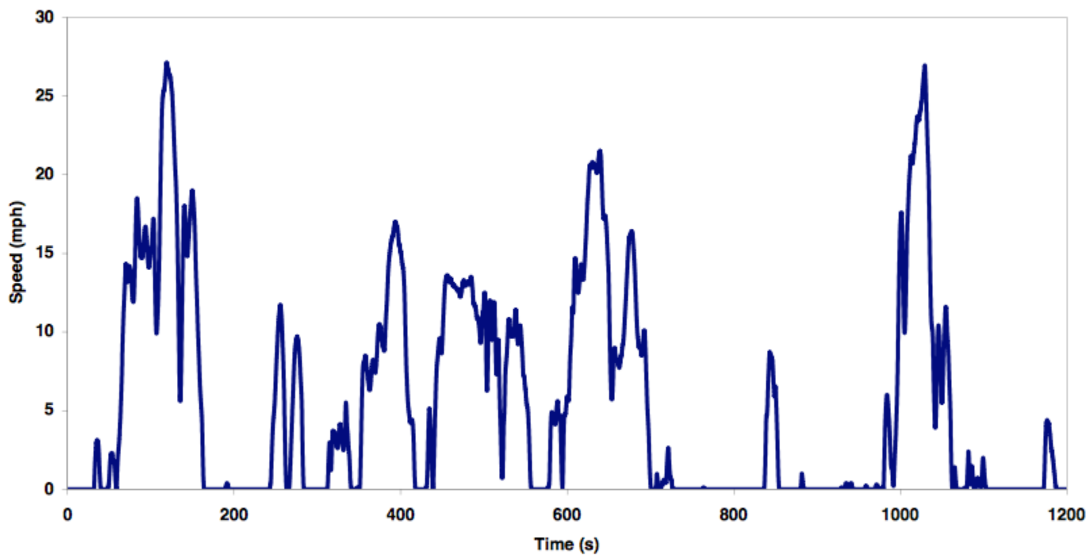
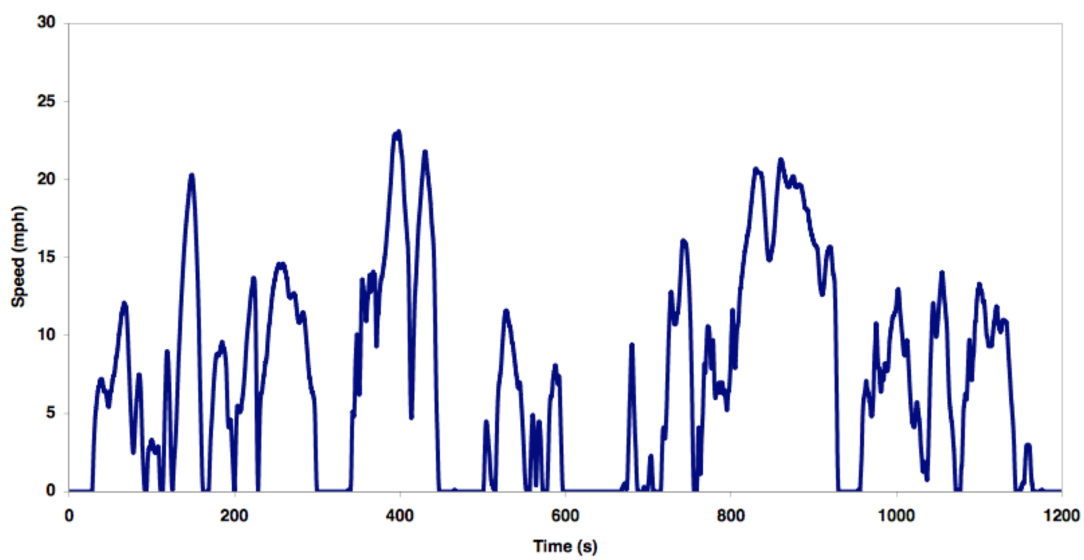


Figure 5-2: Heavy-Heavy Load Driving Schedule



5.2.2 Chassis Dynamometer Testing – Steady-State Test Cycle

The steady state test follows the ISO 8178 test cycle shown below in Table 5-3. For off-road engine certification, this test is normally conducted using an engine dynamometer. For the purpose of the yard tractor test protocol, it is conducted on a chassis dynamometer.

Figure 5-3: ISO 8178-C1 Steady-State Cycle[3]

Mode number (cycle B)	1	2	3	4	5	6	7	8	9	10	11
Mode number (cycle C1)	**1**	**2**	**3**		**4**	**5**	**6**	**7**			**8**
Speed 1)	Rated speed					Intermediate speed					Low-idle speed
Torque 1), %	100	75	50		10	100	75	50			0
Weighting factor	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15

Appendix II of these guidelines describes the chassis dynamometer performance validation testing in greater detail.

5.3 Data Collection & Analysis

Data collected during yard tractor testing includes, but is not limited to load, distance, speed, and environmental 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.

5.4 Reporting

Dynamometer testing reporting should include, at a minimum, a summary of the tests performed, comments during testing, comparisons between chassis and vehicle power measurements, SOC Net energy systems, differences in regeneration power, and analysis of expected all-electric range, if applicable.

[3] Figure courtesy of UCR CE-CERT.

PART C: IN-USE DEMONSTRATION PLAN DEVELOPMENT GUIDELINES

6.0 Recommended On-Terminal Demonstration Protocols

This section describes the port-recommended procedures for conducting an on-terminal demonstration of a zero/near-zero yard tractor Advancement to the on-terminal demonstration phase assumes that the zero/near-zero vehicle has undergone vehicle laboratory testing in accordance with the guidelines included in Part B, Test Plan Development.

