



<b>SURFACE VEHICLE RECOMMENDED PRACTICE</b>	<b>J1711™</b>	<b>FEB2023</b>
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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

The test procedures were reviewed and updated to improve accuracy and reduce testing burden. Procedure and calculation subsections for plug-in hybrid-electric vehicles (PHEVs) were organized and streamlined to improve readability and reduce repetition. For charge-sustaining (CS) tests, a new net energy change (NEC) correction method is included that allows a wider allowable NEC window. Correcting CS hybrid-electric vehicle (HEV) results employs a standard correction factor, whereas PHEV results are corrected using a combination of both CS and charge-depleting (CD) test results. No additional testing is required in either case when compared to previous versions of the procedure.

#### FOREWORD

HEVs combine the powertrain elements of conventional vehicles and electric vehicles (EVs) and demonstrate substantially reduced fuel consumption and exhaust emissions. Legacy test procedures measuring fuel economy and emissions for vehicles with conventional powertrains must be adapted to apply to the operational characteristics of HEVs, including PHEVs. On-board electric energy storage introduces added complexity to determining the “fuel-only” energy consumption and the off-board electric energy consumption (in PHEVs).

The task force that developed SAE J1711 followed a similar effort to develop a recommended practice for testing EVs, which resulted in the publication of SAE J1634. SAE J1711 was first published in 1999. In 2002, SAE published a related document, SAE J2711.

Development in battery technology continued to a point where manufacturers began committing to produce PHEVs—HEVs that are designed to be charged from the grid in addition to using conventional fuels. In 2006, a new task force was formed to revise the expired SAE J1711, with a major objective to appropriately address PHEVs.

In 2020, the SAE J1711 task force reconvened to review the recommended practice. The focus was on achieving more accurate charge-balanced results without stringent limits on changes in battery energy state. Alternatives to requiring multiple tests to correct for net battery energy changes were developed that open the charge-balance window and correct all CS fuel consumption (and CO<sub>2</sub>) results. This new correction option, the S-factor correction method, was proposed. This method allows for the determination of fuel consumption (and CO<sub>2</sub> emissions) associated with a zero change in net battery energy state using less stringent tolerances and fewer test repeats in certain cases.

The task force members realize that both the technology and the methodology for testing are still evolving. As lessons are learned with newer, more advanced HEVs, modifications to this recommended practice may be needed to keep pace.

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## 1. SCOPE

This SAE Recommended Practice establishes uniform chassis dynamometer test procedures for hybrid-electric vehicles (HEVs) and plug-in hybrid-electric vehicles (PHEVs) designed for public roads. This recommended practice provides instructions for measuring and calculating the exhaust emissions and fuel economy of such vehicles over the following standard test cycles: the Urban Dynamometer Driving Schedule (UDDS), the Highway Fuel Economy Driving Schedule (HFEDS), the US06 Driving Schedule (US06), the SC03 Driving Schedule (SC03), and the cold-start Federal Test Procedure (cold FTP), which is based on the UDDS. 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.

This document does not specify which emissions constituents to measure (e.g., HC, CO, NO<sub>x</sub>, CO<sub>2</sub>); instead, that decision will depend on the objectives of the tester. The emissions calculations for 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 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 RESS is assumed to be an electrochemical battery pack because testing HEVs with capacitors or electromechanical flywheels requires a different approach to tracking energy in and out of the energy storage system. Procedures are included to test CD operating modes of PHEVs, which are designed to be routinely charged off-board, and calculations are provided that combine the CD and CS behavior according to in-use driving statistics.

This document does not include test procedures for recharge-dependent (RD) operating modes or vehicles. See Section [3](#) for the definition of recharge-dependent.

This document does not address the methods or equations necessary for calculating the adjusted U.S. Environmental Protection Agency (EPA) miles per gallon (mpg) labels (sometimes referred to as “EPA Five-Cycle” calculations).

### 1.1 Overview of the Recommended Practice

This recommended practice consists of three basic steps: (1) classifying the vehicle as CS HEV or PHEV, (2) testing the vehicle for each required test cycle and applicable test type (CS only for CS HEVs, or both CS and CD for PHEVs), and (3) for PHEVs, weighting (combining CS and CD) results with the appropriate utility factor (UF).

#### 1.1.1 Classifying the HEV

Determine whether the RESS is designed to be recharged from an external (off-board) electric energy source. All HEVs are tested with CS tests, only externally charged HEVs (PHEVs) require CD 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.

#### 1.1.2 Testing to Each Cycle Procedure

Provided are procedures for two separate test types, the charge-sustaining test (CST) and the full charge test (FCT), for five separate drive cycles, each with specific time-speed schedules and test conditions (see Section [5](#)). PHEVs require both depleting mode tests (FCT procedure) and sustaining mode tests (CST procedure). Charge-sustaining HEVs only require CST procedures.

#### 1.1.3 PHEV-Specific Calculations (If Applicable)

Various PHEV calculations are conducted to finalize applicable procedures. From the test data, the charge-depleting range is determined, and CD and CS results can be combined (weighted) to account for the limited CD range utility expected in daily driving (see Section [7](#)).

## 2. REFERENCES

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

### 2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J1634	Battery Electric Vehicle Energy Consumption and Range Test Procedure
SAE J1715	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
SAE J1772	SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler
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 Travel Survey Data

### 2.2 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 23274-1	Hybrid-Electric Road Vehicles - Exhaust Emissions and Fuel Consumption Measurements - Part 1: Non-externally Chargeable Vehicles
ISO 23274-2	Hybrid-Electric Road Vehicles - Exhaust Emissions and Fuel Consumption Measurements - Part 2: Externally Chargeable Vehicles

### 2.3 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, [www.gpo.gov](http://www.gpo.gov).

10 CFR Part 474	Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Petroleum-Equivalent Fuel Economy Calculation
40 CFR Part 86	Control of Emissions from New and In-Use Highway Vehicles and Engines
40 CFR Part 600	Fuel Economy and Greenhouse Gas Exhaust Emissions of Motor Vehicles
40 CFR Part 1066	Vehicle-Testing Procedures

### 2.4 DOE Publications

Clean Cities, U.S. Department of Energy, Alternative Fuels Data Center Fuel Properties Comparison, DOE/GO-102021-5498, January 2021, [https://afdc.energy.gov/files/u/publication/fuel\\_comparison\\_chart.pdf](https://afdc.energy.gov/files/u/publication/fuel_comparison_chart.pdf).

### 2.5 EPA Publications

U.S. Environmental Protection Agency, Greenhouse Gas Emissions from a Typical Passenger Vehicle, EPA-420-F-18-008, March 2018, [www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle](http://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle).

## 2.6 California Air Resources Board Publications

California Code Regulations, Title 13, § 1962.2 - Zero-Emission Vehicle Standards for 2018 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles, referencing “California Exhaust Emission Standards and Test Procedures for 2018 and Subsequent Model Zero-Emission Vehicles and Hybrid Electric Vehicles, in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes,” adopted March 22, 2012, last amended September 3, 2015.

## 3. DEFINITIONS

### 3.1 General Terms

#### 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. The term “HEV” is inclusive of PHEVs (see [3.1.5](#)); if referring specifically to non-PHEVs, the term “CS HEV” (see [3.1.4](#)) is used.

#### 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 electric-only operating modes (with no automatic engagement of the engine or hybrid power unit) in PHEVs are considered 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. An example of an RI operating mode is one in which vehicle propulsion is still possible, even though the RESS is completely depleted of all useful energy. 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 RD.

#### 3.1.4 CHARGE-SUSTAINING HYBRID-ELECTRIC VEHICLE (CS HEV)

A vehicle classification describing an HEV either (1) with an RESS that cannot be recharged from an external electric energy source, or (2) 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)

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: Also known as “off-vehicle charge-capable HEV,” “grid-connected HEV,” and “externally chargeable HEV.”

### 3.1.5.1 BLENDED PHEV TYPE

A PHEV which does not have all-electric full propulsion power capability and will supplant the electric driving with engine operation while in CD mode.

### 3.1.5.2 FULLY ELECTRIC-CAPABLE PHEV TYPE

A PHEV with all-electric full propulsion power capability while in CD mode.

NOTE: Sometimes referred to as “extended range electric vehicle,” “BEVx,” “range extender EV.”

### 3.1.6 CHARGE-SUSTAINING (CS) MODE

An operating mode of an HEV where the RESS may fluctuate over time but on average remains stable and the net energy of the HEV comes from consuming fuel energy.

### 3.1.7 CHARGE-DEPLETING (CD) MODE

An operating mode of an HEV (specifically, a PHEV) in which the vehicle runs by consuming only electric energy from the RESS charged from an external power source or by consuming electric energy along with the fuel energy, simultaneously or sequentially, while generally depleting the usable RESS energy. Upon usable battery energy depletion, the HEV engages CS mode.

### 3.1.8 ALL-ELECTRIC RANGE (AER)

For a PHEV, the total continuous miles driven in a given full-charge test (FCT, see [5.2](#)) prior to the first engine start while the vehicle is in all-electric driving mode (i.e., the mode where the vehicle's combustion engine is not operating).

### 3.1.9 EQUIVALENT ALL-ELECTRIC RANGE (EAER)

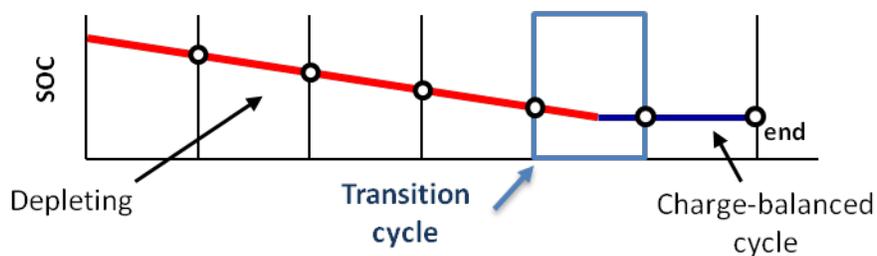
For a PHEV, the calculated distance driven electrically using the total usable battery energy and the electric-only consumption rates from cycles driven all-electrically (see [7.1.1](#) for calculation details).

### 3.1.10 CHARGE-BALANCED CYCLE

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

### 3.1.11 TRANSITION CYCLE

For a PHEV, during the FCT, the test cycle where electrical 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 may be net depleting, and the following cycle or cycles will be in CS mode. This definition is illustrated in [Figure 1](#). The FCT end-of-test (EOT) criterion (see [3.5](#)) identifies the first cycle with negligible net depleting operation and this can be helpful to identify the transition cycle—the cycle preceding the cycle meeting the EOT criterion is often the transition cycle.



**Figure 1 - Transition cycle definition**

### 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 DRIVING DISTANCE

The actual dynamometer driving surface distance in a specific test, test cycle, or test phase (refer to 40 CFR Part 1066.235). Use the average of driven distance of dynamometers if more than one is used.

### 3.1.14 CHARGE-DEPLETING CYCLE RANGE (Rcdc)

For a given FCT, the Rcdc is the product of the total number of cycles driven at least partially in CD mode multiplied by the cycle distance. CS cycles according to the EOT 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 has a period of transient instability before stable CS operation is observed, the Rcdc includes those transient cycles. See [7.1.3](#) for a more detailed description of Rcdc.

### 3.1.15 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 net energy of the transitional cycle compared with the previous cycle. The Rcda will always be less than or equal to the Rcdc. See [7.1.4](#) for the Rcda calculation method.

### 3.1.16 UTILITY FACTOR (UF)

The driven distance fraction associated to CD mode operation as a function of the CD range of a PHEV. The UF curves were calculated based upon in-use daily driving distance statistics. UF weighting of CD and CS modes (based on the CD range) provides the method to combine the two results. See [Appendix A](#) or refer to SAE J2841 for more details.

## 3.2 Vehicle-Related Terms

### 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 expected to be installed on more than 33% of the vehicle line, 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). However, some specific calculations in this document only include constants or conversion factors for gasoline and diesel fuel. If the test vehicle uses alternative fuels, the test operator must use the appropriate constants and factors for that fuel.

### 3.2.4 RECHARGEABLE ENERGY STORAGE SYSTEM (RESS)

A rechargeable storage system that provides electric energy for electrical propulsion, ancillaries, and accessories for which its supply of energy is rechargeable by (1) an electric motor-generator system, or (2) an external electric energy source, or both. The RESS may include subsystem(s) together with the necessary ancillary systems for physical support, thermal management, electronic control, and enclosures. Can also be referred to as simply the "battery."

