SAE International™ **SURFACE VEHICLE RECOMMENDED PRACTICE**

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(R) Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles

RATIONALE

Hybrid-electric vehicle (HEV) technology has progressed significantly since the original publication of SAE standard J1711. The HEV has been in production for over a decade and parts of the original procedure have successfully addressed charge-sustaining HEVs. However, at the time of this revision, plug-in hybrid technology has experienced rapid development. As such, the procedures to address this technology needed to be revisited and modified to accommodate the operational possibilities demonstrated by the diverse set of working prototypes and simulated vehicles in the literature. Also, the list of standard test procedures addressed in SAE J1711 has been expanded to cover all five major test cycle procedures (UDDS, HFEDS, US06, SC03, and Cold FTP) now being used to evaluate vehicle fuel economy.

FOREWORD

Advances in electric powertrain components and computer controls have enabled the widespread development of practical hybrid-electric vehicles (HEVs). HEVs combine the powertrain elements of conventional vehicles and electric vehicles (EVs) and demonstrate substantially reduced fuel consumption and exhaust emissions. One obstacle to the development of commercial HEVs has been the absence of a broadly applicable and widely accepted procedure for measuring HEV exhaust emissions and fuel economy.

In the Fall of 1992, the Light-Duty Vehicle Performance and Economy Measurement Standards Committee of the Society of Automotive Engineers (SAE) established a task force to develop a recommended practice for the uniform testing of HEVs. This HEV task force followed a similar SAE effort to develop a recommended practice for the testing of EVs, which resulted in the publication of SAE J1634. The SAE J1711 was published in 1999. HEVs became more mainstream throughout the first decade of the 21st century. In 2002, SAE published a related document, SAE J2711, "Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles." Development in battery technology continued to a point where manufactures began to make commitments to produce plug-in hybrid-electric vehicles (PHEVs) — HEVs that are designed to be charged from the grid.

In 2006, a new task force was formed to revise the expired SAE J1711-1999, with a major objective to further develop the section relating to PHEVs. The SAE J1711 task force comprised of SAE members employed at major OEMs, automotive suppliers, U.S. Department of Energy laboratories, Environment Canada, U.S. Environmental Protection Agency and the California Air Resources Board (all task force members provide professional input, they do not necessarily reflect employer positions). The lessons learned over the years of research, as well as the emergence of a cottage industry that converts production hybrids to plug-in hybrids, has helped to further develop the procedures for this revision. Prototype vehicles from conversion companies, Argonne National Laboratory, and one original equipment manufacturer were used to help develop the procedures. In support of SAE J1711, vehicles were tested at Argonne National Laboratory, Chrysler, California's Air Resources Board, and Environment Canada. The sustained efforts of all participant organizations and individuals in this complex task are greatly appreciated.

The task force members realize that both the technology and methodology for testing PHEVs are relatively new, and it is likely that more lessons will be learned as new-technology HEVs are tested in practice. Procedure advancements in the coming years may require that this document be refined once again.

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1. SCOPE

This Society of Automotive Engineers (SAE) Recommended Practice establishes uniform chassis dynamometer test procedures for hybrid-electric vehicles (HEVs) that are designed to be driven on public roads. The procedure provides instructions for measuring and calculating the exhaust emissions and fuel economy of HEVs driven on the Urban Dynamometer Driving Schedule (UDDS) and the Highway Fuel Economy Driving Schedule (HFEDS), as well as the exhaust emissions of HEVs driven on the US06 Driving Schedule (US06) and the SC03 Driving Schedule (SC03). However, the procedures are structured so that other driving schedules may be substituted, provided that the corresponding preparatory procedures, test lengths, and weighting factors are modified accordingly.

Furthermore, this document does not specify which emissions constituents to measure (e.g., HC, CO, NO_x, CO_2); instead, that decision will depend on the objectives of the tester. The emissions calculations for plug-in hybrid-electric vehicle (PHEV) operation are provided as inventory results, weighted in the same manner as fuel and electrical energy consumption. Decisions for on-board versus off-board emissions, relative benefits of emissions-free driving, and how best to weight a "cold-start" cycle in charge-depleting (CD) mode must first be made before a certification methodology can be determined. Thus, calculations or test methodology intended to certify a PHEV for compliance of emissions standards is beyond the scope of this document.

For purposes of this test procedure, an HEV is defined as a road vehicle that can draw propulsion energy from both of the following sources of stored energy: (1) a consumable fuel and (2) a rechargeable energy storage system (RESS) that is recharged by the on-board hybrid propulsion system, an external electric energy source, or both. Consumable fuels that are covered by this document are limited to petroleum-based liquid fuels (e.g., gasoline and Diesel fuel), alcohol-based liquid fuels (e.g., methanol and ethanol), and hydrocarbon-based gaseous fuels (e.g., compressed natural gas). The RESSs that are covered by this document include batteries, capacitors, and electromechanical flywheels. Procedures are included to test CD operating modes of HEVs designed to be routinely charged off-board, and calculations are provided that combine the CD and charge-sustaining (CS) behavior according to in-use driving statistics.

The HEVs shall have an RESS with a nominal energy >2% of the fuel consumption energy of a particular test cycle to qualify to be tested with the procedures contained in this document.

Single-roll, electric dynamometer test procedures are specified to minimize the test-to-test variations inherent in track testing and to conform to standard industry practice for exhaust emissions and fuel economy measurements.

This document does not include test procedures for recharge-dependent (RD) operating modes or vehicles (see 3.1.2 for the definition).

This document does not address the methods or equations necessary to calculate the adjusted U.S. Environmental Protection Agency (EPA) label miles per gallon (MPG) (sometimes referred to "EPA 5-Cycle" calculations).

1.1 Requirements Used to Develop the Recommended Practice

The overall goal in developing this document was to allow the testing of any HEV on a fair and comparable basis with conventional vehicles, electric vehicles (EVs), and other HEVs. Meeting this goal required satisfying the following requirements:

a. This document shall provide a recommended practice to measure the exhaust emissions and fuel economy of any type of HEV design or control strategy, as defined in Section 1.

b. Determination of representative exhaust emissions and fuel economy shall account for the driver's usage of external charging and estimations of driving distance between charging and the usage of driver-selected operating modes, if applicable.

c. The EVs and conventional vehicles tested according to this document shall yield the same results as if tested on the test procedures currently established for such vehicles.

d. Measurement methods and driving schedules shall be consistent with those used in existing test procedures for EVs and conventional vehicles.

e. Testing should not require defeating or otherwise forcing a vehicle's control system to perform differently from how it would perform in the driver's hands.

f. This document shall provide a technical foundation to assist government regulatory agencies in developing emissions and fuel economy certification and compliance tests for HEVs.

g. This document shall be as short and simple as possible.

1.2 Overview of the Recommended Practice

This document consists of three basic steps: (1) classifying the HEV, (2) testing the vehicle for each test cycle, and (3) weighting the results.

1.2.1 Classifying the HEV

Classify the vehicle by obtaining the following information from the manufacturer:

a. RESS—Identify the RESS (i.e., battery, capacitor, or electromechanical flywheel).

b. External Charge Capability—Determine whether the RESS is designed to be recharged from an external (off-board) electric energy source. All HEVs are tested according to the charge-sustaining tests, only externally charged HEVs (PHEVs) require charge-depleting tests. If the HEV does have external charging capability, but this capability is intended solely for infrequent RESS conditioning and is not recommended for routine use, then the HEV shall not be classified as a PHEV.

1.2.2 Testing to Each Cycle Procedure

Five separate procedures are provided in this document (Section 4). PHEVs require both depleting mode tests and sustaining mode tests. Charge-sustaining HEVs only require charge-sustaining tests.

1.2.3 Weighting the Results

For PHEVs, the charge-depleting results can be merged with the charge-sustaining results according to the estimations of distance between charge and daily driving distances (see Section 6).

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issues of the SAE and the Code of Federal Regulations (CFR) publications shall apply.

2.1.1 SAE Publications

The SAE publications are available from SAE, 400 Commonwealth Drive, Warrendale, PA, 15096-0001; Tel: 877-606-7323 (inside the USA and Canada) or 724-776-4970 (outside the USA), www.sae.org.

SAE J1634 Electric Vehicle Energy Consumption and Range Test Procedure

SAE J1715 Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology

SAE J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques

SAE J2264 Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques

SAE J2841 Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data, March 2009.

SAE 2005-01-0685 Duoba, M., et al., "Investigating Possible Fuel Economy Bias Due to Regenerative Braking in Testing HEVs on 2wd and 4wd Chassis Dynamometers," April, 2005.

2.1.2 CFR Publications

The CFR is available from the Superintendent of Documents, U.S. Government Printing Office, Mail Stop: SSOP, Washington, DC, 20402-9320, http://www.access.gpo.gov/nara/index.html.

10 CFR Part 474 Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Petroleum-Equivalent Fuel Economy Calculation

40 CFR Part 86 Control of Air Pollution from New and In-Use Motor Vehicles and New and In-Use Motor Vehicle Engines; Certification and Test Procedure

40 CFR Part 600 Fuel Economy of Motor Vehicles

3. DEFINITIONS

3.1 General

3.1.1 Hybrid-Electric Vehicle (HEV)

Defined as a road vehicle that can draw propulsion energy from both of the following sources of stored energy: (1) a consumable fuel and (2) an RESS that is recharged by an electric motor-generator system, an external electric energy source, or both.

3.1.2 Recharge-Dependent (RD)

A classification describing a particular vehicle or driver-selected operating mode in a PHEV in which either or both of the following conditions occur while no other mode is selected: (1) vehicle propulsion is eventually no longer possible if the RESS is never recharged from an external electric energy source, even though the supply of consumable fuel is continually replenished, and (2) the driver is eventually warned or instructed by the vehicle to discontinue driving in this operating mode because the RESS contains too low of a supply of energy. The EV operating modes (with no automatic engagement of the engine or hybrid power unit) in PHEVs are *always* considered to be RD. On the same HEV, it is possible for one HEV operating mode to be classified as RD and another HEV operating mode not to be classified as RD. *The scope of this document does not cover RD PHEVs or operating modes*.

3.1.3 Recharge-Independent (RI)

A classification describing a particular vehicle or driver-selected operating mode in which both of the following conditions occur while no other mode is selected: (1) vehicle propulsion is continually possible with the supply of consumable fuel continually replenished, even though the RESS is never recharged from an external electric energy source, and (2) the driver is never warned or instructed to discontinue driving in this operating mode because the RESS contains too low of a supply of energy. One example of an RI operating mode is one for which vehicle propulsion is still possible, even though the RESS is completely depleted of all useful energy. Also, in a CS HEV that is not externally chargeable, all operating modes are considered to be RI, regardless of whether vehicle propulsion is or is not possible or whether the driver is ever warned to discontinue driving, as described in the definition of recharge-dependent.

3.1.4 Charge-Sustaining Hybrid-Electric Vehicle (CS HEV)

A vehicle classification describing an HEV either with an RESS that cannot be recharged from an external electric energy source, or for which external charging is intended solely for infrequent conditioning of the RESS or other purposes unrelated to vehicle propulsion. The CS HEV derives its net energy from on-board fuel under normal usage. Instantaneously or over a short period of time, CS HEVs may be either charge depleting or charge increasing. The definition means that, in the long term (many hours of driving), the RESS maintains or sustains its charge level.

3.1.5 Plug-In Hybrid-Electric Vehicle (PHEV)

A classification describing an HEV with an RESS that is designed to be recharged from an external (off-vehicle) electric energy source, typically an alternating current (AC) electrical power supply system.

NOTE: Equivalent to an “off-vehicle charge-capable HEV,” a “grid-connected HEV,” and an “externally chargeable HEV.”

3.1.6 Charge-Sustaining (CS) Mode

An operating mode where the HEV runs by consuming the fuel energy while sustaining the electric energy of the RESS.

3.1.7 Charge-Depleting (CD) Mode

An operating mode of an HEV in which the vehicle runs by consuming only electric energy from the RESS charged from an external power source or along with the fuel energy, simultaneously or sequentially, until the CS-mode state.

3.1.8 All-Electric Range (AER)

For a PHEV, the total continuous miles driven for a given full-charge test (FCT, see 4.3) prior to the first engine start while the vehicle is in all-electric mode (i.e., the mode when the vehicle's combustion engine is not operating).

3.1.9 Charge-Balanced Cycle

A drive cycle during which the change (from beginning to end) in the state of charge (SOC) of the vehicle's RESS is maintained within a specified tolerance.

3.1.10 Transition Cycle

For a PHEV, in the FCT, the test cycle where energy monitored from the RESS indicates a transition from a CD mode to a CS mode. The transition cycle will end in CS mode but will be net depleting, and the following cycle or cycles will be CS. This definition is illustrated in Figure 1.

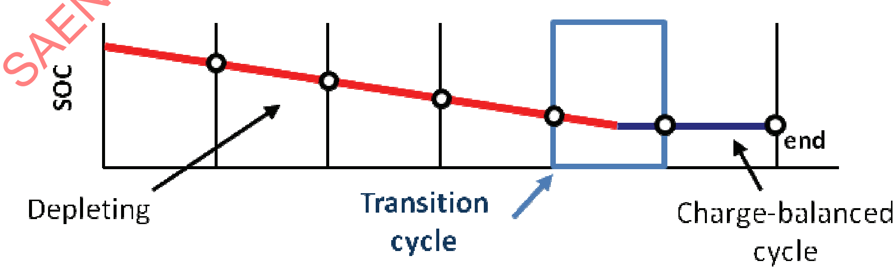

FIGURE 1 - TRANSITION CYCLE DEFINITION

3.1.11 Transition Range

For a PHEV, in the FCT, if the cycle or cycles prior to the first CS cycle(s) are anything but CD, then there will be a distance traveled between CD and CS operational modes. This portion of the FCT is defined as the transition range, see Figure 2.

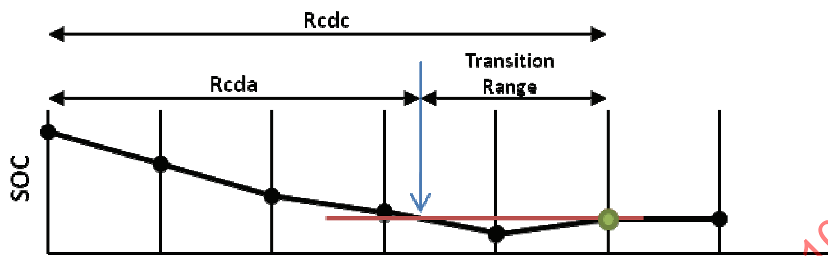

FIGURE 2 - RCDA, RCDC, AND TRANSITIONAL RANGE

3.1.12 Cycle Distance

The distance traveled in a test cycle if the vehicle perfectly followed the prescribed drive schedule. It is a fixed value for any given test schedule.

3.1.13 Charge-Depleting Cycle Range (Rcdc)

For a given FCT, the total number of cycles driven at least partially in CD mode times the cycle distance. Charge-sustaining cycles according to the End of Test Criterion are not included in the Rcdc. The Rcdc includes the transitional cycle, where the vehicle may have operated in both depleting and sustaining modes. If the FCT possesses a transitional range, then the Rcdc includes those transitional cycles or cycles.

3.1.14 Actual Charge-Depleting Range (Rcda)

An estimated distance at which the RESS has exhausted the off-board charged energy. It is the total distance, measured from the start of the FCT, through any subsequent CD test cycles, and ending at a point in the transitional cycle proportional to the change in SOC of the transitional cycle compared with the cycle previous. The Rcda shall always be less than or equal to the Rcdc.

3.1.15 Start of Test

The point during the test sequence when the vehicle key switch (or equivalent) is first placed in the "on" position.

3.1.16 End of Test

The point (in time and distance) when the vehicle has been decelerated to a rest (zero velocity) condition after the appropriate test termination criteria have been met, the key switch (or equivalent) is placed in the “off” position.

3.2 Vehicle

3.2.1 Curb Weight

The total weight of the vehicle with all standard equipment, including batteries/capacitors, lubricants at nominal capacity, and the weight of optional equipment that is expected to be installed on more than 33% of the vehicle line; however, excluding the driver, passengers, and other payloads. Incomplete light-duty trucks shall have the curb weight specified by the manufacturer.

3.2.2 Nominal Fuel Tank Capacity

The volume of the fuel tank(s), specified by the manufacturer to the nearest tenth of a U.S. gallon, that may be filled with fuel from the fuel tank filler inlet.

3.2.3 Consumable Fuel

Any solid, liquid, or gaseous material that releases energy and whose mass is depleted as a result of the test process. Consumable fuels covered by this document are limited to petroleum-based liquid fuels (e.g., gasoline and Diesel fuel), alcohol-based liquid fuels (e.g., methanol and ethanol), and hydrocarbon-based gaseous fuels (e.g., compressed natural gas).

