January 27, 2016 Innovative Technology Regulation (ITR)
Interim Hybrid Technology Emission Test Procedures Public Work Group Meeting

INITIAL CONCEPTS AND LANGUAGE FOR STAKEHOLDER REVIEW

This document provides potential draft concepts and initial regulatory language for the hybrid technology emission test procedure element of the proposed ITR. This document is intended to facilitate stakeholder feedback at the January 27, 2016 ITR Interim Hybrid Technology Emission Test Procedures Work Group meeting. This document is only intended to encourage stakeholder feedback, is incomplete, and should not be construed as a formal regulatory proposal. This document is organized in the following potential draft sections, with hybrid technologies potentially offered multiple emission test options to demonstrate the in-use CO_2 emission benefits and no increase in key criteria pollutants necessary for ITR eligibility:

- **Sections A, B, and C: Applicability, Definitions, and General Requirements**
- **Section D: PEMS Test Procedures**
- **Section E: Chassis Dynamometer Test Procedures**
- **Section F: Post-Transmission Powertrain Vehicle Simulation**
- **Section G: Data Collection and Quality Control**

Blue test boxes throughout this document identify staff comments and key outstanding questions to facilitate stakeholder review. These test procedures are not intended for the purposes of certification of hybrid technology to an emission standard. These ITR test procedures under development are intended to be "interim" procedures as needed to flag hybrid technology that may increase key criteria pollutants (particularly NOx) in-use, and identify potential CO_2 emission benefits from hybrid conversion systems for manufacturer marketing purposes. Staff anticipates that these interim procedures shall be amended in future years to incorporate new information (particularly to refine the PEMS element, for which little regulatory precedent exists).

A. APPLICABILITY

The test procedures set forth in this section are applicable to the following:

1. New 2016 and subsequent model year heavy-duty hybrid motor vehicles with a gross vehicle weight rating (GVWR) greater than 14,000 lbs and engines used to power these vehicles, for which a manufacturer requests on-board diagnostics or certification compliance flexibility pursuant to title 13, sections 2208 and 2208.1 of the California Code of Regulations (CCR); and
2. All hybrid conversion systems for 2007 and subsequent model year medium-duty and 2010 and subsequent model year heavy-duty on-road motor vehicles requesting hybrid conversion system certification pursuant to CCR title 13, sections 2208 and 2208.2.

For new heavy-duty engines, these interim test procedures supplement, and do not replace, California's general procedures and requirements necessary to certify a heavy-duty engine for sale in California set forth in "California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines and Vehicles", as incorporated in title 13, CCR, §1956.8(b), "California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Otto-Cycle Engines, as incorporated in title 13, CCR §1956.8(d), for testing and compliance of heavy-duty diesel and Otto-cycle engines with exhaust emission standards. For new hybrid heavy-duty motor vehicles, these interim test procedures supplement, and do not replace, the "California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric and Other Hybrid Vehicles, in the Urban Bus and Heavy-Duty Vehicle Classes" (December 12, 2013), as incorporated in title 13, CCR, §1956.8.

B. DEFINITIONS

These interim test procedures incorporate by reference the definitions and abbreviations set forth in 40 Code of Federal Regulations (CFR), Chapter I, Subchapter U, Part 1065 (Engine Testing Procedures), California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric and Other Hybrid Vehicles, in the Urban Bus and Heavy-Duty Vehicle Classes (Amended December 13, 2013), and California's Innovative Technology Regulation, unless otherwise amended below.

"Kinetic intensity" means the characteristic acceleration divided by the square of aerodynamic speed as described in: Equation 19 of O'Keefe et al., *Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications*, National Renewable Energy Laboratory, 2007-01-0302, www.nrel.gov/docs/gen/fy07/40929.pdf .

Other definitions to be added as needed…

C. GENERAL REQUIREMENTS

These interim test procedures, for the purposes of determining Innovative Technology Regulation (ITR) eligibility and compliance, identify three methodologies for evaluating hybrid technology exhaust emissions of key criteria pollutants with potential for a measureable increase, as well as potential fuel economy impacts of hybridization. Criteria pollutants to be evaluated include oxides of nitrogen (NOx) for compression ignition engines, and NOx, carbon monoxide (CO), and total hydrocarbon (THC) for spark-ignition engines.

Criteria pollutants to be tested, above, include only those which data and staff's engineering evaluation indicate could be cause for concern due to engine hybridization. Particulate matter is not included as it is less likely to be a pollutant of concern, and is more challenging to flag with confidence via A to B PEMS testing (at new vehicle PM certification levels).

