APPENDIX A: TECHNICAL SUPPORTING INFORMATION

This appendix includes additional details regarding proposed ITR certification flexibility for eligible low-NOx and heavy-duty hybrid engines (Sections 1 and 2 of this Appendix, respectively); hybrid conversion system diagnostic requirements (Section 3); and emission test procedures for participating heavy-duty hybrid engines and hybrid conversion systems (Section 4).

1. Proposed Low-NOx Engine Certification Flexibility Provisions

A manufacturer would be eligible for the following flexibility when applying to ARB for certification of an eligible optional low-NOx engine.

Assigned Deterioration Factors

ARB's existing heavy-duty engine certification requirements allow manufacturers with sales of 300 or fewer vehicles and engines per year to certify their heavy-duty engines using assigned DFs "that the Executive Officer determines and prescribes based on design specifications or sufficient control over design specifications, development data, in-house testing procedures, and in-use experience."[1] These requirements would continue to apply under the proposed ITR. Additionally, under the proposed ITR, if an ARB assigned DF is not available, a manufacturer would have the opportunity to use an appropriate U.S. EPA assigned DF[2] or, in lieu of an appropriate U.S. EPA assigned DF, propose an assigned DF to ARB.

This proposed certification flexibility provision would provide participating low-NOx engine manufacturers with the certainty that they may use assigned DFs in lieu of conducting high-mileage emission tests. This certification flexibility provision, requested by engine manufacturers during ITR development, is intended to encourage early low-NOx engine deployment by reducing the time and expense required for engine aging for an engine that is likely to initially be deployed in low volumes, similar to the premise underlying small volume manufacturing provision described above. By allowing use of an assigned DF, this proposed regulation would also provide manufacturers up to three MYs to age an in-use certified engine, reducing the potential need and associated expense of accelerated engine aging conducted prior to initial certification.

On-Board Diagnostics Flexibility Provisions

An eligible low-NOx engine family would be subject to all existing heavy-duty OBD requirements, as described in California Code of Regulations, title 13, sections 1971.1 and 1971.5, with the following exceptions:

[1] ARB; *California Exhaust Emission Standards and Test Procedures for 2004 and Subsequent Model Heavy-Duty Diesel Engines and Vehicles*; Amended September 2, 2015; http://www.arb.ca.gov/msprog/onroadhd/hddtps_lev_iii_clean_complete_10-15.pdf .

[2] U.S. EPA; National Vehicle and Fuel Emissions Laboratory guidance letter CD-12-07 (Revised); March 30, 2012; https://ofmpub.epa.gov/otaqpub/display_file.jsp?docid=26974&flag=1 .

OBD System Demonstration. ARB selects the engine family or families manufacturers must demonstrate for each MY. Test data from the demonstration enables ARB to ensure that the OBD emission monitors function correctly through validation on a subset of a manufacturer's engine offerings.

Some manufacturers have expressed concern that certification of a new engine family meeting the low-NOx emission standard could cause a manufacturer's total engine family number for a given MY to increase to the next tier for OBD demonstration engines. For example, a manufacturer previously certifying five engine families per year that adds a low-NOx engine family would now have six total engine families and would then be required to conduct an OBD system demonstration on an additional engine family (i.e., a total of two OBD system demonstrations would be required instead of one OBD system demonstration). Considering the unknown demand for low-NOx engines and the resource intensive demands for conducting an OBD system demonstration test, staff acknowledges that the current OBD system demonstration requirements may disincentivize the introduction of a low-NOx engine if its introduction would require another engine to be demonstration tested.

Calculation of Fines for Deficiencies. California Code of Regulations, title 13, section 1971.1, subdivision (k) permits ARB to allow certification of heavy-duty OBD systems with "deficiencies" in cases where a good faith effort to fully comply has been demonstrated. Specifically, in granting deficiencies pursuant to California Code of Regulations, title 13, section 1971.1, subdivision (k), the Executive Officer considers the following factors: the extent to which the requirements of the OBD regulation are satisfied overall based on the description in the application, the relative performance of the OBD system compared to systems fully compliant with the requirements of the OBD regulation, and a demonstrated good-faith effort on the part of the manufacturer to: (1) meet the requirements in full by evaluating and considering the best available monitoring technology, and (2) come into compliance as expeditiously as possible. The deficiency provisions facilitate OBD implementation by minimizing the risk that manufacturers may not be able to certify engines with relatively minor implementation problems. However, to prevent misuse of the provision and ensure equity for manufacturers able to meet the proposed requirements in full, manufacturers are subject to fines for deficiencies in excess of two for each OBD system. Therefore, the first two deficiencies are "free" and any additional deficiencies would include a fine of $25 or $50 each, depending upon the monitoring requirement at issue.

The proposed ITR extends the "free" deficiency provision of the OBD regulation by allowing up to four allowable deficiencies related to monitoring of low-NOx technologies to be excluded from the calculation of fines described in California Code of Regulations, title 13, section 1971.1, subdivision (k)(2). This proposed regulation would require that these four allowable "free" deficiencies be related to achievement of the low-NOx emission standard. The proposed ITR recognizes the potential OBD compliance challenges associated with integrating new systems and technologies to meet the low-NOx standard, such as selective catalytic reduction (SCR) catalysts, NOx adsorbers, exhaust gas recirculation, air/fuel ratio imbalance monitoring, cold start emission reduction strategies, or other emission controls or strategies needed for low-NOx emission compliance. This provision reduces the cost of compliance for manufacturers of low-NOx engine manufacturers who work in good faith to comply with the ITR OBD requirements.

Emission Threshold Liability. California Code of Regulations, title 13, section 1971.5, subdivision (d)(3)(A)(ii) requires that major OBD monitors indicate a malfunction and illuminate the MIL before emissions exceed a certain emission threshold. If the OBD system is unable to detect emissions that are 3 times the major monitor malfunction criteria in the 2013 through 2015 MYs, 2.5 times the major monitor malfunction criteria in the 2016 through 2018 MYs, or 2 times the major monitor malfunction criteria thereafter, that engine cannot be certified, or must be recalled and repaired if the non-compliance is discovered after certification. For example, if the major monitor malfunction criteria is 2.5 times the applicable standard, the engine cannot be certified if the monitor cannot detect a malfunction before emissions exceed 7.5 times the applicable standard.

The proposed ITR increases the recall or no certification emission threshold for major monitors to 3 times the applicable malfunction threshold for eligible 2016 and subsequent MY engines. This proposed allowance is intended to help mitigate a manufacturer's risk of an engine recall for a new engine technology for which it may not yet have the experience, expertise, or data to ensure the engine will not exceed the lower recall emission threshold. This proposed allowance is the same as that given to heavy-duty engine manufacturers for 2013 through 2015 MY engines during the early years of heavy-duty OBD implementation.

Production Engine/Vehicle Evaluation Testing. California Code of Regulations, title 13, section 1971.1, subdivision (l) requires that manufacturers conduct testing each MY on a subset of engines installed in in-use vehicles and provide the results of such testing to ARB within a certain period of time. This in-use vehicle testing must demonstrate effective communication between all emission-related on-board computers and any J1978/J1939 scan tool, including demonstration of OBD readiness for all on-board computers, storage and communication of fault codes, and MIL functionality checks (i.e., verification of standardization requirements). Production Engine/Vehicle Evaluation testing also involves testing selected vehicles to verify that the OBD system correctly identifies any emissions-related malfunction (i.e., verification of monitoring requirements), and requires manufacturers to provide the monitoring frequency data from in-use vehicles that illustrates how often monitors run during in-use operation (i.e., verification and reporting of in-use monitoring performance).

The proposed ITR allows production engine evaluation test results to be provided one year from the start of production, unless problems are found from the testing, instead of at three months for verification of standardization requirements, and at six months for IUMPR requirements, as otherwise required by California Code of Regulations, title 13, section 1971.1, subdivisions (l)(1) through (l)(3). Additionally, for verification of standardized requirements, a manufacturer would test five unique production vehicles per engine family instead of ten, as required by California Code of Regulations, title 13, section 1971.1, subdivisions (l)(1.2.1) through (l)(1.2.3). For reporting of IUMPR, a manufacturer could request ARB approval for testing of a minimum of ten percent of vehicles produced for sale per monitoring performance group, instead of fifteen vehicles per monitoring group, as otherwise required by California Code of Regulations, title 13, section 1971.1, subdivision (l)(3). These production engine/vehicle evaluation testing flexibilities reduce the resource and testing burdens for low-NOx engine manufacturers and provide a reduction in engine certification costs, particularly when increasing the number of engine families certified, by enabling manufacturers to better prioritize use of their testing staff and resources.

Multiple Low-NOx Engine Option

The proposed ITR provides an additional option to further encourage manufacturers to bring a diversity of low-NOx engines to the California market. A manufacturer of two new eligible low-NOx engines that have not utilized this proposed regulation's certification flexibility in any previous MY, and that each have at least three MYs of potential ITR eligibility remaining, would be eligible for this proposed regulation's "multiple low-NOx engine option." This option would require a manufacturer's two otherwise eligible low-NOx engines to forgo this regulation's certification flexibility and not participate in any NOx emission averaging, banking, or trading programs in the current and the two subsequent MYs. In exchange, one of the participating manufacturer's low-NOx engine families would be exempt from OBD emission threshold monitoring requirements for one MY.

