SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Battery Electric Vehicle Energy Consumption and Range Test Procedure

RATIONALE

Battery electric vehicle (BEV) technology has continued to progress since SAE J1634 was revised to include the multi-cycle test (MCT). BEV driving ranges and capabilities continue to increase along with the addition of many new BEV models in the marketplace, further taxing lab testing.

In order to reduce lab test burden, a short multi-cycle test (SMCT) is introduced to allow longer range BEVs to perform a fixed distance test in approximately 50% of the dynamometer time of an MCT test, while achieving comparable range and energy consumption results. This method utilizes an off-board discharge process to determine remaining energy in the battery pack.

A short multi-cycle test plus steady state (SMCT+) is also introduced to provide driver flexibility for longer range BEVs to perform testing for range, energy consumption, and five-cycle test data simultaneously without the need for additional off-board discharge equipment.

Single-cycle test (SCT), MCT, SMCT, SMCT+, and BEV five-cycle testing (Appendix B) have also been amended to allow thermal conditioning prior to driving, a desired customer feature in today's BEV marketplace to improve vehicle range.

FOREWORD

Historically, the determination of range and energy consumption for battery electric vehicles (BEV) has relied on the SCT methodology. The SCT requires that a vehicle be repeatedly driven over the same speed versus time profile (i.e., drive cycle) until the vehicle's battery energy is completely exhausted. The long and indeterminate nature of the SCT places significant logistical strains on test facilities, a situation that will worsen as battery technology advancements enable even greater range capability. It is also possible that additional test cycles—beyond the currently required UDDS ("city") and HFEDS ("highway") cycles—will be necessary in order to better characterize the effects of temperature and accessory loads on range performance, making the SCT paradigm even less practical. For these reasons, a multi-cycle test (MCT) procedure was been developed.

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The MCT method enables range and alternating current (AC) energy consumption determinations for multiple drive cycle types using a single full depletion test. This is accomplished by measuring: (1) the DC energy consumption for each included cycle type, and (2) the battery's useable direct current (DC) energy content. Given the total energy content of the battery, the range for each drive cycle type follows directly from its respective energy consumption. Similarly, the appropriate quantity of AC recharge energy attributable to each drive cycle can be determined according to its respective DC energy consumption. The MCT method is applicable to vehicles powered by lithium ion batteries and tested using the existing standard drive cycles; new battery technologies, new drive schedules, or significantly different vehicle designs should be evaluated to determine if this method adds test burden over time. Significant reductions in the testing resources needed to produce both a city and highway range determination are possible using the MCT method as compared to the SCT method. For example, a BEV with a 150 mile unadjusted UDDS range would consume about 18-1/2 hours of total dynamometer test time in order to perform the necessary city and highway SCT tests. The same city and highway range determinations could be accomplished in about 4-1/2 hours using a single MCT (a reduction of over 75%). Given a 200 mile UDDS range, the differential between the on-dyno test times increases further to 24-1/2 hours and 5-1/2 hours, respectively, for the SCT and MCT. These estimates do not account for the additional savings that accrue from the elimination of one of the two recharging periods required by the SCT procedure.

As vehicles powered by new battery technologies continue to evolve into longer range vehicles, the SMCT method enables range and AC energy consumption determination by means of a shorter test method as compared to the MCT method. While the recorded data elements of the testing remain similar, dynamometer usage may be reduced by approximately 50% using the SMCT method, allowing longer lead time measurements (e.g., useable battery energy) to conclude in a soak room setting using on-board discharging capability to a load device. Additionally, all vehicles are subjected to the same drive cycle duration, which avoids the need for iterative steady state calculations and unique drive profiles that are required by the MCT cycle. The SMCT cycle also avoids additional test days to quantify FTP, HFEDS, and US06 data required when five-cycle testing is applied by combining these cycles within the SMCT cycle profile.

To further reduce test burden for long-range BEV vehicles that do not have on-board discharging capability to a device, the SMCT+ test is introduced. The phase testing of the SMCT+ test remains the same as SMCT, a fixed distance, which eliminates the need for a variable mid-test depletion required on MCT. The SMCT and SMCT+ tests allow the variable depletion portion of the test to occur after the specific phase measurements are completed.

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1. SCOPE

This SAE Recommended Practice establishes uniform procedures for testing battery electric vehicles (BEVs) which are capable of being operated on public and private roads. The procedure applies only to vehicles using batteries as their sole source of power. It is the intent of this document to provide standard tests which will allow for the determination of energy consumption and range for light-duty vehicles (LDVs) based on the federal emission test procedure (FTP) using the urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) and provide a flexible testing methodology that is capable of accommodating additional test cycles as needed. Additionally, this SAE Recommended Practice provides five-cycle testing guidelines for vehicles performing supplementary testing on the US06, SC03, and cold FTP procedure. Realistic alternatives should be allowed for new technology. Evaluations are based on the total vehicle system's performance and not on subsystems apart from the vehicle.

NOTE: The range and energy consumption values specified in this document are the raw, test-derived values. Additional corrections are typically applied to these quantities when used for regulatory purposes (corporate average fuel economy, vehicle labeling, etc.).

2. REFERENCES

2.1 Applicable Documents

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.

2.1.1 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.

SAE J1263 Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques

SAE J1711 Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles

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

2.1.2 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.

40 CFR § 86 EPA; Control of Emissions from New and In-Use Highway Vehicles and Engines

40 CFR § 600 EPA; Fuel Economy and Carbon-Related Exhaust Emissions of Motor Vehicles

40 CFR § 1066 EPA; Vehicle-Testing Procedures

2.1.3 Other Publications

United States Advanced Battery Consortium, Electric Vehicle Battery Test Procedures Manual

United States Environmental Protection Agency, Specifications for Electric Chassis Dynamometers, Attachment A, RFP C100081T1, 1991

3. DEFINITIONS

3.1 CURB WEIGHT

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

3.2 BATTERY

A device, consisting of one or more electrochemical cells electrically connected in a series and/or parallel arrangement. Often used as shorthand for traction battery, a battery that provides power to propel a vehicle. Traction batteries are typically electrically rechargeable, with charge power supplied from the electrical grid through a charger or from energy captured through regenerative braking.