### 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 EXTERNAL ELECTRICAL ENERGY SOURCE

A source of electrical energy that is not connected or coupled to the vehicle in any way while the vehicle is being driven. An example of an external electrical energy source is an electrical 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.

### 3.2.7 AC RECHARGE ENERGY

The electrical energy taken from an external electrical energy source that powers the charger to recharge the RESS, measured in AC watt-hours (Wh).

### 3.2.8 ELECTRICAL ENERGY (Edc or Eac)

The amount of electrical energy used by a vehicle during one or all CD cycles in the FCT. Expressed as a total amount in Wh. This can be attributed to the direct current (DC) Wh measured at the RESS terminals on-board (Edc), or the AC Wh measured during recharging (Eac).

### 3.2.9 ELECTRICAL ENERGY CONSUMPTION RATE (ECdc or ECac)

The consumption rate of electrical energy used by a vehicle during one or all CD cycles in the FCT. Expressed as a rate per unit distance, as in watt-hours/mile (Wh/mi). This can be attributed to the DC Wh measured at the RESS terminals on-board per unit distance (ECdc), or the AC Wh per unit distance (ECac) determined from recharge energy (Eac).

### 3.2.10 FUEL (F)

The amount of fuel used by a vehicle during any cycle or phase described in this document, expressed as a total amount for a given cycle in units of mass or volume.

### 3.2.11 FUEL CONSUMPTION RATE (FC)

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

### 3.2.12 REGENERATIVE BRAKING

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

## 3.3 RESS-Related Terms

### 3.3.1 ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

Equipment that delivers electrical energy from an electricity source to charge electric or plug-in hybrid-electric vehicle batteries. It includes the ungrounded, grounded, and equipment grounding conductors and the plug-in vehicle connectors, attachment plugs, and all other fittings, devices, or apparatuses installed specifically for the purpose of delivering energy from the premises to the vehicle.

### 3.3.2 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).

### 3.3.3 FULL CHARGE

The RESS state associated with maximum 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. Full charge state must be reliably achieved (repeatable end point of full charge) from test to test for accurate and reliable calculations of AC kWh energy consumption (Eac).

### 3.3.4 BATTERY STATE OF CHARGE (SOC)

The percentage of useable energy remaining in the battery pack relative to the battery pack's full charge useable energy. Because comprehensive battery testing is not within the scope of this procedure, this value is typically reported by the vehicle's control and monitoring computers and could be in terms of either percent of total capacity or usable capacity.

### 3.3.5 CYCLE VOLTAGE ( $V_{CYCLE}$ )

The average battery terminal voltage during a specific cycle or test phase. This calculation is presumably performed by a computer by taking the average (mean) of all the sampled voltage readings for the test or test segment considered. To reduce instrumentation burden in CS tests,  $V_{CYCLE}$  may be supplied by the manufacturer from previous testing.

### 3.3.6 NET ENERGY CHANGE (NEC)

The change in RESS energy state that occurs between a starting point and ending point within a test. Changes in SOC states are typically tracked with ampere-hours. NEC provides a similar result but in units of energy (Wh), which makes it more useful in other calculations. Equation 1 defines the NEC calculation.

$$NEC = ([A \cdot h]_{final} - [A \cdot h]_{initial}) \times V_{CYCLE} \quad (\text{Eq. 1})$$

where:

$A \cdot h_{initial}$  = initial reading of integrated RESS ampere-hours from a power analyzer at start of cycle (or phase)

$A \cdot h_{final}$  = end reading of integrated RESS ampere-hours from a power analyzer at end of cycle (or phase)

$V_{CYCLE}$  = system average voltage during particular cycle or test phase, in volts

### 3.3.7 NET ENERGY CHANGE/FUEL RATIO (NECFR)

To quantify the relative significance of the NEC in charge-sustaining tests, the NEC (in units of Wh) is divided by the consumed fuel energy (also in Wh) to arrive at the dimensionless value for NECFR. NECFR can be calculated in any convenient way, two examples are shown in Equation 2.

$$\text{NECFR} = \frac{\text{NEC}}{F \times \text{GE}} = \frac{\text{NEC}}{m_{\text{fuel}} \times \text{LHV}_{\text{fuel}}} \quad (\text{Eq. 2})$$

where:

NEC = net energy change, in Wh

F = fuel consumed, in gallons

GE = gallon equivalent energy content of the fuel, in watt-hour per gallon (see [6.2.1.1](#))

$m_{\text{fuel}}$  = mass of consumed fuel, in kg

$\text{LHV}_{\text{fuel}}$  = lower heating value of fuel, in Wh/kg

NOTE: The NECFR is dimensionless. The numerator and denominators in Equation 2 are in units of energy; thus, fuel can be in units of mass or volume, provided that when multiplied by the equivalent energy content (i.e., lower heating value), the resulting units in the denominator are the same as the units for NEC (Wh).

### 3.3.8 NET ENERGY CHANGE/FUEL RATIO CRITERIA

The NECFR is calculated for each CS test to determine whether the change in battery energy state is within a window that allows specific application of NEC corrections. The allowable limits are as follows:

Using standard S-factors:  $-0.02 < \text{NECFR} < 0.02$

For PHEVs using FCT data:  $-0.03 < \text{NECFR} < 0.03$

See [6.2.1](#) for details of the S-factor correction to fuel and CO<sub>2</sub> results and [Appendix C](#) for additional NEC correction options.

### 3.3.9 S-FACTOR

The S-factor is a dimensionless value of the change in fuel (in units of energy) divided by the change in NEC (also in units of energy) relating test-to-test variations in fuel to test-to-test variations in NEC. When a set of individual cycle tests are plotted on a graph of fuel versus NEC (both in units of Wh), typically they fall on a line; this line's slope is the S-factor. The inverse (1/S) can be analyzed as a conversion efficiency value relating marginal adjustments in consumed fuel with changes in stored electrical energy.

## 3.4 Driving Schedules

There are five driving schedules utilized in this document, all of which are required by 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):

- a. UDDS—The Urban Dynamometer Driving Schedule is defined in 40 CFR Part 1066.801(c)(1)(i) and in paragraph (a) of Appendix I in Part 86. It has a duration of 22 minutes, 52 seconds. It is used to represent vehicle city driving. Refer to second-by-second speed requirements in Appendix I of 40 CFR Part 86 online in the eCFR ([www.ecfr.gov](http://www.ecfr.gov)).
- b. HFEDS—The Highway Fuel Economy Driving Schedule is defined in 40 CFR Part 600 Subpart F, 40 Part CFR 600.109-08 (b)(1). It has a duration of 12 minutes, 45 seconds. It is used to represent vehicle highway driving. Refer to second-by-second speed requirements in Appendix I of 40 CFR Part 600 online in the eCFR ([www.ecfr.gov](http://www.ecfr.gov)).

- c. US06—The US06 Driving Schedule is defined in 40 CFR Part 1066.801(c)(2) and in paragraph (g) of 40 CFR Part 86, Appendix I. It has a duration of 10 minutes. It is used to represent vehicles driving at heavy speeds and accelerations. Refer to second-by-second speed requirements online in the eCFR ([www.ecfr.gov](http://www.ecfr.gov)).
- d. SC03—The SC03 Driving Schedule is defined in 40 CFR Part 1066.801(c)(2) and in paragraph (h) of 40 CFR Part 86, Appendix I. It has a duration of 10 minutes. It is used to represent vehicle operation with air conditioning. Refer to second-by-second speed requirements online in the eCFR ([www.ecfr.gov](http://www.ecfr.gov)).
- e. “Cold” UDDS—The same as in the UDDS schedule, the test is performed in cold ambient conditions as defined in CFR Part 1066.710 and in 40 CFR Part 86, Subpart C.

### 3.4.1 SPEED TOLERANCE

There are two speed tolerances to consider.

- 3.4.1.1 The first speed tolerance for any given time on these driving schedules, defined by the upper and lower limits, as described in 40 CFR Part 1066.425.
- 3.4.1.2 The second speed tolerance is like [3.4.1.1](#) but with an upper and lower limit of  $\pm 4$  mph (also within a time window of  $\pm 1$  second).

### 3.4.2 SPEED TOLERANCE VIOLATIONS

As in 40 CFR Part 1066.425, short violations (less than 2 seconds) of the speed tolerance in [3.4.1.1](#) are allowed. For an entire full charge test (FCT) procedure consisting of many test phases, infrequent speed excursions from [3.4.1.1](#) longer than 2 seconds, are acceptable, if due to driver variability. The criterion for a valid full charge test (FCT) includes having no more than one violation of [3.4.1.1](#) for more than 2 seconds per test cycle. Individual violations should not exceed [3.4.1.2](#). Additional allowances for tire slippage, brake spikes or other vehicle and/or dynamometer-related anomalies shall be considered according to 40 CFR Part 1066.425. Vehicles with a maximum speed capability that is less than the maximum speed on the drive cycle shall be operated at maximum available power (or full throttle) when the vehicle cannot achieve the speed trace within the speed and time tolerances specified in [3.4.1](#). Good engineering judgment shall be used in applying this speed tolerance allowance given the additional demands on personnel associated with testing PHEVs.

All speed violations shall be noted.

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 40 CFR 1066.415(e)(4). The EPA says to operate the vehicle with the appropriate accelerator pedal movement necessary to follow the scheduled speeds in the driving schedule and avoid smoothing speed variations and unnecessary movement of the accelerator pedal.

### 3.5 FCT End-of-Test (EOT) Criteria

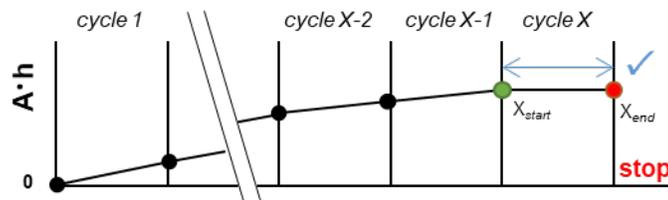
In the FCT, test cycles are repeated until the vehicle has exhausted the energy designed to be consumed during CD mode. The EOT criteria allow for the determination of this endpoint during testing so that the FCT can be terminated. The manufacturer shall inform the tester if the vehicle controls only temporarily operate in sustaining mode (if driven farther the vehicle significantly charges or discharges) to avoid stopping the FCT 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 similar to the SOC in CS mode. Ending in CS mode ensures the correct recharge energy is measured.

NOTE: Stopping the FCT too early would provide inaccurate results. However, testing additional cycles beyond what is needed is not necessarily detrimental to achieving accurate and repeatable results. These criteria are a guide for test operators to conduct a successful test without unnecessary testing burden.

### 3.5.1 Recommended EOT Criterion Determination

The FCT is complete when the last cycle tested has demonstrated an end to CD operation. This EOT criterion establishes best practices in making this determination. This criterion is satisfied when the last cycle has depleted <2% of the total A·h depleted in the FCT to that point.

Figure 2 is a depiction of an FCT where the current completed cycle (cycle X) satisfies the EOT criterion according to the terms in Equation 3. If the absolute value of integrated A·h in the last cycle ( $X_{start}$  to  $X_{end}$ ) is less than 0.02 (2%) of the net A·h depleted throughout the entire test up until that point (point 0 to end of cycle X) then the criterion is satisfied.



**Figure 2 - End-of-test (EOT) criterion**

$$\text{FCT EOT Criterion: } \left| \frac{A \cdot h_{X_{end}} - A \cdot h_{X_{start}}}{A \cdot h_{X_{end}} - A \cdot h_0} \right| < 0.02 \quad (\text{Eq. 3})$$

NOTE: This EOT criterion is defined with the absolute value of integrated A·h because charge gaining beyond 2% in a cycle may indicate SOC rebound or other unstable SOC behavior. If the vehicle exhibits unstable behavior transitioning from CD to CS mode, more information (gathered from additional testing or from the manufacturer) is needed to ensure all transient CD behavior is captured in the FCT.