3.2.4 Rechargeable Energy Storage System (RESS)

A component or system of components that stores energy and for which its supply of energy is rechargeable by an electric motor-generator system, an external electric energy source, or both. Examples of RESSs for HEVs include batteries, capacitors, and electromechanical flywheels.

3.2.5 Engine

A device that converts the energy stored in a consumable fuel into mechanical energy. Examples include a spark-ignition engine and a compression-ignition engine.

NOTE: Although a fuel cell uses a consumable fuel, it is not considered an engine by itself because it does not produce mechanical energy.

3.2.6 Electric Motor-Generator System

A device permanently located on the vehicle with the capability to convert mechanical energy into electrical energy (e.g., to recharge the RESS), electrical energy into mechanical energy (e.g., to propel the vehicle), or both.

3.2.7 External Electric Energy Source

A source of electric energy that is not connected or coupled to the vehicle in any way while the vehicle is being driven. An example of an external electric energy source is an electric outlet to which the vehicle can be connected for battery charging. In contrast, an inductive charger built into the roadway would not fit this definition.

3.2.8 AC Recharge Energy

The electrical energy taken from a wall outlet that powers the charger to recharge the RESS, measured in real AC Watt-hours.

3.2.9 Electrical Energy Consumption (EC)

The amount of electrical energy used by a vehicle during one or all CD cycles in the FCT. Expressed either as a total amount in Watt-hours (W•h) or a rate per unit distance, as in Watt-hours/mile (W•h/mi).

NOTE: This can be attributed to the direct current (DC) W•h measured at the RESS terminals on-board or the AC W•h measured during charging and associated to consumption during driving. Thus, electrical energy consumption must always be expressed in “DC W•h/mi” or “AC W•h/mi.”

3.2.10 Fuel Consumption (FC)

The amount of fuel used by a vehicle during any cycle described in this document, expressed either as a total amount for a given cycle in units of mass of volume or as a rate per unit distance, as in gallons/mile (gal/mi) or liters per 100 kilometers (L/100 km).

3.2.11 Regenerative Braking

Deceleration of the vehicle caused by operating an electric motor-generator system, thereby providing the charge to the RESS.

3.2.12 Charger

The component that recharges the RESS by connecting to the electric grid (“wall plug”) and converting AC electrical power to DC electrical power at the appropriate voltage and current levels to charge the RESS.

NOTE: For the purposes of this procedure, the charger is considered part of the vehicle system (on- or off-board charger). The electrical energy consumption measurements produced from this procedure will include charger performance (charger efficiency).

3.2.13 Charge-Sustaining (CS) Switch

A feature designed by the manufacturer for the vehicle tester to manually invoke the CS mode, either by using setting controls included in the vehicle or by attaching an external computer device.

NOTE: This is not a requirement for testing.

3.2.14 Charge-Sustaining (CS) Indicator

An indicator designed by the manufacturer to enable the vehicle tester to determine if the vehicle is in its CS mode, either by using indicators included in the vehicle’s instrument cluster or by monitoring an external computer device display.

NOTE: This is not a requirement for testing. A vehicle indicating CS mode may not reliably predict charge-balanced operation during a standard cycle.

3.2.15 Full Charge

The RESS state associated with maximum off-board stored energy capacity established by using the manufacturer's recommended charging procedure and appropriate equipment. The charger should indicate full charge by an easily read indicator somewhere in or on the vehicle and/or charger connections. The state must be indicated to the vehicle tester and also be achieved repeatably from test to test for accurate and reliable calculations of AC kW•h energy consumption.

3.2.16 AC Charge Energy (AC W•h)

The total AC energy required to recharge the RESS back to the state at which a test started.

3.2.17 DC Energy Consumption

The total net DC energy that was measured leaving the RESS during the entire FCT, expressed as a total (DC W•h) or per unit distance (DC W•h/mi).

3.3 Battery

A device that stores chemical energy and releases electrical energy.

3.3.1 Rated Ampere-Hour (A•h) Capacity

The manufacturer-rated capacity of a battery in Ampere-hours obtained from a battery discharged at the manufacturer's recommended discharge rate, such that a specified minimum cut-off terminal voltage is reached.

3.3.2 Battery State of Charge (SOC)

The remaining capacity of a battery expressed in Ampere-hours (A•h). It may also be expressed as a percent of the battery's maximum-rated A•h capacity.

NOTE: To quantify a change in battery SOC does not require information for battery total capacity. Thus, ΔSOC can be expressed by ΔA•h. The SOC value used in this definition is not to be confused with the SOC reported from the vehicle.

3.3.3 System Voltage (V_{system})

The nominal propulsion battery voltage associated with the SOC in CS operation. This value should be supplied by the manufacturer.

3.4 Capacitor

A device that stores energy electrostatically and releases electrical energy.

3.4.1 Capacitor State of Charge (SOC)

The remaining capacity of a capacitor expressed in volts squared (V^2). It may also be expressed as a percent of the capacitor's maximum-rated V^2.

3.4.2 Capacitor Upper Voltage Limit

The upper voltage limit at which capacitor damage could occur, as determined by the manufacturer.

3.4.3 Capacitor Capacitance

Capacitance (C) is known to be the ratio of Charge (Q) and Voltage (V) in the formula: C = Q/V (in Farads).

3.5 Electromechanical Flywheel

A device that stores rotational kinetic energy and that can release that kinetic energy to an electric motor-generator system, thereby producing electrical energy.

3.5.1 Electromechanical Flywheel State of Charge (SOC)

The remaining capacity of an electromechanical flywheel expressed in revolutions per minute, squared (rpm^2). It may also be expressed as a percent of the flywheel's maximum-rated rpm^2.

3.5.2 Maximum Rated Rotational Speed

The fully charged electromechanical flywheel speed, as defined by the manufacturer.

3.6 Driving Schedules

There are five driving schedules referenced in this document, which are required by the the EPA and the California Air Resources Board during emissions and fuel economy certification. They are the Urban Dynamometer Driving Schedule (UDDS), the "Cold" UDDS, the Highway Fuel Economy Driving Schedule (HFEDS), the US06 Driving Schedule (US06), and the SC03 Driving Schedule (SC03):

UDDS—The Urban Dynamometer Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 22 min, 52 s. It is used to represent vehicle city driving. Two speed-versus-time errors may have been published in various versions of the CFR (at driving schedule times equaling 961 s and 1345 s). A version of the UDDS without speed errors appears in SAE J1634.

HFEDS—The Highway Fuel Economy Driving Schedule is defined in 40 CFR Part 600, Appendix 1. It has a duration of 12 min, 45 s. It is used to represent vehicle highway driving.

US06—The US06 Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 10 min. It is used to represent vehicles driving at heavy speeds and accelerations.

SC03—The SC03 Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 10 min. It is used to represent vehicle operation with air conditioning.

“Cold” UDDS—Same as UDDS schedule, the test is performed in cold ambient conditions as defined in 40 CFR Part 86, Subpart C

3.6.1 Speed Tolerance

The speed tolerance at any given time on these driving schedules is defined by the upper and lower limits, as described in 40 CFR (Part 86.115-78 and Appendix 1).

NOTE: Driving "style" can also have a significant effect on emissions and/or fuel economy results. To address this factor, the EPA has provided guidance per § 86.128-00 (d): The vehicle shall be driven with appropriate accelerator pedal movement necessary to achieve the speed versus time relationship prescribed by the driving schedule. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided.

The diagrams Figure 3 show the EPA range of acceptable speed tolerances for typical points, per § 86.115-78: EPA Urban Dynamometer Driving Schedules. The curve on the left is typical of portions of the speed curve that are increasing or decreasing throughout the 2-s time interval. The curve on the right is typical of portions of the speed curve that include a maximum or minimum value.

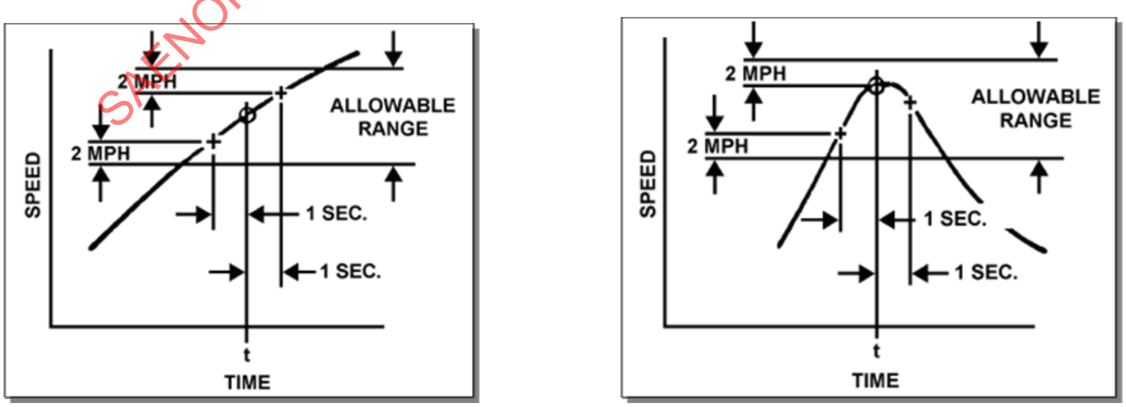

FIGURE 3 - SPEED TOLERANCE DEFINITIONS

3.6.2 Speed Tolerance Violations

Speeds that violate the speed tolerance constitute an invalid test. However, for the entire FCT procedure with many cycles required, the criteria for a valid FCT should be less than one violation per two test cycles (rounds to less than 0.5). All speed violations shall be noted.

Infrequent speed excursions that exceed the speed tolerance described in 3.6.1 are acceptable for FCT procedures where many cycles are required, if due to driver variability. The criteria for a valid FCT is: less than one 2 s period with an expanded tolerance of < ± 4 mph, per test cycle. In this case, a "test cycle" is a UDDS, US06, HWY, or SC03 cycle. Allowances for tire slippage shall be considered according to § 86.115-78. Good engineering judgment should be used in applying this speed tolerance allowance given the additional requirements on personnel for testing PHEVs.

NOTE: Regarding the allowable number of violations, for example, in an FCT with three cycles, a single violation will not invalidate the entire FCT, but two violations would. Likewise, 2/5, 3/7, etc., are acceptable.

3.7 State-of-Charge (SOC) Terminology

The SOC of a battery, capacitor, and electromechanical flywheel was defined in 3.2.3, 3.3.2, and 3.4.2, respectively. There are several terms used to distinguish the different values of the SOC in this test procedure. Each term refers to a specific driving schedule:

SOCu	Identifies an SOC value during the UDDS
SOCh	Identifies an SOC value during the HFEDS
SOC6	Identifies an SOC value during the US06 driving schedule
SOC3	Identifies an SOC value during the SC03 driving schedule
SOCcu	Identifies an SOC value during the Cold UDDS

For each of these driving schedules, there are additional SOC terms:

$SOCu_{initial}$	Identifies the SOC at the beginning of the first UDDS in a charge-sustaining test (CST); see 4.3 for more details on the CST.
$SOCu_{final}$	Identifies the SOC at the end of the second UDDS in a CST.
$SOCh_{initial}$	Identifies the SOC at the beginning of the first HFEDS in a CST.
$SOCh_{pause}$	Identifies the SOC at the beginning of the second HFEDS in a CST. The term “pause” refers to the 15-s pause between the first and second HFEDSs.
$SOCh_{final}$	Identifies the SOC at the end of the second HFEDS in a CST.
$SOC6_{initial}$	Identifies the SOC at the beginning of the first US06 in a CST.
$SOC6_{pause}$	Identifies the SOC at the beginning of the second US06 in a CST. The term “pause” refers to the 1- to 2-min pause between the first and second US06s.
$SOC6_{final}$	Identifies the SOC at the end of the second US06 in a CST.
$SOC3_{initial}$	Identifies the SOC at the beginning of the first SC03 in a CST.
$SOC3_{pause}$	Identifies the SOC at the beginning of the second SC03 in a CST. The term “pause” refers to the 10-min soak between the first and second SC03s.
$SOC3_{final}$	Identifies the SOC at the end of the second SC03 in a CST.
$SOCcu_{initial}$	Identifies the SOC at the beginning of the Cold Federal Test Procedure (FTP) in a CST.
$SOCcu_{final}$	Identifies the SOC at the end of the third phase (the “505”) in a CST.

3.8 Net Energy Change (NEC) Tolerances

For CS tests, one of the test validation criteria is that the RESS shall not have an NEC over the test cycle greater than a defined tolerance. The tolerance must be kept small enough to ensure that the vehicle is operated over the test cycle as nearly as possible to CS operation to achieve repeatable test results. However, current RESS and measurement technologies are limited in their abilities to produce repeatable test results. Therefore, some tolerance must be allowed in initial versus final net energy levels to avoid a high rate of invalid tests.

For purposes of the document, an objective has been set to be able to measure a value for fuel consumption that is within ±3% of the vehicle's true, representative fuel consumption, on any given CST. Analysis and test experience suggests that this goal can be met by limiting the change in RESS stored electrical energy over the test cycle to ±1% of the total fuel energy consumed over the same cycle. Equation 1 shows the NEC tolerance:

NEC Tolerance: $$\left|\frac{NetEnergyChange}{TotalFuelEnergy}\right| \le 1\% \quad \text{(Eq. 1)}$$

During the FCT, the EOT Criterion (3.9) uses the NEC tolerance in determining CS operation. Calculating the NEC tolerance immediately at the end of each cycle in the FCT based upon the fuel just consumed may be challenging for some test facilities, because bag sampling and calculations may not be completed before the next test cycle must begin. If such a delay is problematic, the NEC tolerance can also be defined with the fuel energy obtained in the corresponding CS test cycles to remedy the situation. For the UDDS and Cold UDDS (-7 °C) FCT tests, the NEC tolerance is calculated using the fuel consumed in both UDDS CST test cycles and dividing by two. All other CSTs outlined in this document have only one test cycle where fuel consumption is measured.

Because different RESSs store energy differently, each type of RESS will use different equations to define the NEC limit. The NEC tolerances for batteries, capacitors, and electromechanical flywheels and their supporting equations are detailed in 3.8.1 through 3.8.3.

3.8.1 Batteries

For batteries, Equations 2 and 3 are used for electrical and fuel energy, respectively:

$$\text{Net Energy Change} = \left((A \bullet h)_{final} - (A \bullet h)_{initial}\right) * V_{system} \quad \text{(Eq. 2)}$$

$$\text{Total Fuel Energy} = NHV_{fuel} * m_{fuel} \quad \text{(Eq. 3)}$$

Solving for the maximum and minimum allowed final battery NEC gives (see Equations 4 and 5):

$$(A \bullet h_{final})_{\max} = (A \bullet h_{initial}) + \frac{NHV_{fuel} * m_{fuel}}{V_{system} * K_1} * 0.01 \quad \text{(Eq. 4)}$$

$$(A \bullet h_{final})_{\min} = (A \bullet h_{initial}) - \frac{NHV_{fuel} * m_{fuel}}{V_{system} * K_1} * 0.01 \quad \text{(Eq. 5)}$$

Therefore, the NEC tolerance for batteries is (see Equation 6):

$$-\frac{NHV_{fuel} * m_{fuel}}{V_{system} * K_1} * 0.01 \le NEC \le \frac{NHV_{fuel} * m_{fuel}}{V_{system} * K_1} * 0.01 \quad \text{(Eq. 6)}$$

where:

NEC	=	Net change in battery energy over the test, in units of Watt-hours
$(A\bullet h_{final})_{max}$	=	Maximum allowed stored battery Ampere-hours at the end of the test phase
$(A\bullet h_{final})_{min}$	=	Minimum allowed stored battery Ampere-hours at the end of the test phase
$(A\bullet h_{initial})$	=	Battery Ampere-hours stored at the beginning of the test phase
NHV_{fuel}	=	Net heating value (per consumable fuel analysis), in Joules per kilogram
m_{fuel}	=	Total mass of fuel consumed over the test phase, in kilograms
V_{system}	=	Battery's DC nominal system voltage at the CS SOC level
K_1	=	Conversion factor = 3600 s/h

3.8.2 Capacitors

For capacitors, Equations 7 and 8 are used for electrical and fuel energy:

$$\text{Net Energy Change} = \frac{C}{2} * (V_{final}^2 - V_{initial}^2) \quad \text{(Eq. 7)}$$

$$\text{Total Fuel Energy} = NHV_{fuel} * m_{fuel} \quad \text{(Eq. 8)}$$

Solving for the maximum and minimum allowed final capacitor SOC gives (see Equations 9 and 10):

$$(V_{final}^2)_{max} = V_{initial}^2 + \frac{NHV_{fuel} * m_{fuel}}{C/2} * 0.01 \quad \text{(Eq. 9)}$$

$$(V_{final}^2)_{min} = V_{initial}^2 - \frac{NHV_{fuel} * m_{fuel}}{C/2} * 0.01 \quad \text{(Eq. 10)}$$