3.2.1 BATTERY AMPERE-HOUR CAPACITY

The capacity of a battery in A•h obtained from a battery discharged at the manufacturer's recommended discharge rate such that a specified cut-off terminal voltage (see 3.2.3) is reached. This is generally provided as guidance for battery size and is not intended to replace measured data from testing within this procedure.

3.2.2 STATE OF CHARGE (SOC)

The percentage of useable energy remaining in the battery pack relative to the battery pack's full charge useable energy.

3.2.3 CUT-OFF TERMINAL VOLTAGE

The manufacturer-recommended minimum operating voltage of the battery. This voltage can be either a function of load and/or temperature, or an absolute minimum.

3.2.4 FULL CHARGE (FC)

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

3.3 THERMAL CONDITIONING

Thermal conditioning consists of either heating or cooling of the propulsion components (HV battery, motors, drive units, etc.) and/or heating or cooling of the vehicle's interior cabin during the following three events: (1) vehicle charging period, (2) the soak period after charging while vehicle is connected to AC charging, and/or (3) prior to test with the vehicle loaded on the dynamometer and connected to AC charging. 12 V battery maintenance is not considered as thermal conditioning unless it leads to a significant change in propulsion component temperatures. Thermal conditioning, as defined in this paragraph, should not be performed when the vehicle is un-plugged. All tests utilizing thermal conditioning require monitoring of the pre-test AC recharge energy.

3.4 DIRECT CURRENT FAST CHARGE (DCFC) CONTACTORS

A direct connection between the fast charge port external to the vehicle and the high voltage battery pack can be completed with a secondary set of battery contactors.

3.5 HV BATTERY NOMINAL VOLTAGE (V_{nom})

The open circuit voltage (OCV) of a battery at a point which results in approximately 50% of the useable battery energy remaining.

3.6 FULL DEPLETION TEST (FDT)

A test sequence that fully depletes the useable energy content of a vehicle's battery. The test begins with the battery at FC and terminates when the remaining battery energy is insufficient to allow the vehicle to satisfactorily maintain the prescribed drive trace. Alternatively, a test that in one or more steps will fully deplete the useable energy content of a vehicle's battery if a partial depletion test is followed by further discharging of the battery.

3.7 PARTIAL DEPLETION TEST (PDT)

A dynamometer sequence that does not fully deplete the useable energy content of a vehicle's battery.

3.8 SINGLE-CYCLE TEST (SCT)

An FDT consisting of multiple phases of the same drive cycle (i.e., drive schedule).

3.9 MULTI-CYCLE TEST (MCT)

An FDT consisting of multiple phases of one or more drive cycles. The MCT enables the determination of range and energy consumption for multiple drive cycles using a single FDT. Data from the MCT can also be used to make range determinations for additional drive cycles that are not included in the MCT, but that are run in a standalone PDT.

3.10 SHORT MULTI-CYCLE TEST (SMCT)

The SMCT is an FDT consisting of seven phases which can be used as an optional procedure instead of the MCT. The SMCT allows for determination of range and energy consumption for multiple drive cycles using a two-step discharge process. An additional DC discharge test procedure is required and performed as a static measurement to complete the useable battery energy (UBE) determination. As such, the SMCT test requires use of an off-board discharge unit or cycler to complete the DC discharge test procedure.

3.11 SHORT MULTI-CYCLE TEST PLUS STEADY STATE (SMCT+)

The SMCT+ is an FDT consisting of eight phases which can be used as an optional procedure instead of the MCT. The SMCT+ allows for determination of range and energy consumption for multiple drive cycles using a single FDT. The SMCT+ parallels the SMCT test with the exception of the final depletion phase performed on the dynamometer at a constant speed.

3.12 DC DISCHARGE TEST

A test that discharges the remaining useable energy content of a vehicle's battery through the use of an off-board battery cycler or other means.

3.13 ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.

3.14 POST-TEST AC RECHARGE ENERGY (Eac_{post})

The AC energy, measured in AC Wh, from the power outlet required to return the battery to full charge after a drive cycle test, with the high voltage (HV) battery starting the charge event from a fully depleted state. This measurement must include energy needed to power charging equipment (e.g., EVSE).

3.15 PRE-TEST AC RECHARGE ENERGY (Eac_{pre})

The AC energy, measured in AC Wh, from the power outlet required to return the battery to full charge before a drive cycle test, with the HV battery starting the charge event from a fully depleted state. This measurement must include energy needed to power charging equipment (e.g., EVSE). This measurement method must be used when thermal conditioning is present before a test cycle.

3.16 DISCHARGE ENERGY (Edc)

The net DC energy output of the battery, in DC Wh, measured while a vehicle is driven on a test cycle and/or additionally as measured during a constant discharge of the battery through the charge port terminal to a specified load bank or other device converting DC power on the vehicle to alternative power sources. The equation for calculating vehicle DC energy is given in Equation 1; however, in practice it is expected that this calculation will typically be performed internally by a power analyzer as specified in 4.6. Battery voltage measurements made by the vehicle's own on-board sensors (such as those available via a diagnostic port) may be used for calculating discharge energy if these measurements are equivalent to those produced by applicable external measurement equipment, such as a power analyzer.

$$Edc = \frac{1}{3600 \times f} \times \sum_{j=0}^{n} V_j \times i_j \quad \text{(Eq. 1)}$$

Table 1 - Equation symbol explanations

Symbol	Symbol Represents	Units
V_j	Battery DC bus voltage	Volts
i_j	Battery current	Amps
$\sum_{j=0}^{n} V_j \times i_j$	The sum of the product of battery voltage and current flow into and out of the battery throughout the length of the test and/or cycle	Watts
f	The frequency of current measurements	Hertz
n	Number of samples	-

NOTE: The measurement point(s) for the battery(ies) current must be selected such that any and all of the current flowing through the battery(ies) is measured, including current associated with regenerative braking (if applicable). Multiple measurement points may be necessary to accomplish the summation of total energy.