In-Use Demonstration is comprised of three primary phases:

1) Yard Tractor Acceptance Testing
2) Controlled On-Terminal Testing
3) Revenue On-Terminal Demonstration

Each of the phases of In-Use Demonstration is detailed in Sections 6.1 through 6.3.

6.1 Acceptance Testing

Prior to conducting any zero/near-zero yard tractor performance testing or container movement within a marine terminal or intermodal rail yard, it is recommended that the vehicle undergo thorough acceptance testing. Acceptance testing is typically conducted jointly by the vehicle manufacturer and the marine terminal that will demonstrate the vehicle.

6.1.1 Acceptance Testing Parameters

The following parameters are recommended for inclusion in any zero/near-zero yard tractor 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 zero/near-zero yard tractor.

- Complete electrical system audit, including EVSE charging efficiency
- Dimensional requirements audit
- Water test to ensure integrity of electrical drivetrain components at the system and subsystem level, including EVSE
- Function test of OEM yard tractor systems, subsystems and components not modified during vehicle conversion
- Vehicle top speed or verification of top speed if governed
- Acceleration tests
- Brake stop tests
- Gradeability test, including both starting grade and sustained speed at grade
- Air/brake system audit, as applicable
- Vehicle weight
- Individual axle weight
- 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 (if DOT certified)
- 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

6.1.2 Documentation and Reporting Guidelines

The results of yard tractor 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 marine terminal or intermodal facility participating in the testing should certify the acceptance testing results, including recommended corrective actions.

6.2 Controlled On-Terminal Testing

Following successful completion of vehicle acceptance testing, the marine terminal, in coordination with the prototype yard tractor manufacturer, will initiate on-terminal driving trials and performance testing. This is to ensure the yard tractor is capable of meeting the rigorous duty cycle requirements for ship and rail work.

6.2.1 On-Terminal Testing

Because yard tractors typically operate in a limited access, regulated facility alongside other professional operators, there is a lower level of risk as compared to prototype vehicles that operate on public roadways. Due to the reduced liability, the on-terminal testing guidelines for an advanced technology yard tractor allow for greater manufacturer and operator flexibility in designing initial performance testing.

The Ports recommend that manufacturers and operators develop an on-terminal testing plan that duplicates the minimum performance goals outlined in Section 3, Table 3-2 (shown below). This can be done in an accelerated manner to duplicate an 8-hour shift in a shorter time period and the actual number of container pulls is left to the discretion of the yard tractor manufacturer and marine terminal operator.

Number of Container Movements (pulls per shift)	Duration (sec.)	Load (lbs.)	Average Speed (mph)
84	60	45,000	9
30	45	50,000	8
6	120	30,000	15

On-terminal testing should be conducted on an instrumented vehicle equipped with a data acquisition system. Note that the data collected during on-terminal testing will be specific to the zero/near-zero 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 zero/near-zero;
- 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, documentation of vehicle system, subsystem, or component failures, vehicle planned and unplanned maintenance requirements, and qualitative observations of vehicle performance, including driver observations.

6.2.2 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-Terminal Testing, one or more prototype yard tractors will enter the revenue service demonstration phase. The revenue service demonstration is conducted by the marine terminal in coordination with the vehicle manufacturer or vendor. The following sections describe the minimum expectations as they pertain to the revenue service vehicle demonstration.

6.3.1 Demonstration Period

Yard tractor testing in revenue service should encompass an approximately 6-month period of continuous service and include a minimum of 4,000 container pulls. The 6-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 so that a minimum of 4,000 container pulls is accrued.

6.3.2 Demonstration Data Collection Parameters

The marine terminal or intermodal facility operating the yard tractor in revenue service should record, at a minimum, basic operating data in each duty cycle tested, including but not limited to:

- Fuel economy
- Range or minutes of operation 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 zero/near-zero emission yard tractor. 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 Vehicle - A battery electric vehicle 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.

California Unified Cycle - a dynamometer driving schedule for light-duty vehicles developed by the California Air Resources Board. The test has been also referred to as the Unified Cycle Driving Schedule (UCDS) or as the LA92 (also spelled LA-92) cycle.

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 (Container) - a special type of undercarriage or chassis developed specifically to transport containers. Container chassis refer to the skeleton structure that is a part of the semi-trailer designed specifically to transport containers.

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.

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.

Cornerless Chassis – A container chassis with a 'cornerless' design, leaves the container corners accessible with the container loaded. Also referred to as a 'bomb cart'.

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.

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 (τ) and angular velocity (ω) 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 – A fuel cell 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 a vehicle.

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 Tractors using Alternative Fuel – This definition is for yard tractors 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 Tractors using Conventional Fuel – This definition is for yard tractors 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.

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.

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.

Intermodal Rail Yard - Any transportation facility primarily dedicated to the business of rail and/or intermodal rail operations where cargo is transferred to or from a train and any other form of conveyance, such as train to ship, ship to train, train to truck, or truck to train.

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.

Minimum Energy - The minimum energy is defined as the lowest energy state, as designed by the manufacturer of the zero/near-zero 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.

Near-Zero Emission Tractor – "Near-zero" emission levels are defined as approximately 90% lower than the EPA 2010 heavy-duty emission standards. This equates to oxide of nitrogen emissions less than or equal to 0.02 g/bhp-hr and total particulate matter (PM) emissions of 0.01 g/bhp-hr and as measured on a CARB-certified chassis dynamometer under the UDDS drive cycle. In the context of the Ports' yard tractor test and demonstration guidelines, "near-zero" yard tractors are capable of demonstrating emissions equivalency to the CARB Optional NOx emissions levels.