Therefore, the SOC Net Change Tolerance for capacitors is (see Equation 11):

$$-\frac{NHV_{fuel} * m_{fuel}}{C/2} * 0.01 \le NEC \le \frac{NHV_{fuel} * m_{fuel}}{C/2} * 0.01 \quad \text{(Eq. 11)}$$

where:

NEC	=	Net change in capacitor SOV over the test phase, in (V^2)
$(V^2_{final})_{max}$	=	The square of the maximum allowed stored capacitor voltage at the end of the test phase
$(V^2_{final})_{min}$	=	The square of the minimum allowed stored capacitor voltage at the end of the test phase
$V^2_{initial}$	=	The square of the capacitor voltage stored at the beginning of test phase
NHV_{fuel}	=	Net heating value (per consumable fuel analysis), in Joules per kilogram
m_{fuel}	=	Total mass of fuel consumed over the test phase, in kilograms
C	=	Rated capacitance of the capacitor, in Farads

3.8.3 Electromechanical Flywheels

For electromechanical flywheels, Equations 12 and 13 are used for the electrical and fuel energy, respectively:

$$\text{NEC} = \frac{1}{2} * I * (rpm_{final}^2 - rpm_{initial}^2) \qquad \text{(Eq. 12)}$$

$$\text{Total Fuel Energy} = NHV_{fuel} * m_{fuel} \qquad \text{(Eq. 13)}$$

Solving for the maximum and minimum allowed final flywheel NEC gives (see Equations 14 and 15):

$$(rpm_{final}^2)_{max} = rpm_{initial}^2 + \frac{NHV_{fuel} * m_{fuel}}{(1/2) * I * K_3} * 0.01 \qquad \text{(Eq. 14)}$$

$$(rpm_{final}^2)_{min} = rpm_{initial}^2 - \frac{NHV_{fuel} * m_{fuel}}{(1/2) * I * K_3} * 0.01 \qquad \text{(Eq. 15)}$$

Therefore, the SOC Net Change Tolerance for electromechanical flywheels is (see Equation 16):

$$-\frac{NHV_{fuel} * m_{fuel}}{1/2 * I * K_3} * 0.01 \le NEC \le \frac{NHV_{fuel} * m_{fuel}}{1/2 * I * K_3} * 0.01 \qquad \text{(Eq. 16)}$$

where:

NEC = Net change in flywheel energy over the test phase, in units of (rpm^2)
$(rpm^2_{final})_{max}$ = The square of the maximum flywheel rotational speed allowed at the end of the test phase, in (rpm^2)
$(rpm^2_{final})_{min}$ = The square of the minimum flywheel rotational speed allowed at the end of the test phase, in (rpm^2)
$rpm^2_{initial}$ = The squared flywheel rotational speed at the beginning of the test phase
NHV_{fuel} = Net heating value (per fuel analysis), in Joules per kilogram
m_{fuel} = Total mass of fuel consumed over the test phase, in kilograms
K_3 = Conversion factor = $4\pi^2/3600$ ($rad^2/s^2/rpm^2$)
I = Rated moment of inertia of the flywheel system, in kilogram-meter^2

3.9 FCT End-of-Test (EOT) Criterion

In the FCT, test cycles are repeated until the vehicle has exhausted the energy designed to be consumed during CD mode. The manufacturer shall inform the tester if the vehicle controls only temporarily operate in sustaining mode (if the vehicle significantly charges or discharges if driven farther) to avoid stopping the test too early. This test end point shall represent an SOC level that corresponds to energy consumed only in the depleting cycles of the FCT. Thus, the end point SOC should be close to the SOC corresponding to the Rcdc in order to achieve the correct recharge energy for the FCT.

The EOT Criterion is met when the first window of one or more cycles satisfies the NEC tolerance. Following CD operation, CS operation may not always satisfy the NEC tolerance within one cycle. However, the FCT may be terminated if the cumulative NEC over two or more cycles is less than 1% of the fuel consumed (or as described in 3.8, the NEC can be calculated using fuel consumption results from the CST).

The test facility should have an indicating system in place to alert the driver and other testing staff that the FCT ending criterion is achieved during the intra-test pauses.

Several examples are illustrated in Figure 4 to show how the EOT Criterion is applied. Figure 4A shows the NEC tolerance satisfied for the last cycle, where the NEC is less than 1% of the fuel energy. Figure 4B and Figure 4C show more possible scenarios, where windows of multiple cycles satisfy the EOT Criterion.

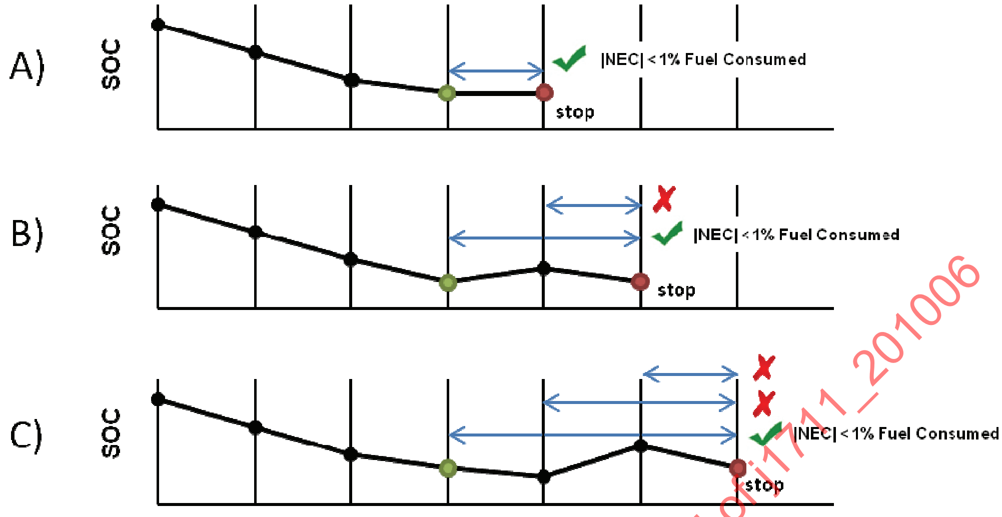

FIGURE 4 - SEVERAL SCENARIOS OF EOT CRITERION

3.9.1 Alternative FCT End-of-Test (EOT) Criterion

Achieving the NEC tolerance repeatably may be challenging for some vehicles. Therefore, an alternative EOT Criterion was developed that may be useful for some vehicle designs. The method is the same, but the tolerance uses the total capacity as the criterion when considering test termination. The alternative EOT Criterion finds CS operation validated if the ΔSOC of the last cycle or last series of cycles is less than 2% of the total depleted capacity or the NEC tolerance, whichever is larger.

Several examples to illustrate this alternative criterion are shown in Figure 5. Figure 5A shows the EOT Criterion satisfied for the last cycle, where the absolute value of SOC_2 minus SOC_3 is less than 2% of SOC_1 minus SOC_3. Figure 5B and Figure 5C show more possible scenarios, where windows of multiple cycles satisfy the alternative EOT Criterion.

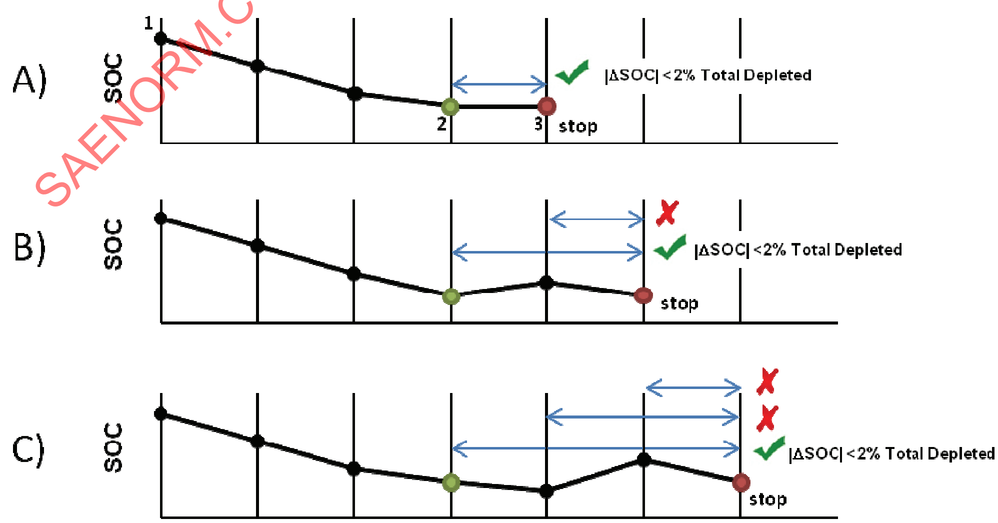

FIGURE 5 - ALTERNATIVE EOT CRITERION

4. TEST PROCEDURES

4.1 Test Conditions

Adequate test site capabilities for safe venting and cooling of batteries, containment of flywheels, protection from exposure to high voltage, or any other necessary safety precaution shall be provided during testing and external charging. The conditions in 4.1.1, 4.1.2, and 4.1.3 shall also apply to all tests defined in this document. For other test conditions not specifically addressed in this document, the test conditions specified in 40 CFR Part 86 shall apply, where appropriate.

4.1.1 Condition of Vehicle

4.1.1.1 Vehicle Stabilization

Prior to testing, the test vehicle shall be stabilized as specified in 40 CFR Part 86.098-26, which includes vehicle mileage accumulation either to a manufacturer-determined distance or to 2000 mi (per 40 CFR Part 86.1831-01c) over the Durability Driving Schedule (defined in Appendix IV of Part 86). Vehicles for which regular, external charging is recommended shall have their RESS recharged to full charge at least once between each refilling of consumable fuel. However, charging frequency for the RESS shall not be greater than is anticipated during normal vehicle use.

4.1.1.2 Vehicle Appendages

Vehicles shall be tested with normal appendages (e.g., mirrors, bumpers, etc.). Certain items (e.g., hub caps) may be removed where necessary for safety on the dynamometer.

4.1.1.3 Vehicle Test Weight

The vehicle shall be tested at the weight specified in 40 CFR Part 86, which includes definitions for loaded vehicle weight (curb weight plus 136.1 kg [300 lb]) and adjusted loaded vehicle weight (curb weight plus one-half vehicle payload).

4.1.1.4 Tires

Manufacturer's recommended tires shall be used.

4.1.1.4.1 Tire Pressure

For dynamometer testing, tire pressures should be set at the beginning of the test according to the manufacturer recommended values. These same tire pressures values should also be used to establish the dynamometer road-load coefficients (see 4.1.3.7) and shall not exceed levels necessary for safe operation.

4.1.1.4.2 Tire Conditioning

Tires shall be conditioned as recommended by the vehicle manufacturer. They shall have accumulated a minimum of 100 km (62 mi) and have at least 50% of the original usable tread depth remaining.

4.1.1.5 Lubricants

The vehicle lubricants normally specified by the manufacturer shall be used.

4.1.1.6 Gear Shifting

During testing, the vehicle's transmission shall be operated as specified in 40 CFR Part 86.128, which includes the requirement to follow in-use shifting patterns for manual-transmission vehicles.

4.1.1.7 Regenerative Braking

If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all dynamometer testing (with the exception of preparatory testing such as Dynamometer Load Coefficient Determination as described in 4.1.3.6). Depending upon how the regenerative braking is blended with the foundation (friction) braking system, the most accurate way to account for the effect of regenerative braking is to test the vehicle on a four-wheel drive electric dynamometer. However, it has been shown (Duoba 2005; refer to 2.1.1 of this document) that the contribution of regenerative braking in many modern hybrid vehicle designs results in nearly the exact outcome on either a two-wheel drive dynamometer or four-wheel drive dynamometer. Manufacturers must declare if testing the vehicle on a two-wheel drive dynamometer may significantly change the contributions of regenerative braking on the final results.

4.1.1.8 Traction Control

If the vehicle is equipped with an Antilock Braking System (ABS) or a Traction Control System (TCS) and is tested on a two-wheel dynamometer, the vehicle's ABS or TCS may inadvertently interpret the non-movement of the set of wheels that are off the dynamometer as a malfunctioning system. If so, then modifications to the ABS or TCS shall be made to achieve normal operation of the remaining vehicle systems, including the electric motor assist, engine start-stop, and regenerative braking system.

4.1.1.9 Vehicle Preparation

The vehicle shall be prepared for testing as specified in 40 CFR Part 86-131-00, which includes provisions for the installation of fittings for draining fuel and a throttle position sensing signal to control dynamometer dynamic inertia weight adjustments when applicable.

4.1.2 Condition of Rechargeable Energy Storage System (RESS)

4.1.2.1 RESS Stabilization

The RESS shall have been stabilized with the vehicle, as defined in 4.1.1.1 or by equivalent conditioning. In the event that a stabilization cycle different from the one specified in 4.1.1.1 is used, it is the vehicle manufacturer's responsibility to establish that the cycle used is equivalent in its ability to stabilize the RESS.

4.1.2.2 External Charging

If the vehicle is equipped with a charger, that charger shall be used for all external charging of the RESS. Otherwise, the RESS shall be charged with the external charger recommended by the vehicle manufacturer. If multiple charging power levels are acceptable, the RESS shall be recharged with the highest power level that it is capable of accepting. As an example, if the vehicle can connect to either 110V/15A or 220V/30A service, the 220V/30A service shall be used for recharging. The charge period includes the time from when the vehicle is first connected to when it is finally disconnected from the off-vehicle electric energy supply.

4.1.2.3 RESS Failure

In the event that the RESS is damaged or has an energy storage capability below the manufacturer's specified rating, the RESS shall be repaired or replaced, stabilized in accordance with 4.1.2.1, and the test procedure repeated. Data from tests with a faulty RESS shall be considered invalid.

4.1.3 Condition of Dynamometer

4.1.3.1 Dynamometer Capabilities

Dynamometers used in testing HEVs shall have the capabilities specified in 40 CFR Part 86.108-00, which include the capability of dynamically controlling inertia load during the US06 Test Procedure.

4.1.3.2 Dynamometer Configurations

Dynamometers used in testing HEVs shall be configured as specified in 40 CFR Part 86-108-00 (b)(2), which is a 48-inch, single-roll, electric, chassis dynamometer. If the HEV has a four-wheel drive design, it shall be tested on a four-wheel-drive dynamometer. Otherwise, four-wheel-drive vehicles may be tested in a two-wheel-drive mode of operation, per 40 CFR Part 86.135-90(i).

4.1.3.3 Dynamometer Calibration

The dynamometer shall be calibrated as specified in 40 CFR Part 86-118-00.

4.1.3.4 Dynamometer Augmented braking

The augmented braking feature on the dynamometer (if any) should be turned off while performing HEV or PHEV testing, because it interferes with the proper functioning of the regenerative braking on such vehicles and may adversely impact the benefit of regenerative braking in hybrid testing.

4.1.3.5 Dynamometer Warm-up

If the dynamometer has not been operated during the 2-h period immediately preceding usage, it shall be warmed up using a non-test vehicle, as recommended by the dynamometer manufacturer or as specified in 40 CFR Part 86-135-00 (f).

4.1.3.6 Dynamometer Load Coefficient Determination

The dynamometer coefficients that simulate road-load forces shall be determined as specified in SAE J2263 and SAE J2264, with the following provisions:

a. Vehicles equipped with regenerative braking systems that are actuated only by the brake pedal shall require no special actions for coastdown testing on both the test track and dynamometer.

b. Vehicles equipped with regenerative braking systems that are activated at least in part when the brake pedal is not depressed shall have regenerative braking disabled during the deceleration portion of coastdown testing on both the test track and dynamometer, preferably through the use of a “neutral” gear with no active regenerative braking or through temporary software changes in the vehicle's control system. Mechanical changes to the vehicle to deactivate regenerative braking (such as completely removing the drive shaft) are discouraged. However, if this practice becomes necessary as a last resort, every safety precaution shall be taken during vehicle operation, and the same mechanical modifications shall occur on both the test track and dynamometer. Methods to accelerate a vehicle without a drive shaft on both the test track and the dynamometer shall be determined by the manufacturer.

c. If the vehicle does not have a mechanical neutral, the manufacturer shall prescribe procedures and calculation methods for coastdown and road-load determination that correctly account for the possibly significant amount (possibly 5% or more of the vehicle mass) of rotating inertia not present in more conventional vehicles.

4.1.3.7 Dynamometer Settings

The dynamometer's power absorption and inertia simulation shall be set as specified in 40 CFR Part 86-129-00.

4.1.3.8 Practice Runs

Practice runs over the prescribed driving schedules are encouraged to allow time for the test driver to practice following the driving schedules and to feel comfortable with the vehicle's operation.