3.17 PHASE AND CYCLE DISCHARGE ENERGY ($Edc_{[cycle]\_i}$, $Edc_{[cycle]}$)

The phase discharge energy, measured in DC Wh, is the discharge energy associated with a specific phase of a test. The phase discharge energy is given by $Edc_{[cycle]\_i}$, with [cycle] indicating the drive cycle type and subscript "i" indicating the phase number (i.e., the run order of the phase relative to other phases of the same drive cycle type). The cycle discharge energy is the summation of phase discharge energies for all phases of the same drive cycle type, excluding soaks. For example, Edc_{UDDS_2} indicates the phase discharge energy for the second UDDS driven during a test, and Edc_{UDDS} is the summation of discharge energies for all UDDS phases contained in the test.

$$Edc_{[cycle]} = \sum_{1}^{\text{number of phases of given cycle}} Edc_{[cycle]\_i} \quad \text{(Eq. 2)}$$

3.18 TEST DISCHARGE ENERGY (Edc_{total})

The sum of the discharge energies, measured in DC Wh, for all phases of a test including any energy consumed during soaks or any discharge energies measured during constant discharge events using a battery cycler or other means, inclusive of all drive cycle types above 10 °C ambient.

$$Edc_{total} = \sum^{\text{all test cycles}} Edc_{[cycle]} + \sum^{\text{all test soaks}} Edc_{[soak]} \quad \text{(Eq. 3)}$$

3.19 DC DISCHARGE TEST PROCEDURE

A process by which a static battery cycler is used to discharge and measure the remaining energy from a high voltage battery at a constant rate.

3.20 DC DISCHARGE TEST PROCEDURE - TOTAL DISCHARGE ENERGY ($Edc_{discharge}$)

The sum of the discharge energies, measured in DC Wh, from the completion of the DC discharge test procedure.

$$\mathrm{Edc_{discharge}} = \sum \mathrm{Edc_{DTP}} \quad \text{(Eq. 4)}$$

3.21 USEABLE BATTERY ENERGY (UBE)

The useable battery energy is defined as the total DC discharge energy, measured in DC Wh, from an FDT or from the combination of the PDT and DC discharge test procedure for the SMCT (3.20). The UBE represents the total delivered energy the battery is capable of providing while a vehicle is driving a test cycle on a chassis dynamometer or in combination with chassis dyno operation and battery cycler depletion.

$$\mathrm{UBE} = \mathrm{Edc_{totalFDT}} \quad \text{(Eq. 5)}$$

The UBE that is determined during the FDT is generally applicable to other tests consisting of the cycles listed in Section 6, provided the test temperature is at or above 10 °C (50 °F).

It is required for the SMCT test procedure that UBE is determined using both the SMCT total DC discharge energy and DC discharge test procedure energy outlined in 9.3.6.

$$\mathrm{UBE} = \mathrm{Edc_{total}}|_{\mathrm{PDT}} + \mathrm{Edc_{discharge}} \quad \text{(Eq. 6)}$$

3.22 ENERGY CONSUMPTION (ECac, ECdc)

Energy consumption is the energy used by the vehicle per unit of distance traveled. Two types of energy consumption are used in this procedure: (1) AC energy consumption (ECac) calculated using the AC recharge energy and expressed in AC Wh/km (or AC Wh/mile), and, (2) DC discharge energy consumption (ECdc) calculated using the DC discharge energy and expressed in DC Wh/km (or DC Wh/mile).

In the case where the SCT, MCT, SMCT, or SMCT+ is performed at 20 to 30 °C ambient with vehicles utilizing thermal conditioning:

$$\mathrm{ECac} = \frac{\mathrm{Eac_{pre}}}{\text{distance travelled}} \quad \text{(Eq. 7)}$$

$$\mathrm{ECdc} = \frac{\mathrm{Edc_{total}}}{\text{distance travelled}} \quad \text{(Eq. 8)}$$

In the case where the SCT, MCT, SMCT, or SMCT+ is performed at 20 to 30 °C ambient with vehicles not utilizing thermal conditioning:

$$\mathrm{ECac} = \frac{\mathrm{Eac_{post}}}{\text{distance travelled}} \quad \text{(Eq. 9)}$$

$$\mathrm{ECdc} = \frac{\mathrm{Edc_{total}}}{\text{distance travelled}} \quad \text{(Eq. 10)}$$

3.23 FULL RECHARGE ENERGY (FRE)

The full recharge energy is the AC recharge energy, measured in AC Wh, needed to return the battery to FC in the recharging period. If the vehicle is performing FCTs between 20 to 30 °C ambient and the vehicle does not utilize thermal conditioning, the FRE will be determined after the drive cycle is completed immediately following an FDT. The battery recharge energy measurement procedure is specified in 7.2.6.

$$\mathrm{FRE_{post}} = \mathrm{Eac_{post}}|_{\mathrm{FDT}} \quad \text{(Eq. 11)}$$

If the vehicle is performing FCTs between 20 °C and 30 °C ambient and the vehicle utilizes thermal conditioning prior to a FCT, the FRE will be determined before the drive cycle is completed:

$$\text{FRE}_{\text{pre}} = \text{Eac}_{\text{pre}}|_{\text{FDT}} \quad \text{(Eq. 12)}$$

3.24 RECHARGE ALLOCATION FACTOR (RAF)

The ratio of the FRE and the full depletion DC discharge energy (UBE). The RAF is used to allocate the measured AC recharge energy to the individual test phases based on the DC discharge energy expended in each phase. This factor enables AC energy consumption determinations for multiple drive cycle phases using a single recharging event.