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.

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 transported by a truck including the loaded container and simple or cornerless chassis.

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 – Regeneration is the process where the vehicle's energy is reversed during deceleration. This can be from braking or other deceleration events while operating the vehicle.

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.

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 yard tractor 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.
Simple Chassis – See chassis (container).
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 standalone weight of the yard tractor without the chassis and container.
Trailer Weight – The tare weight of a container chassis, either a simple chassis or cornerless chassis.
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).

Wireless Charging – See Inductive Charging.

Yard Tractor – an off-road mobile utility vehicle used to carry cargo containers with or without chassis; also known as utility tractor rig (UTR), yard tractor, yard goat, yard hostler, yard hustler, or prime mover.

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 yard tractors, fuel cell yard tractors, and inductive yard tractors.

APPENDIX II: LABORATORY TESTING PROTOCOL

Purpose

The purpose of this Appendix is to provide a uniform set of test protocols/guidelines for the evaluation of zero/near-zero yard tractors 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 zero/near-zero vehicles. The testing will utilize driving test cycles designed to simulate port marine terminal operations and certification-like cycles. The test cycles were developed specifically for heavy-duty yard tractors using empirically derived data; thus, the test cycles simulate marine terminal operations with a high degree of accuracy. The information provided through this laboratory testing effort will develop a performance baseline for zero/near-zero yard tractors 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 zero/near-zero yard tractors intended for marine terminal and intermodal rail yard operation.

Approach

This document describes methods to accommodate chassis dynamometer testing of zero/near-zero yard tractors in one full day of testing, and includes the following sections:

- **Section 1 – Chassis Laboratory Setup**: Describes vehicle chassis dynamometer setup and verifications. This section is applicable to both zero and near-zero yard tractors.
- **Section 2 – Chassis Testing**: Describes testing and validation for the vehicle performance without emissions measurements. This section would apply to zero emission yard tractors.
- **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 applicable to yard tractors that need to show near-zero emissions equivalency.
- **Section 4 – Reporting:** Describes the data, formats, and recommended validation reports to include as elements of dynamometer test reporting. The purpose 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 –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 zero/near-zero vehicles for a quick summary reference.

General Testing Scope
This guidance document is designed for yard tractors operating at a marine terminal or intermodal rail yard. These are vehicles governed for speeds slower than 30 mph.

Zero Emission Yard Tractors
Yard tractors that have zero tailpipe emissions will not need to perform emissions measurements; thus, only Sections 1, 2, and 4 of this document are applicable. The following yard tractor configurations are defined as zero emission:

- Battery Electric Trucks
- Fuel Cell Trucks
- Inductively Charged Trucks

Near-Zero Emission Vehicles
The Ports 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 near-zero emission yard tractor's emissions as part of this testing.

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

- Alternative Fuel Yard Tractors – yard tractors equipped with a near-zero engine operating on dedicated alternative fuel. 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 Yard Tractors using Alternative Fuel – yard tractors equipped with a hybrid drivetrain configuration or plug-in hybrid drivetrain incorporating an internal combustion engine (ICE) utilizing Alternative Fuels.
- Hybrid and Plug-in Hybrid Trucks using Conventional Fuel – yard tractors 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 motor vehicle fuels that are petroleum derived, such as gasoline and diesel fuels. Conventional fuels with renewable content include, as examples, biodiesel and gasoline ethanol blends such as E85.

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 (τ) and angular velocity (ω) 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 dynamometer. 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.

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 yard tractors. 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 zero/near-zero vehicles.

1.3 Test Weight

Chassis testing requires the estimation of vehicle weight that may include the yard tractor, chassis (either simple or cornerless), and loaded container weights. For this guidance document, two yard tractor loads are used – a medium-heavy load and heavy-heavy load.

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). A cornerless chassis, also referred to as a bomb cart, often is equipped with solid tires.

As a result of the significant variability in physical load (weight) of the yard tractor during operation and the constraints of typical heavy-duty chassis dynamometers, the yard tractor duty cycle was split into two (2) sub-cycles. Each sub-cycle corresponds to that portion of the yard tractor duty cycle associated with yard tractor operation in one of two (2) weight categories: medium-heavy duty and heavy-heavy duty. The "dividing line" between the medium-heavy duty and heavy-heavy duty weight categories was chosen as a Gross Combined Vehicle Weight (GCVW) of 20,040 kg. (44,181 lb.). The choice of this "dividing line" was based on an analysis of the combined vehicle, trailer and container weights of all potential tractor/trailer combinations. Average weights for each category were then calculated based on actual data as the number of pound-trips in each category divided by the total number of trips in each category. The results are as follows:

- Average weight for medium-heavy duty category: 11,888 kg. (26,209 lbs.)
- Average weight for heavy-heavy duty category: 32,837 kg. (72,393 lbs.)

From the yard tractor in-use data collection, the actual percentage of time spent in each weight category was as follows:

- Percentage of time in medium-heavy duty category: 64.1%
- Percentage of time in heavy-heavy duty category: 35.9%

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.

Normally a coast down test would be carried out in which the vehicle to be emissions tested is accelerated up to a set speed in actual driving and then allowed to "coast down" to a lower speed. The time it takes to coast down from the higher to lower speed while the vehicle is coasting in neutral is used to determine the vehicle's drag (A) and rolling resistance (C). However, for a yard tractor, the top speed is typically 25 miles per hour or less, so vehicle drag ("wind resistance") was assumed to be negligible.