4.2 Test Instrumentation

Equipment referenced in 40 CFR Part 86.106 (including exhaust emissions sampling and analytical systems) is required for emissions measurements, where appropriate. All measurements shall be NIST-traceable (National Institute of Standards and Technology). The following instruments are either additionally required or recommended for as-needed usage.

a. A DC wideband voltage, Ampere, and Watt-hour meter (power analyzer): Voltage and current of the RESS are measured directly with this meter. It shall be installed in such a way as to measure all current leaving and entering the RESS (no other connections upstream of the measurement point). Ampere-hour meters using an integration technique shall have an integration period of less than 0.05 s, so that abrupt changes of current can be accommodated without introducing significant integration errors. Total accuracy of current measurements shall be ±1% of reading. Instruments shall not be susceptible to offset errors measuring current, because very small current offsets can be integrated throughout the cycle and provide erroneous NEC results.

b. A DC wideband Ampere-hour meter: If voltage sensing is not available, then one should optionally measure ampere-hours without directly sensing voltage. In this case, the voltage shall be monitored (logged) from vehicle network data.

c. An instrument to measure a capacitor's voltage (if applicable).

d. An instrument to measure an electromechanical flywheel's rotational speed (if applicable).

e. An AC Watt-hour meter to measure AC recharge energy (if applicable): It shall be installed in such a way as to measure all AC electrical energy entering the charger. The AC Watt-hour meter shall have a total accuracy of 1% or better.

f. A means to verify and record engine operation for the purpose of determining the dynamometer distance traveled before initial engine startup.

g. A voltmeter and ammeter for as-needed usage (recommended).

h. An instrument to measure the throttle pedal position (or an equivalent indicator of the driver's acceleration demands) for US06 dynamometer load adjustments (when applicable).

The accuracy of each instrument shall be as specified in 40 CFR Part 86 and SAE J1634, as applicable. Instrument accuracy for coastdown measurements shall be as specified in SAE J2263 and SAE J2264, as applicable.

4.3 Exhaust Emissions and Fuel Economy Tests

There are two basic exhaust emissions and fuel economy tests described in this document. One test begins with operation assumed to be CS for HEV operating modes, it is called the Charge-Sustaining Test (CST). The other test begins with a fully charged RESS for capturing CD operating modes for PHEVs, it is called the Full Charge Test (FCT). The tests are described in greater detail in 4.3.1 and 4.3.2:

a. CST for HEV Operating Modes: The CST is administered to all HEVs, including PHEVs.

b. FCT for CD (PHEV) Operating Modes: The FCT is administered to only PHEVs.

4.3.1 CSTs for CS Operating Modes

The CST is to be conducted over particular driving schedules. Test conditions are provided as follows for conducting this test with the UDDS (see 4.3.1.4), the HFEDS (see 4.3.1.5), the US06 driving schedule (see 4.3.1.6), the SC03 driving schedule (see 4.3.1.7) and the Cold UDDS (-7 °C) driving schedule (see 4.3.1.8).

4.3.1.1 Purpose of Test

The purpose of the CST for HEV modes is to measure the exhaust emissions and fuel economy of an HEV over one or a series of driving schedules in an HEV operating mode, while representing operation of an CS HEV, or a PHEV that has traveled beyond its CD range (without charging) and is operating in CS mode.

4.3.1.2 Applicability

The CST applies to HEVs in CS operating modes. If there are separate driver-selectable operating modes, the procedures can be repeated for those modes and the results attributed to that particular operating mode. If settings are not discrete, then good engineering judgment should be used to determine the particular settings testing.

4.3.1.3 Test Product

The following information will be the product of this testing:

a. Exhaust Emissions and Fuel Economy—The exhaust emissions and fuel economy of the HEV shall be measured during each test phase in which such measurements are required.

b. Actual Distance Traveled—The actual distance that the dynamometer roll surface traveled shall be measured during each test phase in which such measurements are required.

c. SOC—The SOC level of the RESS shall be recorded using the instrumentation described in 4.2 at every start and end of each test cycle phase (each portion of test where a single bag is sampled) in order to calculate the NEC of each test phase (to determine NEC tolerance criteria).

4.3.1.4 UDDS Charge-Sustaining Test (CST) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86, Subpart B, shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The vehicle shall be preconditioned in the driver-selected operating mode in which it will be tested. The preconditioning is subject to the requirements of 40 CFR Part 86.132, which includes fuel tank drain-and-fill, evaporative canister purge and load, driving over the UDDS, and a 12- to 36-h vehicle soak. One or more preconditioning cycles may have to be run in the same manner as the UDDS tests in order to provide the best chance to satisfy the NEC tolerance criteria.

b. Initial SOC—After vehicle preconditioning and before the vehicle is left to soak, the SOC of the RESS shall be adjusted to SOCuinitial (subject to the charging requirements of 4.1.2.2), attempting to achieve SOCufinal equal to SOCuinitial (refer to 3.7 for SOC terminology). However, if the only way to adjust the SOC is by operating the vehicle and the desired SOCuinitial is not achieved at the end of preconditioning, then any further SOC adjustments shall be made after vehicle preconditioning, and the soak period shall begin immediately after the adjustments are made.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS at the appropriate SOC (i.e., at SOCuinitial), the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a “cold” condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting, but with the words “propulsion system” generically substituted for the word “engine.”

f. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two UDDSs with a 10-min ± 1-min key-off soak period in between the two UDDSs. Tailpipe emissions on each of the UDDSs shall be collected.

g. Intra-Test Pause—Between the two UDDSs, the vehicle shall soak for 10 min ± 1 min with the key switch in the “off” position, the hood closed, test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pause. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire test until the test is concluded.

h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during both of the two UDDSs. Although two sample constant volume sampler (CVS) or Bag Mini Diluter (BMD) bag sets are used consecutively during the UDDS for conventional vehicles, it is recommended for the CST–HEV to use only one sample bag set during each UDDS and, therefore, to conduct the CST–HEV in a test site designed for that capability. Using two sample bag sets during each UDDS is an acceptable option for the CST–HEV; however, the time to analyze and purge sample bag emissions shall not require violating the intra-test pause requirement.

i. Test Termination—This test shall terminate at the completion of both UDDSs.

j. Test Validation—This test is considered invalid if the difference between SOCufinal and SOCuinitial violates the SOC NEC tolerance (refer to Equations 6, 11, and 16 for the tolerances for batteries, capacitors, and electromechanical flywheels, respectively).

k. Post-Test Recharging—No post-test recharging is required for this test.

4.3.1.5 HFEDS Charge-Sustaining Test (CST) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 600, Subpart B shall be referenced for any procedural requirement that is not specifically detailed in this document.

a. Vehicle Preconditioning—The vehicle shall be preconditioned in the driver-selected operating mode in which it will be tested. The preconditioning is subject to the requirements of 40 CFR Part 600.111-80(e)(1,2), which includes driving over one UDDS and a 0- to 3-h soak. One or more preconditioning cycles may have to be run in order to provide the best chance to achieve the NEC tolerance in the measured test.

b. Initial SOC—After vehicle preconditioning (if any), the SOC of the RESS may be adjusted to SOChinitial (subject to the charging requirements of 4.1.2.2), attempting to achieve SOChfinal equal to SOChpause (refer to 3.7 for SOC terminology). Adjusting the SOC by operating the vehicle before the test begins is acceptable. The challenge in meeting the previous requirement (that is, to attempt to maintain a level SOC over the second HFEDS) is to choose the right value for SOChinitial. However, in addition to this challenge, it is also the intent of this test that the vehicle be adequately preconditioned through engine operation before the second HFEDS begins. Therefore, in choosing the initial SOC, it is recommended (but not required) that SOChinitial be equal to or less than SOChpause to ensure that the contribution of the RESS toward vehicle propulsion during the first HFEDS is minimized.

c. Moving the Vehicle into Position—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 600.111-93(g) shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."

f. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two HFEDSs.

g. Intra-Test Pause—Between the two HFEDSs, there is to be a 15-s pause, which is to be at zero speed, with the key switch in the "on" position, the brake pedal depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pause. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire test until the test is concluded.

h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured only during the second HFEDS. The first HFEDS serves as additional vehicle preconditioning, during which such measurements are not required.

i. Test Termination—This test shall terminate at the completion of both HFEDSs.

j. Test Validation—This test is considered invalid if the difference between SOChfinal and SOChpause violates the SOC NEC tolerance (refer to Equations 6, 11, and 16 for the tolerances for batteries, capacitors, and electromechanical flywheels, respectively).

k. Post-Test Recharging—No post-test recharging is required for this test.

4.3.1.6 US06 Charge-Sustaining Test (CST) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86-159 shall be referenced for any procedural requirement that is not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The consumable fuel shall be drained and the tank refilled unless (1) the vehicle underwent a cycle in CS mode (over any driving schedule) within the last 72 h in the same driver-selected operating mode as to be tested in the US06 Test Procedure, and (2) the vehicle has since remained under ambient laboratory conditions. No other vehicle preconditioning is necessary for the US06 Test Procedure.

b. Initial SOC—After vehicle preconditioning (if any), the SOC of the RESS shall be adjusted to SOC6initial (subject to the charging requirements of 4.1.2.2), attempting to achieve SOC6final equal to SOC6pause (refer to 3.7 for SOC terminology). Adjusting the SOC by operating the vehicle before the test begins is acceptable. The challenge in meeting the previous requirement (that is, to attempt to maintain a level SOC over the second US06) is to choose the right value for SOC6initial. However, in addition to this challenge, it is also the intent of this test that the vehicle be adequately preconditioned through engine operation before the second US06 begins. Therefore, in choosing the initial SOC, it is recommended (but not required) that SOC6initial be equal to or less than SOC6pause to ensure that the contribution of the RESS toward vehicle propulsion during the first US06 is minimized. However, if the only way to achieve SOC6final equal to SOC6pause is by setting the SOC6initial to a level that is not expected to occur under normal operating conditions with no external charging (e.g., 0% SOC or 100% SOC), then SOC6initial shall be set to a level that is equal to or less than the level of SOCuinitial from the UDDS Test Procedure of the PCT–HEV with the same HEV operating mode. In this case, the SOC NEC tolerances (as described in paragraph j) shall not apply.

c. Moving the Vehicle into Position—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.159-00 (b)(9). Dynamometer load reduction for low-powered vehicles may be used in accordance with 40 CFR Part 86.108-00(b)(2)(ii).

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."

f. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two US06s.

g. Intra-Test Pause—Between the two US06s, there is to be an idle for 90 s ± 30 s, which is to be at zero speed, with the key switch in the "on" position, the brake pedal depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pause. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire test until the test is concluded.

h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured only during the second US06. The first US06 serves as additional vehicle preconditioning during, which such measurements are not required.

i. Test Termination—This test shall terminate at the completion of both US06s.

j. Test Validation—This test is considered invalid if the difference between.SOC6final and SOC6pause violates the SOC NEC tolerance (refer to Equations 6, 11, and 16 for the tolerances for batteries, capacitors, and electromechanical flywheels, respectively).

k. Post-Test Recharging—No post-test recharging is required for this test.

4.3.1.7 SC03 Charge-Sustaining Test (CST) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86.160 shall be referenced for any procedural requirement that is not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The consumable fuel shall be drained and the tank refilled unless (1) the vehicle underwent a cycle in CS mode (over any driving schedule) within the last 72 h in the same driver-selected operating mode as to be tested in the SC03 Test Procedure, and (2) the vehicle has since remained under ambient laboratory conditions. No other vehicle preconditioning is necessary for the SC03 Test Procedure.

b. Initial SOC—After vehicle preconditioning (if any), the SOC of the RESS shall be adjusted to SOC3initial (subject to the charging requirements of 4.1.2.2), attempting to achieve SOC3final equal to SOC3pause (refer to 3.7 for SOC terminology). Adjusting the SOC by operating the vehicle before the test begins is acceptable. The challenge in meeting the previous requirement (that is, to attempt to maintain a level SOC over the second SC03) is to choose the right value for SOC3initial. However, in addition to this challenge, it is also the intent of this test that the vehicle be adequately preconditioned through engine operation before the second SC03 begins. Therefore, in choosing the initial SOC, it is recommended (but not required) that SOC3initial be equal to or less than SOC3pause to ensure that the contribution of the RESS toward vehicle propulsion during the first SC03 is minimized. However, if the only way to achieve SOC3final equal to SOC3pause is by setting the SOC3initial to a level that is not expected to occur under normal operating conditions with no external charging (e.g., 0% SOC or 100% SOC), then SOC3initial shall be set to a level that is equal to or less than the level of SOCuinitial from the UDDS Test Procedure of the PCT-HEV with the same HEV operating mode. In this case, the SOC NEC tolerances (as described in paragraph j) shall not apply.

c. Moving the Vehicle into Position—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.

d. Test Site Conditions—The entire test is either to be conducted in an FEC (as specified in 40 CFR Part 86.161) or under test conditions that simulate testing in an FEC (as specified in 40 CFR Part 86.162). For testing in an FEC, the following ambient test conditions shall be provided: 35 °C (95 °F) air temperature, 100 grains of water/pound of dry air, a solar heat load intensity of 850 W/m^2, and a vehicle cooling air flow proportional to vehicle speed. Furthermore, for FEC testing, all vehicle windows shall be closed, and the vehicle air-conditioning system shall operate as specified in 40 CFR Part 86.160-00 (c)(6). For testing under conditions that simulate testing in an FEC, the conditions as specified in 40 CFR Part 86.162-00 shall apply.

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."

f. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two SC03s.

g. Intra-Test Pause—Between the two SC03s, the vehicle shall soak for 10 min ± 1 min with the key switch in the “off” position, the hood closed, the test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pause. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire test until the test is concluded.

h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured only during the second SC03. The first SC03 serves as additional vehicle preconditioning, during which such measurements are not required.

i. Test Termination—This test shall terminate at the completion of both SC03s.

j. Test Validation—This test is considered invalid if the difference between SOC3final and SOC3pause violates the SOC NEC tolerance (refer to Equations 6, 11, and 16 for the tolerances for batteries, capacitors, and electromechanical flywheels, respectively).

k. Post-Test Recharging—No post-test recharging is required for this test.

4.3.1.8 Cold UDDS Charge-Sustaining Test (CST) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86, Subpart C, shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The vehicle shall be preconditioned in the operating mode in which it will be tested. The fuel specifications are subject to the requirements of 40 CFR Part 86.213, with an RVP of 11.5 ± 0.3. The preconditioning is subject to the requirements of 40 CFR Part 86.232, which includes fuel tank drain-and-fill and driving over the UDDS, starting at a temperature of - 7 °C ± 1.7 °C (20 °F ± 3 °F). The ambient temperature shall average -7 °C ± 2.8 °C (20 °F ± 5 °F) and shall not be less than -14 °C (10 °F), nor more than -1 °C (30 °F), during the preconditioning. Humidity should be set low enough to prevent condensation on the dynamometer rolls. A 12- to 36-h vehicle soak follows the preconditioning at the same ambient conditions mentioned above. One or more preconditioning cycles may have to be run in the same manner as the UDDS tests in order to provide the best chance to reach a charge-balance operation.

b. Initial SOC—After vehicle preconditioning (if any) and before the vehicle is left to soak, the SOC of the RESS shall be adjusted to SOCcuinitial (subject to the charging requirements of 4.1.2.2), attempting to achieve SOCcufinal equal to SOCcuinitial (refer to 3.7 for SOC terminology). This charged balanced operation may be satisfied by initially setting the SOC of the RESS to a level for which the net change in SOC is equal to or greater than zero over the preconditioning cycle. If, however, it is not possible to prevent a net decrease in SOC during preconditioning, then the SOC shall be set in an attempt to minimize the decrease. However, if the only way to adjust the SOC is by operating the vehicle and the desired SOCcuinitial is not achieved at the end of preconditioning, then any further SOC adjustments shall be made after vehicle preconditioning, and the soak period shall begin immediately after the adjustments are made.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS at the appropriate SOC (i.e., at SOCuinitial), the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a “cold” condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test.

d. Test Site Conditions—The ambient temperature levels encountered at the start of the test shall be at -7 °C ± 1.7 °C (20 °F ± 3 °F). The average temperature during the test must be -7 °C ± 2.8 °C (20 °F ± 5 °F). The maximum excursions must be between -12.2 °C (10 °F) minimum and -1.1 °C (30 °F) maximum. Maximum excursions lasting up to 3 min must not exceed -9.4 °C (15 °F) minimum and -3.9 °C (25 °F) maximum. During dynamometer driving a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Heater/Defroster—At the start of the test, manually controlled climate control systems should have the airflow directed to the windshield for optimal defrosting, the airflow source set to outside air (not recirculation), the fan speed set to “off” or low," and the air temperature set to the hottest setting. At the second idle of the test (approximately 2 min into the test, allowing the engine to accumulate some heat), the fan speed should be set to maximum. At the sixth idle of the test, at approximately 505 s into the test (corresponds with the end of Bag 1 and the start of Bag 2 of the Cold FTP), the fan speed setting should be reduced to the lowest possible setting to maintain air flow, and the temperature setting will remain at the hottest setting. These settings should be held for the remainder of the test, including the two bags following the 10-min soak period. For automatic climate control systems, the manufacturer can manually override the system and use the provisions specified for manual systems, or the system selector should be set to heater or defroster mode and the temperature should be set to 72 °F for the duration of the test. For vehicles with multiple zone climate control systems (e.g., front and rear temperature/fan controls and/or separate driver/passenger temperature/fan controls), the same fan and temperature settings should be set and maintained for all the zones for both manual and automatic interior climate control systems. For any further information on this topic, please refer to “Fuel Economy Labeling of Motor Vehicles: Revisions to Improve Calculation of Fuel Economy Estimates” in CFR Parts 86 and 600, volume 71 number 248.

f. Propulsion system Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting.

g. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over a three-phase FTP test, this consists of a cold UDDS (phase 1 and phase 2), engine shutdown for a 10-min soak and then propulsion system startup and operation over 505 s (hot start or phase 3).

h. Intra-Test Pause—Between the two UDDSs, the vehicle shall soak for 10 min ± 1 min with the key switch in the “off” position, the hood closed, test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pause. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire test until the test is concluded.

i. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during all three phases of the test. Three sample CVS or BMD bags are used to collect the exhaust emissions from the test.

j. Test Termination—This test shall terminate at the completion of the three (or four) phase test.

k. Test Validation—This test is considered invalid if the difference between SOCcufinal and SOCcuinitial violates the NEC tolerance in discharge. The test can be considered valid if the NEC reflects RESS charging beyond the NEC tolerance.

l. Post-Test Recharging—No post-test recharging is required for this test.