For example, a manufacturer with two alternative fuel engine families certified to a 0.02 or 0.05 g/bhp-hr NOx standard in the 2018 MY would be ineligible for the proposed certification flexibility provisions described in the previous sections for one of these engine families (i.e., the early compliance engine family) in 2018, 2019 and 2020 MYs. The manufacturer's second low-NOx engine family for the 2018 MY (i.e., the enhanced flexibility engine family) would be exempt from the OBD emission threshold monitoring requirements of California Code of Regulations, title 13, section 1971.1, subdivisions (e) through (f) for the 2018 MY, and would be ineligible for any other certification flexibility pursuant to this proposed regulation in the 2018, 2019, or 2020 MYs. Staff discussions with stakeholders suggest that this option will enable at least one large engine manufacturer to certify two, rather than one, heavy-duty spark-ignition engine families meeting a 0.02 g/bhp-hr NOx standard in the 2018 MY, when OBD is first required for heavy-duty alternative fuel engines.

All engines that are part of an engine family that is exempt from emission threshold monitoring requirements pursuant to the multiple low-NOx engine option in a given MY must be labeled as described in subsection 2208.1(a)(4) of this regulation. This requirement is necessary for enforcement purposes, and to alert inspection and maintenance technicians that such an engine is exempt from the specified emission threshold monitoring requirements pursuant to this regulation.

Low-NOx Engine Surplus Emission Reductions

A low-NOx engine family receiving certification flexibility or participating in the multiple low-NOx engine option must not already be required to comply with any existing emission standard in a given MY. In addition, such an engine family may not participate in any NOx emissions averaging, banking, or trading (ABT) program. An engine family that is eligible for the proposed ITR based on meeting the optional low-NOx emission standard is not prohibited from participation in an ABT program for other pollutants. NOx and CO_2 emission reductions achieved by an engine receiving this proposed regulation's certification flexibility must be surplus to engine or vehicle emission standards. This proposed regulation is intended to work synergistically with potential technology advancing fleet rules (such as a potential Advanced Clean Transit regulation) and funding programs. Staff's proposal does not require that NOx emissions achieved by a participating low-NOx engine be surplus to air quality regulations that apply exclusively to fleets, nor does it necessarily exclude a low-NOx engine from incentive funding eligibility.

2. Heavy-Duty Hybrid Engine Certification Flexibility Provisions

A manufacturer would be eligible for the following flexibility when applying to ARB for certification of an eligible heavy-duty hybrid engine.

Tier 1 Certification Flexibility

Assigned DFs. An engine family would be eligible for the same flexibility to use an assigned DF in lieu of engine aging as provided for a heavy-duty low-NOx engine pursuant to the proposed ITR. See low-NOx engine certification flexibility, above, for more information regarding assigned DFs.

Engine Manufacturer Diagnostics (EMD). The engine family would be subject to the EMD requirements of California Code of Regulations, title 13, section 1971.1, subdivision (d)(7.1.3), typically referred to as "EMD plus," in lieu of the full OBD requirements of California Code of Regulations, title 13, section 1971.1, subdivision (d)(7.1.1). EMD requirements for heavy-duty engines were originally adopted by the Board in 2004, in anticipation of the more comprehensive heavy-duty OBD requirements to be implemented beginning with the 2010 MY. EMD requires manufacturers to monitor the fuel system, exhaust gas recirculation (EGR) system, the PM filter, and emission-related electronic components but does not have stringent performance requirements for the monitors like the OBD requirements, which specify that monitors shall detect malfunctions when a component deteriorates to levels such that an emission threshold is exceeded. Instead, with EMD, the manufacturer decides what level of monitoring is appropriate for most monitors, and allows a total lack of function of monitors (i.e., the component or emission control is totally non-functional) for a few specified emission controls.

"EMD plus" includes an additional requirement to monitor the NOx aftertreatment system for a total lack of function. When a malfunction is detected, the regulation requires the EMD system to illuminate a warning light, which could be an existing light or a new light, at the manufacturer's preference. Additionally, though the EMD system will be required to output diagnostic information for use by repair technicians, it does not establish standardized requirements defining the content or format of specific information required to be outputted. Staff anticipates that allowing manufacturers to meet EMD plus in the first few years a new hybrid technology is certified will provide manufacturers a significant incentive to bring hybrid truck and bus technology to market by providing time to demonstrate OBD compliance as the technology matures and volumes increase. This approach is consistent with existing provisions allowing alternative fuel-heavy-duty engines to comply with EMD plus rather than heavy-duty OBD until the 2018 MY.

In addition, all hybrid engines from an engine family receiving Tier 1 certification flexibility in a given MY must be labeled as described in subsection 2208.1(a)(4) of the proposed ITR. This requirement is for enforcement purposes, and to alert inspection and maintenance technicians that such an engine is subject to EMD rather than heavy-duty OBD requirements.

<u>Tier 2 Certification Flexibility</u>

This proposed regulation's Tier 2 certification flexibility provisions for a new heavy-duty hybrid engine are similar to that proposed for an engine meeting the optional low-NOx emission standard, with the exceptions described below:

Assigned DFs. An engine family would be eligible for the same flexibility to use an assigned DF in lieu of engine aging as provided for a heavy-duty low-NOx engine and heavy-duty hybrid engines in Tier 1.

Tier 2 OBD Flexibility Provisions. An eligible heavy-duty hybrid engine family would be subject to all existing heavy-duty OBD requirements, as described in California Code of Regulations, title 13, section 1971.1 and 1971.5, with the following exceptions:

- OBD System Demonstration: As mentioned earlier, California Code of Regulations, title 13, section 1971.1, subdivision (i)(2.2.3) requires that manufacturers supply OBD emission test data from one or more durability demonstration test engines. A manufacturer certifying one to five engine families in a MY must provide these data for at least one engine rating, a manufacturer of six to ten engine families must do so for at least two engine ratings, and a manufacturer of eleven or more engine families must do so for at least three engine ratings.

  The proposed ITR would exempt up to three heavy-duty hybrid engine families from the calculation of a manufacturer's total number of engine families for determining the number of OBD system demonstration vehicles for a given MY. By doing this, the proposed ITR would remove a potential disincentive to certify additional hybrid engine families; ARB in turn would undertake a minimal risk of "auditing" a smaller number of engine families in a MY.

In addition, a hybrid engine family that is identical to one previously certified in a non-hybrid configuration would be exempt from fault testing currently required pursuant to California Code of Regulations, title 13, section 1971.1, subdivision (i)(3). A hybrid engine family whose OBD system has been modified relative to that of the previously certified identical non-hybrid engine family would be ineligible for this exemption, unless the Executive Officer approves the manufacturer's demonstration that such modifications do not adversely impact such systems' ability to meet the requirements of California Code of Regulations, title 13, section 1971.1, subdivision (i)(3). This proposed provision would reduce a manufacturer's testing costs by allowing manufacturers to avoid or reduce demonstration testing of a hybrid engine's OBD system if it is identical or nearly identical to a previously-certified engine and OBD system.

- Production Engine Evaluation Testing: The proposed ITR would allow production engine evaluation test results for heavy-duty hybrid engines to be provided one year from the start of production, unless problems are found from the testing, instead of at three months for verification of standardization requirements, and six months for IUMPR requirements, as otherwise required by California Code of Regulations, title 13, section 1971.1, subdivisions (l)(1) through (l)(3). Additionally, for verification of standardized requirements, a manufacturer would test five unique production vehicles per engine family instead of ten, as otherwise required by California Code of Regulations, title 13, section 1971.1, subdivisions (l)(1.2.1) through (l)(1.2.3). For reporting of IUMPR, a manufacturer could request ARB approval for testing of a minimum of ten percent of vehicles produced for sale per monitoring performance group, instead of fifteen vehicles per monitoring group, as otherwise required by California Code of Regulations, title 13, section 1971.1, subdivision (l)(3). These production engine/vehicle evaluation testing flexibilities reduce the resource and testing burdens for hybrid engine manufacturers, and provide a reduction in engine certification costs, particularly when increasing the number of engine families certified, by enabling manufacturers to better prioritize use of their testing staff and resources.

- Calculation of Fines for Deficiencies: The proposed ITR would extend the "free" deficiency provision of the OBD regulation by allowing up to four allowable deficiencies related to monitoring of hybrid engine and driveline technologies to be excluded from the calculation of fines described in California Code of Regulations, title 13, section 1971.1, subdivision (k)(2). This proposed regulation would require that these four allowable "free" deficiencies be related to engine hybridization (such as energy storage performance and hybrid thermal management performance monitors). This provision reduces the cost of compliance for manufacturers of hybrid engines and drivelines who work in good faith to comply with the proposed ITR OBD requirements.

Staff does not recommend that a heavy-duty hybrid engine be eligible for the emission threshold liability provisions proposed for optional low-NOx engines pursuant to this regulation. Staff believes this flexibility is not necessary for a hybrid engine, since the emission threshold monitors for a hybrid engine are likely to be equivalent to its non-hybrid counterpart, and because considerable emission threshold relaxation is already provided for eligible heavy-duty hybrid engines in Tier 1.