For vehicles that do not utilize thermal conditioning before an FDT between 20 to 30 °C ambient:

$$\text{RAF} = \frac{\text{Eac}_{\text{post}}|_{\text{FDT}}}{\text{Edc}_{\text{total}}|_{\text{FDT}}} = \frac{\text{FRE}_{\text{post}}}{\text{UBE}} \left(\frac{\text{AC, W}\cdot\text{hr}}{\text{DC, W}\cdot\text{hr}}\right) \quad \text{(Eq. 13)}$$

For vehicles that utilize thermal conditioning before an FDT between 20 to 30 °C ambient:

$$\text{RAF} = \frac{\text{Eac}_{\text{pre}}|_{\text{FDT}}}{\text{Edc}_{\text{total}}|_{\text{FDT}}} = \frac{\text{FRE}_{\text{pre}}}{\text{UBE}} \left(\frac{\text{AC, W}\cdot\text{hr}}{\text{DC, W}\cdot\text{hr}}\right) \quad \text{(Eq. 14)}$$

The RAF, UBE, and FRE that are determined are generally applicable to other tests consisting of the cycles listed in Section 6, provided the ambient test temperature is at or above 10 °C (50 °F) and these cycles follow the same usage of thermal conditioning.

3.25 DC DISCHARGE AMPERE-HOURS (C_D)

The net DC A•h discharged from the battery during a test.

NOTE: The measurement points for the battery(ies) must capture any and all of the current flowing into and out of the battery(ies) during vehicle operation on the dynamometer or during the DC discharge test, including current associated with regenerative braking while operated on the dynamometer. Multiple measurement points may be necessary to accomplish the summation of total energy.

3.26 BATTERY ELECTRIC VEHICLE (BEV)

A vehicle that receives its power solely from batteries, unlike a hybrid vehicle that may receive a portion of its power from a separately fueled power source.

3.27 MILES PER GALLON EQUIVALENT (MPGe)

This parameter is generally used to quantify a fuel economy for vehicles that use a fuel other than gasoline or diesel. This value represents the miles a vehicle can drive with the energy equivalent to one gallon of gasoline. At the time of this document's publication, 33705 Wh per gallon of gasoline was accepted and used by the EPA for fuel economy labeling purposes.

3.28 CYCLE

The specific speed versus time profile associated with test phase (e.g., UDDS, HFEDS, etc.), used synonymously with drive cycle or schedule. Also refers to specific groupings of phases of the same drive cycle type, for example: city (UDDS phases), highway (HFEDS phases).

3.29 PHASE

A time period consisting of a specific subset of the overall test duration. Phases are typically delineated by a single occurrence of a drive cycle (or in some cases by a predefined subset of a drive cycle). The phase number indicates the run order of a phase within a test relative to other phases of the same drive cycle.

3.30 TEST

A test consists of a series of phases that run in succession until the end-of-test criteria are met.

3.31 START OF TEST

The time during a test at which the vehicle power switch is first placed in the "on" or "run" position, following applicable manufacturer "starting" procedures.

3.32 END OF TEST (EOT)

The point (in time and distance) at which the vehicle has been decelerated to a rest (zero speed) condition after the appropriate test termination criteria have been met and the vehicle power switch is placed in the "off" position.

3.33 END-OF-TEST DC DISCHARGE TEST (EOT_dc)

The point (in time) after the appropriate test termination criteria have been met for the DC discharge test when either the vehicle's charging contactors (vehicle initiated or load bank/external device initiated) or load bank/external device contactors are open to disengage discharging and hence powerflow of the HV battery. In the event AC discharge is used, the point (in time) when discharging of the HV battery has ceased at the AC-DC converter/charger.

3.34 Acronyms

ABS	Antilock Braking System
AC	Alternating Current
ALVW	Adjusted Loaded Vehicle Weight
BEV	Battery Electric Vehicles
CDR	Constant Discharge Rate
CSC	Constant Speed Cycle
DC	Direct Current
DCFC	Direct Current Fast Charge
EC	Electric Consumption
EOT	End of Test
ETW	Equivalent Test Weight
EVSE	Electric Vehicle Supply Equipment
FC	Full Charge
FDT	Full Deplete Test
FRE	Full Recharge Energy
FTP	Federal Emission Test Procedure
GVW	Gross Vehicle Weight
HFEDS	Highway Fuel Economy Driving Schedule

HV	High Voltage
LDV	Light-Duty Vehicle
LVW	Loaded Vehicle Weight
MCT	Multi-Cycle Test
MPGe	Miles Per Gallon Equivalent
NIST	National Institute of Standards and Technology
PDT	Partial Depletion Test
RAF	Recharge Allocation Factor
SCT	Single-Cycle Test
SMCT	Short Multi-Cycle Test
SMCT+	Short Multi-Cycle Test Plus Steady State
SOC	State of Charge
TCS	Traction Control System
UBE	Useable Battery Energy
UDDS	Urban Dynamometer Driving Schedule

4. TEST CONDITIONS AND INSTRUMENTATION

The following conditions shall apply to all tests defined in this document unless otherwise stated in specific test procedures.

4.1 Condition of Vehicle

4.1.1 Vehicles shall be stabilized as determined by the manufacturer and shall have accumulated a minimum of 1600 km (1000 miles), but no more than 9978 km (6200 miles) (40 CFR § 600.006), on the Durability Driving Schedule as defined in 40 CFR § 86, Appendix V or an equivalent driving schedule. Vehicle conditioning generated from SCT, MCT, SMCT, or SMCT+ can be used in place of other conditioning methods.

4.1.2 All accessories shall be turned off except those required by the test procedure.

4.1.3 For testing on a 2WD dynamometer, the vehicle shall be tested at equivalent test weight (ETW), which is assigned according to its loaded vehicle weight (LVW) (curb weight plus 136 kg [300 pounds]) (40 CFR § 1066.850).

NOTE: For trucks over 3856 kg (8500 pounds) GVW, conduct the testing at the weight specified in 40 CFR § 1066.410.

4.1.4 If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all dynamometer testing, with the exception of coastdown testing (e.g., SAE J2264). Sections 4.4.2 and 4.4.3 provide additional guidance on proper implementation of regenerative braking for track and dynamometer testing.

4.1.5 If the vehicle is equipped with an antilock braking system (ABS) or a traction control system (TCS) and is tested on a 2WD dynamometer, the vehicle's ABS or TCS may inadvertently interpret the non-movement of the set of wheels that are off the dynamometer as a malfunctioning system. If so, modifications to the ABS or TCS shall be made to achieve normal operation of the remaining vehicle systems, including the regenerative braking system.