4.3.2 Full-Charge Test (FCT) for CD Operating Modes

The FCT for PHEVs is to be conducted using a particular driving schedule. Test conditions are provided below for conducting this test with the UDDS (see 4.3.2.4), the HFEDS (see 4.3.2.5), the US06 (see 4.3.2.6), the SC03 (see 4.3.2.7), and the cold UDDS (-7 °C) cycles (see 4.3.2.8). However, with the appropriate test conditions, this test may be applied with any driving schedule.

4.3.2.1 Purpose of Test

The purpose of the FCT is to measure the exhaust emissions, fuel economy, and energy consumption over a series of driving schedules in CD mode after the vehicle RESS has been charged to full charge.

4.3.2.2 Applicability

The FCT only applies to PHEVs in any possible CD operating modes.

4.3.2.3 Test Product

The following information will be the product of the FCT:

a. Exhaust Emissions and Fuel Economy—The exhaust emissions and fuel economy of the HEV shall be measured during each test cycle (or phase where appropriate) in which such measurements are required.

b. Actual Distance Traveled—The actual distance that the dynamometer roll surface traveled shall be measured during each test cycle (or phase where appropriate) in which such measurements are required.

c. AC Recharge Energy—After dynamometer testing is completed, the AC recharge energy shall be measured while the RESS is being recharged. All AC W•h energy is recorded while the charger is plugged into the grid.

d. SOCi and SOCf—Initial and final SOC of the RESS for each cycle in the FCT shall be recorded (e.g., for electrochemical batteries, ΔA•h readings).

e. DC Electric Energy Consumption—The net DC W•h shall be measured during each test cycle. If voltage is not measured directly, then the appropriate calculation method is used.

f. Vi and Vf—Initial and final voltage measurement of RESS (electrochemical batteries only) in each test cycle of the FCT. If voltage is not measured directly, then this information comes from the vehicle communication network.

4.3.2.4 UDDS Full-Charge Test (FCT) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86, Subpart B, shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate. This procedure can also be conducted at ambient temperatures of 10 °C (50 °F), as described in the State of California Air Resources Board Exhaust Emission Standards Test Procedures.

a. Vehicle Preconditioning—The vehicle shall be preconditioned in the driver-selected operating mode in which it will be tested and at a CS SOC level. The preconditioning is subject to the requirements of 40 CFR Part 86.132, which includes fuel tank drain-and-fill, driving over the UDDS, and a 12- to 36-h vehicle soak.

b. RESS Charging/Vehicle Soak—After preconditioning and while the vehicle is soaking, the RESS shall be brought to Full Charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for minimum of 12 h, after which the charger is electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates "Full Charge" (no DC current going into battery). The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. All AC W•h energy shall be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS fully charged, the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a "cold" condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."

f. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over multiple continuous CD UDDS cycles, followed by one or more CS UDDS cycles until the EOT Criterion is met (see 3.9). The tailpipe emissions for each UDDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final SOC readings and DC W•h for each cycle shall be recorded. Figure 6 shows an example UDDS FCT.

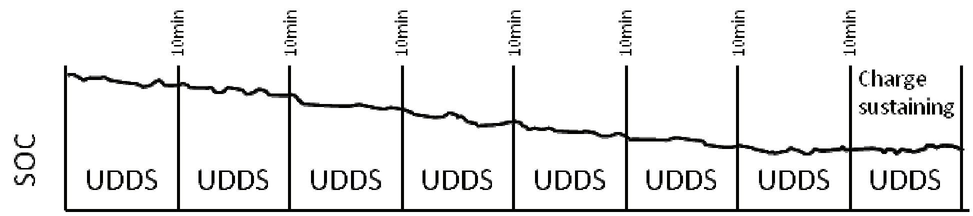

FIGURE 6 - RECOMMENDED UDDS TEST LAYOUT FOR CHARGE-DEPLETING FCT

g. Intra-Test Pauses— Between the UDDS cycles, the vehicle should soak for 10 min ± 1 min with the key switch in the "off" position, the hood closed, test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source. The SOC instrumentation should not be turned off or reset to zero during the intra-test pauses. In the case of Ampere-hour meter measurement, the integration should remain active throughout the entire FCT until it is concluded.

It is preferred that the pauses be consistently 10 min ± 1 min. However, it is acknowledged that many test facilities do not have the software and or hardware to do so without longer pauses at some time after two to four cycles for data collection or test setup. In this case, a duration window of 10 to 30 min shall be allowed during intra-test pauses. Good engineering judgment should be applied in arranging these test pauses, thus causing the least disruption in the test procedure. It is strongly preferred that the majority of soak periods remain as close to the 10-min recommendation as possible. During all soak periods, the key switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, the brake pedal not depressed, and the RESS not recharged from an external energy source.

NOTE: Any number of multiple UDDS cycles can be run in one test setup with the purpose of deviating as little as possible from the 10-min soak recommendation. This may require rewriting of software, and possibly reconfiguring of hardware, to accommodate running UDDS cycles continuously until the EOT Criterion (3.9) is met. Several examples illustrating approaches meeting the requirements are shown in Figure 7.

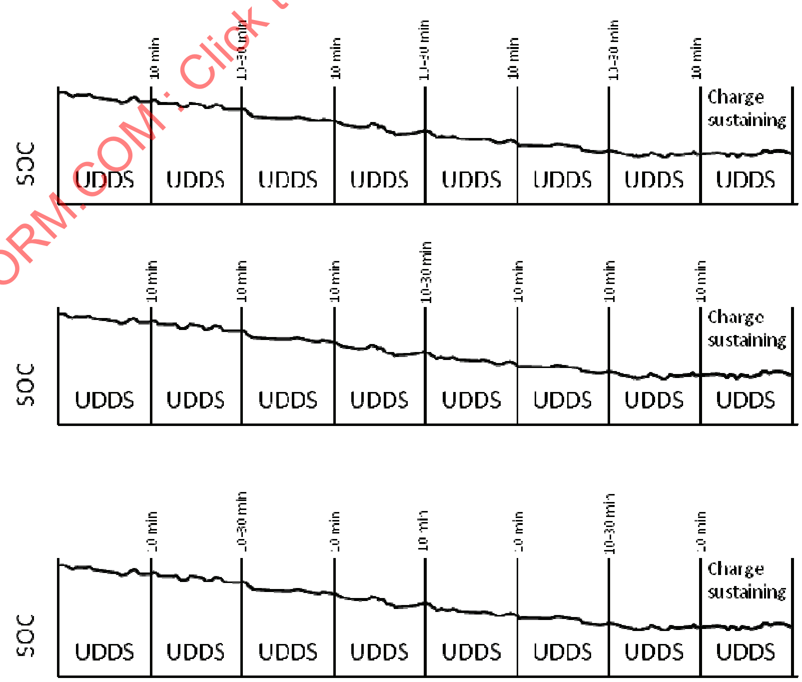

FIGURE 7 - EXAMPLES OF BACKUP TEST OPTIONS USING LONGER SOAK PERIODS DURING SOME INTRA-TEST PAUSES

h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during each of the UDDS cycles. Although two sample bag sets are used consecutively during a UDDS for conventional vehicles (Bag 1 and Bag 2), it is necessary in the FCT to use only one sample bag set during each UDDS and, therefore, to conduct the FCT in a test site designed for that capability.

i. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in End of Test (EOT) Criterion (3.9).

j. Test Validation—If at any point during the test, vehicle propulsion is not possible or the driver is warned by the vehicle to discontinue driving because the RESS contains too low of a supply of energy, the test is considered invalid.

k. Post-Test Recharging—Starting within 3 h of the end of the test, the RESS shall be brought to Full Charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates Full Charge. The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable to have interruptions during the first 12 h of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

   NOTE: The CS operation and charging event after this FCT can serve as the required vehicle preconditioning and charging event for another FCT (with the exception of tests requiring soak conditions at other than 20 to 30 °C).

4.3.2.5 HFEDS Full-Charge Test (FCT) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 600, Subpart B, shall be referenced for any procedural requirement that is not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The preconditioning is subject to the requirements of 40 CFR Part 86.132. The consumable fuel shall be drained and the tank refilled unless (1) the vehicle underwent a previous CST (in any driving schedule) within the last 72 h in CS mode, and (2) the vehicle has since remained under ambient laboratory conditions. A preconditioning cycle(s) consisting of one or more UDDS, HFEDS, or US06 cycles run in CS mode shall be run within 36 h before the FCT. The vehicle shall be at a CS SOC level before charging.

b. RESS Charging/Vehicle Soak—After preconditioning and while the vehicle is soaking (20 to 30 °C, as specified in 40 CFR Part 86.132), the RESS shall be brought to Full Charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until the charger indicates "Full Charge." The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period not compromised.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS at Full Charge, the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a "cold" condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Propulsion System Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 600.111-93(g) shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."

f. Dynamometer Driving Procedure—Unlike HFEDS testing for conventional or CS HEVs, this test is a cold-start beginning with a fully charged RESS. As soon as the vehicle propulsion system has started, the vehicle shall be driven over multiple continuous CD HFEDS cycles, followed by one or more CS HFEDS cycles until the EOT Criterion (3.9) is met. The tailpipe emissions for each HFEDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final SOC readings and DC W•h for each cycle shall be recorded.

g. Dynamometer Driving Procedure with a CS Switch Option—Conventional HFEDS tests are typically run as a set of two HFEDSs, with the first HFEDS acting as a preconditioning for the second cycle. If the vehicle has a CS switch and the test objectives are to avoid cold-start conditions in the HFEDS FCT, a procedure option exists to use the a CS mode during the first highway cycle to maintain a fully charged RESS during warm-up (prep cycle). This first cycle serves as preconditioning to warm up the vehicle, as is done with HFEDS cycles with conventional vehicles. As with conventional vehicles, the preconditioning cycle is not included in the results calculations. In order to make sure that the RESS stays fully charged, the NEC Tolerance (3.8) must be satisfied during the first highway cycle run with the CS switch activated. As soon as the first highway cycle drive trace is completed and the vehicle is at idle, before the second highway cycle drive trace starts, the CS mode is deactivated to initiate CD operation. The options for intra-test pauses are the same when using the switch. The vehicle shall be driven over multiple continuous CD HFEDS cycles, followed by a number of CS HFEDS cycles until the End of Test Criterion (3.9) are met. The tailpipe emissions for each HFEDS cycle shall be filled in one CVS or BMD emission sample bag. The SOC initial and final readings for each cycle shall be recorded. This optional method can be used regardless of the type of PHEV (i.e., full electric capable or engine/battery blended depleting operation). Initial and final SOC readings and the DC W•h for each cycle shall be recorded.

h. Intra-Test Pauses—The vehicle should be driven over as many HFEDS cycles in CD mode, separated by a 15-s key-on idle rest (without pauses), as the facility capabilities allow. If test pauses are required to stop testing and reinitialize the test system, then these pauses shall be less than 30 min in length. It is strongly preferred that the majority of intra-test pauses be key-on 15-s idle periods. If possible, four (4) HFEDSs should be run in a row, separated by 0- to 30-min key-off soak periods. Many (but not all) emissions labs can run four cycles on either CVS or BMD sampling systems. The 0- to 30-min range for the soak period is chosen based on the capability of the labs to read, evacuate, and purge the four bags and to initialize a new test. Good engineering judgment will be applied in arranging these test pauses, thus causing the least disruption in the test procedure. During all test pauses, the vehicle shall be at zero speed, the key switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, the brake pedal not depressed, and the RESS not recharged from an external energy source. Several examples illustrating approaches meeting the requirements are shown in Figure 8. The SOC instrumentation should not be turned off or reset to zero during the intra-test pauses. In the case of the Ampere-hour meter measurement, the integration should remain active throughout the entire FCT until it is concluded.

i. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during each of the HFEDSs.

j. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in End of Test (EOT) Criterion (3.9).

k. Test Validation—If at any point during the test, vehicle propulsion is not possible or the driver is warned by the vehicle to discontinue driving because the RESS contains too low of a supply of energy, the test is considered invalid.

l. Post-Test Recharging—Starting within 3 h of the end of the test, the RESS shall be brought to Full Charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates Full Charge. The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

NOTE: The CS operation and charging event after this FCT can serve as the required vehicle preconditioning and charging event for another FCT (with the exception of tests requiring soak conditions at other than 20 to 30 °C).

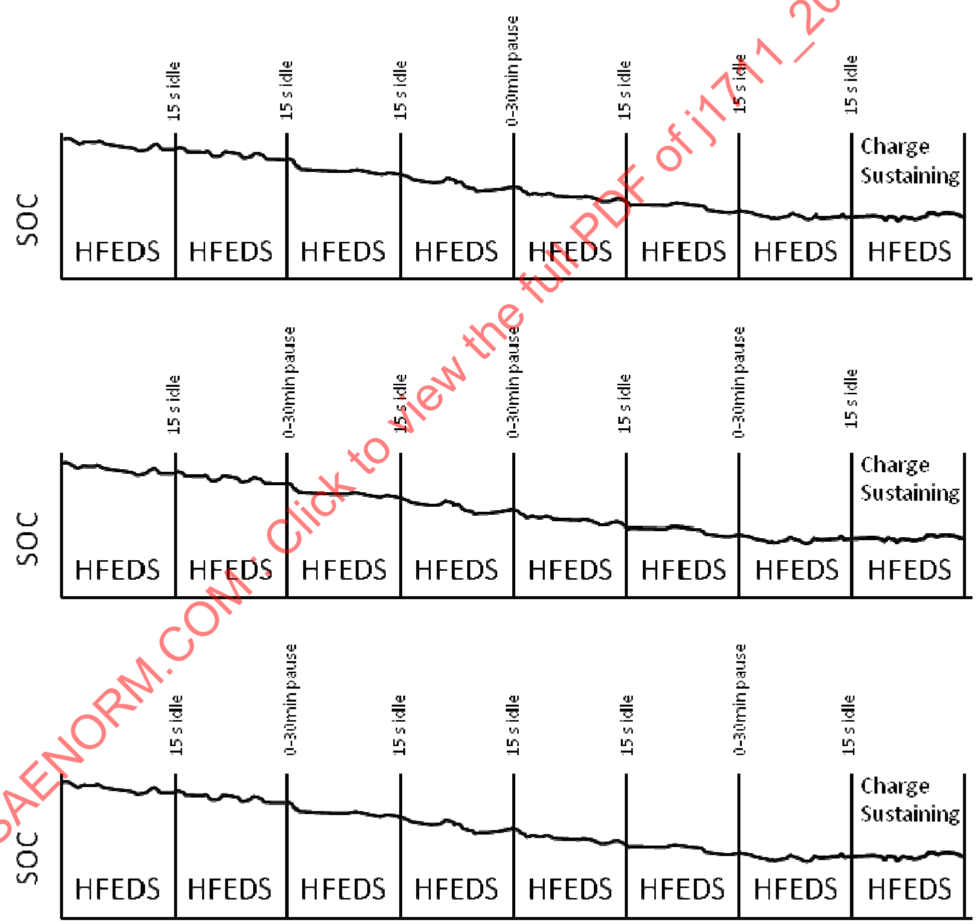

FIGURE 8 - EXAMPLES OF HFEDS TEST OPTIONS USING VARIATIONS OF INTRA-TEST PAUSES

4.3.2.6 US06 FCT Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86.159-00 shall be referenced for any procedural requirement that is not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The preconditioning is subject to the requirements of 40 CFR Part 86.159-00. The consumable fuel shall be drained and the tank refilled unless (1) the vehicle underwent a previous CST (in any driving schedule) within the last 72 h in CS mode, and (2) the vehicle has since remained under ambient laboratory conditions. A preconditioning cycle(s) consisting of one or more UDDS, HFEDS, or US06 cycles run in CS mode shall be run within 36 h before the FCT. The vehicle shall be at a CS SOC level before charging.