Anti-Backsliding Provisions

A handful of manufacturers already offer OBD-compliant hybrid engines, and are anticipated to continue certifying the same hybrid engine in coming years. For these OBD-compliant engines, a manufacturer is not eligible for an OBD flexibility for which it has already demonstrated compliance in a previous MY. This prohibition ensures that a manufacturer does not backslide on an engine diagnostic requirement for which it has already engineered a compliance solution. This proposed ITR does, however, exempt such a hybrid engine from fines related to OBD deficiencies and from the requirement that it address deficiencies of its otherwise OBD compliant system as expeditiously as possible, through the 2020 MY. Such a provision helps level the playing field with new hybrid engines that would have significant relief from such provisions as part of Tier 1 and Tier 2 flexibility.

Hybrid Heavy-Duty Engine Surplus Emission Reductions

A hybrid heavy-duty engine would have to demonstrate it is not used for compliance with any CO_2 emission standard, such as Phase 1 or Phase 2 GHG Standards, to be eligible for the proposed ITR certification flexibility. An engine manufacturer would be required to demonstrate that any CO_2 emission reductions from hybridization are not used in determination of compliance with a GHG standard in the given MY, and that the reductions will not be banked or otherwise credited in the given or any future MY. The proposed requirement for "surplus" emission reductions are intended to help ensure that manufacturers benefitting from proposed ITR certification flexibility are bringing these technologies to market earlier than they otherwise would have been required to by a regulatory mandate.

Both Phase 1 and Federal Phase 2 GHG Standards require the CO_2 benefits of engine hybridization to be quantified via specified regulatory emission test procedures. One option for a manufacturer to demonstrate emission reductions from hybridization are not used for Phase 1 or Phase 2 GHG Standards compliance purposes would be to permanently retire the identified CO_2 emission reduction attributed to engine hybridization of the proposed engine family prior to demonstrating compliance with GHG engine emission standards for a given MY. This process would require a hybrid engine to certify to the applicable Phase 1 or Phase 2 GHG Standards in the given MY, prior to certifying the engine with ARB to meet criteria pollutant emission standards.

3. OBD System Requirements for Hybrid Conversion Systems

The OBD system requirements to which the base light-duty or medium-duty vehicle or heavy-duty engine was originally certified remain applicable (i.e., California Code of Regulations, title 13, sections 1968.2 or 1971.1, respectively), except for the following differences:

<u>Tier 1 Hybrid Conversion System OBD System Exceptions.</u>

EMD. Staff is proposing that Tier 1 hybrid conversion systems meet "EMD plus" in lieu of heavy-duty OBD requirements for new hybrid heavy-duty engines.

Hybrid System Diagnostic Link Connector (HSDLC). OBD regulations require all new vehicles to incorporate a diagnostic link connector (DLC) conforming to the specifications described in their respective requirements (California Code of Regulations, title 13, section 1968.2 for light- and medium-duty vehicles or section 1971.1 for heavy-duty engines). This single connector is currently required to be located in the driver's side foot-well region of the vehicle interior below the steering wheel and is used for communicating emission-related inspection and diagnostic information from the OBD system to a standardized diagnostic or scan tool.

On new hybrid vehicles, the DLC is required to communicate with the OBD system for all diagnostic or emission critical electronic powertrain control units (i.e., on-board electronic powertrain control units containing significant OBD software), such as the hybrid control system module and transmission control module. However, on vehicles that are converted into hybrids, the conversion system manufacturer may not have the expertise or original vehicle's proprietary information necessary to integrate the hybrid control computer diagnostic system with the original vehicle's or engine's OBD system, and may therefore need to use a separate HSDLC to communicate with its proprietary hybrid system scan tool.

The proposed ITR would require the HSDLC to be located to the right-side of the centerline of the vehicle to avoid confusion with the standardized OBD diagnostic link connector location that is on the left-hand side of the vehicle below the steering wheel. Other than the location of the HSDLC, no additional requirements are proposed for the connector (e.g., shape, type, communication protocol, etc.). While current OBD regulations do not prohibit the use of other diagnostic connectors on the vehicle, this proposed requirement specifying the location of the HSDLC is intended to enable inspection and maintenance technicians to more easily identify the HSDLC and differentiate it from the other potentially similar connectors on the vehicle.

Monitoring Conditions – In-Use Monitoring Performance. OBD regulations (i.e., California Code of Regulations, title 13, sections 1968.2 and 1971.1) require manufacturers to use a standardized method for determining real world monitoring performance of select critical emission control components and hold manufacturers liable if the monitoring of these components occurs less frequently than a minimum acceptable level, expressed as a minimum acceptable IUMPR. For example, if the minimum acceptable IUMPR for the catalyst system monitor is 0.100, this means that a vehicle's catalyst monitor IUMPR must be equal to or greater than 0.100 to be compliant. IUMPRs for select OBD system monitors are required to be stored in the vehicle's OBD computers and communicated through the OBD DLC when requested with an OBD diagnostic or scan tool. The process of connecting a scan tool and retrieving the IUMPR data from the vehicle requires minimal resources and should take a few minutes, but provides ARB and the conversion manufacturer valuable information on whether the OBD monitors run frequently in use. If the monitors do not run with a minimum frequency during in-use operation, then the OBD system may be ineffective. Therefore, IUMPR data collection is an important tool for validating OBD system performance. While it is expected that the IUMPR for most OBD monitors will not be negatively impacted by the addition of the hybrid conversion system, monitors that only run when the vehicle is within certain operating regimes (such as engine idle or during "fuel cut"), that are no longer achievable because the hybrid system's engine control strategy eliminates these operating regimes, would be negatively impacted if the conversion manufacturer does not ensure the required monitoring conditions occur during normal driving operation.

Since hybrid conversion manufacturers may not have access to the OBD system diagnostic information for the vehicles that will be converted, the IUMPR performance for some monitors may not perform as required by the OBD regulations. Taking this into account, the proposed ITR would require hybrid conversion system manufacturers to comply with the required minimum IUMPRs stated in California Code of Regulations, title 13, sections 1968.2 and 1971.1. However, the enforcement of the minimum IUMPRs on in-use conversion vehicles would not be conducted on Tier 1 vehicles. Additionally, in order to determine if the hybrid conversion system may have a negative impact on the OBD system's IUMPR performance, the proposed ITR would require conversion manufacturers to submit data from a minimum of one hybrid conversion vehicle to ARB within one year after the certified hybrid conversion system is first manufactured for sale in California.

OBD System Modifications. In order to ensure that the hybrid conversion system does not impact the vehicle's OBD system, ARB is proposing that modifications to the vehicle's OBD system, including the emission controls and control strategies, be limited to changes that are solely to prevent false malfunction determination for OBD system diagnostics. Additionally, the modifications should not prevent the base engine OBD system from detecting when major monitors (i.e., monitors that are required to be calibrated to an emission threshold, as specified in California Code of Regulations, title 13, sections 1968.2 and 1971.1) have a total lack of function. Since hybrid conversion system manufacturers typically do not have access to proprietary information from vehicle manufacturers regarding the operation of the vehicle's OBD system, the proposed ITR would restrict the modifications that can be done to the vehicle's OBD system and emission controls. If modifications to the base vehicle system are made by the conversion manufacturer, the OBD performance of the system would need to be revalidated with OBD performance tests similar to those a new vehicle manufacturer would have to conduct to receive approval of the OBD system design. For the testing, hybrid conversion system manufacturers would be required to individually implant or simulate malfunctions to verify that the OBD system correctly identifies any emissions-related malfunction. The data must be submitted and approved by ARB before Tier 1 approval could be granted.

Production Vehicle Evaluation Testing – Verification of Standardized Requirements. OBD standardization requirements are essential to the success of the OBD program for on-road vehicles, since they help ensure that the stored OBD data in the vehicle's on-board computer can be accessed by inspection, maintenance, and enforcement personnel by a common "generic" scan tool. Because proper standardized communication with the OBD system is critical to the success of the OBD program, the OBD regulation (i.e., California Code of Regulations, title 13, sections 1968.2 and 1971.1) requires verification of the standardized requirements by requiring new engine and vehicle manufacturers to test a sample of production vehicles from the assembly line to verify that the vehicles have indeed been designed and built to the required specifications for communication with a generic scan tool.

The proposed ITR also includes a requirement of verification of the standardized requirements that mirrors the OBD regulation. However, in order to reduce the testing burden on conversion manufacturers, staff would require testing on one vehicle per engine model/vehicle combination instead of ten vehicles per engine model/vehicle combination as required in the OBD regulation (i.e., California Code of Regulations, title 13, section 1971.1). The testing and reporting of the test results would need to be completed and submitted to ARB before Tier 1 approval could be granted.