### 3.5.2 Legacy (Stricter) EOT Criterion Determination

A stricter approach to determining the end of the FCT can be utilized if desired. This criterion compares each cycle's measured fuel and NEC in the FCT during testing. First the NECFR is calculated (see 3.3.7), and if the absolute value of the NECFR is less than 0.01 (1%), the EOT criterion is satisfied and the FCT can be terminated (see Equation 4). Following CD operation, CS operation may not always satisfy the NECFR tolerance within one cycle. However, the FCT may be terminated if the cumulative NECFR over two or more consecutive cycles is less than 1% of the fuel consumed.

$$\text{Alternative FCT EOT Criterion: } |NEC / \text{Fuel Ratio}| < 0.01 \quad (\text{Eq. 4})$$

NOTE: This criterion is more challenging to accomplish in real time during testing. The fuel consumption needs to be measured after each cycle before calculating the criterion and deciding if the next cycle shall be carried out. Sometimes fuel consumption results may not be available until after the next test cycle has begun, but the additional cycle following CD test completion shall not invalidate the test.

## 4. TEST CONDITIONS AND INSTRUMENTATION

Adequate test site capabilities for safe venting and cooling of batteries (if applicable), protection from exposure to high voltage, and any other necessary safety precautions shall be provided during testing and external charging. The conditions in 4.1, 4.2, and 4.3 shall 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 1066 and 40 CFR Part 86 shall apply, where appropriate.

### 4.1 Condition of Vehicle

#### 4.1.1 Vehicle Stabilization

Prior to testing, the test vehicle shall be stabilized as specified in 40 CFR Part 86.1831-01(c), which includes vehicle mileage accumulation either to a manufacturer-determined distance or to 2000 miles 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.

#### 4.1.2 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.

#### 4.1.3 Vehicle Test Weight

The vehicle shall be tested at the weight specified in 40 CFR Part 1066.805, which includes definitions for loaded vehicle weight (curb weight plus 136.1 kg [300 pounds]) and adjusted loaded vehicle weight (curb weight plus one-half vehicle payload).

#### 4.1.4 Tires

Manufacturer's recommended tires shall be used.

##### 4.1.4.1 Tire Pressure

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

##### 4.1.4.2 Tire Conditioning

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

#### 4.1.5 Lubricants

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

#### 4.1.6 Gear Shifting

During testing, the vehicle's transmission shall be operated as specified in 40 CFR Part 1066.415, which includes the requirement to follow in-use shifting patterns for manual-transmission vehicles.

#### 4.1.7 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 [4.3.6](#)). Depending upon how the regenerative braking is blended with the foundation (friction) braking system, a two-wheel-drive test vehicle may need to be tested on a four-wheel-drive electric dynamometer. However, the contribution of regenerative braking in modern hybrid vehicle designs typically results in nearly the same 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. Refer to 40 CFR Part 1066.410(g), which states, "Use good engineering judgment when testing vehicles in four-wheel drive or all-wheel drive mode."

#### 4.1.8 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 nonmovement 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.

#### 4.1.9 Vehicle Preparation

The vehicle shall be prepared for testing as specified in 40 CFR Part 1066.810, which includes provisions for the installation of fittings for draining fuel and instrumentation needed for evaporative testing.

## 4.2 Condition of Rechargeable Energy Storage System (RESS)

### 4.2.1 RESS Stabilization

The RESS shall be stabilized with the vehicle, as defined in [4.1.1](#), or by equivalent conditioning. If a stabilization cycle different from the one specified in [4.1.1](#) is used, it is the vehicle manufacturer's responsibility to establish that the cycle used is equivalent in its ability to stabilize the RESS.

### 4.2.2 Vehicle Recharging

If the vehicle is equipped with an on-board charger, that charger shall be used for all recharging of the RESS using the manufacturer's recommended recharging procedure and appropriate electric vehicle supply equipment (EVSE), as defined in SAE J1772. Otherwise, the RESS shall be recharged with the external charger recommended by the vehicle manufacturer. If multiple AC charging power levels are acceptable, the RESS shall be recharged with the highest AC power level it is capable of accepting, or as recommended by the manufacturer for testing. For example, if the vehicle can connect to either 120 VAC or 240 VAC service, the 240 VAC service shall be used for recharging. DC "fast-charging" is not recommended during testing unless expressly for the purposes of testing such systems at the option of the test lab and manufacturer (in which case, input energy would be measured upstream of the DC fast charger at the AC grid connection). 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.

### 4.2.3 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 [4.2.1](#), and the test procedure repeated. Data from tests with a faulty RESS shall be considered invalid.

## 4.3 Condition of Dynamometer

### 4.3.1 Dynamometer Capabilities

Dynamometers used in testing HEVs shall have the capabilities specified in 40 CFR Part 1066 Subpart C which includes a summary of the required dynamometer verifications with scope and minimum frequency.

### 4.3.2 Dynamometer Configuration

A dynamometer used in testing HEVs shall be configured as specified in 40 CFR Part 1066.210, 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 1066.410(g). If the HEV has a two-wheel-drive design, it may be tested on a four-wheel-drive dynamometer with the unpowered chassis dynamometer set to match the speed of the powered axle unless otherwise specified by the vehicle manufacturer.

### 4.3.3 Dynamometer Calibration

The dynamometer shall be calibrated as specified in 40 CFR Part 1066 Subpart C.

### 4.3.4 Dynamometer Augmented Braking

The augmented braking feature on the dynamometer (if applicable) shall be turned off or deactivated while performing HEV testing, because it interferes with the proper functioning of the regenerative braking system.

### 4.3.5 Dynamometer Warm-Up

Many modern dynamometers have heated and motorized pendulum bearings that do not require warm-up. Follow dynamometer manufacturer recommendations for preparing dynamometer for test. If the dynamometer has not been operated during the two-hour period immediately preceding usage, and the if the dyno manufacturer requires warmup within two hours of testing, it shall be warmed up using a non-test vehicle, as recommended by the dynamometer manufacturer or as specified in 40 CFR Part 1066.250.

#### 4.3.6 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 either the test track or the 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 additional factors (such as additional inertia or rotating losses) caused by the rotating gears and electric motor(s) such that the behavior of the dynamometer properly emulates the loads experienced on-road.

#### 4.3.7 Dynamometer Settings

The dynamometer's power absorption and inertia simulation shall be set as specified in 40 CFR Part 1066.301.

#### 4.3.8 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.

### 4.4 Test Instrumentation

The equipment specified in 40 CFR Part 1066.110 (including analytical systems and equipment for exhaust emissions and particulate matter [PM] sampling) 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 or equal to 0.05 seconds (20 Hz), so that abrupt changes of current can be accommodated without introducing significant integration errors. 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 (A·h) without directly sensing voltage. In this case, the voltage from vehicle network data shall be monitored (logged) for later processing.
- c. An AC watt-hour meter to measure AC recharge energy (when applicable)—The meter probe shall be installed to measure all AC electrical energy entering the EVSE (measurement point is “at the wall plug”).
- d. A means to verify and record engine operation for the purpose of determining the dynamometer distance traveled before engine startup.
- e. An instrument to measure the accelerator pedal position (or an equivalent indicator of the driver's acceleration demands) for US06 dynamometer load adjustments (when applicable).

Recommended accuracies of critical RESS-related measurements are listed in [Table 1](#). Other measurement specifications can be found in 40 Part CFR 1065.205.

**Table 1 - Recommended accuracies of critical RESS measurements**

Parameter	Unit	Accuracy
RESS terminal voltage	V	±0.5% of reading
RESS current	A	±(0.5% of reading + 0.25% of max reading)
RESS AC energy	Wh	1% of reading

## 5. EXHAUST EMISSIONS AND FUEL ECONOMY TEST PROCEDURES

Two basic types of exhaust emissions and fuel economy tests are described in this document: (1) CST, which begins with operation assumed to be CS for HEV operating modes and is administered to both HEVs and PHEVs, and (2) FCT, which begins with a fully charged RESS for capturing CD operating modes for PHEVs and is not administered to CS HEVs. These tests are described in greater detail in [5.1](#) and [5.2](#).

### 5.1 Charge-Sustaining Test (CST) Procedures

The CST is conducted using one of several standardized driving schedules. Test conditions and cycle-specific procedures are provided for conducting the CST with the UDDS (see [5.1.4](#)), the HFEDS (see [5.1.5](#)), the US06 driving schedule (see [5.1.6](#)), the SC03 driving schedule (see [5.1.7](#)), and the cold FTP (-7 °C) driving schedule (see [5.1.8](#)).

#### 5.1.1 Purpose of Test

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

#### 5.1.2 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 (varied adjustments), then good engineering judgment should be used to determine these settings during testing.

#### 5.1.3 Test Product

The following information will be the product of this testing:

- a. Exhaust Emissions and Fuel Consumption—The exhaust emissions and fuel consumption of the HEV/PHEV shall be measured during each test cycle (or phase where appropriate) in which such measurements are required.
- b. Actual Distance Traveled—The actual driving 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.  $V_{\text{CYCLE}}$ —The mean value of logged RESS voltages (see [3.3.5](#)) for each test cycle (or phase where appropriate). Care must be taken to eliminate voltage samples that momentarily occur when the main contactors are open and voltage readings are zero. If voltage is not measured directly, RESS voltage must be logged (and time-aligned with other logged measurements) from the vehicle communication network. For best results it is recommended to log voltage at a rate of at least 10Hz for an accurate  $V_{\text{CYCLE}}$  determination.
- d.  $A \cdot h$ —The integrated current (in units of ampere-hours) shall be calculated and recorded for each test cycle (or phase where appropriate) using the instrumentation described in [4.4](#) for each test cycle.
- e. NEC—The NEC (see [3.3.6](#)) shall be calculated and recorded for each test cycle (or phase where appropriate) using the results from  $V_{\text{CYCLE}}$  and  $A \cdot h$  measurements.

#### 5.1.4 UDDS CST Procedure

This test shall be conducted subject to the test conditions set forth in Section 4, the test instrumentation requirements specified in 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.815 shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate. This procedure can also be adapted for 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. The preconditioning is subject to the requirements of 40 CFR Part 86.132-96, which includes fuel tank drain-and-fill, evaporative canister purge and load, driving over the UDDS, and a 12- to 36-hour vehicle soak. One or more preconditioning cycles may have to be run in the same manner to provide the best chance to satisfy the NECFR tolerance criteria during the sampled test.
- b. **Moving the Vehicle into Position**—After the 12- to 36-hour soak and with the RESS at the appropriate SOC after preconditioning, 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 mile) between the end of the soak period and the start of this test.
- c. **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, as described in 40 CFR Part 1066.801. A fixed-speed cooling fan or a road-speed modulated fan may be used to direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105.
- d. **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 1066.415 shall apply for starting and restarting, but with the words “propulsion system” generically substituted for the word “engine.”
- e. **Dynamometer Driving Procedure**—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two UDDSs with a 10 minutes ± 1 minute key-off soak period in between. Tailpipe emissions for each of the UDDSs shall be collected.
- f. **Intra-Test Pause**—Between the two UDDSs, the vehicle shall soak for 10 minutes ± 1 minute 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.
- g. **Measurements and Emissions Sampling**—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during both UDDSs. Although two constant volume sampler (CVS) or bag mini-diluter (BMD) sets are used consecutively during the UDDS for conventional vehicles, it is recommended for the HEV CST to use only one sample bag set during each UDDS and, therefore, to conduct the HEV CST at a test site designed for that capability. Using two sample bag sets during each UDDS is an acceptable option for the HEV CST; however, the time to analyze and purge sample bag emissions shall not require violating the intra-test pause requirement.
- h. **Test Termination**—This test shall terminate at the completion of both UDDSs.
- i. **Test Validation**—This test is acceptable if the NECFR in each UDDS cycle (that portion of the drive schedule where exhaust sampling is prescribed) is within ±2% if using standard S-factors, or within ±3% for PHEVs using S-factors derived from FCT and CST data. If the applicable NECFR is outside of this specification, basic SOC corrections requiring more test data are required to correct the results for changes in NEC (see [Appendix C](#)).
- j. **Post-Test Recharging**—No post-test recharging is required for this test.

### 5.1.5 HFEDS CST Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.840 shall be referenced for any procedural requirement 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 1066.840, which includes driving over the HFEDS right after the FTP. If the HFEDS procedure starts more than 3 hours after an FTP, operate it after one UDDS and preconditioning cycle. A separate HFEDS cycle may also be used as preconditioning cycle with a 15-second idle in between. One or more preconditioning cycles may have to be run in order to provide the best chance to achieve a small NECFR in the measured cycle.
- b. **Moving the Vehicle into Position**—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.
- c. **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. A fixed-speed cooling fan or a road-speed modulated fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105.
- d. **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 1066.415 shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."
- e. **Dynamometer Driving Procedure**—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two HFEDSs.
- f. **Intra-Test Pause**—Between the two HFEDSs, there is to be a 15-second 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.
- g. **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.
- h. **Test Termination**—This test shall terminate at the completion of both HFEDSs.
- i. **Test Validation**—This test is acceptable if the NECFR over the second HFEDS cycle is within  $\pm 2\%$  if using standard S-factors, or within  $\pm 3\%$  for PHEVs using S-factors derived from FCT and CST data. If the applicable NECFR is outside of this specification, basic SOC corrections requiring more test data are required to correct the result for changes in NEC (see [Appendix C](#)).
- j. **Post-Test Recharging**—No post-test recharging is required for this test.