4.2 Condition of Battery

4.2.1 The battery shall have been aged with the vehicle as defined in 4.1.1, or equivalent conditioning. The battery aging may be performed either with the vehicle or by using an equivalent bench aging procedure (Procedure #2, Constant Current Discharge Test Series, in the United States Advanced Battery Consortium EV Battery Test Procedures Manual, Revision 2). The number of charge/discharge cycles for bench aging a lead-acid battery shall be equivalent to at least 1000 vehicle miles. Other battery aging periods may be used for non-lead-acid battery technologies, if supported by the manufacturer as being equivalent. All batteries shall be cycled in accordance with the vehicle manufacturer's recommendations before starting testing. Non-lead acid battery conditioning to at least 1000 vehicle miles generated from SCT, MCT, SMCT, or SMCT+ can be used in place of other conditioning methods.

4.2.2 Battery ampere-hour capacity shall be verified to be within acceptable limits using the manufacturer's recommended procedure or previously generated SCT, MCT, SMCT, or SMCT+ test data.

4.3 Environmental Conditions

4.3.1 Ambient temperatures during vehicle and battery ambient soak, test, and recharge period shall all be within the range of 20 to 30 °C (68 to 86 °F). For tests performed at other temperatures (such as an SC03 or cold FTP), see Appendix B. In general, the pre-test and post-test soak/recharging period should be conducted at the same ambient temperature as the test cycle.

4.4 Dynamometer

4.4.1 Dynamometers used for testing BEVs shall have the capabilities specified in 40 CFR § 1066.201-290.

4.4.2 Dynamometer coefficients shall be determined as specified in SAE J2263 and SAE J2264, with the following provisions:

a. Vehicles equipped with regenerative braking systems that are activated only when the brake pedal is depressed or that are disengaged when the vehicle is in neutral require no special actions for coastdown testing on the test track or dynamometer. Vehicles equipped with regenerative braking systems that are automatically actuated during decelerations (without brake pedal input from the driver) shall have regenerative braking disabled during the deceleration portion of coastdown testing on both the test track and dynamometer. Methods to disable regenerative braking on both the test track and the dynamometer shall be determined by the manufacturer.

b. The dynamometer's inertia simulation shall be set as specified in 40 CFR § 1066.850. If the effective rotational mass of the vehicle differs significantly from the estimates given in SAE J2263 and SAE J2264 (1.5% of test mass per axle), the actual effective mass should be experimentally determined. If the vehicle does not have a mechanical neutral, the manufacturer shall prescribe procedures and calculation methods for coastdown and road-load determination that correctly account for the actual rotational inertia.

4.4.3 4WD, AWD, or vehicles with regenerative braking on only one axle are preferably tested on 4WD dynamometers. If tested on 2WD dynamometers or in 2WD mode, the vehicle must be properly configured per 40 CFR § 1066.410. The vehicle should be configured in such a way as to account for any significant additional regenerative braking due to the loss of friction braking on the non-regenerative axle.

4.4.4 Dynamometer assisted braking shall be turned off during testing.

4.5 Test Instrumentation

This section provides a list of instruments that are required to perform the tests specified in this document, except for distance measurements which must be within ±0.5% of the total distance traveled. Coastdown measurement instrument accuracy is described in SAE J2263 or SAE J2264, as applicable.

4.6 General Instrumentation

Equipment referenced in 40 CFR § 86.106 is required, 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-hour, and watt-hour meter(s) (power analyzer): Voltage and current of the battery pack are measured directly with the meter(s). It shall be installed in such a way as to measure all current leaving and entering the battery pack (no other connections upstream of the measurement point). Ampere-hour meters using an integration technique shall have a maximum integration period of 0.05 second, so that abrupt changes of current can be accommodated without introducing significant integration errors. Total accuracy of current and voltage measurements shall be 1% of the reading or 0.3% of full scale, whichever is larger. Instruments shall not be susceptible to offset errors while measuring current, because very small current offsets can be integrated throughout the cycle and provide erroneous energy or ampere-hour results.

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

c. An AC watt-hour meter to measure AC recharge energy (if applicable): It shall be installed in such a way as to measure all AC electrical energy entering the EVSE. The AC watt-hour meter shall have a total accuracy of voltage and current of 1.0% of the reading or 0.3% of full scale, whichever is larger.

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

e. If following the SMCT: A device to accept either AC or DC discharge energy as discharged from the high voltage battery via the charge port or other accepted means (e.g., direct connection to the battery pack) while performing 9.3.6.

f. If following the SMCT: A device to measure DC discharge energy between the vehicle's charge receptacle or other means (e.g., direction connection to battery pack) and load device while performing 9.3.6.

g. If following the SMCT: A device capable of communicating with the vehicle's DC fast charge (DCFC) contactors to allow powerflow from the vehicle to the DC cycler by closing this set of contactors in addition to the battery main contactors. The DCFC contactor ideally should be located between the HV battery and the vehicle's DC fast charge port, with no additional powerflow between these locations. These contactors may be located internally to the HV battery pack.

Wideband instruments (bandwidth of at least ten times that of the maximum fundamental frequency of interest) are required where pulsed power electronics are implemented. Any watt-hour meter(s) using an integration technique shall have a maximum integration period of 0.05 second so that short bursts of regeneration energy and current can be accommodated without causing integration errors.

In the event more than one meter is required for measurement during a test cycle in order to measure all current leaving the battery, the individual integrated results from each meter shall be summed together during the specific time interval of measurement.

5. DATA TO BE RECORDED FOR ALL TESTS

Table 2 lists the data and parameters that must be recorded in order to perform the SCT, MCT, SMCT, SMCT+, and five-cycle test procedures not utilizing thermal conditioning, as described in this document, unless explicitly stated in Table 2 for thermal conditioning cases. The determination of certain items in this table may inherently require the measurement of intermediate quantities not explicitly listed (e.g., current, voltage).