<u>Tier 2 Hybrid Conversion System OBD Certification Requirements</u>

In order to encourage hybrid conversion manufacturers that have introduced Tier 1 hybrid conversion systems and have successfully achieved their allotted volume caps to continue to strive toward reaching full OBD compliance for hybrid conversion systems (i.e., Tier 3), Tier 2 proposal would maintain some of the flexibilities from Tier 1 while including some new requirements that are closer to the final proposed Tier 3 requirements. Depending upon their engineering resources, competencies, and projected sales, some conversion manufacturers may choose to skip Tier 1 entirely with its additional flexibilities but low volume caps, and instead go straight to Tier 2, with its larger volume caps, and still considerable OBD compliance flexibilities. For these manufacturers, the stability and cost savings to engineer just one OBD system for an extended time outweighs the relatively short-term increased compliance flexibility of Tier 1. Details of the proposed Tier 2 OBD requirements are described below.

For Tier 2, all Tier 1 OBD requirements described above in the previous section would need to be met. Additionally, the following requirements would also need to be met for Tier 2 OBD certification:

OBD Readiness Requirements. The OBD regulations require new vehicle manufacturers to incorporate readiness status indications of major emission control systems and components into their vehicles, which would determine if the OBD monitors have performed their system evaluations. When the vehicle is scanned with a generic scan tool, the monitor would report a readiness status of either “complete” (if the monitor has run a sufficient number of times to detect a malfunction since the memory was last cleared), “incomplete” (if the monitor has not yet had the chance to run since the memory was last cleared), or “not applicable” (if the monitored component in question is not equipped or monitored on the vehicle). The main intent of the readiness status is to ensure a vehicle is ready for an OBD-based inspection and maintenance program (such as “Smog Check” for light- and medium-duty vehicles), and to prevent fraudulent testing. In general, for OBD-based inspections, technicians “fail” a vehicle if the MIL is illuminated, which indicates a fault is currently present. Without readiness status, drivers (or even technicians) could possibly avoid “fail” designations by disconnecting the battery and clearing the computer memory prior to an inspection, which erases any pre-existing fault codes and extinguishes the MIL. The readiness status information allows a technician or inspector to determine if the memory in the on-board computer has been recently cleared (e.g., by a technician clearing fault codes or disconnecting the battery). Although readiness status is not currently utilized in the existing heavy-duty inspection program for California, it is expected to be incorporated into any future proposal for the program. Additionally, new light-duty, medium-duty, and heavy-duty vehicles and engines cannot be certified if the readiness status of major monitors cannot be properly set such that inspection and maintenance programs would be impacted.

In light of the important role OBD readiness status plays in California’s inspection and maintenance program, the proposed ITR requires an OBD readiness status demonstration for Tier 2 certification of a hybrid conversion system. Hybrid conversion manufacturers would be required to demonstrate that the OBD system on their hybrid conversion vehicle or vehicles can be set to “complete” with no false detections of malfunctions after the fault memory was last cleared for each of the installed monitored components and systems identified in the OBD regulations (i.e., California Code of Regulations, title 13, section 1971.1, subdivision (h)(4.1)).

Data Durability Vehicle (DDV) Testing. OBD regulations require manufacturers to design OBD monitors for each emission-related component or system such that they will indicate a malfunction before emissions exceed a designated emission malfunction threshold. In order to spot-check OBD malfunction threshold values set by manufacturers, OBD regulations require that manufacturers conduct certification demonstration testing on the major monitors of one to three engines or vehicles per year to verify their malfunction threshold values (California Code of Regulations, title 13, section 1971.1, subdivision (i)). As part of the demonstration and reporting requirements, manufacturers are required to submit documentation and emission data demonstrating that the major monitors are able to detect a malfunction before emissions exceed the emission threshold.

For Tier 2 approval, ARB is proposing that DDV testing be conducted, but the amount of required tests and the testing demands proposed are considerably less and require fewer resources than required in current OBD regulations. Typically, new gasoline vehicles have about 10 to 13 emission threshold monitors that need to be tested on the DDV, while new diesel engines or vehicles usually have twice as many emission threshold monitors that are evaluated during the OBD demonstration testing. The proposed ITR would require manufacturers to demonstrate only up to three major monitors, to be selected by ARB, for testing. In addition, emission tests would not be required for the DDV tests. Instead, manufacturers would be required to demonstrate that the selected monitors can detect a non-functioning component or system. To test this type of malfunction, a “worst case” deteriorated component or system that no longer has any detectable “function” is installed on the DDV. Since emission tests would not be required, the testing could be done on the road or on a chassis dynamometer.

Verification and Reporting of In-use Monitoring Performance. The background information for the in-use monitoring performance testing described above in the proposed Tier 1 section would also apply here for Tier 2, but the proposed testing requirements are slightly different. Instead of proposing that conversion manufacturers submit IUMPR data from only one hybrid conversion vehicle to ARB within one year after the certified hybrid conversion system is first produced for sale in California, conversion manufacturers would be required to submit IUMPR data for at least 5 vehicles after 50 hybrid conversion systems certified pursuant to the proposed ITR have been installed on vehicles or engines for sale or lease in California. Additionally, prior to submitting the IUMPR data, conversion manufacturers would be required to submit a plan to ARB for review and approval that details the types and number of conversion vehicles to be tested, the sampling method, the time line to collect the data, and the reporting format. The plan would need to be submitted within 30 days after 50 hybrid conversion systems certified pursuant to the proposed ITR have been installed on a vehicle or engine for sale or lease in California. The additional data would provide ARB with a more accurate understanding of the in-use performance of diagnostics on the converted vehicles, with minimal additional expenditure of resources.

Tier 3 Hybrid Conversion System Certification Requirements

Tier 3 is the final, most stringent proposed tier of compliance for hybrid conversion vehicles and is required for all hybrid conversion vehicles after the proposed ITR regulation has sunset. For this tier, all Tier 1 and Tier 2 requirements described in the previous sections apply, with a few differences, described in more detail below.

Comprehensive Component Monitoring – Hybrid System. The first two tiers of the proposed ITR would allow hybrid conversion manufactures to determine the scope of monitoring that will be conducted on the hybrid components of the converted vehicle. For Tier 3, staff is proposing prescribed monitoring requirements for the hybrid components. Added electronic hybrid components/systems that either provide input to or receive commands from the on-board hybrid system computers, and that meet the definition of a comprehensive component according to California Code of Regulations, title 13, section 1971.1 for heavy-duty engines, or California Code of Regulations, title 13, section 1968.2 for medium-duty vehicles or engines, would be required to comply with the comprehensive component monitoring requirements of California Code of Regulations, title 13, section 1971.1, subdivision (g)(3) or California Code of Regulations, title 13, section 1968.2, subdivision (e)(15) or subdivision (f)(15).

Proposed Tier 3 comprehensive component monitoring requirements specify that input components be monitored continuously for out-of-range and circuit continuity faults (shorts, opens, etc.). Additionally, input components are monitored for rationality faults (e.g., where a sensor reads inappropriately high or low but, unlike out-of-range faults, still within the valid operating range of the sensor) whenever the monitoring conditions are met. Finally, "two-sided" rationality checks (i.e., detection of both inappropriately high and low readings) are conducted to the extent feasible and have reasonable malfunction thresholds and operating conditions (not extreme operating conditions) so that faults are detected efficiently. Input components for hybrid conversion systems could include components such as temperature sensors and voltage sensors for the energy storage system (e.g., battery). For output components, the comprehensive component monitoring requirements specify that output components be monitored for proper functional response (i.e., that the component has properly carried out a command from the on-board computer) at least once per driving cycle. If functional monitoring is not feasible, then circuit continuity monitoring is required. Typical output components on hybrids include systems and components such as electrical relays, motors, inverters, battery cell balancing, on-board chargers, generators, regenerative braking performance, hybrid thermal management performance, and energy storage system performance. For both input and output components, the stored fault code should pinpoint malfunction to the smallest replaceable unit for in-use repair.

Data Durability Vehicle (DDV) Testing. The background information for DDV testing described for the proposed Tier 2 provisions in the previous section also applies to the proposed Tier 3 requirements. However, there are some significant differences between the proposed Tier 2 and Tier 3 DDV testing requirements that require further explanation. ARB's proposed approach for the proposed Tier 3 requirements is to remove the additional compliance allowances from Tier 2 and make the hybrid conversion manufacturer adhere to the applicable OBD regulations (e.g., OBD II or HD OBD) as close as technically possible, considering the limited resources and access that conversion manufacturers have to OEM OBD information. As described earlier, light-duty vehicles and most medium-duty vehicles are normally emission certified as complete vehicles on a chassis dynamometer while some medium-duty vehicles and all heavy-duty vehicles are emission certified on an engine dynamometer. Since different weight classifications utilize different certification methods, the DDV testing requirements also have to accommodate these certification methods. As such, the proposed Tier 3 DDV requirements are separately tailored for chassis-certified vehicles and engine-certified vehicles.

- *DDV Testing Requirements for Chassis-Certified Vehicles.* Proposed Tier 3 DDV requirements are similar to those proposed for Tier 2, except that hybrid conversion system manufacturers would also be required to demonstrate up to 5 major monitors. The manufacturer would be required to utilize threshold parts and conduct emission measurements as specified in the OBD II regulation (i.e., California Code of Regulations, title 13, section 1968.1). While the demonstration of 5 major monitors is a significant increase from the 3 demonstration tests required in Tier 2, it is less than half the 10 to 13 tests normally conducted on new gasoline vehicles, and less than a 25 percent of the 20 to 26 tests typically conducted on new diesel vehicles. ARB believes that conducting five demonstration tests is the minimum needed to spot-check that the OBD malfunction threshold values for key monitors are still appropriate for the converted vehicle, while reducing certification costs and incentivizing technology development.