b. RESS Charging/Vehicle Soak—After preconditioning and while the vehicle is soaking (20 to 30° C, as specified in 40 CFR Part 86.159-00), the RESS shall be brought to Full Charge subject to the charging requirements of 4.1.2.2. It shall remain on charge for 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until the charger indicates "Full Charge." The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h and other conditions of the soak period not compromised.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS appropriately charged, the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a "cold" condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test. The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.

d. Test Site Conditions—The ambient temperature levels encountered by the test vehicle shall be no less than 20 °C (68 °F) and no more than 30 °C (86 °F). During dynamometer driving, all vehicle accessories shall be turned off, and a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.159-00 (b)(9). Dynamometer load reduction for low-powered vehicles may be used in accordance with 40 CFR Part 86.108-00(b)(2)(ii).

e. Engine Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting.

f. Dynamometer Driving Procedure—Unlike US06 tests with conventional vehicles, this test is a cold start beginning with a fully charged RESS. As soon as the vehicle propulsion system has started, the vehicle shall be driven over multiple continuous CD US06 cycles, followed by one or more CS US06 cycles until the End of Test Criterion (3.9) are met. The tailpipe emissions for each US06 cycle shall be filled in one CVS or BMD emission sample bag. Initial and final SOC readings and DC W•h for each cycle shall be recorded.

g. Dynamometer Driving Procedure with a CS Switch Option—Conventional US06 tests are typically run as a set of two, with the first US06 acting as a preconditioning for the second cycle. If the vehicle has a CS switch and the test objectives are to avoid cold-start conditions in the US06 FCT, a procedure option exists to activate the CS mode during the first US06 cycle to maintain a fully charged RESS during warm-up. This first cycle serves as preconditioning to warm up the vehicle, as is done with US06 cycles with conventional vehicles. As with conventional vehicles, the preconditioning cycle is not included in the results calculations. In order to make sure that the RESS stays fully charged, the NEC tolerance (3.8) must be satisfied during the first highway cycle run with the CS switch activated. As soon as the first US06 cycle drive trace is completed and the vehicle is at idle, before the second US06 cycle drive trace starts, the CS switch is disabled to initiate CD operation. The options for intra-test pauses are the same when using the switch. The vehicle shall be driven over multiple continuous CD US06 cycles, followed by one or more CS US06 cycles until the EOT Criterion (3.9) is met. The tailpipe emissions for each HFEDS cycle shall be filled in one CVS or BMD emission sample bag. The SOC initial and final readings for each cycle shall be recorded. This option can be used regardless of the type of PHEV (i.e., electric capable or blended depleting operation).

h. Intra-Test Pauses—The vehicle should be driven over as many US06 cycles in CD mode, separated by a 1- to 2-min (90 s) key-on idle rest (without pauses), as the facility capabilities allow. If test pauses are required to stop testing and reinitialize the test system, then these pauses shall be less than 30 min in length. It is strongly preferred that the majority of intra-test pauses be key-on 90-s idle periods. If possible, four US06 cycles should be run in a row, separated by 0-30 min key-off soak periods. Many (but not all) emissions labs can run four cycles on either CVS or BMD sampling systems. The 0- to 30-min range for the soak period is chosen based on the capability of the labs to read, evacuate, and purge the four bags and to initialize a new test. Good engineering judgment will be applied in arranging these test pauses, thus causing the least disruption in the test procedure. During all test pauses, the vehicle shall be at zero speed, the key switch must be in the “off” position, the hood must be closed, the test cell fan(s) must be off, the brake pedal not depressed, and the RESS not recharged from an external energy source. Several examples illustrating approaches that meet the requirements are shown in Figure 9.

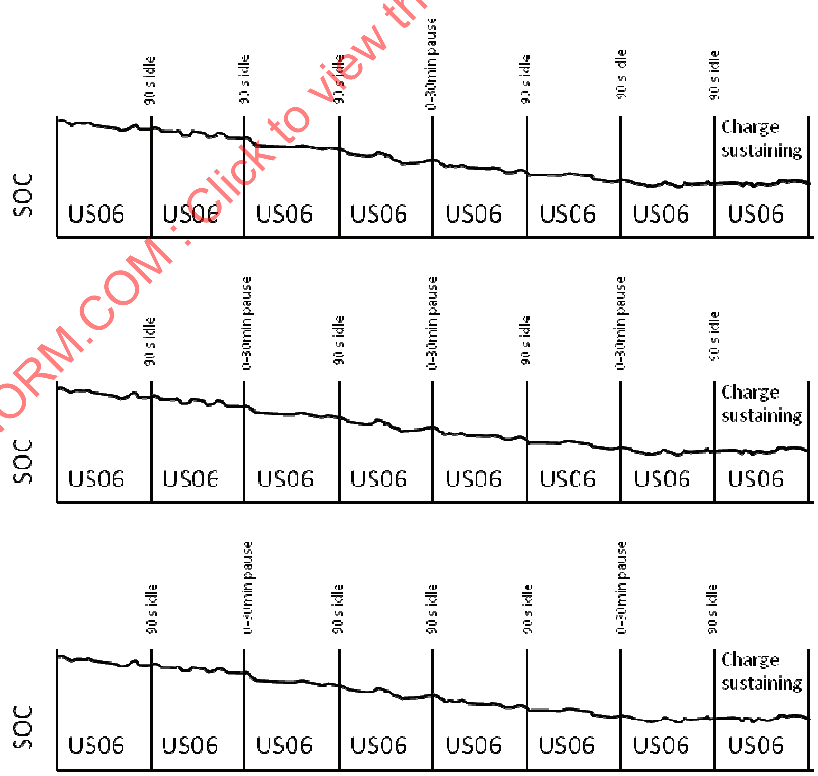

FIGURE 9 - EXAMPLES OF US06 TEST OPTIONS USING VARIATIONS OF INTRA-TEST PAUSES

i. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during each of the US06 cycles.

j. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in End of Test Criterion (3.9).

k. Test Validation—If at any point during the test, vehicle propulsion is not possible or the driver is warned by the vehicle to discontinue driving because the RESS contains too low of a supply of energy, the test is considered invalid.

l. Post-Test Recharging—Starting within 3 h of the end of the test, the RESS shall be brought to full charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates "Full Charge." The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable to have interruptions during the first 12 h of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h and other conditions of the soak period not compromised.

   NOTE: The CS operation and charging event after this FCT can serve as the required vehicle preconditioning and charging event for another FCT (with the exception of tests requiring soak conditions at other than 20 to 30 °C).

4.3.2.7 SC03 Full-Charge Test (FCT) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86.160 shall be referenced for any procedural requirement that is not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The preconditioning is subject to the requirements of 40 CFR Part 86.132. The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle shall be run unless (1) the vehicle underwent a previous CST (in any driving schedule) within the last 72 h in CS mode, and (2) the vehicle has since remained under ambient laboratory conditions. A preconditioning cycle(s) consisting of one or more UDDS, HFEDS, or US06 cycles run in CS mode at normal ambient conditions (20 to 30 °C) shall be run within 36 h before the FCT. The vehicle shall be at a CS SOC level before charging.

b. RESS Charging/Vehicle Soak—After preconditioning and while the vehicle is soaking (20 to 30 °C, as specified in 40 CFR Part 86.132), the RESS shall be brought to Full Charge, subject to the charging requirements of 4.1.2.2 It shall remain on charge for 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until the charger indicates Full Charge. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period, then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period not compromised.

c. Moving the Vehicle into Position—After the 12- to 36-h soak, and with the RESS appropriately charged, the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a "cold" condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test. The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained. The vehicle shall remain on the dynamometer at the Test Site Condition for at least 30 min prior to the start of the FCT.

d. Test Site Conditions—The entire test is to be conducted either in an full environmental chamber (FEC) (as specified in 40 CFR Part 86.161) or under test conditions that simulate testing in an FEC (as specified in 40 CFR Part 86.162). For testing in an FEC, the following ambient test conditions shall be provided: 35 °C (95 °F) air temperature, 100 grains of water/pound of dry air, a solar heat load intensity of 850 W/m^2, and vehicle cooling air flow proportional to vehicle speed.

e. A/C Operation—For FEC testing, all vehicle windows shall be closed, and the vehicle air-conditioning system shall operate as specified in 40 CFR Part 86.160-00 (c)(6). For testing under conditions that simulate testing in an FEC, the conditions as specified in 40 CFR Part 86.162-00 shall apply. For vehicles with manual climate control settings, after the second SC03 cycle is completed, the fan speed can be set to minimum in order to avoid cooling the cabin beyond normal driver comfort levels.

f. Engine Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting.

g. Dynamometer Driving Procedure—Unlike the SC03 CST test, this test has no prep cycle and starts with a fully charged RESS. As soon as the vehicle propulsion system has started, the vehicle shall be driven over multiple continuous CD SC03 cycles, followed by one or more CS SC03 cycles until the End of Test Criterion (3.9) is met. The tailpipe emissions for each SC03 cycle shall be filled in one CVS or BMD emission sample bag. Initial and final SOC readings for each cycle shall be recorded. The vehicle shall be driven over multiple continuous CD SC03 cycles separated by 10-min ± 1-min key-off soak periods, followed by a number of CS SC03 cycles also separated by a 10-min key-off soak until charge-sustaining operation is achieved (Figure 10). Unless the PHEV has a CS switch to maintain a fully charged RESS, the cold start on the first SC03 cannot be avoided. The vehicle shall continue to be driven over additional SC03 cycles until the vehicle satisfies the EOT Criterion. Initial and final SOC readings and DC W•h for each cycle shall be recorded.

h. Dynamometer Driving Procedure with a CS Switch Option—Conventional SC03 tests are typically run as a set of two SC03s, with the first SC03 acting as a preconditioning for the second cycle with a 10- min key-off soak in between. If the vehicle has a CS switch, as soon the vehicle propulsion system is started the CS switch is depressed during the first SC03 cycle to maintain a fully charged RESS. This first SC03 cycle serves as preconditioning to warm up the vehicle, as is done with conventional SC03 tests with conventional vehicles. As with conventional vehicle testing, the preconditioning cycle is not included in the results calculations. In order to make sure that the RESS stays fully charged, the 1% NEC must be satisfied during the first SC03 cycle run with the CS switch depressed. As soon as the first SC03 cycle drive trace is completed and the vehicle is at idle and before the second SC03 cycle drive trace starts, the CS switch is disabled to initiate CD operation. The vehicle shall continue to be driven over additional SC03 cycles until the vehicle satisfies the EOT Criterion. Initial and final SOC readings and DC W•h for each cycle shall be recorded.

i. Intra-Test Pauses—Between the SC03 cycles, the vehicle should soak for 10 min ± 1 min with the key switch in the “off” position, the hood closed, the test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source.

It is preferred that the pauses be consistently 10 min ± 1 min. However, it is acknowledged that many test facilities do not have the software and or hardware to do so without longer pauses at some time after two to four cycles for data collection or test setup. In this case, a duration window of 10- to -30 min shall be allowed during intra-test pauses. Good engineering judgment will be applied in arranging these test pauses, thus causing the least disruption in the test procedure. It is strongly preferred that the majority of soak periods remain as close to the 10-min recommendation as possible. During all soak periods, the key switch must be in the “off” position, the hood must be closed, the test cell fan(s) must be off, the brake pedal not depressed, and the RESS not recharged from an external energy source.

a. NOTE: Any number of multiple SC03 cycles can be run in one test setup, as long as the Intra-Test Pause specifications are being met. This may require significant rewriting of software, and possibly reconfiguring of hardware, to accommodate all the requirements of running the UDDS cycle continuously with 10-min ± 1-min soak periods. Several examples illustrating approaches that meet the requirements are shown in

Figure 10.

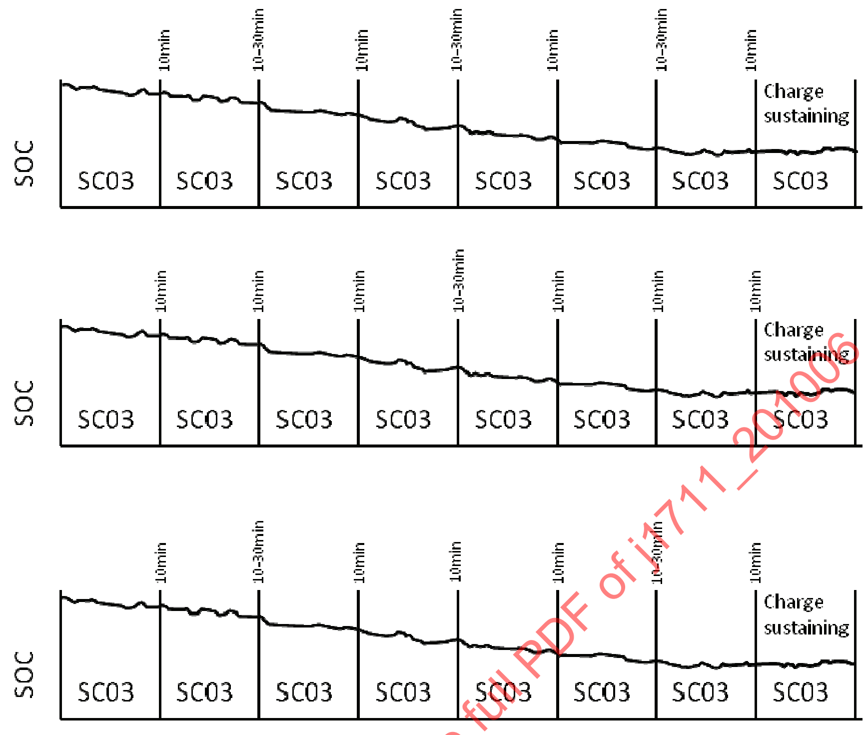

FIGURE 10 - EXAMPLES OF SC03 TEST OPTIONS USING VARIATIONS OF INTRA-TEST PAUSES

j. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during all SC03 cycles.

k. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in End of Test Criterion (3.9).

l. Test Validation—If at any point during the test, vehicle propulsion is not possible or the driver is warned by the vehicle to discontinue driving because the RESS contains too low of a supply of energy, the test is considered invalid.

m. Post-Test Recharging—Starting within 3 h of the end of the test, the RESS shall be taken to an ambient soak area (20 to 30 °C, as specified in 40 CFR 86.130-96), and brought to Full Charge subject to the charging requirements of 4.1.2.2. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates Full Charge. The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

4.3.2.8 Cold UDDS (-7 °C) Full-Charge Test (FCT) Procedure

This test is to be conducted subject to the test conditions described in 4.1, the test instrumentation requirements of 4.2, and the requirements listed as follows. However, 40 CFR Part 86, Subpart C, shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate.

a. Vehicle Preconditioning—The vehicle shall be preconditioned in the driver-selected operating mode in which it will be tested. The fuel specifications are subject to the requirements of 40 CFR Part 86.213, with an RVP of 11.5 ± 0,3. The preconditioning is subject to the requirements of 40 CFR Part 86.232, which includes fuel tank drain-and-fill and driving over the UDDS, starting at a temperature of -7 °C ± 1.7 °C (20 °F ± 3 °F). The ambient temperature shall average -7 °C ± 2.8 °C (20 °F ± 5 °F), and it shall not be less than -14 °C (10 °F) nor more than -1 °C (30 °F) during the preconditioning. Humidity should be set low enough to prevent condensation on the dynamometer rolls. A 12- to 36-h vehicle soak follows the preconditioning at the same ambient conditions mentioned above.

b. RESS Charging/Vehicle Soak—After preconditioning and while the vehicle is soaking at -7 °C ± 1.7 °C (20 °F ± 3 °F), the RESS shall be brought to Full Charge subject to the charging requirements of 4.1.2.2. It shall remain on charge for 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until the charger indicates Full Charge. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period, then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

c. Moving the Vehicle into Position—After the 12- to 36-h soak and with the RESS appropriately charged, the vehicle shall be moved (pushed or towed — not driven) into position on the dynamometer and restrained. The vehicle drivetrain shall be in a “cold” condition at the start of this test; therefore, the vehicle shall not be rolled more than 1.6 km (1 mi) between the end of the soak period and the start of this test.

d. Test Site Conditions—The ambient temperature levels encountered at the start of the test shall be at -7 °C ± 1.7 °C (20 °F ± 3 °F). The average temperature during the test must be -7 °C ± 2.8 °C (20 °F ± 5 °F). The maximum excursions must be between -12.2 °C (10 °F) minimum and -1.1 °C (30 °F) maximum. Maximum excursions lasting up to 3 min must not exceed -9.4 °C (15 °F) minimum and -3.9 °C (25 °F) maximum. During dynamometer driving a fixed-speed-cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 86.135-94.

e. Heater/Defroster—At the start of the test, manually controlled climate control systems will have the airflow directed to the windshield for optimal defrosting, the airflow source set to outside air (not recirculation), the fan speed set to “off” or “low,'' and the air temperature set to the hottest setting. At the second idle of the test (approximately 2 min into the test, allowing the engine to accumulate some heat), the fan speed will be set to maximum. At the sixth idle of the test, at approximately 505 s into the test (corresponds with the end of Bag 1 and the start of Bag 2 of the Cold FTP), the fan speed setting will be reduced to the lowest possible setting to maintain air flow, and the temperature setting will remain at the hottest setting. These settings will be held for the remainder of the test, including the two bags following the 10-min soak period. For automatic climate control systems, the manufacturer can manually override the system and use the provisions specified for manual systems, or the system selector will be set to heater or defroster mode and the temperature will be set to 22.2 °C (72 °F) for the duration of the test. For vehicles with multiple zone climate control systems (e.g., front and rear temperature/fan controls and/or separate driver/passenger temperature/fan controls), the same fan and temperature settings should be set and maintained for all the zones for both manual and automatic interior climate control systems.

f. Propulsion system Starting and Restarting—The vehicle's propulsion system shall be started according to the manufacturer's recommended starting procedures in the owner's manual. The requirements of 40 CFR Part 86.136-90(c-e) shall apply for starting and restarting,

g. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over multiple continuous CD UDDS cycles until the EOT Criterion is met (see 3.9). The tailpipe emissions for each UDDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final SOC readings and the DC W•h for each cycle shall be recorded. Figure 11 shows an example of Cold (-7 °C) UDDS FCT.