1.5 Test cycles

Port-recommended chassis dynamometer testing includes two yard tractor-specific transient test cycles and one steady-state test cycle. West Virginia University – Center for Alternative Fuels, Engines, and Emissions (WVU) developed the two transient test cycles based on data acquired from data logged yard tractors operating under in-use conditions at the Port of Long Beach. Inclusion of a steady-state test cycle in yard tractor emissions and performance testing was recommended by the University of California-Riverside, Center for Environmental Research and Technology (UCR CE-CERT). UCR has successfully employed this chassis dynamometer testing protocol for battery-electric yard tractors, and there are no known limitations for applying this test protocol to ICE, hybrid, or any other advanced technology yard tractor drivetrain configuration.

The transient test cycles developed by WVU include one cycle representing a medium-heavy load and a second cycle representing a heavy-heavy load. The gross combined vehicle weights (GCVW) corresponding to medium–heavy and heavy-heavy loads are as follows:

- Average weight for medium-heavy duty category: 11,888 kg. (26,209 lbs.)
- Average weight for heavy-heavy duty category: 32,837 kg. (72,393 lbs.)

Each transient test cycle is 1200 seconds in duration, the first 300 seconds representing rail work activity and the last 900 seconds representing ship work activity. The Driving Schedule, represented as yard tractor speed as a function of time for the medium-heavy and heavy-heavy test cycles are shown below in Figures 1-1 and 1-2, respectively:

Figure 1-1: Medium-Heavy Load Driving Schedule

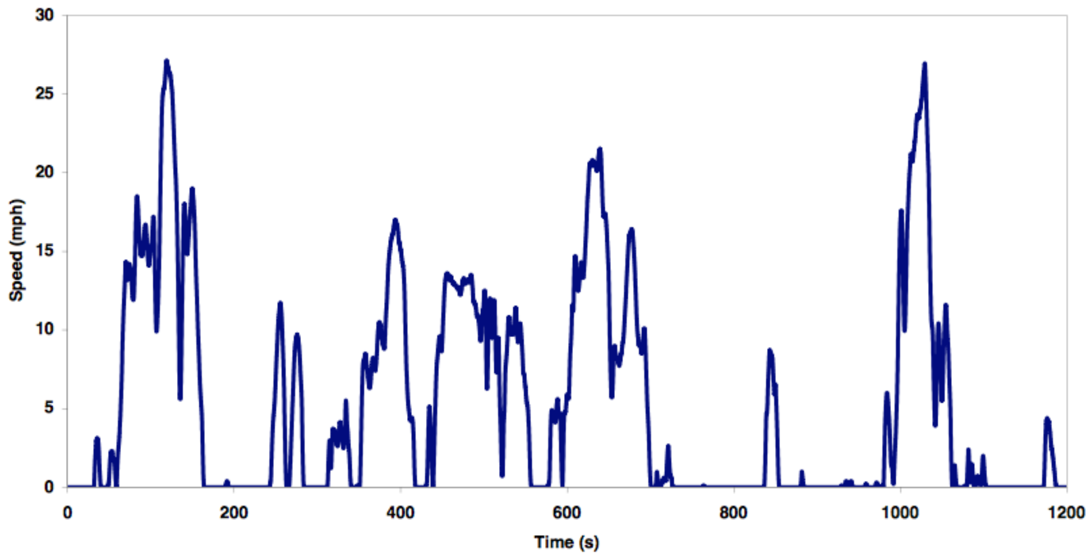
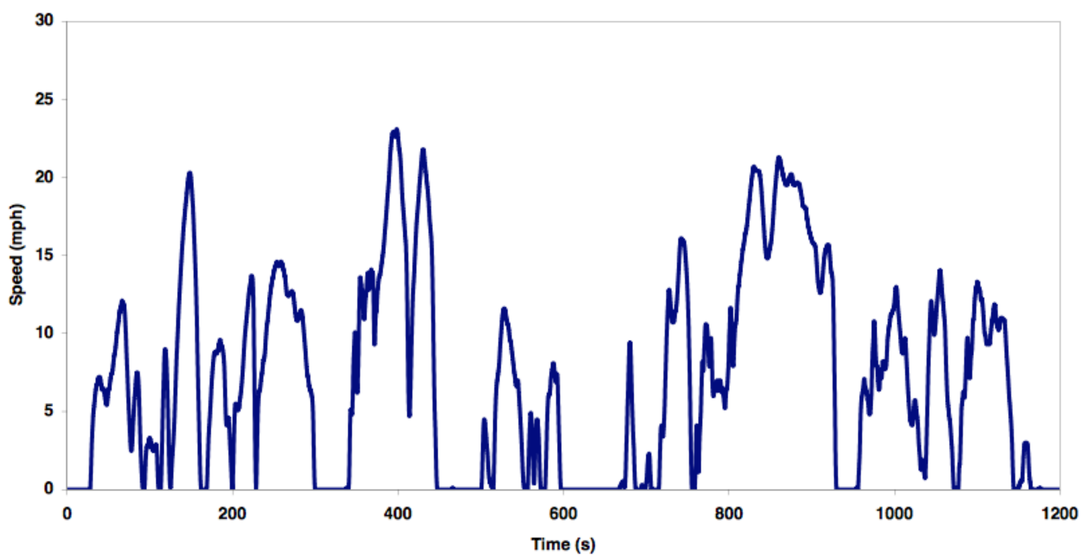


Figure 1-2: Heavy-Heavy Load Driving Schedule



The steady state test follows the ISO 8178 test cycle shown below in Table 1-1. For off-road engine certification, this test is normally conducted using an engine dynamometer. For the purpose of the yard tractor test protocol, it is conducted on a chassis dynamometer.