Potential emission test options available to new hybrids and hybrid conversions are identified in the bullets below. New hybrids could potentially piggyback on drivetrain testing required to demonstrate compliance with federal Phase 1 heavy-duty vehicle greenhouse gas (GHG) standards by simultaneously testing for key criteria pollutants needed for ITR compliance. Hybrid conversions would not conduct such federal drivetrain testing, and staff is therefore not proposing this be an option for hybrid conversions. Staff recommends that PEMS testing be allowed for heavy-duty hybrid technology, due in part to potential manufacturer challenges procuring a heavy-duty chassis dynamometer. Chassis dynamometer testing, however, would be required for medium-duty hybrid technology, in part due to greater repeatability of chassis dynamometer testing results, and because medium-duty chassis dynamometers are relatively more common and easier to procure in a timely manner.

Hybrid technologies may utilize the following interim test procedures identified in this document for the purposes of Innovative Technology Regulation compliance:

- New heavy-duty hybrid engines and vehicles may be tested utilizing portable emissions measurement system (PEMS) test procedures pursuant to Section D, chassis dynamometer test procedures pursuant to Section E, or drivetrain testing pursuant to Section F.
- Hybrid conversion systems for vehicles over 14,000 lbs GVWR may be tested using PEMS test procedures pursuant to Section D, or chassis dynamometer test procedures pursuant to Section E.
- Hybrid conversion systems for vehicles between 8,500 and 14,000 lbs GVWR must be tested using chassis dynamometer test procedures pursuant to Section E.

All three testing options require a comparison of emissions from an appropriate non-hybrid "base" vehicle and the applicable hybrid "test" vehicle over a duty cycle or on-road test route that is typical of the hybrid vehicle class and vocation.

D. PORTABLE EMISSIONS MEASUREMENT SYSTEM TEST PROCEDURES

Unless otherwise indicated in this section, PEMS units, calibrations, verifications, and data collection and analysis shall follow recommended practices and meet the requirements of 40 CFR, Chapter I, Subchapter U, Part 1065.

Unless otherwise indicated, potential criteria for most Vehicle Selection and Preparation and Ambient Conditions mirror or have been adapted from relevant portions of *SAE International J1321: Fuel Consumption Test Procedure – Type II* (Revised February 2012) and US EPA's *SmartWay Fuel Efficiency Test Protocol for Medium- and Heavy-Duty Vehicles Working Draft* (November 2007). Staff welcomes stakeholder comment regarding use of these or other potential draft criteria for the purposes of ensuring transparent and robust emission testing.

1. **Vehicle Selection and Preparation.** When selecting vehicles for testing, the baseline and hybrid vehicles shall be of the same vehicle class and intended vocation, and be identical or as closely matched as possible in model year, engine power and displacement (and multipollutant fuel map), number of axles, electrical and mechanical accessory power demand, vehicle mass and payload, body style and external surface contours, aerodynamic configuration, and accessories, unless a difference in one of the above variables between the base and hybrid vehicle is directly related to the effective functioning of the hybrid vehicle's hybrid system. For example, the power and displacement of a baseline vehicle's engine may be higher than that for a hybrid vehicle if the hybrid vehicle utilizes a downsized engine as part of its hybridization strategy. In this case, the baseline vehicle would use an engine typical if its vehicle class and vocation, while the hybrid vehicle would use the intended downsized engine.

To be comparable, the baseline and hybrid vehicle must be able to accomplish the same function, with similar performance, utility, and durability attributes. Vehicles shall be tested with the normal appendages (mirrors, bumpers, etc…). A baseline vehicle may be from a different model year relative to the hybrid vehicle, if the engine, after-treatment, and on-board diagnostics system is functionally unchanged between the two and if all other vehicle characteristics are substantially similar, with the exception of the hybrid system, as described in this Attachment.

For hybrid conversion systems, the base vehicle shall be the vehicle on which the hybrid conversion system shall be installed, and the hybrid vehicle shall be the identical vehicle after the hybrid conversion system has been installed.

1.1 Mileage. Minimum mileage of baseline and hybrid vehicles for testing shall be as follows (*borrowed and adapted from SAE J1321*):

- To ensure emission stability, the minimum mileage at the time of testing for both the baseline and hybrid vehicle shall be 4,000 miles. Utility trucks may alternately accumulate a minimum of 125 hours of operation prior to testing, if verified by a non-resettable, vehicle-integrated hour meter.
- The mileage on all baseline and hybrid vehicles must be within 1,000 miles if each other if the odometer of one vehicle is less than 5,000 miles.
- The mileage on all vehicles must be within 3,000 miles of each other if the odometer on all vehicles is greater than 5,000 miles but less than 10,000 miles on one vehicle.
- The mileage on all vehicles must be within 10,000 miles of each other if the odometer on all vehicles is greater than 10,000 miles but less than 30,000 miles on one vehicle.
- The mileage on all vehicles must be within 20,000 miles of each other if the odometer is greater than 30,000 miles on all vehicles.