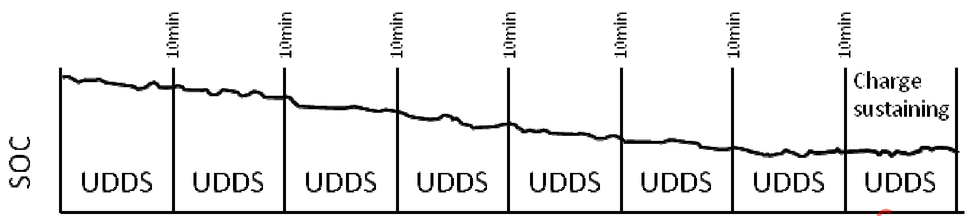

FIGURE 11 - RECOMMENDED TEST LAYOUT FOR COLD UDDS CHARGE-DEPLETING FCT

h. Intra-Test Pauses—Between the UDDS cycles, the vehicle should soak for 10 min ± 1 min with the key switch in the "off" position, the hood closed, the test cell fan(s) off, the brake pedal not depressed, and the RESS not recharged from an external electric energy source.

It is preferred that the pauses be consistently 10 min ± 1 min. However, it is acknowledged that many test facilities do not have the software and or hardware to do so without longer pauses at some time after sets of two to four cycles for data collection or test setup. In this case, a duration window of 10 to 30 min shall be allowed during intra-test pauses. Good engineering judgment will be applied in arranging these test pauses, thus causing the least disruption in the test procedure. It is strongly preferred that the majority of soak periods remain as close to the 10-min recommendation as possible. During all soak periods, the key switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, the brake pedal not depressed, and the RESS not recharged from an external energy source.

NOTE: Any number of multiple UDDS cycles can be run in one test setup, with the purpose of deviating as little as possible from the 10-min soak recommendation. This may require rewriting of software, and possibly reconfiguring of hardware, to accommodate running UDDS cycles continuously until the End of Test Criterion (3.9) is met. Several examples illustrating approaches that meet the requirements are shown in Figure 12.

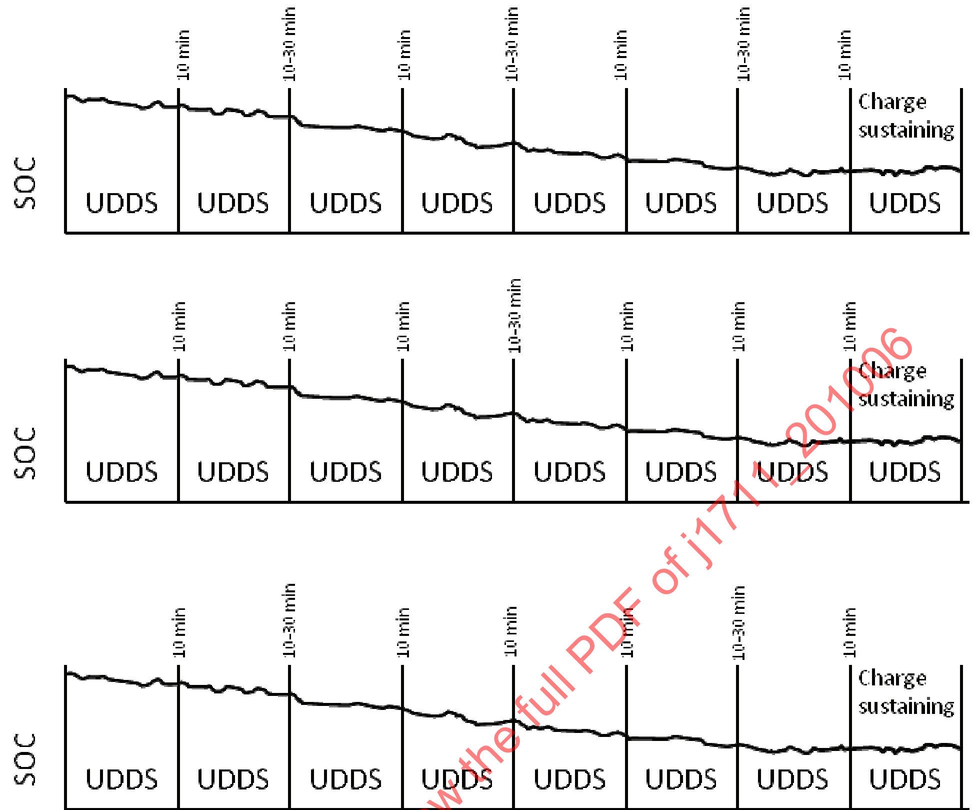

FIGURE 12 - EXAMPLES OF BACKUP TEST OPTIONS USING LONGER SOAK PERIODS DURING SOME INTRA-TEST PAUSES

i. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during each of the UDDS cycles. Although two sample bag sets are used consecutively during a UDDS for conventional vehicles (Bag 1 and Bag 2), it is necessary in the FCT to use only one sample bag set during each UDDS and, therefore, to conduct the FCT in a test site designed for that capability. Using two sample bag sets during each UDDS is an acceptable option for the Cold UDDS FCT; however, the time to analyze and purge sample bag emissions shall not require violating the intra-test pause requirement of 10 min ± 1 min.

j. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in End of Test (EOT) Criterion (3.9).

k. Test Validation—If at any point during the test, vehicle propulsion is not possible or the driver is warned by the vehicle to discontinue driving because the RESS contains too low of a supply of energy, the test is considered invalid.

l. Post-Test Recharging—Starting within 3 h of the end of the test, the RESS shall be taken back to the cold soak area (20 °F ± 3 °F [-7 °C ± 1.7 °C]) and brought to Full Charge, subject to the charging requirements of 4.1.2.2. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates Full Charge. The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 h of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 h, and other conditions of the soak period are not compromised.

m. It shall remain on charge for at least 12 h, after which the charger shall be electrically disconnected from the grid by means of an automatic timer or by simply unplugging the AC cord at the appropriate time. However, if after 12 h the charger indicates that the charging cycle is not complete (see Full Charge, 3.2.15), then the charger shall be left to charge the vehicle until after the charger indicates Full Charge. The charger is then electrically disconnected from the grid. The total AC W•h shall be recorded after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), then the charger should remain connected to the grid accordingly. Again, all AC W•h energy must be accounted as energy consumed.

5. CS HEV CALCULATIONS

A series of calculations are necessary to find the emissions and fuel economy from CS HEVs from the tests given in Section 4 of this document. Exhaust emissions and fuel economy calculations are prescribed for the UDDS, HFEDS, US06, SC03, and the -7˚C FTP test.

5.1 CS HEV Exhaust Emissions

5.1.1 UDDS Exhaust Emissions of CS HEVs

For CS HEVs, only the CST is conducted. The CST exhaust emissions data from the first UDDS shall be weighted differently than the results from the second UDDS (see CFR 86.144-94), as described in Equation 23:

$$Y_{CST} = 0.43\frac{Y_{UDDS(1)}}{D_{UDDS(1)}} + 0.57\frac{Y_{UDDS(2)}}{D_{UDDS(2)}} \quad \text{(Eq. 17)}$$

where:

$Y_{CST,}$ = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile
$Y_{UDDS(1)}$ = Mass emissions measured during the first UDDS, in grams
$D_{UDDS(1)}$ = Measured driving distance during the first UDDS, in miles
$Y_{UDDS(2)}$ = Mass emissions measured during the second UDDS, in grams
$D_{UDDS(2)}$ = Measured driving distance during the second UDDS, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 23 in measuring each individual gas, where appropriate.

5.1.2 HFEDS Exhaust Emissions of CS HEVs

Only the CST is conducted to test CS HEVs. The exhaust emissions data shall be calculated using data from the second HFEDS and not from the first HFEDS, as described in Equation 29:

$$Y_{CST} = 0.0\frac{Y_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0\frac{Y_{HFEDS(2)}}{D_{HFEDS(2)}} \quad \text{(Eq. 18)}$$

where:

$Y_{CST,}$ = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile in the CS mode
$Y_{HFEDS(1)}$ = Unmeasured mass emissions during the first HFEDS, in grams
$D_{HFEDS(1)}$ = Unmeasured driving distance during the first HFEDS, in miles
$Y_{HFEDS(2)}$ = Mass emissions as measured during the second HFEDS, in grams
$D_{HFEDS(2)}$ = Measured driving distance during the second HFEDS, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 29 in measuring each individual gas, where appropriate.

5.1.3 US06 Exhaust Emissions of CS HEVs

Only the CST is conducted to test CS HEVs. The exhaust emissions data shall be calculated using data from the second US06 and not from the first US06, as described in Equation 36:

$$Y_{CST} = 0.0\frac{Y_{US06(1)}}{D_{US06(1)}} + 1.0\frac{Y_{US06(2)}}{D_{US06(2)}} \quad \text{(Eq. 19)}$$

where:

$Y_{CST,}$ = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile
$Y_{US06(1)}$ = Unmeasured mass emissions during the first US06, in grams
$D_{US06(1)}$ = Unmeasured driving distance during the first US06, in miles
$Y_{US06(2)}$) = Mass emissions as measured during the second US06, in grams
$D_{US06(2)}$) = Measured driving distance during the second US06, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 36 in measuring each individual gas, where appropriate.

5.1.4 SC03 Exhaust Emissions of CS HEVs

Only the CST is required to test CS HEVs. The exhaust emissions data shall be calculated using data from the second SC03 and not from the first SC03, as described in Equation 44:

$$Y_{CST} = 0.0\frac{Y_{SC03(1)}}{D_{SC03(1)}} + 1.0\frac{Y_{SC03(2)}}{D_{SC03(2)}} \quad \text{(Eq. 20)}$$

where:

Y_{CST} = Weighted mass emissions of a particular measured (e.g., HC, CO, NO_x, CO_2), in grams per miles
$Y_{SC03(1)}$ = Unmeasured mass emissions during the first SC03, in grams
$D_{SC03(01)}$ = Unmeasured driving distance during the first SC03, in miles
$Y_{SC03(2)}$ = Mass emissions as measured during the second SC03, in grams
$D_{SC03(2)}$ = Unmeasured driving distance during the second SC03, in grams

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 44 in measuring each individual gas, where appropriate.

5.1.5 Cold (-7 °C) UDDS Exhaust Emissions of CS HEVs

Only the CST is required to test CS HEVs. The exhaust emissions data shall be weighted using the calculations described in Equation 44:

$$Y_{CST} = 0.43\frac{Y_{UDDS(phase1)} + Y_{UDDS(phase2)}}{D_{UDDS(phase1)} + D_{UDDS(phase2)}} + 0.57\frac{Y_{UDDS(phase3)} + Y_{UDDS(phase2)}}{D_{UDDS(phase3)} + D_{UDDS(phase2)}} \quad \text{(Eq. 21)}$$

where:

Y_{CST} = Weighted mass emissions of a particular measured (e.g., HC, CO, NO_x, CO_2), in grams per miles
$Y_{UDDS(phase1)}$ = Unmeasured mass emissions during the first phase (505 s) of the Cold UDDS, in grams
$D_{UDDS(phase1)}$ = Unmeasured driving distance during the first phase (505 s) of the Cold UDDS, in miles
$Y_{UDDS(phase2)}$ = Mass emissions as measured during the second phase (after 505 s) of the Cold UDDS, in grams
$D_{UDDS(phase2)}$ = Unmeasured driving distance during the second phase (after 505 s) of the Cold UDDS, in grams
$Y_{UDDS(phase3)}$ = Mass emissions as measured during the third phase (505 s) of the Cold UDDS, in grams
$D_{UDDS(phase3)}$ = Unmeasured driving distance during the third phase (505 s) of the Cold UDDS, in grams

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 44 in measuring each individual gas, where appropriate.

5.2 CS HEV Fuel Economy

5.2.1 UDDS Fuel Economy of CS HEVs

Only the CST is required to test CS HEVs. For the CST, it is assumed that the ultimate source of all energy the vehicle uses is consumable fuel. Calculate the fuel economy of the CST by using the weighted mass emissions results from Equation 23 and the calculations specified in 40 CFR Part 600.113. Then, calculate the fuel consumption (in gallons per mile) by taking the reciprocal of the fuel economy just calculated:

$$Y_{CST} = 0.43\frac{Y_{UDDS(1)}}{D_{UDDS(1)}} + 0.57\frac{Y_{UDDS(2)}}{D_{UDDS(2)}} \quad \text{(Eq. 22)}$$

where:

$Y_{CST,}$ = Fuel consumed per mile in the CS test
$Y_{UDDS(1)}$ = Fuel as measured during the first UDDS, in gallons
$D_{UDDS(1)}$ = Measured driving distance during the first UDDS, in miles
$Y_{UDDS(2)}$ = Fuel as measured during the first UDDS, in gallons
$D_{UDDS(2)}$ = Measured driving distance during the second UDDS, in miles

The fuel consumption value just calculated is an acceptable result, even though there may have been a non-zero NEC over the test phase within the tolerance specified in 3.8. However, the fuel consumption may be corrected to a zero-change in SOC by using a methodology defined in Appendix C.

5.2.2 HFEDS Fuel Economy of CS HEVs

Only the CST is required to test CS HEVs. For the CST, it is assumed that the ultimate source of all energy the vehicle uses is consumable fuel. Calculate the fuel economy of the CST using the weighted mass emissions results from Equation 23 and the calculations specified in 40 CFR Part 600.113. Then, calculate the fuel consumption (in gallons per mile) by taking the reciprocal of the fuel economy just calculated:

$$Y_{CST} = 0.0\frac{Y_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0\frac{Y_{HFEDS(2)}}{D_{HFEDS(2)}} \qquad \text{(Eq. 23)}$$

where:

$Y_{CST,}$ = Fuel consumed per mile in the CS test
$Y_{HFEDS(1)}$ = Fuel as measured during the first HFEDS, in gallons
$D_{HFEDS(1)}$ = Measured driving distance during the first HFEDS, in miles
$Y_{HFEDS(2)}$ = Fuel as measured during the first HFEDS, in gallons
$D_{HFEDS(2)}$ = Measured driving distance during the second HFEDS, in miles

The fuel consumption value just calculated is an acceptable result, even though there may have been a non-zero NEC over the test phase within the tolerance specified in 3.8. However, the fuel consumption may be corrected to a zero-change in state-of-charge, using a methodology defined in Appendix C.

5.2.3 US06 Fuel Economy of CS HEVs

Only the CST is required to test CS HEVs. For the CST, it is assumed that the ultimate source of all energy the vehicle uses is the consumable fuel. Calculate the fuel economy of the CST using the weighted mass emissions results from Equation 23 and the calculations specified in 40 CFR Part 600.113. Then, calculate the fuel consumption (in gallons per mile) by taking the reciprocal of the fuel economy just calculated:

$$Y_{CST} = 0.0\frac{Y_{US06(1)}}{D_{US06(1)}} + 1.0\frac{Y_{US06(2)}}{D_{US06(2)}} \qquad \text{(Eq. 24)}$$

where:

$Y_{CST,}$ = Fuel consumed per mile in the CS test
$Y_{US06(1)}$ = Fuel as measured during the first US06, in gallons
$D_{US06(1)}$ = Measured driving distance during the first US06, in miles
$Y_{US06(2)}$ = Fuel as measured during the first US06, in gallons
$D_{US06(2)}$ = Measured driving distance during the second US06, in miles

The fuel consumption value just calculated is an acceptable result, even though there may have been a non-zero NEC over the test phase within the tolerance specified in 3.8. However, the fuel consumption may be corrected to a zero-change in SOC by using a methodology defined in Appendix C.

