APPENDIX H

TECHNICAL SUPPORT DOCUMENT FOR PROPOSED AMENDMENTS RELATED TO EXHAUST TEST PROCEDURES

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Hybrid-Electric Vehicle Range Tests

The current hybrid-electric vehicle (HEV) exhaust test procedures determine the all-electric range (AER) of a hybrid by measuring the mileage driven from when the vehicle starts driving with a fully charged battery over defined test cycles to when the IC engine first starts. This mode of operation is called the "charge depleting mode" because the battery state of charge is continually depleted since it is the sole source of vehicle motive power. Once the IC engine starts, the vehicle operates in the "charge-sustaining mode" (also called "charge balanced operation") in which continuous charge and discharge of the battery occurs, but there is no substantial net increase or decrease in battery energy or state-of-charge (SOC) over the driving cycle.

For a plug-in HEV (PHEV)[1] that has a distinct all-electric charge depleting range of operation and a distinct IC engine-assisted charge-sustaining range of operation, the current HEV test procedures provide an accurate measure of the electric range of the vehicle. However, future PHEV designs may engage the IC engine during the charge depleting mode. This is referred to as a "blended operation mode". A blended operation mode is a different category of charge depleting mode where propulsion power is provided either by the electric motor, the IC engine, or some combination of both, but where a significant portion of the propulsion power nonetheless is provided by electricity derived from off-vehicle sources. During blended operation the SOC of the battery continually decreases. This design feature may be included because the battery is sized such that it cannot provide sufficient power to provide full vehicle performance capability. Since the existing test procedure is incapable of measuring the contribution of the battery during blended operation, a new test procedure is required.

The following sections provide brief descriptions of and rationale for the proposed amendments to the Exhaust Test Procedures to accommodate PHEVs.

Urban Charge Depleting Range Test

For PHEVs which have two distinct modes of operation, one using battery power alone and another in which motive power is derived from the IC engine only, the current procedure for the urban charge depleting range test to determine all electric range is accurate. For the urban charge depleting range test, continuous urban dynamometer driving schedule (UDDS) test cycles with a 10-minute soak period between each UDDS are conducted until charge-sustaining operation is achieved for two consecutive UDDS cycles. A second UDDS may be omitted if

[1] Staff is using the more common term of PHEV for readability. The use of PHEV is not meant to restrict the use of the vehicles to receive charging only from the grid, as with the PHEV definition used in Pavely. To address this restriction, staff refers to these vehicles as OVCC HEVs through out the test procedures and regulatory text.

data is provided showing charge-sustaining operation can be determined from one UDDS.

Alternative Urban Charge Depleting Range Test

For test laboratories with equipment that are not readily adaptable to the proposed charge depleting range test, an alternative urban charge depleting range test sequence is provided whereby pairs of urban cycles are conducted with a 10 minute soak after the first urban cycle and a 10-20 minute soak after the second urban test cycle. The longer hot soak periods provide additional time to perform emission measurements and reset test equipment.

Highway Charge Depleting Range Test

Similarly, for the highway charge depleting range test, four continuous highway fuel economy driving schedule (HFEDS) test cycles with a 15 second key-on hot soak period between tests are conducted. After every fourth HFEDS, an optional key-off soak period of 0-30 minutes is provided to reset test cell equipment. The test sequence is continued until the vehicle achieves charge-sustaining operation for one highway cycle.

Alternative Highway Charge Depleting Range Test

Again, for test laboratories with equipment that are not readily adaptable to the new test procedure, an alternative HFEDS test sequence is provided whereby two HFEDS cycles with a 15 second key-on hot soak period between tests are conducted followed by a 10-20 minute key-off soak period between each pair of HFEDS. The longer hot soak periods provide additional time to perform emission measurements and reset test equipment.

US06 Charge Depleting Range Test

The US06 charge depleting range test is being proposed to determine the all-electric range during aggressive driving modes and is used to demonstrate that the HEV meets the criteria for a Type G advanced componentry allowance. The US06 charge depleting range test consists of a repeated series of US06 driving cycles with a 1-2 minute key-on soak between each US06. The test ends when the IC engine first starts or when the vehicle fails to meet the speed tolerance of the US06 test cycle. Since this is an all-electric range test, emission measurements are not required. To qualify as for a Type G advanced componentry allowance, the vehicle must demonstrate a minimum 10 mile all-electric range over the US06 test cycle while meeting a speed tolerance of ± 2 mph of the required speed within ± one second of the given time of the US06 driving schedule.

Equivalent All-Electric Range (EAER)

Testing for equivalent all-electric range (EAER) is a new procedure designed to quantify the electric driving range provided by the battery-powered electric motor during a blended operation mode of a PHEV.