## 5.1.6 US06 CST Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.831 shall be referenced for any procedural requirement not specifically detailed in this document, where appropriate.

- a. Vehicle Preconditioning—The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle shall be run unless (1) the vehicle underwent a cycle in CS mode (over any driving schedule) within the last 72 hours in the same driver-selected operating mode as to be tested in the US06 CST Procedure, and (2) the vehicle has since remained under ambient laboratory conditions. No other vehicle preconditioning is necessary for the US06 CST Procedure.
- b. Moving the Vehicle into Position—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.
- c. 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, as described in 40 CFR Part 1066.801. A fixed-speed cooling fan or a road-speed-modulated fan may be used to direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105. Dynamometer load reduction for low-powered vehicles may be used in accordance with 40 CFR Part 86.108-00(b)(2)(ii).
- d. 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 1066.415 shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."
- e. Dynamometer Driving Procedure—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two US06s.
- f. Intra-Test Pause—Between the two US06s, there is to be an idle for 90 seconds  $\pm$  30 seconds, 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.
- g. 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. Take the steps described in 40 CFR Part 1066.831(c) to measure emissions over separate city and highway test intervals of the US06.
- h. Test Termination—This test shall terminate at the completion of both US06s.
- i. Test Validation—This test is acceptable if the NECFR of the second US06 cycle is within  $\pm$ 2% if using standard S-factors, or within  $\pm$ 3% for PHEVs using S-factors derived from FCT and CST data. If the applicable NECFR is outside of this specification, basic SOC corrections along with more test data are required to correct the result for changes in NEC (see [Appendix C](#)).
- j. Post-Test Recharging—No post-test recharging is required for this test.

## 5.1.7 SC03 CST Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.835 shall be referenced for any procedural requirement not specifically detailed in this document, where appropriate.

- a. **Vehicle Preconditioning**—The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle run unless (1) the vehicle underwent a cycle in CS mode (over any driving schedule) within the last 72 hours in the same driver-selected operating mode as to be tested in the SC03 CST Procedure, and (2) the vehicle has since remained under ambient laboratory conditions. No other vehicle preconditioning is necessary for the SC03 CST Procedure.
- b. **Moving the Vehicle into Position**—The drive wheels of the vehicle shall be placed on the dynamometer, and the vehicle shall be restrained.
- c. **Test Site Conditions**—The entire test shall be conducted in accordance with the test conditions specified in 40 CFR Part 1066.835 (35 °C ± 3 °C [95 °F ± 1.8 °F] air temperature, 100 grains of water/pound of dry air, a solar heat load intensity of 850 W/m<sup>2</sup>, and a vehicle cooling air flow proportional to vehicle speed). All vehicle windows shall be closed, and the vehicle air-conditioning system shall operate as specified in 40 CFR Part 1066.835.
- d. **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 1066.415 shall apply for starting and restarting, but with the words "propulsion system" generically substituted for the word "engine."
- e. **Dynamometer Driving Procedure**—As soon as the vehicle propulsion system has started, the vehicle shall be driven over two SC03s.
- f. **Intra-Test Pause**—Between the two SC03s, the vehicle shall soak for 10 minutes ± 1 minute 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.
- g. **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.
- h. **Test Termination**—This test shall terminate at the completion of both SC03s.
- i. **Test Validation**—This test is acceptable if the NECFR of the second SC03 cycle is within ±2% if using standard S-factors, or within ±3% for PHEVs using S-factors derived from FCT and CST data. If the applicable NECFR is outside of this specification, basic SOC corrections along with more test data are required to correct the result for changes in NEC (see [Appendix C](#)).
- j. **Post-Test Recharging**—No post-test recharging is required for this test.

### 5.1.8 Cold FTP CST Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.710 shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate. Unlike the 20 to 30 °C double-UDDS CST (with two or four bags; see 5.1.4), this test is run as a three-bag FTP test.

- 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 1065.710. The preconditioning is subject to the requirements of 40 CFR Part 1066.710, which includes fuel tank drain-and-fill and driving over the UDDS, starting at a temperature of  $-7\text{ °C} \pm 1.7\text{ °C}$  ( $20\text{ °F} \pm 3\text{ °F}$ ). The ambient temperature shall average  $-7\text{ °C} \pm 2.8\text{ °C}$  ( $20\text{ °F} \pm 5\text{ °F}$ ) and shall not be less than  $-12\text{ °C}$  ( $10.4\text{ °F}$ ) or more than  $-1\text{ °C}$  ( $30\text{ °F}$ ) during the preconditioning. Humidity should be set low enough to prevent condensation on the dynamometer rolls. A 12- to 36-hour vehicle soak follows the preconditioning at the same ambient conditions mentioned above.
- b. **Moving the Vehicle into Position**—After the 12- to 36-hour soak 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 mile) between the end of the soak period and the start of the test.
- c. **Test Site Conditions**—The ambient temperature levels encountered at the start of the test shall be at  $-7\text{ °C} \pm 1.7\text{ °C}$  ( $20\text{ °F} \pm 3\text{ °F}$ ). The average temperature during the test must be  $-7\text{ °C} \pm 2.8\text{ °C}$  ( $20\text{ °F} \pm 5\text{ °F}$ ). The maximum excursions must be between  $-12\text{ °C}$  ( $10.4\text{ °F}$ ) minimum and  $-1\text{ °C}$  ( $30\text{ °F}$ ) maximum. Maximum excursions lasting up to 3 minutes must not exceed  $-9.4\text{ °C}$  ( $15\text{ °F}$ ) minimum and  $-4\text{ °C}$  ( $25\text{ °F}$ ) maximum as specified in 40 CFR Part 1066.710. During dynamometer driving, a fixed-speed cooling fan or a road-speed-modulated fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105.
- d. **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 minutes 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 seconds 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 third bag following the 10-minute soak period. For automatic climate control systems, test personnel can manually override the system and use the provisions specified for manual systems, or the system selector should be set to automatic (fan speed and vent selection) with temperature set to  $22\text{ °C}$  ( $72\text{ °F}$ ) 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 further information on this topic, please refer to 40 CFR Part 1066.710.
- 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 1066.415 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 a three-phase FTP test. This consists of a cold UDDS (Phase 1 and Phase 2), engine shutdown for a 10-minute soak, then propulsion system startup and operation over 505 seconds (hot start or Phase 3).
- g. **Intra-Test Pause**—Between Bag 2 and Bag 3, the vehicle shall soak for 10 minutes  $\pm$  1 minute 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.
- h. **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.

- i. Test Termination—This test shall terminate at the completion of the three phases of the FTP.
- j. Test Validation—This test is acceptable if the NECFR of the entire cold FTP is within  $\pm 2\%$  if using standard S-factors, or within  $\pm 3\%$  for PHEVs using S-factors derived from FCT and CST data. If the applicable NECFR is outside of this specification, or confidence in the standard S-factors for the test vehicle running the cold FTP is lacking, NEC corrections with more test data may be required to correct results for changes in NEC (see [Appendix C](#)).
- k. Post-Test Recharging—No post-test recharging is required for this test.

## 5.2 Full Charge Test (FCT) Procedures for CD Operating Modes (PHEVs Only)

This test is designed to be conducted using one driving schedule repeated in succession until the off-board usable energy has been depleted. Test conditions are provided in section [5.2.4](#) to [5.2.8](#) for conducting this test with the UDDS, HFEDS, US06, SC03, and Cold FTP (-7 °C) schedules. However, with the appropriate test conditions, the FCT may be applied with any desired driving schedule.

### 5.2.1 Purpose of Test

The purpose of the FCT is to measure the exhaust emissions, fuel economy, and electric energy consumption over a series of driving schedules in CD mode after the vehicle RESS has been fully charged, and to provide the data to calculate the vehicle's expected driving range metrics in CD mode.

### 5.2.2 Applicability

The FCT only applies to PHEVs in CD operating modes.

### 5.2.3 Test Product

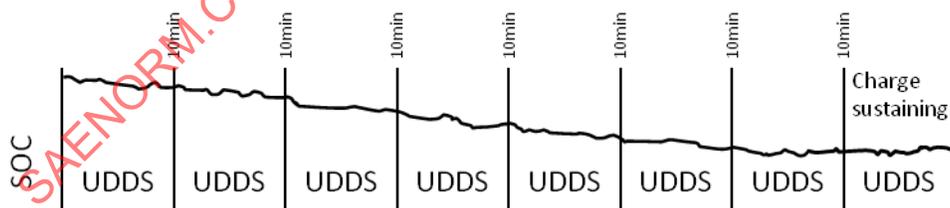
The following information is the product of an FCT:

- a. Exhaust Emissions and Fuel Consumption—The exhaust emissions and fuel consumption of the PHEV shall be measured during each test cycle completed in the FCT.
- b. Actual Distance Traveled—The actual driving distance that the dynamometer roll surface traveled shall be measured during each test cycle completed in the FCT.
- c.  $V_{\text{CYCLE}}$ —The mean value of measured RESS voltages for each test cycle completed in the FCT (see [3.3.5](#)). Care must be taken to eliminate voltage samples that momentarily occur when the main contactors are open and voltage readings are zero. If voltage is not measured directly, RESS voltage must be logged (and time-aligned with other logged measurements) from the vehicle communication network. For best results it is recommended to log voltage at a rate of at least 10Hz for accurate  $V_{\text{CYCLE}}$  results.
- d. A·h—The integrated current (in units of ampere-hours) shall be calculated and recorded for each test cycle completed in the FCT using the instrumentation described in [4.4](#) for each test cycle.
- e. NEC—The NEC (see [3.3.6](#)) shall be calculated and recorded for each test cycle completed in the FCT using the results from  $V_{\text{CYCLE}}$  and A·h measurements.
- f. AC Recharge Energy—After an FCT is completed, the AC recharge energy shall be measured while the RESS is being recharged. AC Wh energy ( $E_{ac\text{total}}$ ) is measured upstream of the EVSE using the equipment described in [4.4](#).

#### 5.2.4 UDDS FCT Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.815 shall be referenced for procedural requirements not specifically detailed in this document, where appropriate. This procedure can also be adapted for ambient temperatures of 10 °C (50 °F), as described in the State of California Air Resources Board “California Exhaust Emission Standards and Test Procedures for 2018 and Subsequent Model Zero-Emission Vehicles and Hybrid Electric Vehicles, in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes.”

- 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 86.132-96, which includes fuel tank drain-and-fill, driving over the UDDS, and a 12- to 36-hour vehicle soak.
- b. **RESS Charging/Vehicle Soak**—After preconditioning and while the vehicle is soaking (20 to 30 °C, as specified in 40 CFR Part 86.132-96), the RESS shall be brought to full charge, subject to the charging requirements of 4.2.2. The vehicle shall remain on charge for a minimum of 12 hours, or until the vehicle completes the charging event.
- c. **Moving the Vehicle into Position**—After the 12- to 36-hour soak and with the RESS fully recharged, 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 mile) 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, as described in 40 CFR Part 1066.801. A fixed-speed cooling fan or a road-speed-modulated fan may be used to direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105.
- 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 1066.415 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 UDDS cycles until the EOT criterion is met (see 3.5). The tailpipe emissions for each UDDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final A·h readings and  $V_{CYCLE}$  for each cycle shall be recorded. Figure 3 shows an example of UDDS FCT.