Table 2 - Required parameters to be recorded

Item	Parameter/Measurement	Description	Units
1	Battery ampere-hour capacity	Net DC ampere-hours discharged during test	DC A•h
2	Ambient test temperature	-	°C (°F)
3	Time, soak start	Pre-test soak time	-
4	Time, soak end	Pre-test soak time	-
5	Time, test start	-	-
6	Distance driven (total)	-	km (miles)
7	Distance driven per phase ($D_{[cycle]\_i}$)	-	km (miles)
8	Discharge energy[1] (Edc_{total}, $Edc_{totalN7C}$[4])	Net DC watt-hours discharged during test	DC W•h
9	Discharge energy ($Edc_{discharge}$[5], $Edc_{dischargeN7C}$[4])	Net DC watt-hours discharged during DC discharge test procedure	DC W•h
10	Phase and cycle discharge energy ($Edc_{[phase]\_i}$, $Edc_{[cycle]\_i}$)	Net DC watt-hours discharged per phase and/or per cycle	DC W•h
11	Time, end of test	-	-
12	Vehicle charging mode	If multiple settings available	-
13	Time, start of charge	Time connected to EVSE	-
14	Power outlet voltage	Nominal AC voltage at power outlet	AC volts
15	AC recharge voltage[2]	Real-time RMS voltage measured at power outlet (one sample per minute minimum)	AC volts
16	AC recharge energy (Eac_{post}, FRE_{post}, Eac_{pre}[3], FRE_{pre}[3])	Total AC energy from power outlet	AC W•h
17	Time, end of vehicle soak period	Total time vehicle is soaking	-
18	Time, end of recharging period	Time full charge (FC) is achieved (may include thermal conditioning time)	-

[1] Optional for SCT
[2] Recommended
[3] Thermal conditioning only
[4] Five-cycle procedure only
[5] SMCT only

6. DRIVE SCHEDULES

There are five driving schedules (also known as drive cycles) referenced in this document which are required by the Environmental Protection Agency and the California Air Resources Board during emissions and fuel economy certification of internal combustion engine vehicles. They are (1) the urban dynamometer driving schedule (UDDS), (2) the "cold" FTP, (3) the highway fuel economy driving schedule (HFEDS), (4) the US06 driving schedule (US06), and (5) the SC03 driving schedule (SC03). Additionally, a constant-speed cycle (CSC) is defined for use in this procedure.

NOTE: At the time of this document's publication, only the UDDS and HFEDS tests are required for BEV certification in the United States and Canada.

6.1 UDDS

The UDDS is defined in 40 CFR § 86, Appendix I. It has a duration of 22 minutes, 52 seconds. It is used to represent vehicle city driving.

6.2 HFEDS

The HFEDS is defined in 40 CFR § 600, Appendix I. It has a duration of 12 minutes, 45 seconds. It is used to represent vehicle highway driving.

6.3 US06

The US06 driving schedule is defined in 40 CFR § 86, Appendix I. It has a duration of 10 minutes. It is used to represent vehicles driving at high speeds and accelerations. Dynamometer load reduction for low-powered vehicles may be used in accordance with 40 CFR § 86.108 00(b)(2)(ii).

6.4 SC03

The SC03 driving schedule is defined in 40 CFR § 86, Appendix I. It has a duration of 10 minutes. It is used to represent vehicle operation with air conditioning.

6.5 Cold FTP

Same as UDDS schedule. The test is performed in cold ambient conditions as defined in 40 CFR § 1066, Subpart H.

6.6 CSC

The constant speed cycle is used to rapidly deplete battery energy and consists of a steady-state speed schedule of 105 km/h (65 mph). The initial acceleration to 105 km/h (65 mph)—or 90% of maximum sustainable speed if a vehicle cannot reach 65 mph—must be smooth and accomplished within 1 minute of the key switch being placed in the "on" position. The vehicle's speed must be held within the tolerances defined in 6.7. The CSC may be broken into distinct sub-phases of at least 5 minutes (unless the test termination criteria are met before this time). A 5 to 30 minute key-off soak must be performed between each CSC sub-phase.

6.7 Speed Tolerance

The speed tolerance at any given time on these driving schedules is defined by the upper and lower limits, as described in 40 CFR § 1066.425.

6.8 Speed Tolerance Violations

Speeds that violate the speed tolerance may constitute an invalid test; however, for an entire full depletion test procedure consisting of many test phases, infrequent speed excursions that exceed the speed tolerance described in 6.7 are acceptable, if due to driver variability. The criterion for a valid full depletion test is: no more than one violation of the tolerances referenced in 6.7 per test phase. Individual violations should not exceed a tolerance of ±4 mph of the target speed within a 2 second period. Additional allowances for tire slippage, brake spikes, or other vehicle- and/or dynamometer-related anomalies shall be considered according to 40 CFR § 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 6.7. Good engineering judgment shall be used in applying this speed tolerance allowance given the additional demands on personnel associated with testing BEVs.

7. SINGLE-CYCLE RANGE AND ENERGY CONSUMPTION TEST (SCT)

7.1 Purpose of Test

The purpose of this test is to determine either the total city or total highway range and energy consumption for a BEV when operated on a chassis dynamometer over repeated UDDS or HFEDS driving cycles, respectively. This is an FDT where the vehicle is driven until the useable energy content of the vehicle's battery is completely exhausted. It is the intent of this section to provide standard procedures for testing BEVs so that their performances can be compared when operated over standard drive cycles. This procedure should only be used for vehicles with a dynamometer unadjusted range capability of 96.54 km (60 miles) or less.

7.2 Test Methodology

The SCT consists of a multi-day test wherein the city range is determined on a single day and the highway range is determined on a subsequent day after battery re-charging has occurred. The total test length for city or highway range testing is determined by the vehicle's driving efficiency and battery capacity on each drive cycle. The results of the multi-day test are then combined to form a composite vehicle range and electric consumption value.

7.2.1 Dynamometer Test Preparation

The SCT is used to determine both the city and highway range and energy consumption values and is to be conducted subject to the test conditions and data requirements of Sections 4 and 5.

7.2.1.1 Dynamometer Determination

Prior to dynamometer testing, a dynamometer determination should be performed as described in 40 CFR § 1066.305.