1.2 Tires. Manufacturer's recommended tires and pressures shall be used. Tires and wheels shall be of the same or similar type, condition, mileage, pressure and tire model year per tire position. Tires shall be representative of a typical (e.g., best-selling)

tire for a given vehicle application. Prior to each day of testing, cold tire pressures shall be measured and inflated to the vehicle or tire manufacturer's recommended specifications to within a tolerance of ±1 psi (6895 Pa). Tire pressures shall be set and recorded at the beginning of the day following overnight cold soaks and measured and recorded at the end of each day of testing.

1.3 Fuel Specifications. Both base and hybrid vehicles shall use an identical gaseous or liquid fuel, unless a base vehicle using a different fuel is approved in advance by the ARB Executive Officer. If an appropriate base vehicle that utilizes the same fuel type as the hybrid vehicle is unavailable, the Executive Officer may approve use of an alternate base vehicle fuel type that best represents the typical fuel used by a newly manufactured vehicle in the intended vehicle class and vocation. For example, a gasoline powered Class 6 hybrid truck may warrant use of a diesel-fueled Class 6 base truck for the purposes of emission testing, since Class 6 vehicles are typically diesel fueled.

1.4 Vehicle Test Weight. Heavy-duty vehicles shall be tested at the prescribed weight identified in ARB's Hybrid Heavy-Duty Vehicle Test Procedures (Amended December 12, 2013) Section D. 1.4.2. Medium-duty vehicle test weight shall be as specified in 40 CFR Part 86.129-94.

Staff is unaware of precedent for ensuring similar test weight of the base and hybrid vehicle for purposes of emission testing. Staff welcomes comment regarding the potential approach identified in 1.4.1, below.

1.4.1 The test weight of the base vehicle must be within two percent of and not exceed the hybrid vehicle test weight. For example, if the hybrid vehicle test weight is 25,000 lbs, the base vehicle must weigh between 24,500 and 25,000 pounds during PEMS testing.

1.4.2 Where a test payload is required to meet vehicle test weight requirements, the payload shall be evenly distributed and securely fastened down to prevent weight shifting during emission testing

1.4.3 Test vehicles must be weighed using properly calibrated truck weight scales that conform to the most current provisions established by the National Institute of Standards and Technology (NIST). It is recommended that the truck scales also have a National Type Evaluation Program (NTEP) Certificate of Conformance.

1.5 Additional Vehicle Preparation. Fuels and vehicles shall meet the requirements of ARB's Hybrid Heavy-Duty Vehicle Test Procedures (Amended December 12, 2013) Section D. 1.3 (Fuel Specifications) and 1.4 (Vehicle Preparation) through 1.4.5 and 1.4.8 through 1.4.9.

1.6 Mechanical Preparation of Test Vehicle. Vehicles shall be representative of production fleet vehicles. Test vehicles need not be new, but they must be in good mechanical order and operating condition. All components and equipment shall be calibrated and maintained to within manufacturer-recommended specifications. The exception is any component that has been deliberately modified as part of the test truck design. Vehicles shall be mechanically prepared and maintained in accordance with SAE J1321, Sections §8.6 to §8.10. Vehicles must not have any mechanical or physical defects that may affect fuel efficiency. Vehicles must not have any fluid, exhaust, or air suspension leaks. There must be a visual inspection of the tires prior to each test day, to detect any signs of tire or wheel damage or unusual wear. The air cleaner monitor and engine fault codes must be checked prior to the test, and any abnormal conditions must be corrected, to ensure that the vehicle is in proper working order. If the test method uses the carbon balance method of fuel consumption measurement, the additional vehicle preparation requirements in CFR 40 §86.131-90 must be followed.

1.6.1 All detectable sources of exhaust gas leaks must be sealed or plugged. Records of vehicle identification and condition must be kept. Vehicles must be weighed before the test to ensure proper test weight, and over axle weighting, and weight records must be maintained.

2. Ambient Conditions. Ambient conditions during emission tests should be as similar as can be possible. Ambient temperature shall be no less than 40 º F and no greater than 100 º F, and shall change no more than 30 º F during a test and vary no more than 30 º F among all the tests. Ambient temperatures shall be recorded at the beginning and end of the test period.

2.1 Testing can be conducted at any humidity level; however, an optimal range is between 35 percent and 75 percent relative humidity.