Table 1-1: ISO 8178-C1 Steady-State Cycle[4]

Mode number (cycle B)	1	2	3	4	5	6	7	8	9	10	11
Mode number (cycle C1)	**1**	**2**	**3**		**4**	**5**	**6**	**7**			**8**
Speed 1)	Rated speed					Intermediate speed					Low-idle speed
Torque 1), %	100	75	50		10	100	75	50			0
Weighting factor	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15

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 heavy-duty yard tractor on a chassis dynamometer.

2.1 General Zero and Near-Zero Emission Yard Tractor Testing Provisions

The yard tractor 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.
- Brakes and systems will function normally.
- 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 minutes between selected test cycles to accommodate near-zero yard tractor testing and possible zero-emission yard tractor needs.

[4] Figure courtesy of UCR CE-CERT.

- Cold starts will not be performed for any of the tests.

2.2 Zero Emission Yard Tractor Testing

Typically, preconditioning and vehicle warm up is needed to stabilize the emissions control and engine combustion systems. For electric vehicles and other zero-emission yard tractors, pre-conditioning is not needed and may actually impact the vehicles range estimation. As such, no preconditioning for zero-emission vehicles 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 zero-emission tractor 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 zero-emission yard tractor. 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 Near-Zero Yard Tractor Testing

Since near-zero 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.

Section 3: Emissions Testing

The near-zero yard tractor 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 near-zero emission yard tractor 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_2O) 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 near-zero vehicle 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 Near-Zero (g/bhp-hr)

Species [1]	Standard [2]	Near-Zero 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 near-zero 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]	Near-Zero 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_2O 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 near-zero emission yard tractors will be low-emitting vehicles - 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 near-zero emission yard tractors. For the purposes of minimizing costs, nominal fuel properties should be reported. These would include diesel #2, 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 near-zero emission vehicle.

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 near-zero emission yard tractors 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 Zero Emission Yard Tractor Reporting

The zero-emission 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 Zero-Emission Yard Tractor 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 Zero/Near-Zero 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:

$$Vehicle\ CAN\ Power_i = \sum Current_i * Voltage_i$$

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 is a relative parameter and is dependent on each manufacturer's claims for range and usage. 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. The other method 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. The vehicle net energy is measured by the laboratory's power meter and vehicle CAN system.

4.4 Near Zero-Emission Yard Tractor Reporting

The near-zero 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 near-zero yard tractor, 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 near-zero 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 near-zero emission tractors with selected catalysts and fuels
NOx and NO_2	NH_3 for selected near-zero emission tractor fuel systems
PM, CO, and CO_2	Real-time PM, PM fines, and other for some near-zero emission tractors without DPFs

Table 4-4: Data to Be Collected on the Near Zero-Emission Yard Tractor 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.
- *https://www.epa.gov/smartway/resource-pages-current-smartway-partners-and-affiliates*
- 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 30 mph. 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[5]. 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:

Equation 1

$$M\frac{dV}{dt} = \frac{1}{2}\rho AC_D V^2 + \mu Mg\cos(\theta) + Mg\sin(\theta)$$

Where:

M = mass of vehicle in lb. (tractor + payload + trailer+ 125 lb/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 (zero/near-zero 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[6]. 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.

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 zero/near-zero 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., μstd, $C_D$std

[5] 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

[6] 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

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 Heavy-Duty Vehicles

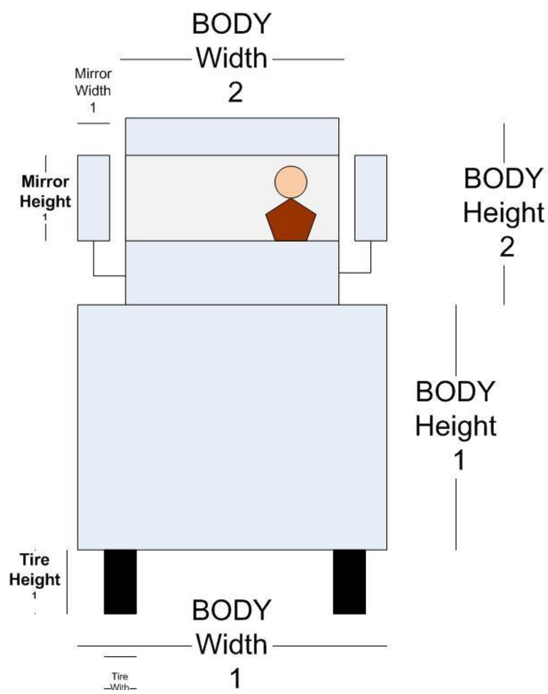
Variable	Value	Description
θ	0	no grade in these tests
ρ	1.202	standard air density kg/m^3
μ_{std}	0.00710	standard tires
μ_{adv}	0.00696	low rolling resistant tires
C_{D_std}	0.750	for non-SmartWay tractor
C_{D_adv}	0.712	for SmartWay tractor
g	9.806	nominal value m/sec^2
M	Varies	mass: final test weight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