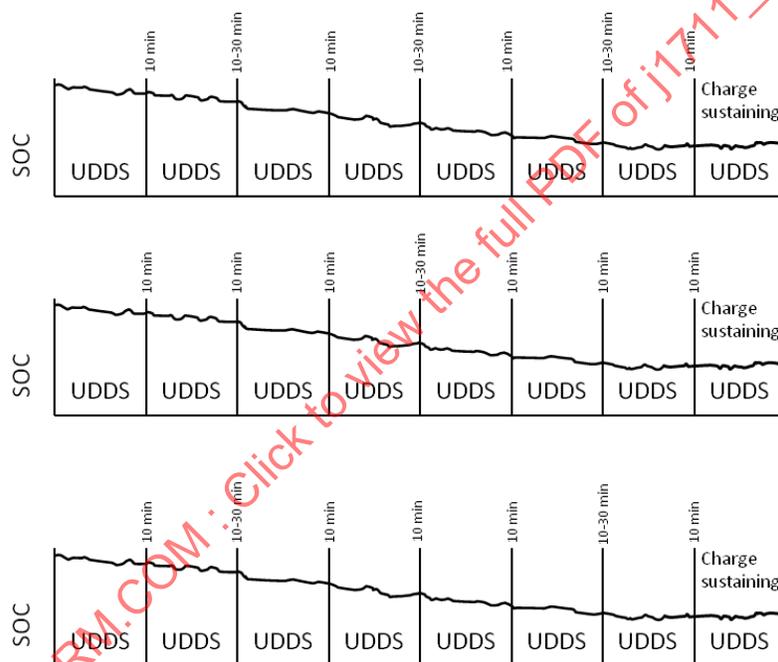


**Figure 3 - Recommended UDDS test layout for CD FCT**

- g. Intra-Test Pauses—Between the UDDS cycles, the vehicle should soak for 10 minutes  $\pm$  1 minute 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 minutes  $\pm$  1 minute. 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 minutes shall be allowed during intra-test pauses. Good engineering judgment should be applied in arranging these test pauses to cause the least disruption in the test procedure. It is strongly preferred that the majority of soak periods remain as close to the 10-minute 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-minute soak recommendation. This may require rewriting of software, and possibly reconfiguring of hardware, to accommodate running UDDS cycles continuously until the EOT Criterion (see [3.5](#)) is met. Several examples illustrating approaches meeting the requirements are shown in [Figure 4](#).



**Figure 4 - 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.
- i. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in EOT criterion (see [3.5](#)).
- 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 hours of the end of the test, the RESS shall be brought to full charge, subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge, and recharge energy measured, for minimum of 12 hours or until the vehicle completes the charging event, whichever is longest in duration. The total AC Wh shall be recorded ( $E_{ac_{total}}$ ) after the charging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), the charger should remain connected to the grid accordingly. All AC Wh of energy must be counted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 hours of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 hours, and test personnel must ensure the 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 for a subsequent FCT (except for tests requiring soak conditions at other than 20 to 30 °C).

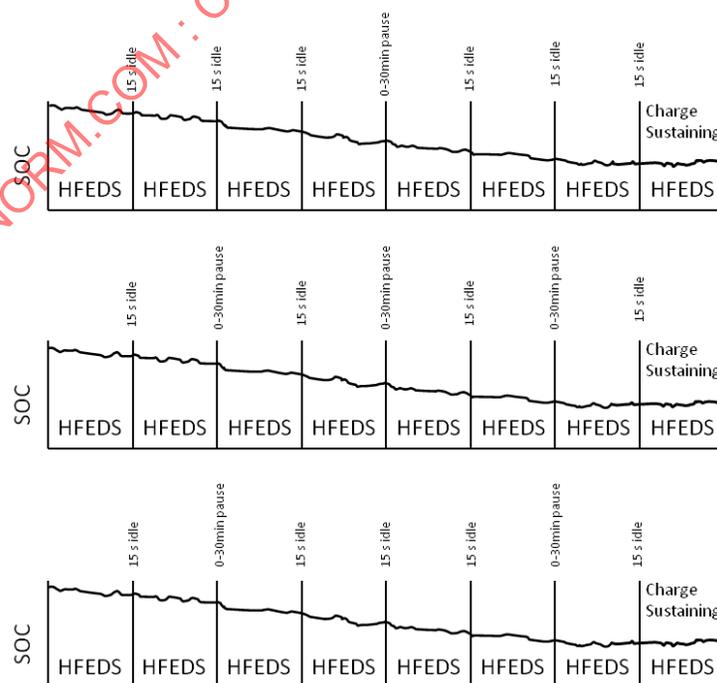
#### 5.2.5 HFEDS FCT Procedure

This test is to be conducted subject to the test conditions described in Section [4](#), the test instrumentation requirements of [4.4](#), and the requirements listed below. The requirements of 40 CFR Part 1066.840 shall be referenced for any procedural requirement not specifically detailed in this document, where appropriate.

- a. Vehicle Preconditioning—The preconditioning is subject to the requirements of 40 CFR Part 86.132-96. The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle run unless (1) the vehicle underwent a previous CST (in any driving schedule) within the last 72 hours 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 hours 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 86.132-96), the RESS shall be brought to full charge, subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge for a minimum of 12 hours, or until the vehicle completes the charging event.
- c. Moving the Vehicle into Position—After the 12- to 36-hour 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 mile) 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 1066.105.
- 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 1066.415 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 until the EOT criterion (see [3.5](#)) is met. The tailpipe emissions for each HFEDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final A-h readings and  $V_{CYCLE}$  for each cycle shall be recorded.

- g. Intra-Test Pauses—The vehicle should be driven over as many HFEDS cycles in CD mode, separated by a 15-second 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 minutes in length. It is strongly preferred that intra-test pauses be key-on 15-second idle periods as often as possible. For example, four HFEDSs can be run in a row, separated by 0- to 30-minute 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-minute range for the soak period is chosen based on the capability of the labs to read, evacuate, and purge the sampled bags and to initialize a new test. Good engineering judgment will be applied in arranging these test pauses to cause 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 5](#).
- h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during each of the HFEDSs.
- i. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in EOT criterion (see [3.5](#)).
- 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 hours of the end of the test, the RESS shall be brought to full charge, subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge, and recharge energy measured, for minimum of 12 hours or until the vehicle completes the charging event, whichever is longest in duration. The total AC Wh shall be recorded ( $E_{aCtotal}$ ) after the recharging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), the charger should remain connected to the grid accordingly. All AC Wh of energy must be counted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 hours of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 hours, and test personnel must ensure the 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 for a subsequent FCT (except for tests requiring soak conditions at other than 20 to 30 °C).

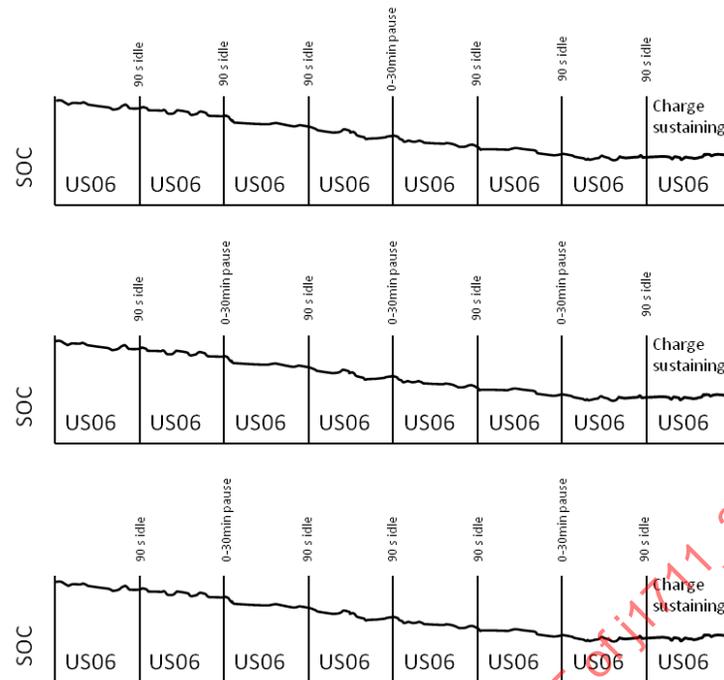


**Figure 5 - Examples of HFEDS test options using variations of intra-test pauses**

## 5.2.6 US06 FCT Procedure

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.831 shall be referenced for any procedural requirement not specifically detailed in this document, where appropriate. This test is typically run for zero-emissions vehicle (ZEV) credits (refer to California Code Regulations, Title 13, § 1962.2).

- a. **Vehicle Preconditioning**—The preconditioning is subject to the requirements of 40 CFR Part 1066.831. The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle run unless (1) the vehicle underwent a previous CST (in any driving schedule) within the last 72 hours 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 hours 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 86.132-96), the RESS shall be brought to full charge, subject to the charging requirements of 4.2.2. The vehicle shall remain on charge for a minimum of 12 hours, or until the vehicle completes the charging event.
- c. **Moving the Vehicle into Position**—After the 12- to 36-hour soak and with the RESS fully recharged, 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 mile) 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 or a road-speed-modulated fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105. 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 1066.415 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 until the EOT criterion (see 3.5) is met. The tailpipe emissions for each US06 cycle shall be filled in one CVS or BMD emission sample bag. Initial and final A-h readings and  $V_{\text{CYCLE}}$  for each cycle shall be recorded.
- g. **Intra-Test Pauses**—The vehicle should be driven over as many US06 cycles in CD mode, separated by a 1- to 2-minute (90 seconds) key-on idle rest (without pauses), as the facility capabilities allow. If test pauses are required to stop testing and reinitialize the test system, these pauses shall be less than 30 minutes in length. It is strongly preferred that intra-test pauses be key-on 90-second idle periods as much as possible. For example, four US06 cycles can be run in a row, separated by 0- to 30-minute 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-minute 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 shall 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, key switch in the “off” position, hood closed, test cell fan(s) off, brake pedal not depressed, and RESS not recharged from an external energy source. Several examples illustrating approaches that meet the requirements are shown in [Figure 6](#).



**Figure 6 - Examples of US06 test options using variations of 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 US06 cycles.
- i. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in EOT criterion (see [3.5](#)).
- 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 hours of the end of the test, the RESS shall be brought to full charge, subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge, and recharge energy measured, for minimum of 12 hours or until the vehicle completes the charging event, whichever is longest in duration. The total AC Wh shall be recorded ( $E_{aCtotal}$ ) after the recharging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), the charger should remain connected to the grid accordingly. All AC Wh of energy must be counted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 hours of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 hours, and test personnel must ensure the 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 for a subsequent FCT (except for tests requiring soak conditions at other than 20 to 30 °C).

### 5.2.7 SC03 FCT Procedure

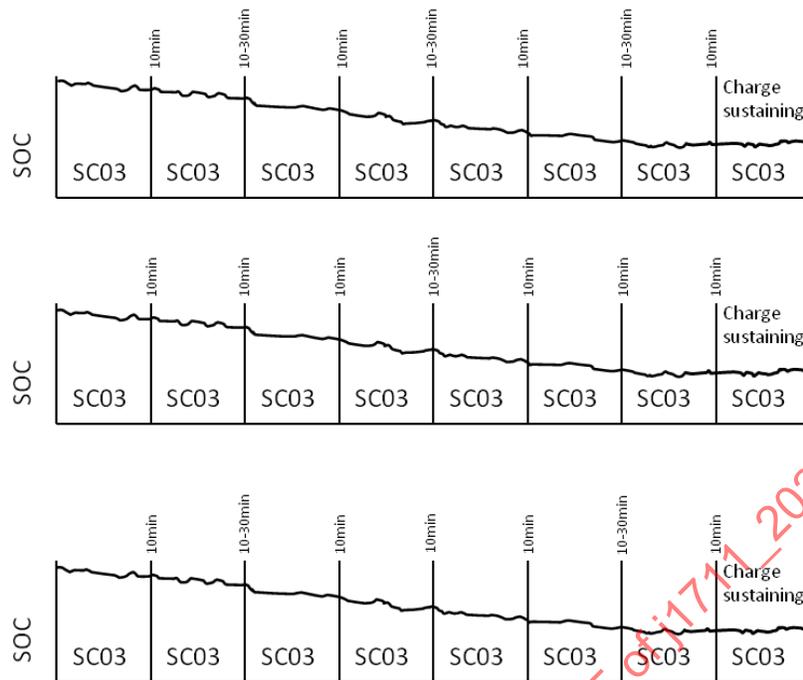
NOTE: This test isn't commonly performed, but it is included for completeness.

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.835 shall be referenced for any procedural requirement not specifically detailed in this document, where appropriate.