- *DDV Testing for Engine-Certified Vehicles:* Since it is very resource intensive to remove the engine from a vehicle to conduct engine-dynamometer testing, the Tier 3 proposal would allow chassis-certified vehicles to continue to be tested on the chassis dynamometer, as allowed under Tier 2. The proposed DDV test procedures described for Tier 2 apply to Tier 3, with the exception that all major monitors would be required to be demonstrated instead of just three major monitors, as required in Tier 2. Similar to Tier 2, testing would be conducted on either the heavy-duty vehicle urban dynamometer driving schedule (UDDS) (40 Code of Federal Regulations part 86, Appendix I(a)) or on the heavy-duty transient test cycle (40 Code of Federal Regulations part 1037, Appendix I) although there is an option for an alternative chassis test cycle if the manufacturer can demonstrate the cycle is representative of in-use operation of its vehicles. Emissions data collection would not be required for DDV tests of these vehicles, only a functional demonstration would be required in which the OBD system must detect a “worst case” deteriorated component installed on the DDV for each required DDV monitor. This flexibility provision further incentivizes deployment of hybrid truck and bus technology by reducing the engineering and financial resources needed to certify hybrid conversion systems.

4. Hybrid Truck and Bus Technology Emission Test Requirements

<u>Overview</u>

The proposed ITR includes requirements for a new heavy-duty hybrid engine and a hybrid conversion system to demonstrate at least a ten percent CO_2 emission reduction and no increase of NOx, CO, or HC relative to its non-hybrid counterpart. While these proposed emission test procedures are in Section 7 of the proposed “California Certification and Installation Procedures for Medium- and Heavy-Duty Vehicle Hybrid Conversion Systems” (Attachment E), the proposed test procedures also apply to new heavy-duty hybrid engines receiving certification flexibility pursuant to the proposed ITR.

<u>Proposed Emission Test Options</u>

The proposed ITR’s hybrid technology emission test procedures include the following three potential pathways for a manufacturer to demonstrate hybrid technology exhaust emission compliance for NOx, CO, HC, PM, and CO_2:

- *Chassis Dynamometer:* Hybrid conversion systems and new hybrid heavy-duty engines would both have the option to demonstrate proposed ITR emission compliance on a chassis dynamometer. Chassis dynamometers are used for light- and medium-duty vehicle emission certification purposes, but not currently for heavy-duty vehicle certification. Relatively few heavy-duty vehicle chassis dynamometers exist and heavy-duty vehicle chassis dynamometer testing can be more challenging and resource intensive than for lighter cars and trucks.

- *PEMS:* PEMS provides a more practical and less resource intensive mechanism for evaluating real-world heavy-duty engine emissions than a chassis dynamometer. ARB and U.S. EPA have required heavy-duty engine manufacturers to use PEMS to demonstrate in-use emission compliance for over a decade,[3] and PEMS is used by the European Union to enforce heavy-duty engine emission limits.[4]

- *Post-Transmission Powertrain Vehicle Simulation:* A new heavy-duty engine would be able to concurrently demonstrate ITR emission compliance when applying for certification of its compliance with Phase 1 GHG Standards pursuant to U.S. EPA's post-transmission powertrain vehicle simulation. This option would save hybrid engine manufacturers also participating in ITR both time and money, while potentially providing insight into possible mechanisms to concurrently certify technology to meet both criteria pollutant and GHG emission standards.

Manufacturer's Proposed Hybrid Technology Emission Test Plan

Hybrid heavy-duty engine manufacturers wishing to be eligible for the proposed new engine certification flexibility, and hybrid conversion system manufacturers wishing to apply for certification of their conversion systems, would have to submit a Hybrid Technology Emission Test Plan to the Executive Officer at least 60 days prior to proposed commencement of emission testing. A manufacturer's Hybrid Technology Emission Test Plan must include the manufacturer's proposal for meeting the proposed ITR emission criteria pursuant to the proposed ITR emission test requirements, and must include:

- Proposed logistical Information, such as a proposed test type (i.e., chassis dynamometer, PEMS, or post-transmission powertrain vehicle simulation), test date(s), location(s), and entity conducting emission testing;
- Proposed 40 Code of Federal Regulations part 1065-compliant emission test equipment specifications, measurement principles, and verification criteria, and emissions measurement, calibration, and verification methodologies;

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[3] U.S. EPA Office of Transportation and Air Quality; Regulatory Announcement: Final Rule on In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles; June 2005; https://www3.epa.gov/otaq/regs/hd-hwy/inuse/420f05021.pdf .

[4] International Council on Clean Transportation; A Technical Summary of Euro 6/VI Vehicle Emission Standards; June 2016; http://www.theicct.org/sites/default/files/publications/ICCT_Euro6-VI_briefing_jun2016.pdf .

- Proposed engine and vehicle information, such as make(s), model(s), engine displacement, maximum power and torque, gear ratios, emission afterteatment technology, and California NOx, HC, CO, and PM certification levels and Family Emission Limits;
- Proposed hybrid technology energy storage information, including a description of the battery (if applicable) specific energy, voltage, thermal management strategy, and weight, and a description of any energy storage systems in addition to, or in lieu of, batteries, such as ultra-capacitors, flywheels , or hydraulic assist devices;
- Description of the proposed hybrid conversion system, if applicable, including but not limited to parts removed or modified from the certified base vehicle or engine, and all major parts installed;
- Description of proposed operation of mechanical or electrical accessories, such as heating or air conditioning, during emission testing; and
- For manufacturers opting to conduct PEMS testing, the Hybrid Technology Emission Test Plan must also include a description of:
    - The proposed equipment and process for measuring required engine and vehicle operating parameters, location, elevation, and weather conditions, pursuant to *SAE International J1526: Fuel Consumption Test Procedure – Engineering Method* (SEPT 2015, SAE J1526);[5]
    - A proposed test route, including test route distance location and average anticipated speeds;
    - A proposed strategy for measuring cold-start emissions; and
    - Proposed criteria for defining a valid test run that shall be included in emission calculations.

The manufacturer's proposed Hybrid Technology Emission Test Plan would have to be approved by the Executive Officer before emission testing could commence. The Executive Officer would evaluate the proposed plan for compliance with the proposed ITR emission test procedures, based upon his or her engineering judgement and data and information provided by the applicant.

Proposed ITR hybrid technology chassis dynamometer, PEMS, and post-transmission powertrain vehicle simulation emission test procedures are described below. These proposed procedures may be updated in the future through potential regulatory amendments, as needed, to incorporate new information that may be obtained during implementation of the proposed ITR, if adopted. Staff anticipates that these proposed procedures may help inform a potential future transition to more holistic, vehicle-based emission testing and certification procedures that address both criteria and GHG emissions in the truck and bus sector.

Chassis Dynamometer Testing

Light- and Medium-Duty Vehicle Conversions. To convert a light- or medium-duty base vehicle that was originally chassis-certified, the hybrid conversion system manufacturer

[5] SAE International; *Surface Vehicle Recommended Practice: J1526: SAE Fuel Consumption Test Procedure (Engineering Method)*; September 2015.

would be required to demonstrate, on a chassis-dynamometer, that the converted vehicle continues to meet the NOx, HC, CO and PM exhaust emission standards to which the original base vehicle was subject. The hybrid vehicle would also have to demonstrate at least a ten percent CO_2 reduction relative to its non-hybrid counterpart over the light-duty Urban Dynamometer Driving Schedule (light-duty UDDS), pursuant to SAE International J1711: Recommended Practice for Evaluating Exhaust Emissions and Fuel Economy of Hybrid Electric Vehicles, including Plug-in Hybrids (SAE J1711), revised June 2010.

Medium-Duty Engine Conversions. To convert an engine that was originally certified on an engine dynamometer for installation in a medium-duty vehicle, the hybrid conversion system manufacturer would be required to test both the applicable pre-converted medium-duty base vehicle and its converted counterpart on a chassis dynamometer over two duty cycles - the light-duty UDDS, and either the US 06 Supplemental Federal Test Procedure (US-06) or the California Unified Cycle (LA-92). These cycles would each have to be repeated at least four times each by the base and hybrid vehicle, with at least one cold start test for each cycle, to demonstrate that the hybrid configuration does not emit more NOx, CO, HC or PM than, and achieves at least a ten percent CO_2 emission reduction from, its pre-converted, non-hybrid vehicle configuration.