Equation 2

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

Figure A-1 Vehicle frontal area dimensions method



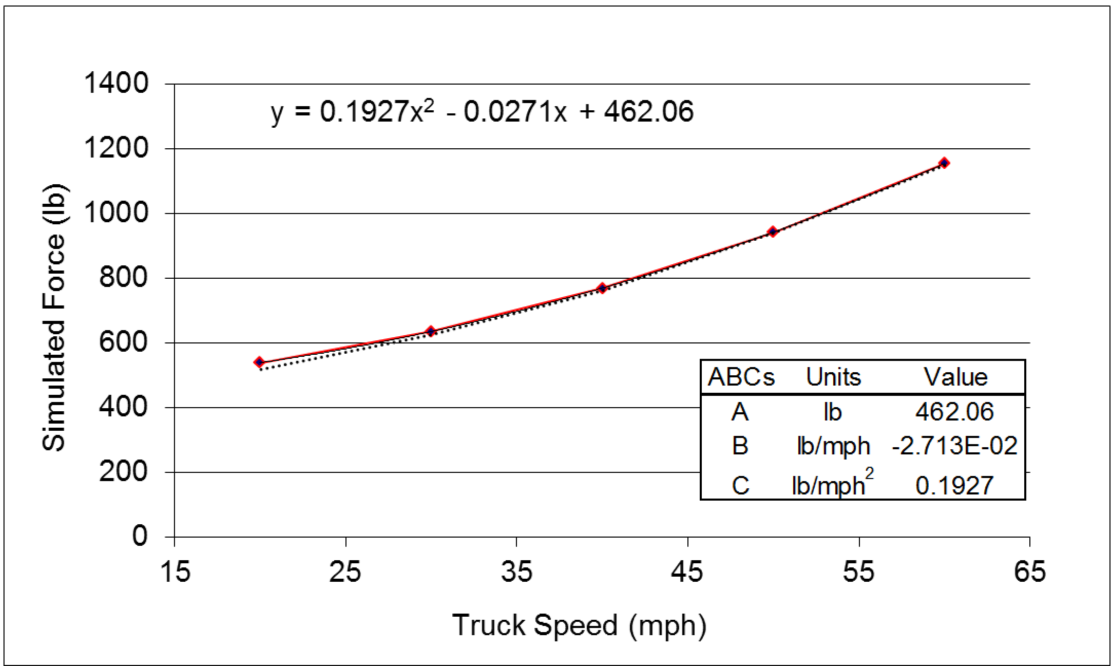
Using Equation 2 (solution for $\frac{dV}{dt}$ or deceleration), one can calculate the deceleration for each average speed bin (60, 50, … down to 20 mph); see Table A-2. From the deceleration time, one can calculate the desired time that is the target for the coast down simulation on the chassis dynamometer. 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 (0th order term), B (1st order term), and C (2nd 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 heavy-duty trucks 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 Heavy-Duty Truck with Standard Components

Data Point	Ave. Speed (mph)	Calc time (sec)	Decel (mph/sec)	Decel (ft/sec2)	Decel (g)	Force (lb)
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[7]

A yard tractor duty cycle was developed as part of the Hybrid Yard Tractor Demonstration and Commercialization Project funded by the Port of Long Beach, the Port of Los Angeles, and the U.S. Environmental Protection Agency (EPA). The purpose of developing a yard tractor duty cycle is to be able to compare the relative emissions and fuel economy of hybrid yard tractors vs. diesel yard tractors at the chassis level. Note that there is currently no standard, chassis-level duty cycle specifically for yard tractors.

This duty cycle was developed based on yard tractor operation in a marine terminal environment at Long Beach Container Terminal (LBCT) at the Port of Long Beach. It may also prove useful in representing other yard tractor applications, such as intermodal rail yards.

Technical Considerations

Yard tractors are heavy-duty tractors used for moving cargo containers within port container terminals and other off-road areas. At any given time during the operation of a particular yard tractor, the physical load being pulled by the yard tractor can vary dramatically depending on the weights of the trailer and container connected to the tractor. In extreme cases, this weight difference can easily exceed 80,000 lb. Therefore, it is necessary to know both the vehicle speed and the physical load (weight) of the trailer and container being pulled by the yard tractor at any given time as both have a significant effect on how hard the engine has to work, (which in turn directly affects emissions and fuel consumption). While the use of data loggers to collect vehicle speed vs. time data is common, determination of the vehicle physical load (weight) vs. time added significant complexity to the real-time data collection procedures.

Another technical issue associated with the yard tractor application is that yard tractors spend a significant portion of their operation in "creep" mode. "Creep" mode is informally defined as forward movement at speeds below 4 mph. (Note that 4 mph is approximately the lowest speed where the transmission can directly couple the engine speed to the drive train speed). This frequently occurs while yard tractors are waiting in a queue to have a cargo container loaded or unloaded. Since GPS-based data loggers typically do not have the resolution to distinguish "creep" operation vs. a stopped or idling vehicle, additional vehicle instrumentation was necessary to identify real-time "creep" operation to ensure that it would be adequately represented in the final yard tractor duty cycle. Note that the loads on the vehicle's propulsion and auxiliary systems can be significantly different during "creep" vs. idle operation, which may in turn affect emissions and fuel consumption.