2.2 Testing shall occur when wind speeds are at or below 12 miles per hour (mph), with gusts no greater than 15 mph.

2.3 The road surface shall be concrete or asphalt.

2.4 Emission testing shall be conducted at an elevation no higher than 4,000 feet, to prevent unintended changes in engine and subsystem operation. The maximum grade change of the test route shall not exceed two percent longitudinally, to prevent excessive forward motion due to grade.

3. Test Route and Emission Testing

Staff is in the early stages of developing potential test route and emission testing criteria for ITR. The concepts identified below are initial staff ideas intended to generate stakeholder feedback and may be updated and refined further during this rulemaking.

Possible Allowable Duty Cycles. Staff suggests it may be appropriate to require at least eight valid PEMS test runs for both a baseline and hybrid vehicle (with a minimum of two cold tests) to demonstrate no NOx increase from a hybrid technology. These might include:

- The PEMS test routes could be chosen to match the characteristics of the three US EPA Heavy-Duty Vehicle Phase 1 GHG Standard drive cycles – the ARB Transient portion of the Heavy Heavy-Duty Truck 5 Mode Cycle (ARB Transient), the 55 Mile-per-Hour Cruise Cycle and 65 the Mile-per-Hour Cruise (55-65 MPH Cruise). Similar to how these drive cycles are weighted for evaluating hybrid GHG emissions in US EPA Phase 1, the ARB-Transient-like transient portion of the PEMS route would be weighted 75 percent, while the higher speed 55/65 mph cruise-like portion would be weighted 25 percent.
- The ARB Transient-like rout and 55-65 MPH Cruise-type route would be run four times each for the hybrid and non-hybrid equivalent, for a total of 16 tests. Each ARB Transient Test would be approximately 45 minutes to one hour, while each 55-65 MPH Cruise Test would be about 30 minutes.
- If a manufacturer feels that an ARB Transient-like route does not fully represent their vehicle's application and they have sufficient field activity data or other information to support it, the manufacturer may propose to conduct the ARB Transient-like PEMS runs over a different test route whose characteristics are representative of the field activity data.
- Staff welcomes stakeholder comment regarding the most appropriate emission test protocol to flag potential excess criteria pollutant emissions from hybrid work trucks with significant zero-emission power take-off operation.

Kinetic Intensity as a Key Metric. Existing research and discussions with experts at NREL and West Virginia University suggest that kinetic intensity (i.e., defined as the characteristic acceleration divided by the square of aerodynamic speed) is strongly correlated to a hybrid heavy-duty vehicle's relative fuel economy benefit and NOx emission profile.

Staff proposes potentially requiring the kinetic intensity (and possibly other metrics, such as average speed and/or stops per mile) of a vehicle operated during PEMS testing mirror the kinetic intensity for the two potential test routes described in the previous text box. For example, a vehicle driven over the ARB Transient-like route would have to closely match the kinetic intensity (and possibly other metrics) of the ARB Transient Cycle, and the vehicle as driven over the 55-65 MPH Cruise-like route would have to closely match the selected metrics of the 55 and 65 MPH Cruise Cycles. The emission results for the base and hybrid vehicles would then be weighted as previously discussed. The ARB Transient Cycle's kinetic intensity is 1.38 1/mile, with an average driving speed of 18.3 mph, and 1.4 stops per mile.

Staff is also exploring use of kinetic intensity (and other metrics) for defining a valid set of PEMS test runs. With this potential approach, the kinetic intensity of the PEMS tests must tightly cluster for each vehicle as driven over the test route. Staff is also evaluating whether to potentially disqualify an emission result from a PEMS test that differs significantly from others coming from the same base or hybrid vehicle (which could be indicative of an aftertreatment regeneration event or other anomaly).

Possible Pass-Fail Criteria for Criteria Pollutants.
California's Heavy-Duty Hybrid Vehicle Test Procedures require four repetitions of the UDDS and Orange County Transit Cycle over a chassis dynamometer, with one test for each cycle being a cold cycle test, and utilize the average of the emission results to help determine the hybrid vehicle certification level. Alternately, California's Heavy-Duty Diesel In-Use Compliance Regulation requires PEMS testing of at least six vehicles in-use, with at least five required to pass specified criteria to demonstrate in-use compliance. Staff believes it may be more appropriate to use the average of the weighted emission results over eight PEMS measurements to flag excess NOx, rather than require a certain number of the of the eight PEMS tests demonstrate no emission increase. Staff welcomes comments regarding the most appropriate mechanism for flagging excess emissions of key criteria pollutants for the purposes of ITR.