The procedure is based on comparing the propulsion energy contributed by the IC engine during charge-sustaining mode (when net energy is supplied by the IC engine only) to the proportion of propulsion energy contributed by the fuel-powered IC engine during charge depleting mode (when net energy is supplied by either the IC engine, the electric motor, or a combination of both). Since any CO_2 emitted during the test cycles can be attributed to the IC engine alone and is proportional to the fuel consumed by the IC engine, when compared over the same driving distance, CO_2 mass emissions can be used to determine the net energy contribution of the IC engine and thereby, indirectly, the net energy contribution of the battery.

Because the test procedure does not require the vehicle to be driven over the same distance during charge depleting and charge-sustaining modes, the CO_2 mass emissions from charge-sustaining mode (M_{cs}) must be adjusted to represent the CO_2 emissions from vehicle operation over the same distance driven during the charge depleting mode. Only two test cycles are required to determine emissions during charge-sustaining mode since there is a net energy balance requirement over the test cycles. Accordingly, the CO_2 mass emissions from the charge-sustaining mode are multiplied by the ratio of the charge depleting distance (R_{cdc}) to the distance driven over one charge-sustaining operation test cycle. For the urban test cycle, the CO_2 mass emissions from charge-sustaining mode are adjusted as follows:

$$\underline{M_{cs} =}\ Y_c + Y_h * \left[\frac{\left(R_{cdcu} - D_c\right)}{D_c} \right]$$

where:

R_{cdcu} = Urban Charge Depleting Cycle Range, in miles

D_c = measured driving distance of the cold start UDDS, in miles.

Y_c = Grams per mile CO_2 emissions from the cold start UDDS

Y_h = Grams per mile CO_2 emissions from the hot start UDDS

The measured CO_2 mass emissions in grams per mile during charge depleting operation (M_{cd}) is then compared to the measured CO_2 mass emissions in grams per mile produced during charge-sustaining operation (M_{cs}) on an equal miles driven basis. The difference in CO_2 mass emissions is proportional to the net energy required to provide propulsion electrically, since the only source of energy besides the fuel used for propulsion is electricity provided by the battery. Dividing this difference by M_{cs} provides the fraction of the propulsion energy

derived from the battery. Multiplying the distance traveled during charge depleting operation (R_{cdc}) by this fraction yields the EAER in miles. For the urban test cycle the formula for EAER is as follows:

$$EAER = \frac{M_{cs} - M_{cd}}{M_{cs}} * R_{cdcu}$$

Where EAER = Equivalent All-Electric Range (mi)

M_{cd} = Mass of CO_2 (g) accumulated during charge depleting mode

M_{cs} = Mass of CO_2 (g) accumulated during charge-sustaining mode for an equal distance of charge depleting cycle range

R_{cdcu} = Urban Charge Depleting Cycle Range (mi)

The transition from charge depleting operation to charge-sustaining operation for a blended PHEV may occur over a period of time as the battery control system responds to battery loading, road load demand, and driver power demand. Therefore, to assure that sufficient emission samples are collected and to simplify the test procedure, charge depleting range testing is measured over discrete test cycles. Accordingly, the transition to charge-sustaining mode will likely occur during the final charge depleting test cycle. Consequently, the measured CO_2 mass emissions for the charge depleting range test will include some fraction of emissions emitted during charge-sustaining operation. These emissions are offset by adjusting the measured charge-sustaining mass emissions to represent emissions emitted over the same distance as the charge depleting range.

Hybrid-Electric Vehicle Emissions Tests

Charge-Sustaining Emission Tests

Emission testing is required for all HEVs during charge-sustaining operation. These tests are designed to determine vehicle emissions during cold-start charge-sustaining operation and are required to demonstrate compliance with all applicable emission requirements.

Urban Charge-sustaining Emission Test

The urban charge-sustaining emission test procedure is essentially the same for conventional HEVs and PHEVs. The test consists of an initial UDDS to precondition the vehicle, a 12-36 hour soak period, and two UDDS emission tests with a 10 minute key-off soak in between each UDDS. Emissions for each UDDS are weighted as described below.

Highway Charge-Sustaining Emission Test

The current highway charge-sustaining emission test consists of a hot-start test conducted within three hours after the urban charge-sustaining test is completed. This proposal changes the requirement for PHEVs to a cold-start test, requiring testing to be conducted after an overnight cold soak.

The emission test consists of an initial HFEDS, a 15 second key-off period, and a second HFEDS. Emissions are measured during both HFEDSs. The SOC criteria must be met during the second HFEDS. If the vehicle does not meet the SOC criterion during the second HFEDS or additional IC engine warm-up is required, a third HFEDS is permitted. Emission data from the final HFEDS shall be used to demonstrate compliance with the highway NOx emission requirement.