[7] Derived from work performed by UCR, WVU, and CALSTART with funding from the Port of Long Beach and Port of Los Angeles

Yard Tractor Duty Cycle Statistics

Yard tractors typically perform three (3) main types of container movements: ship work, rail work and yard work. Ship work and rail work involve a high degree of repetitive activities while dock work tends to involve more non-repetitive activities. In addition, ship and rail work constitute the vast majority of all yard tractor activities at LBCT (about 95%). For these reasons, the in-use data used to develop the yard tractor duty cycle focused on ship and rail activities, purposely excluding dock work activities. A summary of the key statistics associated with the yard tractor in-use data collected at LBCT is given below:

Parameter	*All Activities*	*Rail Only*	*Ship Only*
Avg. Speed	7.5 mph	8.9 mph	7.0 mph
Std. Dev. Speed	3.4 mph	4.2 mph	3.2 mph
Creep	21.4%	15.1%	23.3%
Idle	40.1%	31.7%	41.8%
Creep + Idle	61.5%	46.8%	65.1%

Yard Tractor Weight Categories

As a result of the significant variability in physical load (weight) of the yard tractor during operation and the constraints of typical heavy-duty chassis dynamometers, the yard tractor duty cycle was split into two (2) sub-cycles. Each sub-cycle corresponds to that portion of the yard tractor duty cycle associated with yard tractor operation in one of two (2) weight categories: medium-heavy duty and heavy-heavy duty. The dividing line between the medium-heavy duty and heavy-heavy duty weight categories was chosen as a Gross Combined Vehicle Weight (GCVW) of 20,040 kg. (44,181 lb.). The choice of this "dividing line" was based on an analysis of the combined vehicle, trailer and container weights of all potential tractor/trailer combinations. Average weights for each category were then calculated based on actual data as the number of pound-trips in each category divided by the total number of trips in each category. The results are as follows:

- Average weight for medium-heavy duty category: 11,888 kg. (26,209 lbs.)
- Average weight for heavy-heavy duty category: 32,837 kg. (72,393 lbs.)

From the yard tractor in-use data collection, the actual percentage of time spent in each weight category was as follows:

- Percentage of time in medium-heavy duty category: 64.1%
- Percentage of time in heavy-heavy duty category: 35.9%

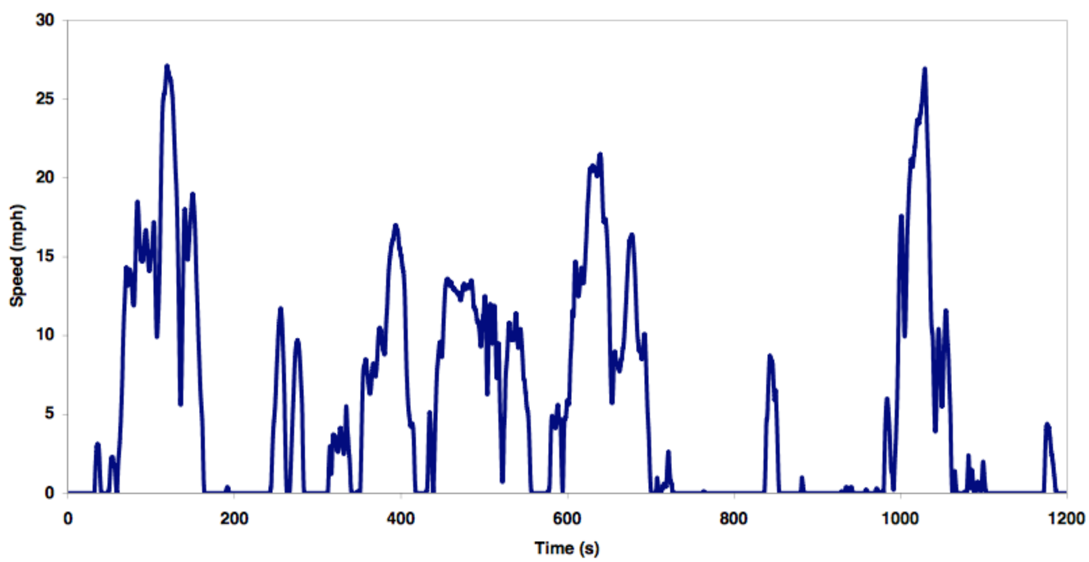
A summary of the key statistics associated with each weight category (i.e., combining rail and ship activities in each weight category) vs. the statistics for all activities is given below:

Parameter	*All Activities*	*Medium-Heavy (Rail + Ship)*	*Heavy-Heavy (Rail + Ship)*
Avg. Speed	7.5 mph	7.3 mph	7.7 mph
Std. Dev. Speed	3.4 mph	3.4 mph	3.4 mph
Creep	21.4%	25.6%	13.9%
Idle	40.1%	44.4%	30.6%
Creep + Idle	61.5%	70.0%	44.5%

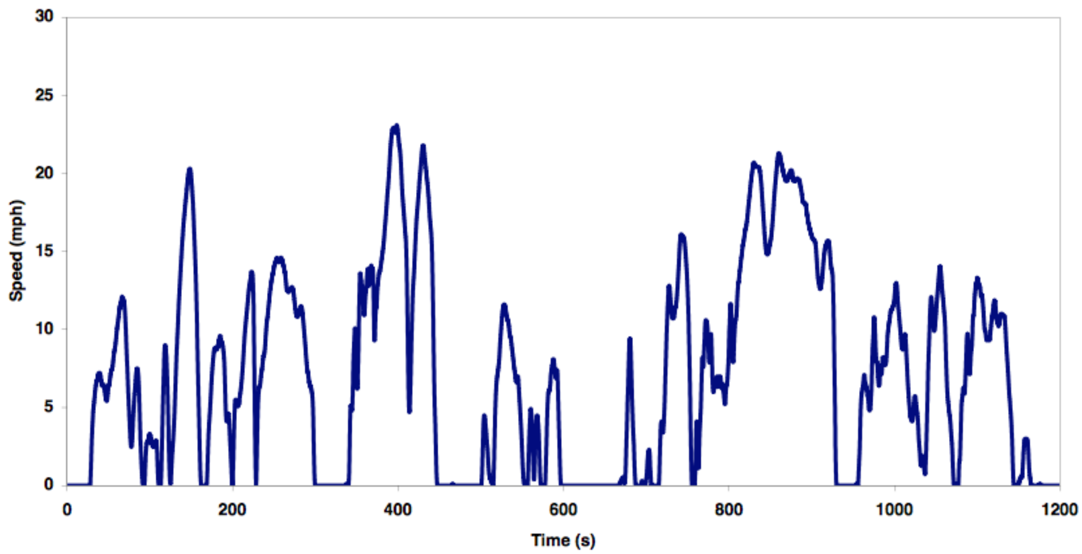
Chassis Dynamometer Testing – Transient Test Cycle