- a. **Vehicle Preconditioning**—The consumable fuel shall be drained, the tank refilled, and a preconditioning cycle run unless (1) the vehicle underwent a previous CST (over any driving schedule) within the last 72 hours 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 hours 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 (35 °C), the RESS shall be brought to full charge, subject to the charging requirements of 4.2.2. The vehicle shall remain on charge for a minimum of 12 hours, or until the vehicle completes the charging event.
- c. **Moving the Vehicle into Position**—After the 12- to 36-hour soak, and with the RESS fully recharged, 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 mile) 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 conditions for at least 30 minutes prior to the start of the FCT.
- d. **Test Site Conditions**—The entire test is to be conducted a full environmental chamber (as specified in 40 CFR Part 1066.835). The following ambient test conditions shall be provided: 35 °C (95 °F) air temperature, 100 g of water/pound of dry air, a solar heat load intensity of 850 W/m<sup>2</sup>, and vehicle cooling air flow proportional to vehicle speed. All vehicle windows shall be closed and the vehicle air-conditioning system shall operate as specified in 40 CFR Part 1066.835.
- 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 1066.415 shall apply for starting and restarting, but with the words “propulsion system” generically substituted for the word “engine.”
- f. **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 until the EOT criterion (see 3.5) 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-minutes ± 1-minute key-off soak periods (Figure 7). Initial and final A·h readings and V<sub>CYCLE</sub> for each cycle shall be recorded.
- g. **Intra-Test Pauses**—Between the SC03 cycles, the vehicle should soak for 10 minutes ± 1 minute 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 minutes ± 1 minute. 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 minutes shall be allowed during intra-test pauses. Good engineering judgment will be applied in arranging these test pauses to cause the least disruption in the test procedure. It is strongly preferred that most soak periods remain as close to the 10-minutes 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 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-minutes ± 1-minute soak periods. Several examples illustrating approaches that meet the requirements are shown in Figure 7.



**Figure 7 - Examples of SC03 FCT options using variations of intra-test pauses**

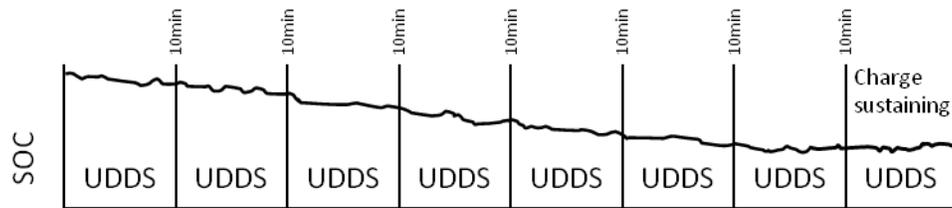
- h. Measurements and Emissions Sampling—Exhaust emissions and the actual distance traveled by the dynamometer roll surface shall be measured during all SC03 cycles.
- i. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in the EOT criterion (see [3.5](#)).
- 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 hours 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 Part 86.130-96), and brought to full charge subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge, and recharge energy measured, for minimum of 12 hours or until the vehicle completes the charging event, whichever is longest in duration. The total AC Wh shall be recorded ( $E_{ac\ total}$ ) after the recharging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), the charger should remain connected to the grid accordingly. All AC Wh of energy must be counted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 hours of the charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 hours, and test personnel must ensure the other conditions of the soak period are not compromised.

## 5.2.8 Cold UDDS (-7 °C) FCT Procedure

NOTE: This test isn't commonly performed, but it is included for completeness.

This test is to be conducted subject to the test conditions described in Section 4, the test instrumentation requirements of 4.4, and the requirements listed below. The requirements of 40 CFR Part 1066.710 shall be referenced for any procedural requirements not specifically detailed in this document, where appropriate.

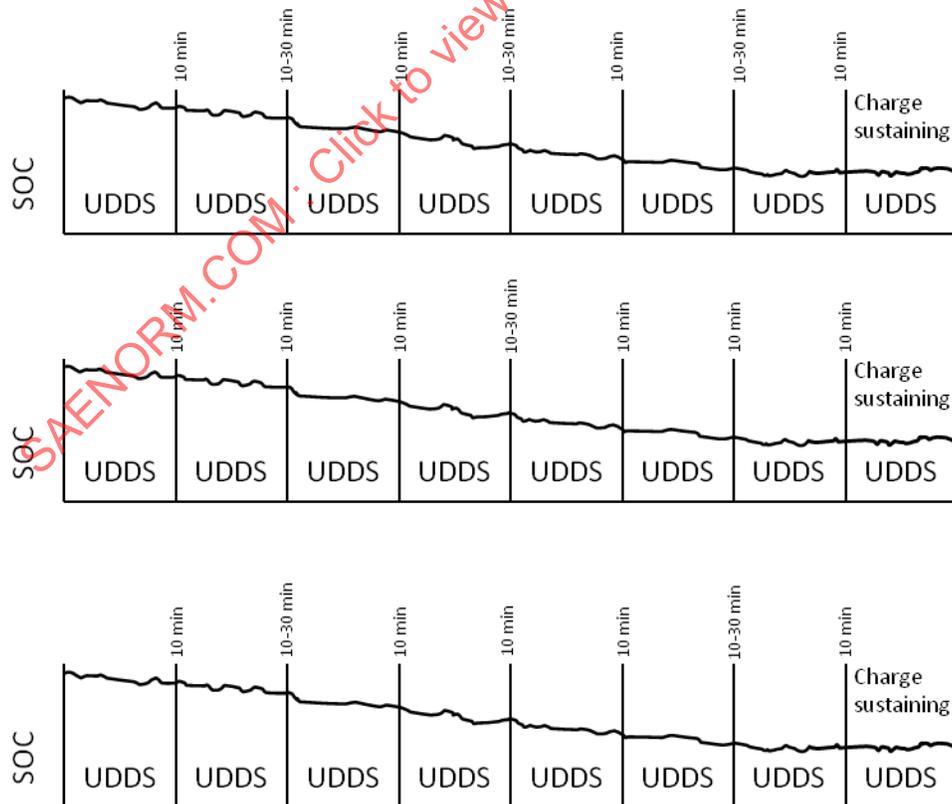
- a. **Vehicle Preconditioning**—The vehicle shall be preconditioned in the driver-selected operating mode in which it will be tested. The fuel specifications are subject to the requirements of 40 CFR Part 1065.710. The preconditioning is subject to the requirements of 40 CFR Part 1066.710, which includes fuel tank drain-and-fill and driving over the UDDS, starting at a temperature of  $-7\text{ °C} \pm 1.7\text{ °C}$  ( $20\text{ °F} \pm 3\text{ °F}$ ). The ambient temperature shall average  $-7\text{ °C} \pm 2.8\text{ °C}$  ( $20\text{ °F} \pm 5\text{ °F}$ ), and it shall not be less than  $-12\text{ °C}$  ( $10.4\text{ °F}$ ) nor more than  $-1\text{ °C}$  ( $30\text{ °F}$ ) during the preconditioning. Humidity should be set low enough to prevent condensation on the dynamometer rolls. A 12- to 36-hour 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  $-7\text{ °C} \pm 1.7\text{ °C}$  ( $20\text{ °F} \pm 3\text{ °F}$ ), the RESS shall be brought to full charge, subject to the recharging requirements of 4.2.2. The vehicle shall remain on charge for a minimum of 12 hours, or until the vehicle completes the charging event.
- c. **Moving the Vehicle into Position**—After the 12- to 36-hour 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 mile) 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  $-7\text{ °C} \pm 1.7\text{ °C}$  ( $20\text{ °F} \pm 3\text{ °F}$ ). The average temperature during the test must be  $-7\text{ °C} \pm 2.8\text{ °C}$  ( $20\text{ °F} \pm 5\text{ °F}$ ). The maximum excursions must be between  $-12\text{ °C}$  ( $10.4\text{ °F}$ ) minimum and  $-1\text{ °C}$  ( $30\text{ °F}$ ) maximum. Maximum excursions lasting up to 3 minutes must not exceed  $-9.4\text{ °C}$  ( $15\text{ °F}$ ) minimum and  $-4\text{ °C}$  ( $25\text{ °F}$ ) maximum as specified in 40 CFR Part 1066.710. During dynamometer driving, a fixed-speed cooling fan shall direct cooling air to the vehicle, as specified in 40 CFR Part 1066.105.
- 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 minutes 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 seconds 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-minute soak period. For automatic climate control systems, test personnel can manually override the system and use the provisions specified for manual systems, or the system selector should be set to automatic (fan speed and vent selection) with temperature set to  $22\text{ °C}$  ( $72\text{ °F}$ ) 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 further information on this topic, please refer to 40 CFR Part 1066.710.
- 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 1066.415 shall apply for starting and restarting, but with the words “propulsion system” generically substituted for the word “engine.”
- 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 3.5). The tailpipe emissions for each UDDS cycle shall be filled in one CVS or BMD emission sample bag. Initial and final A·h readings and  $V_{\text{CYCLE}}$  for each cycle shall be recorded. Figure 8 shows an example of the cold ( $-7\text{ °C}$ ) UDDS FCT.



**Figure 8 - Recommended intra-test pauses for cold UDDS FCT**

- h. FCT Intra-Test Pauses—Between the UDDS cycles, the vehicle should soak for 10 minutes  $\pm$  1 minute 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.
- i. It is preferred that the pauses be consistently 10 minutes  $\pm$  1 minute. 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 minutes shall be allowed during intra-test pauses. Good engineering judgment will be applied in arranging these test pauses, to cause the least disruption in the test procedure. It is strongly preferred that most soak periods remain as close to the 10-minute 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 objective of deviating as little as possible from the 10-minute soak recommendation. This may require rewriting of software, and possibly reconfiguring of hardware, to accommodate running UDDS cycles continuously until the EOT criterion (see [3.5](#)) is met. Several examples illustrating approaches that meet the requirements are shown in [Figure 9](#).



**Figure 9 - Examples of backup test options using longer soak periods during some intra-test pauses**

- j. 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 (Bags 1 and 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 minutes ± 1 minute.
- k. Test Termination—This test shall terminate when the vehicle reaches CS operation achieved according to the definitions in EOT criterion (see [3.5](#)).
- 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 hours of the end of the test, the RESS shall be taken back to the cold soak area (-7 °C ± 1.7 °C [20 °F ± 3 °F]) and brought to full charge, subject to the charging requirements of [4.2.2](#). The vehicle shall remain on charge, and recharge energy measured, for minimum of 12 hours or until the vehicle completes the charging event, whichever is longest in duration. The total AC Wh shall be recorded ( $E_{aCtotal}$ ) after the recharging sequence is complete. If instructions from the manufacturer recommend leaving the charger on throughout the entire soak period (or portion thereof), the charger should remain connected to the grid accordingly. All AC Wh of energy must be counted as energy consumed. It is discouraged, but allowable, to have interruptions during the first 12 hours of charge period due to uncontrolled circumstances. The total time on charge shall be at least 12 hours, and test personnel must ensure that the 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 for a subsequent FCT at cold temperature only.

## 6. CALCULATIONS FOR CHARGE-SUSTAINING TEST PROCEDURES

Both CS HEVs and PHEVs undergo CSTs. A series of calculations are necessary to determine the emissions and fuel economy from CSTs for the UDDS, HFEDS, US06, SC03, and -7 °C FTP test.

There are no recommended corrections for criteria emissions (exhaust emissions other than CO<sub>2</sub>) due to changes in RESS state (NEC). NEC corrections for CO<sub>2</sub> emissions are detailed in [6.2](#).

### 6.1 CST Exhaust Emissions Calculations

This section prescribes the calculations for criteria emissions species (unburned hydrocarbons, oxides of nitrogen, and carbon monoxide, among others) in CSTs. Corrections for changes in NEC are not recommended for criteria emissions species.

#### 6.1.1 UDDS CST Exhaust Emissions Calculations

The UDDS CST exhaust emissions data shall be calculated using a combination of the results from the first (cold-start) and second (hot-start) UDDS cycles, weighted differently, as shown in Equation 5:

$$e = 0.43 \times \frac{m_{UDDS(1)}}{D_{UDDS(1)}} + 0.57 \times \frac{m_{UDDS(2)}}{D_{UDDS(2)}} \quad (\text{Eq. 5})$$

where:

$e$  = UDDS CST weighted emissions of a particular measured gas (e.g., HC, CO, NO<sub>x</sub>, PM), in grams per mile

$m_{UDDS(1)}$  = mass emissions measured during the first UDDS, in grams

$D_{UDDS(1)}$  = measured driving distance during the first UDDS, in miles

$m_{UDDS(2)}$  = mass emissions measured during the second UDDS, in grams

$D_{UDDS(2)}$  = measured driving distance during the second UDDS, in miles

Contents in 40 CFR Part 1066.605 shall be used in conjunction with Equation 5 in measuring each gas, where appropriate.