Heavy-Duty Engines Conversions. To convert an engine that was originally certified on an engine dynamometer for installation in a heavy-duty vehicle, the hybrid conversion system manufacturer would be required to test the applicable heavy-duty hybrid and base vehicle pursuant to 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” (Amended October 21, 2014), with the exception of the required duty-cycles. “California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric and Other Hybrid Vehicles, in the Urban Bus and Heavy-Duty Vehicle Classes” require heavy-duty hybrid vehicles to be tested over two transient-like duty-cycles – the heavy-duty Urban Dynamometer Drive Cycle (heavy-duty UDDS) and the Orange County Bus Cycle. The proposed ITR would instead require use of discrete duty-cycles for heavy-duty vehicles to reflect transient and high-speed operation, consistent with the Phase 1 and Federal Phase 2 GHG Standards approach.[6] The proposed ITR would require all heavy-duty vehicles that are emission tested on a chassis dynamometer to be tested over a 55 mile per hour (mph) cruise duty-cycle identified in Phase 1 and Federal Phase 2 GHG Standards, to represent high-speed operation, plus a transient cycle, as specified below:

- Heavy-duty vehicles that are not transit buses would be tested over the Transient Portion of the Heavy Heavy-Duty Truck 5 Mode Cycle (Heavy-Duty Transient Test Cycle). This cycle was developed by ARB and is utilized to represent the transient

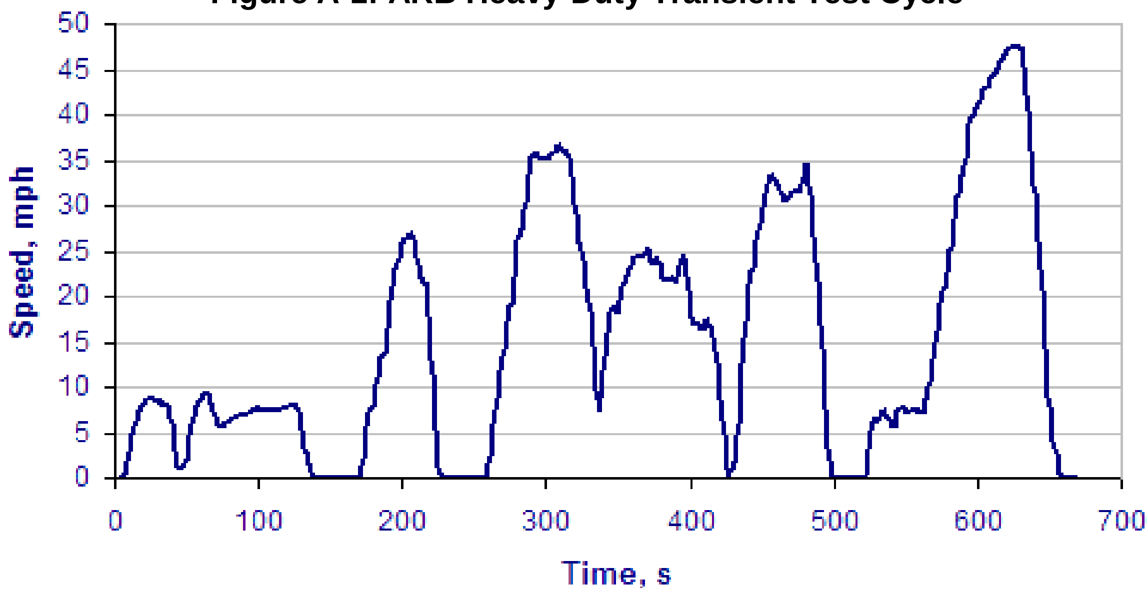
[6] United States Environmental Protection Agency and National Highway Traffic Safety Administration; Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 (Final Rule); August 18, 2016; https://www3.epa.gov/otaq/climate/documents/2016-08-ghg-hd-final-rule-phase2-preamble.pdf .

portion of heavy-duty vehicle operation for the purposes of compliance with Phase 1 GHG Standards and the Federal Phase 2 GHG Standards.[6] The Heavy-Duty Transient Test Cycle is illustrated in Figure A-1.

- Heavy-duty transit buses would be tested over the Orange County Bus Cycle. The Orange County Bus Cycle was developed by West Virginia University based on driving patterns of urban buses in the Los Angeles area, and is used for the purposes of hybrid heavy-duty vehicle certification testing, as described in the above paragraph.[7]

Consistent with the assumed activity factors for urban Class 2b through 7 vehicles in the Federal Phase 2 GHG Standards, the proposed ITR Hybrid Technology Emission Test procedures would require emissions from the transient-like cycles to be weighted by 0.92, and emissions from the high-speed cycle to be weighted by 0.08, to determine the average, weighted emissions of the hybrid vehicle relative to its non-hybrid counterpart.

Figure A-1: ARB Heavy-Duty Transient Test Cycle



Dozens of duty-cycles have been developed to reflect the diversity of truck and bus vocations, types and operating conditions. Given the diversity of potential truck and bus duty-cycles, the proposed ITR allows a manufacturer of a heavy-duty vehicle to propose an alternate transient-like duty-cycle for the purposes of chassis dynamometer emission testing if the manufacturer can demonstrate that the proposed alternate duty-cycle is more reflective of the heavy-duty vehicle's anticipated in-use operation than this regulation's default duty-cycles. Several potential vocation-specific truck and bus duty-

[6] United States Environmental Protection Agency and National Highway Traffic Safety Administration; Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 (Final Rule); August 18, 2016; https://www3.epa.gov/otaq/climate/documents/2016-08-ghg-hd-final-rule-phase2-preamble.pdf .

[7] ARB, Staff Report, Initial Statement of Reasons: Proposed Modifications to the Public Transit Bus Fleet Rule and Interim Certification Procedures for Hybrid Electric Urban Transit Buses; September 6, 2002.

cycles are described in U.S. EPA's *SmartWay Fuel Efficiency Test Protocol for Medium- and Heavy-Duty Vehicles: Working Draft (November 2007).*[8]

PEMS Testing

Emission testing conducted over the past decade has shown that PEMS technologies have performed well and accurately in measuring gaseous emissions from a diversity of on-road vehicles under different driving conditions. PEMS emission analyzers used for measuring gaseous pollutants use the same technology as is used in larger laboratory instruments.

The proposed ITR option for a manufacturer to test hybrid vehicles weighing more than 14,000 pounds over-the-road with PEMS rather than on a chassis dynamometer builds upon an existing PEMS-testing scientific foundation. All PEMS equipment specifications, measurement principles, verification requirements of emissions measurement, calibration, and verification methodologies are provided in 40 Code of Federal Regulations part 1065, which governs ARB and U.S. EPA requirements for use of PEMS as part of heavy-duty engine in-use compliance regulations. Since 40 Code of Federal Regulations part 1065 does not address how to compare emissions from two different vehicles when driven over a given cycle, the proposed ITR also utilizes SAE J1526 criteria to control for potential differences in vehicle type, mileage and technology, environmental conditions, and other factors. SAE J1526 provides a fuel-consumption test procedure that utilizes industry accepted data collection and statistical analysis methods to determine the difference in fuel consumption between vehicles with a gross vehicle weight of more than 10,000 pounds. SAE J1526 also requires concurrent testing of the base and hybrid vehicle over a given test route to better ensure consistency in test conditions. Deviations from SAE J1526 protocols, described below, are proposed to more effectively address hybrid truck and bus technologies, evaluate criteria pollutant emissions (rather than fuel economy), and promote consistency with the proposed chassis dynamometer and post-transmission powertrain vehicle simulation options.

Vehicle Selection and Preparation. For a valid comparison of hybrid and base vehicle emissions, it is critical that the base and hybrid vehicle be as closely matched as possible (with the exception of the hybrid system), so that emission differences can be reliably attributed to hybridization rather than another non-relevant parameter. The proposed ITR identifies the process by which a manufacturer must propose and justify that a base vehicle represents the closest possible non-hybridized version of its hybrid vehicle counterpart for the purposes of emission testing. For hybrid conversion systems, the base engine is represented by the pre-converted version of the converted engine and vehicle, and the hybrid vehicle is represented by a converted version of the same engine and vehicle.

[8] U.S. EPA; SmartWay Fuel Efficiency Test Protocol for Medium- and Heavy-Duty Vehicles; Working Draft; November 2007; https://www3.epa.gov/smartway/forpartners/documents/testing/420p07003.pdf .

For new heavy-duty hybrid vehicles produced by an original vehicle manufacturer, however, it may be challenging to find the exact non-hybridized version of a specific hybrid truck or bus. The proposed ITR would require the base and hybrid engine and vehicle to be as closely matched as possible with regard to the engine certification standard, power and displacement, vehicle class and intended vocation, number of axles and real axle ratios, electrical and mechanical accessories (such as power steering, brakes, etc…), and other key characteristics, unless a difference between the base and hybrid vehicle in one of the above variables is directly required for the effective functioning of the hybrid vehicle's hybrid system. For example, the power and displacement of a baseline vehicle's engine could be higher than that of a hybrid vehicle if the hybrid vehicle utilizes a smaller engine as part of its hybridization strategy. In this case, the baseline vehicle would use an engine typical of 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. The proposed ITR requirement that a base and hybrid vehicle share these key characteristics for the purposes of emission testing derives from 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".