For vehicles not utilizing thermal conditioning: Within 3 hours of completing the dynamometer determination, charge the vehicle to full state of charge and soak a minimum of 12 hours or charge complete, whichever is longer. Thermal conditioning requiring AC or DC electric energy (kWh) cannot be used during charging or prior to the drive cycle if electing to follow procedures not utilizing thermal conditioning. Indirect heating, such as heat loss resulting from charging the vehicle, may be used during this period.

Upon completion of the charge and soak, the vehicle shall be moved (pushed or towed—not driven) into position on the chassis dynamometer in order to complete the test sequence at 20 to 30 °C ambient. 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 charge/soak period and the start of this test. The dynamometer test must begin no more than 1 hour after the vehicle is disconnected from any charging equipment.

For vehicles utilizing thermal conditioning: Before proceeding with the dynamometer determination, ensure that battery state of charge (SOC) is 50% or greater. This will ensure accurate AC recharge energy measurement. Follow 7.2.1.2 and 7.2.2.

7.2.1.2 65 mph Discharge Procedure

The 65 mph discharge procedure should consist of driving the vehicle at 65 mph constant speed until the vehicle's battery is fully depleted.

7.2.2 Post-65 mph Charging Process

During the 65 mph discharge procedure, DC energy should not be recorded.

Following the 65 mph discharge procedure, the vehicle, battery, and thermal management system, if any, shall be soaked for at least 12 hours and not more than 36 hours. The battery shall be recharged during soak. Within 3 hours of completing the 65 mph discharge procedure, the vehicle shall be placed on charge at the beginning of the soak period and the soak shall not end before full charge is reached. Once connected, the vehicle shall begin AC charging. Full AC recharge energy shall be measured during the soak period for a minimum of 12 hours or until the vehicle completes the charge event and post-charge thermal conditioning, whichever is longest in duration. Charge energy is denoted as full recharge energy (FRE) for 20 to 30 °C ambient.

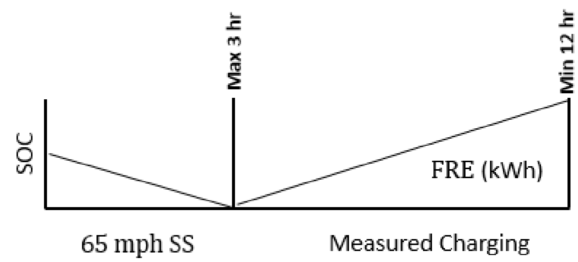

Figure 1 - Prep DC discharge process at 20 to 30 °C ambient and measured charge

Upon completion of the charge and soak, the vehicle shall be moved (pushed or towed—not driven) into position on the chassis dynamometer in order to complete the test sequence at 20 to 30 °C ambient. 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 charge/soak period and the start of this test. The dynamometer test must begin no more than 1 hour after the vehicle is disconnected from any charging equipment.

7.2.3 Range and Energy Consumption Dynamometer Test

The vehicle shall be repeatedly operated over one of the following pairs of drive phases:

City Test: 2 x UDDS

Highway Test: 2 x HFEDS

The cycle pairs are repeated until the end-of-test criteria have been satisfied (7.2.4) as shown in Figures 2 and 3.

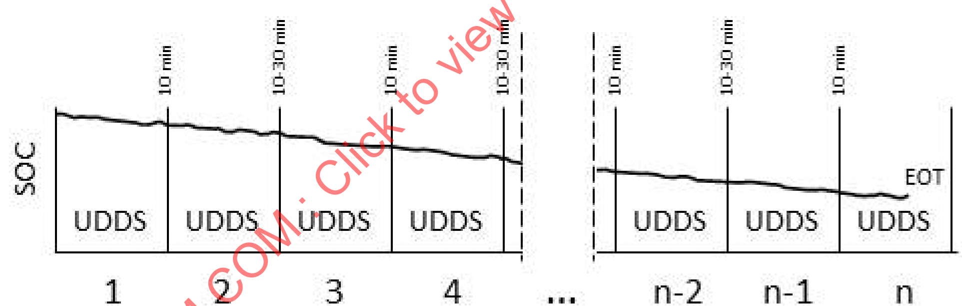

Figure 2 - Repeated city test

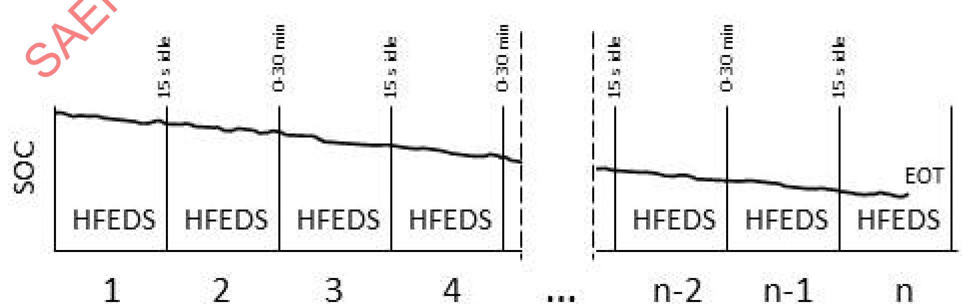

Figure 3 - Repeated highway test

Between each cycle pair, the vehicle must soak for 10 to 30 minutes (±1 minute) for the city test, and 0 to 30 minutes for the highway test (±1 minute), as shown in Figures 2 and 3. Between each HFEDS, there is to be a 15 second key-on pause. During all soak periods, the key or power switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, and the brake pedal not depressed. Test site ambient temperature shall be maintained in accordance with 4.3.1. Dynamometer coastdown "quick checks" are not required.

DC discharge A•h (C_D) must be measured during the entire dynamometer test procedure (driving phases and soaks).

For vehicles utilizing thermal conditioning: Post-dynamometer test charging is not required.

For vehicles not utilizing thermal conditioning: Within 3 hours of completing the test, the vehicle must be placed on-charge following the requirements specified in 7.2.6.