The transient test cycles developed by WVU include one cycle representing a medium-heavy load and a second cycle representing a heavy-heavy load. Each transient test cycle is 1200 seconds in duration, the first 300 seconds representing rail work activity and the last 900 seconds representing ship work activity. The Driving Schedule, represented as yard tractor speed as a function of time for the medium-heavy and heavy-heavy test cycles are shown below:

Medium-Heavy Load Driving Schedule



Heavy-Heavy Load Driving Schedule



Chassis Dynamometer Testing – Steady-State Test Cycle

The steady state test follows the ISO 8178 test cycle shown below. For off-road engine certification, this test is normally conducted using an engine dynamometer. For the purpose of the yard tractor test protocol, it is conducted on a chassis dynamometer.

ISO 8178-C1 Steady-State Cycle[8]

Mode number (cycle B)	1	2	3	4	5	6	7	8	9	10	11
Mode number (cycle C1)	**1**	**2**	**3**		**4**	**5**	**6**	**7**			**8**
Speed 1)	Rated speed					Intermediate speed					Low-idle speed
Torque 1), %	100	75	50		10	100	75	50			0
Weighting factor	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15

8 Figure courtesy of UCR CE-CERT.

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 (container) plus trailer weight (simple chassis or cornerless chassis), 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:

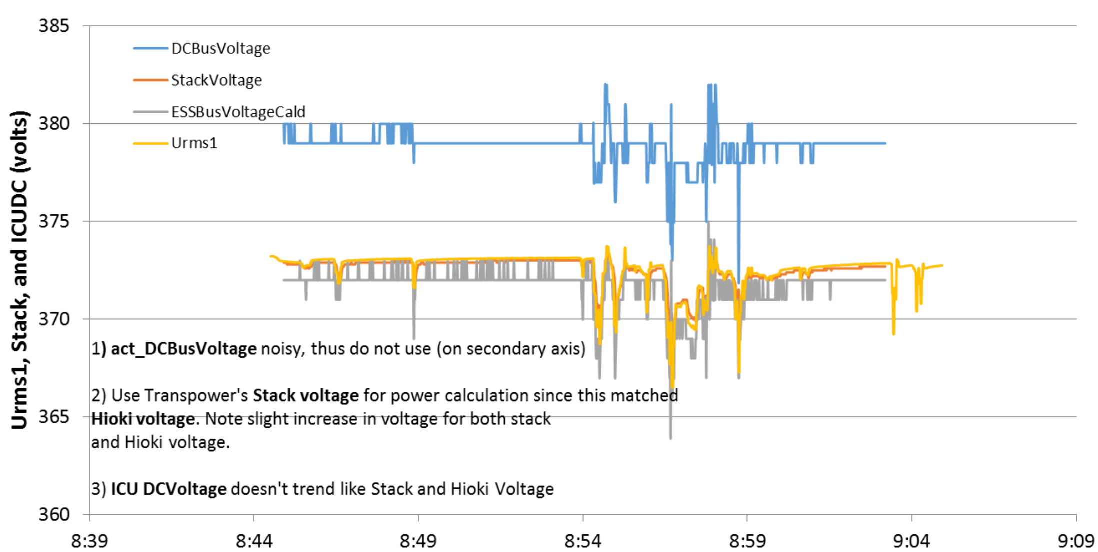
$$\mathit{Vehicle\ CAN\ Power}_{\,i} = \sum Current_i * Voltage_i$$

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 zero/near-zero 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 zero-emission yard tractors only E-1 and E-2 are needed. For near-zero yard tractors Table E-1, E-3 and E-4 should be used.

Table E-1: Vehicle Inspection and Dynamometer Setup – Zero/Near Zero Yard Tractors

Item	Description
1	Secure vehicle and record vehicle related information (Part C-Attachment 1); disable any regeneration devices that would prevent the zero/near-zero 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. Test Weight = Tractor Weight + 52,500 lb. + (No. Tractor Tires+8)*125lb 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 zero/near-zero on the chassis dyno and the dynamometer warmed up following standard practices, perform a coast down validation test. This involves the following: 1. Bring vehicle up to top speed = 70 mph 2. Record the coast down time from each of the speed bins listed in Table A-2 Part A. 3. Compare these times with the desired time (Table A-2) 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) 5. Once the targeted values are achieved within 5% the report these values in Part C.
	The test zero/near-zero is ready for chassis testing

Table E-2: Chassis Testing Zero-Emission Yard Tractor

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 Near-Zero Yard Tractor

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 Near-Zero Yard Tractor

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 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:

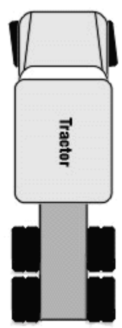
TIRE CONDITION:	FRONT		REAR	
	☐ GOOD	☐ WORN	☐ GOOD	☐ WORN
REMARKS:				

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 testing laboratory):

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 ____

____

____

____