5.2.4 SC03 Fuel Economy of CS HEVs

Only the CST is required to test CS HEVs. For the CST, it is assumed that the ultimate source of all energy the vehicle uses is consumable fuel. Calculate the fuel economy of the CST using the weighted mass emissions results from Equation 23 and the calculations specified in 40 CFR Part 600.113. Then, calculate the fuel consumption (in gallons per mile) by taking the reciprocal of the fuel economy just calculated:

$$Y_{CST} = 0.0\frac{Y_{SC03(1)}}{D_{SC03(1)}} + 1.0\frac{Y_{SC03(2)}}{D_{SC03(2)}} \quad \text{(Eq. 25)}$$

where:

$Y_{CST,}$ = Fuel consumed per mile in the CS test.
$Y_{SC03(1)}$ = Fuel as measured during the first SC03, in gallons
$D_{SC03(1)}$ = Measured driving distance during the first SC03, in miles
$Y_{SC03(2)}$ = Fuel as measured during the first SC03, in gallons
$D_{SC03(2)}$ = Measured driving distance during the second SC03, in miles

At this point, the fuel consumption value just calculated is an acceptable result, even though there may have been a non-zero net change in SOC over the test within the tolerance specified in 3.7. However, the fuel consumption may be corrected to a zero-change in SOC by using a methodology furnished by the manufacturer, provided that the decision to correct was made before the test began.

5.2.5 Cold (-7° C) UDDS Fuel Economy of CS HEVs

Only the CST is required to test CD HEVs. For the CST, it is assumed that the ultimate source of all energy the vehicle uses is consumable fuel. Calculate the fuel economy of the CST using the weighted mass emissions results from Equation 23 and the calculations specified in 40 CFR Part 600.113. Then, calculate the fuel consumption (in gallons per mile) by taking the reciprocal of the fuel economy just calculated:

$$Y_{CST} = 0.43\frac{Y_{UDDS(phase1)} + Y_{UDDS(phase2)}}{D_{UDDS(phase1)} + D_{UDDS(phase2)}} + 0.57\frac{Y_{UDDS(phase3)} + Y_{UDDS(phase2)}}{D_{UDDS(phase3)} + D_{UDDS(phase2)}} \quad \text{(Eq. 26)}$$

where:

$Y_{CST,}$ = Fuel consumed per mile in the CS test
$Y_{UDDS(phase1)}$ = Fuel as measured during the first phase (505 s) of the UDDS cycle, in gallons
$D_{UDDS(phase1)}$ = The measured driving distance during the first phase (505 s) of the UDDS cycle, in miles
$Y_{UDDS(phase2)}$ = Fuel as measured during the second phase (after 505 s) of the UDDS, in gallons
$D_{UDDS(phase2)}$ = Measured driving distance during the second phase (after 505 s) of the UDDS, in miles
$Y_{UDDS(phase3)}$ = Fuel as measured during the first phase (505 s) of the second UDDS cycle, in gallons
$D_{UDDS(phase3)}$ = Measured driving distance during the first phase (505 s) of the second UDDS cycle, in miles

At this point, the fuel consumption value just calculated is an acceptable result, even though there may have been a non-zero net change in SOC over the test within the NEC tolerance specified in 3.8. However, the fuel consumption may be corrected to a zero-change in SOC by using a methodology furnished by the manufacturer, provided that the decision to correct was made before the test began.

6. PHEV CALCULATIONS

When vehicle propulsion is no longer possible in a CD operating mode, it is assumed that the vehicle will operate in a CS manner, until the next time the RESS can be recharged. The limited utility of the CD operating mode is based upon the distance driven between charge events as determined by an individual's driving and charging habits.

In this document, the weighting placed on FCT data will equal the probability that a vehicle (based on national, in-use driving statistics) will be driven that distance segment in a single day. This probability is called the Utility Factor because it indicates the limited utility of a particular operating mode. An operating mode with a very long range, for example, will have a very high utility and, thus, a Utility Factor that approaches 1.0. The Utility Factor data required to calculate the results are given in SAE J2841. The preferred method of applying the Utility Factor is by using cycle length segments of the Utility Factor and applying that to each cycle in the FCT. The CST data is then weighted to this according to the remainder of the CS utility. More information on the Utility Factor is given in Appendix A.

NOTE: The FCT is not weighted for cold/hot start, as is done for some cycles according to 40 CFR Part 86. As such, the emissions results are calculated the same way as fuel economy and represent an "inventory" result. Good engineering judgment by regulating bodies should be used to quantify the metrics for passing emissions certification.

6.1 Range Calculations

The parameters in this section relate to specific range (distance) metrics that provide information for PHEVs and facilitate other calculations in this section. They are applicable to any cycle FCT conducted (UDDS, HFEDS, US06, SC03, and Cold UDDS).

6.1.1 All-Electric Range (AER)

The AER is the total distance from the beginning of the FCT to the distance traveled at the exact point in time during the test when the engine turns on. Accurate determination may require a computer to monitor the engine speed (or other engine process) that indicated the engine start and to couple this information to the recording of distance traveled during testing.

6.1.2 Charge-Depleting Cycle Range (Rcdc)

The Charge-Depleting Cycle Range is the sum of the cycle distances from the beginning of the FCT to the end of the last cycle prior to the cycle or cycles satisfying EOT Criterion. Thus, it is n cycles multiplied by the cycle distance. The Rcdc includes the transitional cycle, where the vehicle may have operated in both depleting and sustaining modes. If the FCT possesses a transitional range, then the Rcdc includes those transitional cycles or cycles.

NOTE: This distance is found by summing the particular schedule distances, not the actual measured distances traveled on the dynamometer. If during a particular cycle, the vehicle was in violation of 3.6.1 Speed Tolerance, then the actual driving distances should be used instead of the cycle schedule distances in the calculations for Rcdc.

6.1.3 Actual Charge-Depleting Range (Rcda)

The Actual Charge-Depleting Range may not be an easily identifiable point in the FCT because the exact transition point may not be a well defined point during the Transition Cycle or at the start of the Transitional Range. An analytical method is recommended that estimates the location of a transition point by using the trends of neighboring cycles. It is also used in Appendix B: Alternative Results Calculations where PHEV results are presented in depleting mode with an associated range (Rcda). Depending upon the type of operation, two sets of equations are used to calculate Rcda.

6.1.3.1 Rcda Calculation, Case 1 (Transition Cycle)

If an FCT has a single Transition Cycle, then the Rcda occurs at some point during this cycle. The Rcda can be calculated by first finding the value for Z_n from the equation below, multiplying it by the distance traveled in the transition cycle "n," and adding this to the cycle distance for the cycle before the Transition Cycle to find the value for Rcda (see Figure 13). Rcda is calculated using Equations 27 and 28.

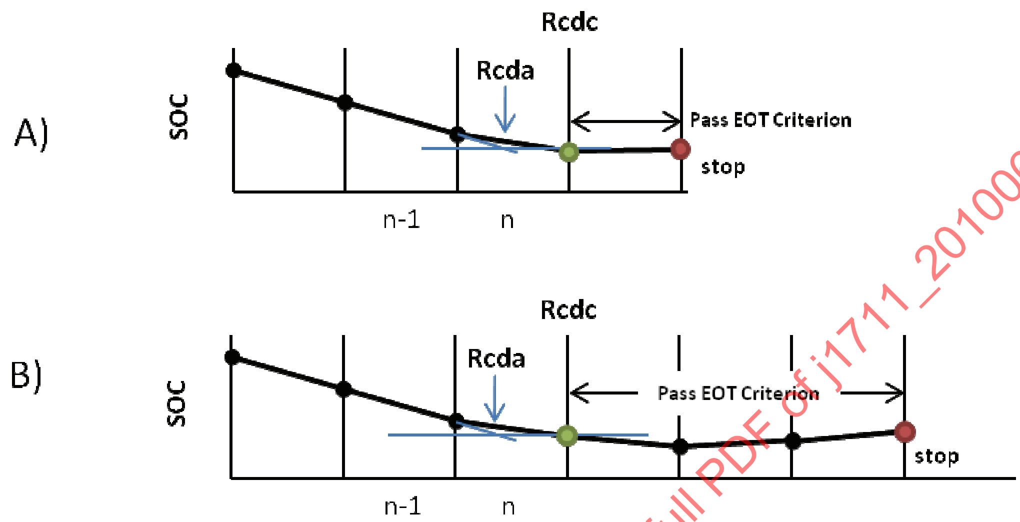

FIGURE 13 - CALCULATING RCDA, CASE 1

$$Z_n = \frac{\Delta SOC_n}{\Delta SOC_{n-1}} \quad \text{(Eq. 27)}$$

$$R_{cda} = R_{n-1} + (Z_n \times D_n) \quad \text{(Eq. 28)}$$

where:

Z_n = Depleting fraction of Transition Cycle (cycle *n*)
n = Transition Cycle (cycle ending at Rcdc)
D_n = The measured cycle distance of cycle *n*
R_{n-1} = The measured distance from the start of the FCT to the end of cycle *n*-1
ΔSOC_n = Change in SOC for cycle *n*

6.1.3.2 Rcda Calculation, Case 2 (Transition Range exists)

If during a particular FCT there is not a single Transition Cycle, but there is a Transitional Range, then a different set of equations shall be used to calculate the Rcda. The end of depleting cycle "n" is found by finding the first cycle in the FCT that depletes the RESS SOC beyond the level found at the beginning of the CS cycle(s) at the end of the FCT. Figure 14 illustrates the second case for Rcda calculations. Rcda for Case 2 is calculated using Equations 29 and 30.

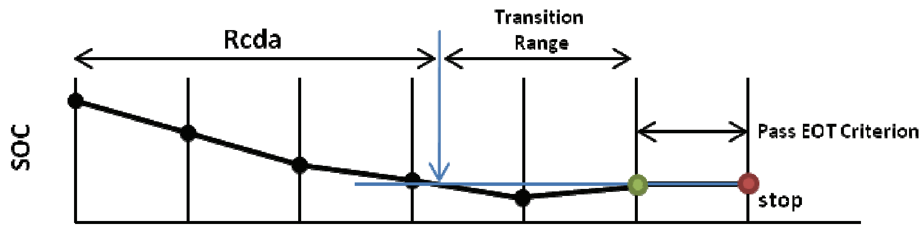

FIGURE 14 - CALCULATING RCDA, CASE 2

$$Z_n = \frac{SOC_{cdc} - SOCi_n}{\Delta SOC_{n-1}} \quad \text{(Eq. 29)}$$

$$R_{cda} = R_{n-1} + \left(Z_n \times D_n\right) \quad \text{(Eq. 30)}$$

where:

n = First cycle in FCT where SOC_{cdc} lies between $SOCi_n$ and $SOCf_n$
Z_n = Depleting fraction of cycle *n* (as defined above)
D_n = The measured cycle distance of cycle *n*
R_{n-1} = The measured distance from the start of the FCT to the end of cycle *n*-1
ΔSOC_n = Change in RESS SOC of cycle *n*
$SOCi_n$ = Initial RESS SOC of cycle *n*
$SOCf_n$ = Final RESS SOC of cycle *n*
SOC_{cdc} = RESS SOC at Rcdc (the ending SOC of the last depleting cycle)

6.2 PHEV Exhaust Emissions

The exhaust emissions over the UDDS of a PHEV shall be calculated by proceeding through the calculations in the sections under 6.2.1.

6.2.1 UDDS Exhaust Emissions of PHEVs

6.2.1.1 Exhaust Emissions Calculations for the UDDS Test Procedure of the CST

The exhaust emissions data from the first UDDS shall be weighted differently than the results from the second UDDS to account for “cold-start/hot-start” weighting, as described in Equation 31:

$$Y_{CST} = 0.43\frac{Y_{UDDS(1)}}{D_{UDDS(1)}} + 0.57\frac{Y_{UDDS(2)}}{D_{UDDS(2)}} \quad \text{(Eq. 31)}$$

where:

Y_{CST} = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile in the CS mode
$Y_{UDDS(1)}$ = Mass emissions as measured during the first UDDS, in grams
$D_{UDDS(1)}$ = Measured driving distance during the first UDDS, in miles
$Y_{UDDS(2)}$ = Mass emissions as measured during the second UDDS, in grams
$D_{UDDS(2)}$ = Measured driving distance during the second UDDS, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 31 in measuring each individual gas, where appropriate.

6.2.1.2 Exhaust Emissions Calculations for the UDDS Test Procedure of the FCT

There is no “cold-start/hot-start” weighting of the different phases of the FCT in the manner that is required in the CST.

6.2.1.3 Weighting Results for the Charge-Depleting (CD) Utility

Calculate the CD utility emissions from the FCT and CST results using Equation 32:

$$Y_{UFW} = \sum_{i=1}^{lastCDcycle} \left[\left(UF(i * D_{cycle}) - UF\left((i-1) * D_{cycle}\right) \right) * Y_{CDi} \right] + \left[1 - UF(R_{CDC})\right] * Y_{CST} \quad \text{(Eq. 32)}$$

where:

Y_{UFW} = Utility Factor weighted exhaust emissions of a particular measured gas, in grams/mile
UF(x) = Appropriate Utility Factor fraction at a given distance “x” (see Appendix A)
Y_{CDi} = Mass emissions for the “I”th test in the FCT of a particular measured gas, in grams/mile
Y_{CST} = Weighted mass emissions for the CST of a particular measured gas, in grams/mile as calculated in Equation 31
D_{cycle} = Distance in miles of a single drive schedule (NOTE: not actual driven distance)

6.2.1.4 Final Weighting for the Driver's Charging Habits

The baseline assumption for correcting results for charging habits is that the effect of “opportunity charging” and “missed charging” events null any need for corrections. Thus, no weighting with respect to charge frequency is recommended. In the future however, a charging frequency factor may be defined that may provide more accurate final results that account for charge-frequency behavior.

6.2.2 HFEDS Exhaust Emissions of PHEVs

6.2.2.1 Exhaust Emissions Calculations for the HFEDS Test Procedure of the CST

The exhaust emissions data shall be calculated using data from the second HFEDS and not from the first HFEDS, as described in Equation 26:

$$Y_{CST} = 0.0 \frac{Y_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0 \frac{Y_{HFEDS(2)}}{D_{HFEDS(2)}} \quad \text{(Eq. 33)}$$

where:

Y_{CST} = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile in the CS mode
$Y_{HFEDS(1)}$ = Unmeasured mass emissions during the first HFEDS, in grams
$D_{HFEDS(1)}$ = Unmeasured driving distance during the first HFEDS, in miles
$Y_{HFEDS(2)}$ = Mass emissions as measured during the second HFEDS, in grams
$D_{HFEDS(2)}$ = Measured driving distance during the second HFEDS, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 33 in measuring each individual gas, where appropriate.

6.2.2.2 Exhaust Emissions Calculations for the HFEDS Test Procedure of the FCT

No additional weighting is recommended for the individual cycles of the HFEDS FCT. If however, the test method utilizes the forced CS mode for the first HFEDS cycle, then the emissions from this cycle are not used in the rest of the calculations. In this case, the first cycle is the first CD cycle in the FCT.

6.2.2.3 Weighting Results for the Charge-Depleting (CD) Utility

Calculate the CD utility emissions from the FCT and CST results using Equation 32 from 6.2.1.3.

6.2.2.4 F inal Weighting for the Driver's Charging Habits

No weighting with respect to charge frequency is recommended. In the future, however, a charging frequency factor may be defined that may provide more accurate final results that account for charge-frequency behavior.

6.2.3 US06 Exhaust Emissions of PHEVs

6.2.3.1 Exhaust Emissions Calculations for the US06 Test Procedure of the CST

The exhaust emissions data shall be calculated using data from the second US06 and not from the first US06, as described in Equation 34:

$$Y_{CST} = 0.0\frac{Y_{US06(1)}}{D_{US06(1)}} + 1.0\frac{Y_{US06(2)}}{D_{US06(2)}} \qquad \text{(Eq. 34)}$$

where:

Y_{CST} = Weighted mass emissions of a particular measured gas (e.g., HC, CO, NO_x, CO_2), in grams per mile in the CS mode
$Y_{US06(1)}$ = Unmeasured mass emissions during the first US06, in grams
$D_{US06(1)}$ = Unmeasured driving distance during the first US06, in miles
$Y_{US06(2)}$ = Mass emissions as measured during the second US06, in grams
$D_{US06(2)}$ = Measured driving distance during the second US06, in miles

The calculations specified in 40 CFR Part 86.144-94(b)-(e) shall be used in conjunction with Equation 34 in measuring each individual gas, where appropriate.

6.2.3.2 Exhaust Emissions Calculations for the US06 Test Procedure of the FCT

There is no weighting of the different phases in the FCT in the same manner as the CS test.