### 6.1.2 HFEDS CST Exhaust Emissions Calculations

The HFEDS CST exhaust emissions data shall be calculated using data from the second HFEDS, and not from the first HFEDS, as shown in Equation 6:

$$e = 0.0 \times \frac{m_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0 \times \frac{m_{HFEDS(2)}}{D_{HFEDS(2)}} \quad (\text{Eq. 6})$$

where:

$e$  = HFEDS CST weighted emissions of a particular measured gas (e.g., HC, CO, NO<sub>x</sub>, PM), in grams per mile

$m_{HFEDS(1)}$  = mass emissions during the first HFEDS, in grams (measurement unnecessary)

$D_{HFEDS(1)}$  = driving distance during the first HFEDS, in miles (measurement unnecessary)

$m_{HFEDS(2)}$  = mass emissions as measured during the second HFEDS, in grams

$D_{HFEDS(2)}$  = measured driving distance during the second HFEDS, in miles

Contents in 40 CFR Part 1066.605 shall be used in conjunction with Equation 6 in measuring each gas, where appropriate

### 6.1.3 US06 CST Exhaust Emissions Calculations

The US06 CST exhaust emissions data shall be calculated using data from the second US06, and not from the first US06, as shown in Equation 7:

$$e = 0.0 \times \frac{m_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{m_{US06(2)}}{D_{US06(2)}} \quad (\text{Eq. 7})$$

where:

$e$  = US06 CST weighted emissions of a particular measured gas (e.g., HC, CO, NO<sub>x</sub>, PM), in grams per mile

$m_{US06(1)}$  = mass emissions during the first US06, in grams (measurement unnecessary)

$D_{US06(1)}$  = driving distance during the first US06, in miles (measurement unnecessary)

$m_{US06(2)}$  = mass emissions as measured during the second US06, in grams

$D_{US06(2)}$  = driving distance during the second US06, in miles

Refer to 40 CFR Part 1066.831(c) to determine emissions over separate city and highway test intervals of the US06. Contents in 40 CFR Part 1066.605 shall be used in conjunction with Equation 7 in measuring each gas, where appropriate.

#### 6.1.4 SC03 CST Exhaust Emissions Calculations

The SC03 CST exhaust emissions data shall be calculated using data from the second SC03, and not from the first SC03, as shown in Equation 8:

$$e = 0.0 \times \frac{m_{SC03(1)}}{D_{SC03(1)}} + 1.0 \times \frac{m_{SC03(2)}}{D_{SC03(2)}} \quad (\text{Eq. 8})$$

where:

$e$  = SC03 CST weighted emissions of a measured gas (e.g., HC, CO, NO<sub>x</sub>, PM), in grams per mile

$m_{SC03(1)}$  = mass emissions during the first SC03, in grams (measurement unnecessary)

$D_{SC03(1)}$  = driving distance during the first SC03, in miles (measurement unnecessary)

$m_{SC03(2)}$  = mass emissions as measured during the second SC03, in grams

$D_{SC03(2)}$  = driving distance during the second SC03, in miles

Contents in 40 CFR Part 1066.605 shall be used in conjunction with Equation 8 in measuring each gas, where appropriate.

#### 6.1.5 Cold (-7 °C) FTP CST Exhaust Emissions Calculations

The cold FTP CST exhaust emissions data shall be weighted using the calculations described in Equation 9:

$$e = 0.43 \times \frac{m_{coldUDDS(Ph1)} + m_{coldUDDS(Ph2)}}{D_{coldUDDS(Ph1)} + D_{coldUDDS(Ph2)}} + 0.57 \times \frac{m_{coldUDDS(Ph3)} + m_{coldUDDS(Ph2)}}{D_{coldUDDS(Ph3)} + D_{coldUDDS(Ph2)}} \quad (\text{Eq. 9})$$

where:

$e$  = cold FTP CST weighted emissions of a measured gas (e.g., HC, CO, NO<sub>x</sub>, PM), in grams per mile

$m_{coldUDDS(Ph1)}$  = mass emissions during the first phase (505 seconds) of the cold UDDS, in grams

$D_{coldUDDS(Ph1)}$  = driving distance during the first phase (505 seconds) of the cold UDDS, in miles

$m_{coldUDDS(Ph2)}$  = mass emissions during the second phase (after 505 seconds) of the cold UDDS, in grams

$D_{coldUDDS(Ph2)}$  = driving distance during the second phase (after 505 seconds) of the cold UDDS, in miles

$m_{coldUDDS(Ph3)}$  = mass emissions during the third phase (505 seconds) of the cold UDDS, in grams

$D_{coldUDDS(Ph3)}$  = driving distance during the third phase (505 seconds) of the cold UDDS, in miles

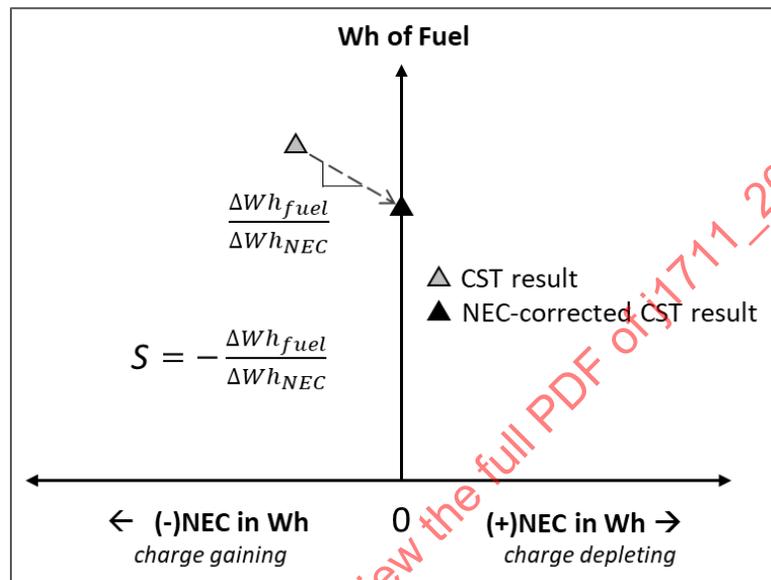
Contents in 40 CFR Part 1066.605 shall be used in conjunction with Equation 9 in measuring each gas, where appropriate.

#### 6.2 CST Fuel Consumption and CO<sub>2</sub> Emissions Calculations

This section includes correction methods for both fuel consumption and CO<sub>2</sub> emissions for each of the CST procedures listed in 5.1. Numbers shown parenthetically after the cycle name denote the cycle order, for example “UDDS(1)” and “UDDS(2)” refer respectively to the first and second UDDS cycles in the CST.

### 6.2.1 NEC Fuel Corrections for CST Results

It is recommended that all CST fuel consumption and CO<sub>2</sub> emissions results be corrected for changes in battery NEC. The S-factor correction concept is presented here to make the appropriate corrections to fuel consumption (see [Figure 10](#)). The S-factor is a dimensionless value of the ratio of fuel correction (in units of energy) per change in NEC (also in units of energy). The inverse (1/S) can be analyzed as a conversion efficiency value relating marginal adjustments in consumed fuel with changes in stored electrical energy in the RESS. CO<sub>2</sub> corrections are based on fuel corrections (with appropriate constants for CO<sub>2</sub> emissions assumed per unit fuel). Standard S-factor values are presented for CST results within the NECFR criteria between -0.02 and 0.02. However, for PHEVs, it is recommended the S-factor be calculated with test data (if available).



**Figure 10 - Plot illustrating fuel corrections using S-factor method**

#### 6.2.1.1 Conversion Constants Used in S-factor Calculations

The S-factor is a dimensionless value. To calculate the appropriate fuel and CO<sub>2</sub> corrections based on the NEC results of a given cycle, the S-factor implementation requires equivalent energy constants to be used in conjunction with the S-factor.

**Gallon Equivalent (GE)**—Gallon equivalent energy content of the fuel in units of watt-hour per gallon. The U.S. Environmental Protection Agency has established the GE for gasoline as 33705 Wh/gal (refer to 10 CFR Part 474) and for diesel as 37750 Wh/gal (refer to DOE/GO-102021-5498). These recommended constants are presented to reduce calculation complexity in conjunction with the S-factor approximation method, actual test fuel specifications can be used to calculate GE if desired.

**C**—Carbon dioxide (CO<sub>2</sub>) emissions from a gallon of burned fuel. This is the assumed amount of tailpipe (not upstream) CO<sub>2</sub> emissions from burning 1 gal of fuel. EPA has established the C value for gasoline as 8887 g/gal and for diesel as 10180 g/gal (refer to EPA-420-F-18-008). These recommended constants are presented to reduce calculation complexity in conjunction with the S-factor approximation method, actual test fuel specifications can be used to calculate new constants if desired.

### 6.2.1.2 Standard S-factors for CST Results

The following S-factors are recommended to correct CST fuel consumption results within the NECFR criteria ( $-0.02 < \text{NECFR} < 0.02$ ).

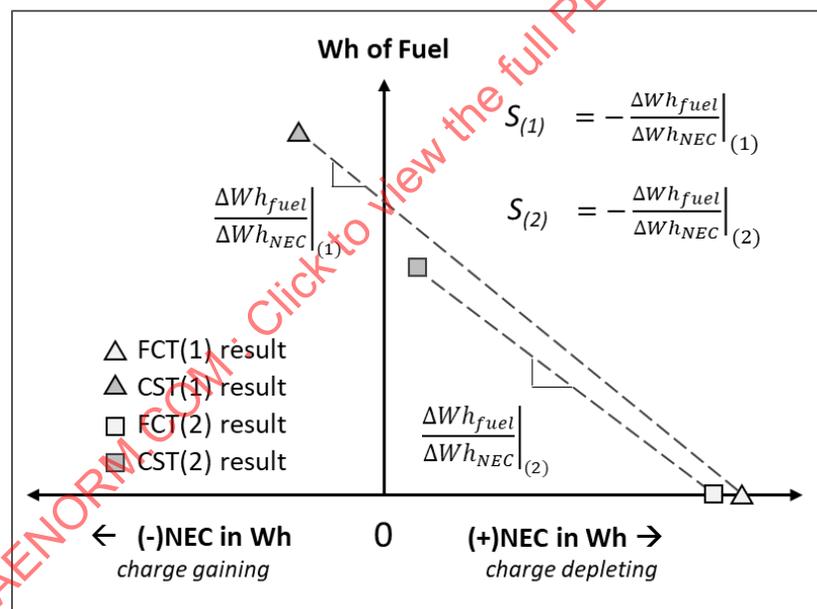
S = 3.1 for UDDS(1) and Cold FTP

S = 2.7 for UDDS(2), HWFET, SC03, and US06

UDDS(1) and UDDS(2) are the first and second UDDS cycles of the CST. The manufacturer may optionally provide additional test results to establish an S-factor exclusively for a given test cycle and vehicle (with a given vehicle configuration and calibration). See [Appendix C](#) for methods to correct CST results using additional test data.

### 6.2.1.3 Calculating S-factors for PHEVs

The S-factor of a particular PHEV can be calculated using FCT and uncorrected CST test results. Additional testing is not required and standard S-factors not necessary (unless FCT and CST test pairs are unavailable). FCT and CST test pairs are grouped to have the most similar state (thermal warm-up of powertrain, tires, bearings, etc.). To do this, the first FCT cycle is matched with the first CST cycle, and the second FCT cycle with the second CST cycle (see [Figure 11](#)). However, because the first CST cycle for HWFET, US06, and SC03 is the unused prep cycle, only the second FCT cycle is paired with the second CST cycle in these tests (see Equation 11). Corresponding fuel consumption and NEC results are entered into Equation 10 and/or Equation 11 to yield S-factor values. Note that the slope in the graph yields a negative number but the S-factor is a positive number, thus Equation 10 and 11 correct for this with a negative sign. The resulting S-factors are then used in the calculations of [6.2.2](#) to [6.2.6](#) (instead of the standard S-factors from [6.2.1.2](#)).