US06 Charge-Sustaining Emission Test

The SC06 charge-sustaining emission test consists of two US06 test cycles separated by a 1-2 minute idle period. A third US06 is permitted if additional IC engine warm up is required. Emissions data from the final US06 shall be used to demonstrate compliance with criteria emission requirements. The vehicle must meet the state-of-charge criterion during the final US06.

SC03 Charge-Sustaining Emission Test

The SC03 charge-sustaining emission test consists of two SC03 test cycles separated by a 1-2 minute idle period. A third SC03 is permitted if additional IC engine warm up is required. Emissions data from the final SC03 shall be used to demonstrate compliance with criteria emission requirements. The vehicle must meet the state-of-charge criterion during the final US03.

Cold Temperature Emission Testing

The current HEV test procedures do not specify UDDS emissions tests for CO emissions at 20°F and for NMOG, CO and NOx emission at 50°F. Accordingly, new procedures are proposed for testing PHEVs at 20°F and 50°F in the "worse case" for emissions during either charge-sustaining or charge depleting operation. Worst case operation is defined as either the urban charge depleting or charge-sustaining test with the highest CO emissions for 20°F emission testing and the highest HC + NOx emissions for 50°F emissio n testing. Testing may be conducted using either the conventional 3 phase UDDS or the optional 4 phase double UDDS. Compliance with the SOC criterion is not required for cold temperature emission testing.

SOC Net Tolerances

Compliance with the SOC net tolerance is required to ensure that the net energy balance of the vehicle battery is maintained during charge-sustaining tests and to validate that the vehicle is operating in charge-sustaining operation. Since 1999, ARB test procedures and SAE J1711 have required SOC net tolerances be based on ±1% of the fuel energy used during the test.

Battery Charging

Vehicle Charge Start Time

Charging requirements have been modified to simplify and add more flexibility to the current procedure. The current ARB test procedure requires battery charging to begin within one hour after a battery discharge event such as completing the all-electric range test. This is consistent with the current SAE J1711 hybrid test procedure. The one hour requirement was specified to avoid either self discharge as in the case of NiMH batteries, or sulfation in the case of lead acid batteries, which requires the batteries be recharged as soon as possible to prevent irreversible damage. However, future PHEVs will likely use lithium ion technology, which is less susceptible to self-discharge or damage from long periods of storage at low states of charge. Accordingly, the new procedure provides for battery charging to occur one to three hours after the urban charge-sustaining emission test or highway charge depleting range test.

Vehicle Charging Equivalency Option

To determine energy consumption of off-vehicle electrical energy, the vehicle must be charged from the battery state of charge level achieved during charge-sustaining operation to a full state of charge. The current procedure requires charging PHEVs to full SOC immediately after the urban charge depleting range test. In the new procedures, vehicle charging is performed after the charge-sustaining emission test, eliminating the requirement that the battery be charged and discharged twice.

Testing can be further streamlined if the manufacturer can demonstrate that the charge energy required to reach full charge is equivalent for both the urban (UDDS) and highway (HFEDS) cycles. If equivalency is demonstrated, then the manufacturer can substitute the charge energy determined from the urban charge results to demonstrate charge energy for the highway test.

Emissions Bag Weighting

When the urban emission test was developed in the early 1970's, driving studies demonstrated that 43% of IC engine starts were cold starts and 57% were hot starts. Therefore, emissions for the first UDDS (cold start UDDS) are weighted

43% and emissions from the second UDDS (hot start UDDS) are weighted 53%. This weighting scheme is still in use today. Accordingly, the UDDS emissions are calculated as follows:

$$Y_{wm} = 0.43 * \left(\frac{Y_c}{D_c}\right) + 0.57 * \left(\frac{Y_h}{D_h}\right)$$

Where:

(1) Y_{wm} = Weighted mass emissions of each pollutant, i.e., THC, CO, THCE, NMOG, NMHCE, CH_4, NO_x, or CO_2, in grams per vehicle mile.

(2) Y_c = Mass emissions as calculated from the cold start test, in grams per test.

(3) Y_h = Mass emissions as calculated from the hot start test, in grams per test.

(4) D_c = The measured driving distance from the cold start test, in miles.

(5) D_h = The measured driving distance from the hot start test, in miles.

Modifications to the ZEV Highway Range Test

In the current HEV Test Procedures the ZEV highway all-electric range test consists of a repeated series of two HFEDS. To provide consistency with PHEV all electric range test requirements, the ZEV highway all-electric range test has been modified to require conducting a series of four HFEDS with a 15 second key-on pause between each HFEDS. After every fourth HFEDS, an optional key-off soak period of 0-30 minutes is provided to reset test cell equipment.