Staff also welcomes stakeholder feedback regarding an appropriate test allowance for the purposes of flagging excess NOx or other criteria pollutant emissions. Staff recognizes the uncertainties inherent in in-use emission testing of hybrid heavy-duty vehicle technology. These include appropriately capturing and weighting drive cycles to represent the multitude of potential vehicle vocations and in-use activities, potential vehicle and driver variability during PEMS testing, and other factors. Staff believes a NOx emission testing allowance may be warranted to ensure a hybrid technology that is unlikely increase emissions in-use is not unjustly flagged. For new heavy-duty hybrids, in particular, the engine is already certified for use in the intended hybrid vehicle's weight class, and ITR chassis-based testing is intended as a supplemental flag for potential excess in-use NOx emissions, as well as to inform potential future chassis based certification efforts. Staff welcomes stakeholder comment regarding an appropriate NOx test allowance for new hybrid heavy-duty technology and hybrid truck and bus conversions.

E. CHASSIS DYNAMOMETER TEST PROCEDURES

Unless otherwise indicated in this section, hybrid and base vehicle emission testing shall confirm to the requirements of California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric and Other Hybrid Vehicles, in the Urban Bus and Heavy-Duty Vehicle Classes (Amended December 13, 2013), Section D.

1. **Vehicle Selection.** The applicant may propose a base vehicle for chassis dynamometer testing pursuant to Section D. 1 through 1.6.1 of these interim test procedures.

2. **Charge-Depleting Hybrid-Electric Vehicles.** *tbd*

3. **Emissions Calculations.** *tbd*

F. POST-TRANSMISSION POWERTRAIN VEHICLE SIMULATION

Staff is exploring potentially allowing a new hybrid heavy-duty vehicle that is demonstrating federal compliance with Phase 1 heavy-duty vehicle GHG standards to pursuant to 40 CFR 1037.555 to concurrently collect NOx emission data as part of the federal Phase 1 GHG compliance demonstration for the purposes of meeting hybrid vehicle NOx emission testing requirements of ITR. In this approach, the relative NOx emissions would be calculated pursuant to 40 CFR 1037.615(b)(2), with the "Improvement Factor" reflective of relative emissions between the hybrid vehicle and its non-hybrid counterpart. However, the US-EPA GHG powertrain testing is for CO2 and thus does not emphasize cold starts or preparation of the NOx aftertreatment system (system temperature, ammonia storage state, time since last regenation, etc). ARB is quite interested in leveraging cost-effective opportunities to obtain criteria pollutant evaluations in the course of this GHG testing and is in ongoing dialogue with US EPA.

G. DATA COLLECTION AND QUALITY CONTROL

(under development)

The following data must be collected (from SAE J1939 broadcast data, analog instrumentation, field records, or manufacturer information/specification sheets) for all baseline and hybrid vehicles participating in PEMS testing. If proprietary equipment or information is needed to collect these signals, the applicant shall make this equipment or information available to ARB upon request if needed for the purposes of confirmatory PEMS testing.

The actual signal value shall always be used instead of a default or limp home value. For purposes of the calculated load, torque, fuel rate, and modeled exhaust flow parameters, manufacturers shall report the most accurate values that are calculated within the applicable electronic control unit (e.g., the engine control module). "Most accurate values", in this context, shall be of sufficient accuracy, resolution, and filtering

to be used for the purposes of in-use emission testing with the engine still in a vehicle (e.g., using PEMS).

The following data are to be collected by engine control unit (ECU):

- Engine Torque
- Engine Speed
- Rechargeable Energy Storage System Battery State-of-Charge (if applicable)
- Rechargeable Energy Storage System Net Energy Change (if applicable)
- Boost Pressure
- Coolant Temperature
- Intake Manifold Temperature
- Fuel Injection Rate
- Fuel Temperature
- Fault Status

The following data are to be collected by global positioning system (GPS):

- Vehicle Speed
- Vehicle Position (X, Y, Z)
- Acceleration
- Distance Traveled
- Elevation

Additional required data and default measurement technique are identified below:

- Intake Air Flow Rate - Flow Sensor
- Exhaust Mass Flow - Exhaust Flow Sensor (Pilot)
- Exhaust Back Pressure - Pressure Sensor
- Exhaust Temperature - Temperature Sensor
- Ambient Humidity – Humidity Sensor
- Ambient Temperature – Temperature Sensor
- Ambient Pressure – Pressure Sensor

NOx, CO, CO_2, CH_4, and other hydrocarbon emissions are to be measured by the PEMS unit. Fuel consumption of the hybrid and baseline vehicle shall be calculated based mass balance of carbon-bearing emission gases as described in 40 CFR Part 86 and SAE test method J1094a.

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