The proposed emission test procedures also require vehicles to meet *SAE J1321: Fuel Consumption Test Procedure – Type II (FEB2012)* criteria to ensure the hybrid and base vehicle of are similar mileage, with three changes to achieve an accurate comparison of vehicle criteria pollutant emissions. First, as required by "California Interim Certification Procedures for 2004 and Subsequent Model Hybrid-Electric and Other Hybrid Vehicles, in the Urban Bus and Heavy-Duty Vehicle Classes", the hybrid and base engine must each have a minimum of 4,000 miles to ensure stability of emission-related components, such as catalysts. Second, SAE J1321 suggests no required limit on the age differential of a hybrid and base vehicle with over 30,000 miles. For example, for the purposes of fuel economy testing, SAE J1321 would allow the hybrid vehicle to have 30,001 miles, and the base vehicle 200,000 miles. However, such a mileage difference could impact criteria pollutant emission testing, since emission-related components for the base vehicle would have degraded significantly more. The proposed ITR's hybrid test procedures would therefore require that such vehicles' mileage be within 50,000 miles of each other, to ensure similar engine and emission control system degradation from the hybrid and base vehicles. Finally, the proposed hybrid test procedures provide the additional requirement that both the base and hybrid vehicle mileage do not exceed their applicable useful life, to prohibit testing of vehicles for which the engine or emission controls could be significantly degraded.

Test Route Selection. The proposed ITR would require PEMS testing to be conducted using two, over-the-road test routes, to be proposed by the applicant – a slower, transient-like test route and a high-speed (55 mph cruise) test route, in order to emulate the regulatory approach taken to evaluate emissions from hybrid vehicles in the

Phase 1 and Federal Phase 2 GHG Standards, as well as the previously described approach for proposed ITR chassis dynamometer testing.[9] To better reflect anticipated real-world operation, each test route would be required to begin and end at the same location (i.e., be a closed circuit), to control for change in elevation and other parameters; be of at least 20 minutes in duration, to collect sufficient emission data; and have an average grade of less than five percent.

In order to ensure the manufacturer's proposed on-road transient route is similar to the Heavy-Duty Transient Test Cycle (i.e., the transient test cycle used in Phase 1 and Federal Phase 2 GHG Standards), the proposed ITR would require a manufacturer to describe the anticipated average driving speed and positive kinetic energy (PKE) of their proposed transient test route. PKE is the acceleration energy required in a certain drive pattern, and is defined as:

$$(1/\text{total distance}) * \sum[(\text{velocity}(i)^2 - (\text{velocity}(i-1)^2)], \text{ in feet/second}^2,$$

for velocity data collected on the interval of i = 1 to n number of time samples, evaluated on a one Hertz basis.[10]

PKE is a critical metric for hybrid vehicles because it measures drive-cycle aggressiveness, meaning the higher the PKE, the greater the anticipated advantage of hybridization. Some studies utilize kinetic intensity (KI), defined as the ratio of a vehicle's characteristic acceleration relative to its aerodynamic speed, instead of PKE as a metric for drive-cycle aggressiveness.[11] Figure A-2, below, illustrates the relationship between KI and average driving speed for established heavy-duty vehicle duty cycles and in-use parcel delivery, linen delivery, and beverage delivery vehicles, as driven by California fleets participating in NREL's hybrid truck emission study.[12] Staff proposes to use PKE as a drive cycle metric, since PKE captures the characteristic acceleration component of KI without involving the grade-related component of KI that is held constant in the proposed ITR fixed-route test procedure. This avoids needless test-to-test variation in the metric due to global positioning system (GPS) filtering, resolution, and vertical accuracy issues related to assessing grade from typical commercial PEMS unit data.

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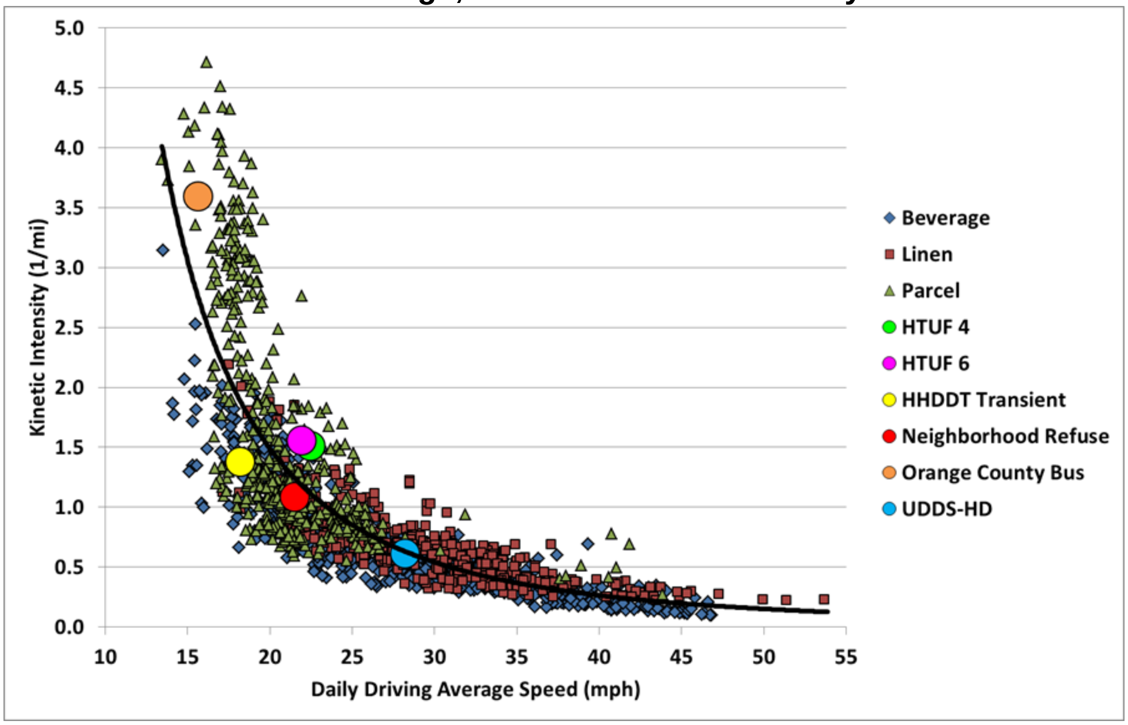
[9] Discrete high-speed emission testing is intended to evaluate hybrid vehicle freeway performance.

[10] Martijn van Ras, TNO; *Report Concerning Drive Cycles: Hybrid Commercial Vehicle (Report No. D.6100.1)*; June 2014; http://www.hcv-project.eu/publications/D6100_1-Report_concerning_drive_cycles-PUBLIC_rev6.pdf .

[11] Michael O'Keefe, et al., National Renewable Energy Lab; *Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications (presented to the SAE World Congress and Exhibition)*; April 16-19, 2007; http://www.nrel.gov/docs/gen/fy07/40929.pdf .

[12] National Renewable Energy Laboratory; *Data Collection, Testing, and Analysis of Hybrid Electric Trucks and Buses Operating in California Fleets - Final Report*; June 2015; www.nrel.gov/docs/fy15osti/62009.pdf .

Figure A-2: Kinetic Intensity and Average Driving Speed for Duty-Cycles Applicable to Common Hybrid Truck or Bus Vocations and In-Use Beverage, Linen and Parcel Delivery Vehicles*



* Adapted from NREL's *Data Collection, Testing, and Analysis of Hybrid Electric Trucks and Buses Operating in California Fleets - Final Report* (June 2015).

Studies also indicate a strong correlation between average driving speed, PKE or KI (which are equivalent for the purposes of the proposed ITR fixed-route testing), and NOx, CO, HC, and CO_2 emissions. European researchers have found that PKE, average driving speed, and relative cubic speed of a vehicle as driven over a given drive cycle provided the strongest correlation to resulting NOx, CO, and HC emissions, with an R^2 of over 95 percent for each pollutant.[10] West Virginia University research provides similar results, with non-parametric Spearman's correlations between average driving speed and NOx, CO, HC, and CO_2 emissions of over 90 percent, and between KI and NOx, CO, and CO_2 emissions of over 90 percent, with the correlation to HC of 88 percent.[13]

Transient Route. The proposed ITR would require that manufacturers propose, as part of their Hybrid Technology Emission Test Plan, a specific over-the-road transient-like test route with an average driving speed of between 15 and 30 mph and a PKE of between 0.85 and 1.50 feet/second^2. This requirement reflects the range of average

[10] Martijn van Ras, TNO; *Report Concerning Drive Cycles: Hybrid Commercial Vehicle (Report No. D.6100.1), Table A-3;* June 2014; http://www.hcv-project.eu/publications/D6100_1-Report_concerning_drive_cycles-PUBLIC_rev6.pdf

[13] Jun Tu et al.; *Correlation Analysis of Duty Cycle Effects on Exhaust Emissions and Fuel Economy*; Journal of the Transportation Research Forum; Spring 2013.

driving speed and PKE for established heavy-duty transient duty-cycles typically used to represent hybrid vehicle operation, as illustrated in Table A-1.