**Figure 11 - Determining PHEV S-factor from FCT and CST results**

$$S_{(1)} = - \frac{\Delta Wh_{fuel}}{\Delta Wh_{NEC}} \Big|_{(1)} = - \frac{(F_{CST(1)} - F_{FCT(1)}) \times GE}{NEC_{CST(1)} - NEC_{FCT(1)}} \quad (\text{Eq. 10})$$

$$S_{(2)} = - \frac{\Delta Wh_{fuel}}{\Delta Wh_{NEC}} \Big|_{(2)} = - \frac{(F_{CST(2)} - F_{FCT(2)}) \times GE}{NEC_{CST(2)} - NEC_{FCT(2)}} \quad (\text{Eq. 11})$$

where:

$S_{(1)}$  = calculated S-factor for first test cycle (for some cycle types this is the prep cycle), dimensionless

$\Delta Wh_{fuel}$  = difference in fuel consumed between CST and FCT converted to units of watt-hours

$\Delta Wh_{NEC}$  = difference in NEC between CST and FCT, in watt-hours

$F_{CST(1)}$  = fuel consumed in first test cycle of the CST (for some cycle types this is the prep cycle), in gallons

$F_{FCT(1)}$  = fuel consumed in first test cycle of the FCT, in gallons

$NEC_{CST(1)}$  = NEC in the first CST, in watt-hours

$NEC_{FCT(1)}$  = NEC in the first FCT, in watt-hours

GE = gallon equivalent fuel energy, in watt-hours per gallon (see [6.2.1.1](#))

$S_{(2)}$  = calculated second cycle S-factor, dimensionless

$F_{CST(2)}$  = fuel consumed in second test cycle in the CST, in gallons

$F_{FCT(2)}$  = fuel consumed in second test cycle in the FCT, in gallons

$NEC_{CST(2)}$  = NEC in the second CST, in watt-hours

$NEC_{FCT(2)}$  = NEC in the second FCT, in watt-hours

## 6.2.2 UDDS CST Fuel Consumption and CO<sub>2</sub> Calculations

Calculate the fuel consumed and CO<sub>2</sub> emissions in each test cycle of the UDDS CST by using the mass emissions results calculations specified in 40 CFR Part 600.113. Note that fuel consumption calculations below are in gallons per mile but CFR calculations are in miles per gallon. The calculations in Equations 12 to 17 show how to weight these results due to corrections in NEC and for relative UDDS(1) and UDDS(2) weighting.

$$F_{NEC(1)} = S_{(1)} \times NEC_{UDDS(1)} / GE \quad (\text{Eq. 12})$$

$$F_{NEC(2)} = S_{(2)} \times NEC_{UDDS(2)} / GE \quad (\text{Eq. 13})$$

$$FC = 0.43 \times \frac{F_{UDDS(1)} + F_{NEC(1)}}{D_{UDDS(1)}} + 0.57 \times \frac{F_{UDDS(2)} + F_{NEC(2)}}{D_{UDDS(2)}} \quad (\text{Eq. 14})$$

$$CO2_{NEC(1)} = F_{NEC(1)} \times C \quad (\text{Eq. 15})$$

$$CO2_{NEC(2)} = F_{NEC(2)} \times C \quad (\text{Eq. 16})$$

$$CO2/mi = 0.43 \times \frac{CO2_{UDDS(1)} + CO2_{NEC(1)}}{D_{UDDS(1)}} + 0.57 \times \frac{CO2_{UDDS(2)} + CO2_{NEC(2)}}{D_{UDDS(2)}} \quad (\text{Eq. 17})$$

where:

$F_{NEC(1),(2)}$  = calculated fuel correction due to the NEC of UDDS(1), and UDDS(2), respectively, in gallons

$S_{(1),(2)}$  = S-factor for first and second UDDS cycles [UDDS(1) and UDDS(2)], respectively, dimensionless

$NEC_{UDDS(1),(2)}$  = NEC for first and second UDDS cycles, respectively, in watt-hours

GE = gallon equivalent fuel energy, in watt-hours per gallon (see [6.2.1.1](#))

$F_{UDDS(1),(2)}$  = fuel consumed during first and second UDDS cycles, respectively, in gallons

$D_{UDDS(1),(2)}$  = measured driving distance for first and second UDDS cycles, respectively, in miles

FC = calculated fuel consumption result for the UDDS CST, in gallons per mile

$CO2_{NEC(1),(2)}$  = CO<sub>2</sub> emissions correction due to the NEC for first and second UDDS cycles, respectively, in grams

C = CO<sub>2</sub> emissions from a gallon of fuel, in grams per gallon (see [6.2.1.1](#))

$CO2_{UDDS(1),(2)}$  = CO<sub>2</sub> emissions during the first and second UDDS cycles, respectively, in grams

CO<sub>2</sub>/mi = calculated CO<sub>2</sub> emission result for the UDDS CST, in grams per mile

### 6.2.3 HFEDS CST Calculations for Fuel Consumption and CO<sub>2</sub> Emissions

Calculate the fuel consumed and CO<sub>2</sub> emissions in each test cycle of the HFEDS CST by using the mass emissions results calculations specified in 40 CFR Part 600.113. Note that fuel consumption calculations below are in gallons per mile but CFR calculations are in miles per gallon. The calculations in Equations 18 to 21 show how to weight these results and provide corrections for NEC.

$$F_{NEC(2)} = S_{(2)} \times NEC_{HFEDS(2)} / GE \quad (\text{Eq. 18})$$

$$FC = 0.0 \times \frac{F_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0 \times \frac{F_{HFEDS(2)} + F_{NEC(2)}}{D_{HFEDS(2)}} \quad (\text{Eq. 19})$$

$$CO2_{NEC(2)} = F_{NEC(2)} \times C \quad (\text{Eq. 20})$$

$$CO2/mi = 0.0 \times \frac{CO2_{HFEDS(1)}}{D_{HFEDS(1)}} + 1.0 \times \frac{CO2_{HFEDS(2)} + CO2_{NEC(2)}}{D_{HFEDS(2)}} \quad (\text{Eq. 21})$$

where:

$F_{NEC(2)}$  = calculated fuel correction due to the NEC of second HFEDS cycle, in gallons

$S_{(2)}$  = S-factor for second HFEDS cycle [HFEDS(2)], dimensionless

$NEC_{HFEDS(2)}$  = NEC for second HFEDS cycle, in watt-hours

GE = gallon equivalent fuel energy, in watt-hours per gallon (see [6.2.1.1](#))

FC = calculated fuel consumption results for the HFEDS CST, in gallons per mile

$F_{HFEDS(1),(2)}$  = fuel consumed during first and second HFEDS cycles, respectively, in gallons

$D_{HFEDS(1),(2)}$  = measured driving distance for first and second HFEDS cycles, respectively, in miles

$CO2_{NEC(2)}$  = CO<sub>2</sub> correction due to the NEC of second HFEDS cycle, in grams

$C$  = CO<sub>2</sub> emissions from a gallon of fuel, in grams per gallon (see 6.2.1.1)

$CO2_{HFEDS(1),(2)}$  = CO<sub>2</sub> emissions for first and second HFEDS cycles, respectively, in grams

$CO2/mi$  = calculated CO<sub>2</sub> emission result for the HFEDS CST, in grams per mile

#### 6.2.4 US06 CST Fuel Consumption and CO<sub>2</sub> Calculations

Calculate the fuel consumed and CO<sub>2</sub> emissions in each test cycle of the US06 CST by using the mass emissions results calculations specified in 40 CFR Part 600.113. Note that fuel consumption calculations below are in gallons per mile but CFR calculations are in miles per gallon. The calculations in Equations 22 to 25 show how to weight these results and provide corrections for NEC for the entire US06 cycle or the specific city and highway intervals per 40 CFR Part 1066.831(c).

$$F_{NEC(2)} = S_{(2)} \times NEC_{US06(2)} / GE$$

or

$$F_{NEC(2_{city})} = S_{(2_{city})} \times NEC_{US06(2_{city})} / GE ,$$

$$F_{NEC(2_{hwy})} = S_{(2_{hwy})} \times NEC_{US06(2_{hwy})} / GE \quad (\text{Eq. 22})$$

$$FC = 0.0 \times \frac{F_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{F_{US06(2)} + F_{NEC(2)}}{D_{US06(2)}}$$

or

$$FC_{city} = 0.0 \times \frac{F_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{F_{US06(2_{city})} + F_{NEC(2_{city})}}{D_{US06(2_{city})}} ,$$

$$FC_{hwy} = 0.0 \times \frac{F_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{F_{US06(2_{hwy})} + F_{NEC(2_{hwy})}}{D_{US06(2_{hwy})}} \quad (\text{Eq. 23})$$

$$CO2_{NEC(2)} = F_{NEC(2)} \times C$$

or

$$CO2_{NEC(2_{city})} = F_{NEC(2_{city})} \times C ,$$

$$CO2_{NEC(2_{hwy})} = F_{NEC(2_{hwy})} \times C \quad (\text{Eq. 24})$$

$$CO2/mi = 0.0 \times \frac{CO2_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{CO2_{US06(2)} + CO2_{NEC(2)}}{D_{US06(2)}}$$

or

$$CO2/mi|_{city} = 0.0 \times \frac{CO2_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{CO2_{US06(2_{city})} + CO2_{NEC(2_{city})}}{D_{US06(2_{city})}} ,$$

$$CO2/mi|_{hwy} = 0.0 \times \frac{CO2_{US06(1)}}{D_{US06(1)}} + 1.0 \times \frac{CO2_{US06(2_{hwy})} + CO2_{NEC(2_{hwy})}}{D_{US06(2_{hwy})}} \quad (\text{Eq. 25})$$

where:

city = the city interval within the US06 cycle as described in 40 CFR Part 1066.831(c)

hwy = the highway interval within the US06 cycle as described in 40 CFR Part 1066.831(c)

$F_{NEC(2)}$  = calculated fuel correction due to change in the NEC for the second US06 cycle, in gallons

$S_{(2)}$  = S-factor used to correct fuel for second US06 cycle [US06(2)], dimensionless

$NEC_{US06(2)}$  = NEC for second US06 cycle, in watt-hours

GE = gallon equivalent fuel energy, in watt-hours per gallon (see [6.2.1.1](#))

FC = calculated fuel consumption results for the US06 CST, in gallons per mile

$F_{US06(1),(2)}$  = fuel as measured during the first and second US06, respectively, in gallons

$D_{US06(1),(2)}$  = measured driving distance during the first and second US06, respectively, in miles

$CO2_{NEC(2)}$  = calculated CO<sub>2</sub> correction due to the NEC of second US06, in grams

C = CO<sub>2</sub> emissions from a gallon of fuel, in grams per gallon (see [6.2.1.1](#))

$CO2_{US06(1),(2)}$  = CO<sub>2</sub> emissions during the first and second US06, respectively, in grams

CO<sub>2</sub>/mi = calculated CO<sub>2</sub> emission result for the US06 CST, in grams per mile

#### 6.2.5 SC03 CST Fuel Consumption and CO<sub>2</sub> Calculations

Calculate the fuel consumed and CO<sub>2</sub> emissions in each test cycle of the SC03 CST by using the mass emissions results calculations specified in 40 CFR Part 600.113. Note that fuel consumption calculations below are in gallons per mile but CFR calculations are in miles per gallon. The calculations in Equations 26 to 29 show how to weight these results and provide corrections for NEC.

$$F_{NEC(2)} = S_{(2)} \times NEC_{SC03(2)} / GE \quad (\text{Eq. 26})$$

$$FC = 0.0 \times \frac{F_{SC03(1)}}{D_{SC03(1)}} + 1.0 \times \frac{F_{SC03(2)} + F_{NEC(2)}}{D_{SC03(2)}} \quad (\text{Eq. 27})$$

$$CO2_{NEC(2)} = F_{NEC(2)} \times C \quad (\text{Eq. 28})$$

$$CO2/mi = 0.0 \times \frac{CO2_{SC03(1)}}{D_{SC03(1)}} + 1.0 \times \frac{CO2_{SC03(2)} + CO2_{NEC(2)}}{D_{SC03(2)}} \quad (\text{Eq. 29})$$

where:

$F_{NEC(2)}$  = calculated fuel correction due to change in the NEC for the second SC03 cycle, in gallons

$S_{(2)}$  = S-factor used to correct fuel for second SC03 [SC03(2)], dimensionless

$NEC_{SC03(2)}$  = NEC for second SC03, in watt-hours

GE = gallon equivalent fuel energy, in watt-hours per gallon (see [6.2.1.1](#))

FC = calculated fuel consumption results for the SC03 CST, in gallons per mile