Table A-1: Key Statistics for Typical Transient Truck and Bus Duty-Cycles

	Average Driving Speed (mph)	PKE (feet/sec^2)	Percent at Zero-Speed
Heavy-Duty UDDS	28.2	0.90	33.3%
Heavy-Duty Transient Test Cycle	18.2	0.98	15.7%
HTUF Class 4 Parcel Delivery Cycle	22.5	1.13	46.4%
HTUF Class 6 Parcel Delivery Cycle	21.9	1.15	54.2%
Neighborhood Refuse Truck Cycle	21.5	1.36	48.1%
Orange County Bus Cycle	15.7	1.43	21.3%

High-Speed Cruise Route. For the high-speed cruise route, the proposed ITR recommends that a vehicle operate at least 80 percent of the time at a 55 mph cruise, plus or minus 2 mph. A manufacturer may propose a variance of more than 2 mph in its Hybrid Technology Emission Test Plan, if it demonstrates that at least 80 percent operation between 53 and 57 mph is infeasible or impractical. Vehicles incapable of 55 mph operation would be tested at their maximum operational speed.

Finally, a manufacturer's proposed Hybrid Technology Emission Test Plan would require a manufacturer to identify and justify the percent of time the hybrid and base vehicle will be idling, based upon the anticipated typical in-use operation of the hybrid truck or bus. Emission testing pursuant to these procedures would exclude the benefits of an engine automatic stop-start system. While these systems can provide CO_2 and fuel efficiency benefits, the proposed ITR test procedures are intended to evaluate the emission benefits of vehicle hybridization, not engine stop-start systems. Table A-1, above, identifies some typical anticipated idle times for various vocations and classes of trucks and buses based on these vehicles' established chassis dynamometer duty cycles.

The proposed ITR would require at least four test runs for each of the two required drive cycles, including at least one cold-start for each drive cycle, consistent with 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" and this proposed regulation's chassis dynamometer test option. Cold-start and hot-start emission test protocols and cold-start emission weighting factors generally mirror those for 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." The proposed ITR also includes emission test protocols for charge-depleting hybrids with AER, for which the time and location of the cold-start are uncertain.

Defining a Valid Test Run. As previously described, average driving speed and PKE are critical metrics for ensuring hybrid heavy-duty vehicles are driven similarly over a given test route, as needed to ensure consistent emission results. The proposed ITR would require a manufacturer to include, as part of its proposed Hybrid Technology Emission Test Plan, a proposed allowable variation in average driving speed and PKE for ensuring that hybrid and base vehicles are driven similarly over the transient test route. The proposed ITR recommends that for all vehicles tested (i.e., both base and hybrid vehicles) over the transient route, the coefficient of variation (CV) of the PKE not exceed 10 percent and the CV of the average driving speed not exceed 10 percent. While NREL drive-cycle testing conducted for ARB has indicated that this CV is achievable by drivers making a good faith effort to drive typical hybrid and base vehicles similarly over a typical transient test route[14], a manufacturer may propose an alternate CV that are reflective of mechanical differences between the selected hybrid and base vehicles (such as manual versus automatic transmission), anticipated traffic challenges for the proposed test route, or other issues that would reduce consistency among test runs. The threshold proposed by the manufacturer and approved by the Executive Officer as part of the Hybrid Technology Emission Test Plan is to be used to define a set of valid transient route test runs.

For a vehicle driven over the high-speed route, PKE is less indicative of driving behavior because of the far fewer acceleration and deceleration events. The proposed ITR instead utilizes average driving speed, and the proximity to 55 mph cruise conditions that are maintained for at least 80 percent of the drive cycle. The proposed ITR recommends, for the high-speed route, that the CV of the average driving speed of all vehicles tested (i.e., both base and hybrid vehicles) not exceed 10 percent, and that a vehicle operate between 53 and 57 mph at least 80 percent of the time. NREL drive cycle testing again indicates that these are achievable during typical freeway operation of well-matched hybrid and base vehicles.[14] However, the manufacturer may propose for the high-speed route, as part of its Hybrid Technology Emission Test Plan, an alternate maximum PKE variance and proximity to 55 mph that the vehicle will spend at least 80 percent of its time.

Emission Calculations. For the transient route and the high-speed cruise route, and for both the hybrid and base vehicle, the proposed ITR would weight cold-start emissions for each valid test run by 1/7 and hot start emissions for each valid test run by 6/7, consistent with typical practice for weighting heavy-duty cold-start engine certification tests. The resulting cold-start adjusted emissions for the transient route would be weighted by a factor of 0.92, and would be weighted by 0.08 for the high-speed cruise route, to reflect anticipated in-use operation, consistent with how typical urban Class 2b through Class 7 vehicle activity is apportioned in Federal Phase 2 GHG Standards.[15] In order to meet proposed ITR emission criteria, the resulting hybrid vehicle NOx, HC, and CO emissions may not exceed those for the base vehicle, and the hybrid vehicle must

[14] NREL; Monthly Progress Report No. 10 for May 1, 2016, through May 31, 2016, "Investigation of Emissions Impacts from Hybrid Powertrains," ARB Agreement Number 14-613, NREL Contract Number FIA-15-1802; June 15, 2016.
[14] NREL; Monthly Progress Report No. 10 for May 1, 2016, through May 31, 2016, "Investigation of Emissions Impacts from Hybrid Powertrains," ARB Agreement Number 14-613, NREL Contract Number FIA-15-1802; June 15, 2016.
[15] Discrete high-speed emission testing is intended to evaluate hybrid vehicle freeway performance.

achieve at least a ten percent CO_2 reduction relative to the base vehicle. For plug-in hybrids between 6,001 and 8,500 pounds GVWR with AER, the applicant may take credit for anticipated CO_2 benefits of its AER by applying Fleet Utility Factors pursuant to SAE International J2841. This approach has been used as part of ARB's zero-emission vehicle regulations to determine appropriate zero-emission vehicle credits based upon a vehicle's AER and anticipated daily mileage profile. Heavier plug-in hybrids with AER would have the opportunity to utilize the same SAE International J2841 criteria to calculate anticipated CO_2 emission reductions due to their hybrid technology, with prior approval of the Executive Officer.

Post-Transmission Powertrain Vehicle Simulation

This emission test option would allow a manufacturer to take advantage of the post-transmission powertrain vehicle simulation offered as an option to comply with the Phase 1 GHG standards. That is, manufacturers could voluntarily report NOx, HC, and CO emissions along with the CO_2 emission results. CO_2, NOx, HC, and CO emissions from the tested base and hybrid vehicles would then be weighted by 0.92 for the transient test, and by 0.08 for the 55 mile-per-hour cruise cycle, and compared to determine if they meet the ITR criteria. Phase 1 GHG standards include detailed criteria for ensuring an appropriate base vehicle is selected and emission tested for comparison with the hybrid vehicle. Federal Phase 2 GHG Standards' powertrain vehicle simulation requirements do not require emission testing of a hybrid vehicle's non-hybrid counterpart, and therefore do not provide the opportunity for identifying appropriate base vehicle NOx, HC, or CO emissions. While default base vehicle NOx, HC, or CO emission values could be used for comparison to those of the applicable hybrid vehicle, default base vehicle values would not be reflective of the numerous heavy-duty truck and bus sizes and vocations that could be hybridized. Staff therefore recommends limiting this option to demonstrate ITR emission compliance only to hybrids utilizing a post-transmission powertrain vehicle simulation to demonstrate Phase 1 GHG Standard compliance.

Evaporative Emission Testing

Evaporative emission test requirements for both new heavy-duty hybrid engines and hybrid conversion systems are structured to ensure evaporative emissions do not increase from the original base vehicle or engine's certified emission limits, while recognizing that some technologies are unlikely to have an impact on evaporative emissions. For example, conversion of a diesel vehicle is unlikely to increase evaporative emissions due to a diesel engine's inherently low evaporative emissions. However, a plug-in gasoline hybrid conversion that typically operates with the engine off could undermine evaporative emission control strategies that require the engine to be running in order to purge captured hydrocarbon emissions.

- For conversion of a vehicle below 14,000 pounds GVWR, the conversion system manufacturer would need to demonstrate that the converted vehicle meets the evaporative emissions standard to which the base vehicle was originally certified, by conducting the three-day diurnal evaporative procedure emissions test as specified in the "California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Motor Vehicles," amended on September 2, 2015. A converted vehicle with a compression-ignition engine or a sealed fuel system that can demonstrate no evaporative emissions would be exempt from evaporative emissions testing. Any such demonstration would need to be approved by the Executive Officer in order to confirm the converted vehicle is exempt from evaporative emission testing.

- For a new hybrid heavy-duty engine or a converted heavy-duty engine, a manufacturer may provide an engineering evaluation to ARB demonstrating that the hybridization does not increase evaporative emissions from the base engine or vehicle, in lieu of the three-day diurnal test.
- A hybrid compression-ignition engine or an engine with a sealed fuel system that can demonstrate no evaporative emissions is exempt from evaporative emissions testing. This demonstration may be based upon an engineering evaluation of the base vehicle and hybrid conversion system, and data submitted by the conversion system manufacturer, and would have to demonstrate that the converted vehicle has no evaporative-related emissions under normal operation.

These proposed evaporative emission compliance criteria enable ARB to identify and address potential evaporative emission concerns, while reducing potential cost to hybrid technology manufacturers.

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