7.2.4 EOT Criteria

The test termination criteria for the full-depletion range and energy consumption test are defined as follows:

a. For vehicles capable of meeting the prescribed speed versus time relationship of the applicable drive cycle, the test termination criterion for the full-depletion range and energy consumption test is defined as when the vehicle—due to power limitations—is incapable of maintaining the speed tolerances as defined in 6.8 while the driver is attempting to follow the drive schedule, or the manufacturer determines that the test should be terminated for safety reasons (e.g., excessively high battery temperature, abnormally low battery voltage, etc.). When this test termination criteria has been satisfied, the driver shall immediately apply the brake and decelerate the vehicle to a stop within 15 seconds. At this point, the test is completed, and all power analyzer measurement should be stopped.

b. For vehicles that are not capable of meeting the prescribed speed versus time relationship of the applicable drive cycle for the initial phase of that cycle (i.e., the phase that begins with the vehicle fully charged) and operated at maximum available power, the test terminates when the following criterion is satisfied: when the vehicle, while operated at maximum available power or "full throttle," is unable to reproduce the best-effort speed versus time relationship established by the vehicle in the first phase of the test. The applicable drive tolerances for the best-effort trace are provided in 6.7.

NOTE: The speed tolerance violation criteria given in 6.8 do not apply to the best-effort trace for low-power vehicles.

7.2.5 Other Manufacturer-Specified Test Termination Criteria

Other earlier test termination criterion may be specified by the vehicle manufacturer. For example, to prevent battery damage, the vehicle manufacturer may specify a battery characteristic such as terminal voltage under load to be the test termination criterion.

7.2.6 Recharging

For vehicles not utilizing thermal conditioning: Within 3 hours of operating the vehicle over the test cycle, the vehicle shall be placed on charge and the battery recharged to full capacity in order to measure full AC recharge energy (FRE).

For vehicles utilizing thermal conditioning: The battery must be recharged to full capacity and full AC recharge energy (FRE), including thermal conditioning energy, recorded prior to the test cycle.

Full charge is to be established using the manufacturer's recommended charging procedure and appropriate EVSE as defined in SAE J1772. The vehicle shall be charged using an external EVSE recommended by the vehicle manufacturer. If multiple AC levels are available, the vehicle shall be recharged at the AC level (voltage and current) recommended by the manufacturer. If not specified by the manufacturer, the AC level expected to be most widely utilized by end users shall be selected. Once the correct AC level has been determined for a vehicle, it shall be consistently used for all pre- and post-test recharging events. All the AC energy supplied to the vehicle from the electrical grid must be measured, including all energy used to power charging equipment (e.g., charger, EVSE, 12 V battery charger, etc.).

For vehicles that require less than 12 hours to reach FC, FRE is determined by measuring the AC recharge energy (Eac) for a 12-hour period following the connection of the vehicle to the EVSE. For vehicles requiring more than 12 hours to reach FC, the data collection period shall continue until FC is achieved and all thermal conditioning energy is accounted. The 12 hour minimum data collection period is intended to better replicate expected in-use charging practices (i.e., overnight charging) and to provide a standard time period that can be used quantify any ancillary recharging loads, such as those resulting from battery thermal conditioning.

Recharging must be conducted at the same nominal ambient temperature as the pre-test soak/charging period. If the vehicle must be moved to a separate charging location, it shall be pushed or towed—not driven. The recharging period must appropriately quantify the energy used to condition or prepare the vehicle or cabin for testing during the pre-test soak/charging period (e.g., cabin preheating or heating of seating surfaces, battery heating/cooling), if applicable. The manufacturer shall declare any strategy requiring recharging energy for thermal conditioning purposes prior to test.

7.3 Range

Range ($R_{[cycle]}$) for the SCT is defined as the total test distance driven, measured in kilometers (miles), from the beginning of the test until the point where the vehicle reaches zero speed after satisfying the EOT criteria (7.2.4).

$$R_{[cycle]} = \text{Total Distance Driven} \quad \text{(Eq. 15)}$$

The city range is total distance driven on repeated UDDS cycles (7.2.3).

$$R_{City} = R_{UDDS} = \text{Total Distance Driven on City Test} \quad \text{(Eq. 16)}$$

The highway range is the total distance driven on repeated HFEDS cycles (7.2.3).

$$R_{Highway} = R_{HFEDS} = \text{Total Distance Driven on Highway Test} \quad \text{(Eq. 17)}$$

7.4 AC Energy Consumption

AC energy consumption ($ECac_{[cycle]}$) serves as an efficiency and cost-of-operation metric and is also used to determine MPGe for fuel economy labeling purposes. Energy consumption is defined as the full AC recharge energy (FRE) measured during the recharging period (7.2.6) divided by the appropriate range value (7.3).

$$ECac_{[cycle]} = \frac{FRE_{[cycle]}}{R_{[cycle]}} \quad \text{(Eq. 18)}$$

Using Equation 19, the city energy consumption is calculated by:

$$EC_{City} = ECac_{UDDS} = \frac{FRE_{UDDS}}{R_{UDDS}} \quad \text{(Eq. 19)}$$

Using Equation 20, the highway energy consumption is calculated by:

$$EC_{Highway} = ECac_{HFEDS} = \frac{FRE_{HFEDS}}{R_{HFEDS}} \quad \text{(Eq. 20)}$$

8. MULTI-CYCLE RANGE AND ENERGY CONSUMPTION TEST (MCT)

8.1 Purpose of Test

The purpose of this test is the determination of multiple range and energy consumption values using a single, continuous test procedure where a vehicle is operated on a chassis dynamometer over repeated driving schedules. This is an FDT where the vehicle is driven until the useable energy content of the vehicle's battery is completely exhausted. It is the intent of this section to provide standard procedures for testing BEVs so that the performance can be compared when operated over standard drive cycles. This procedure is recommended for vehicles with a range capability greater than 96.54 km (60 miles).

8.2 Test Methodology

The MCT consists of a fixed number of phases of standard dynamic drive cycles combined with constant-speed driving phases. The fixed drive cycles are used to determine the energy consumption associated with specific and established driving patterns. The constant-speed driving schedules, which are located in the middle and the end of the test, are intended to (1) reduce test duration by depleting the battery more rapidly than the established certification drive schedules, (2) improve the robustness of the energy determination by minimizing the impact of drive style variation, and (3) prevent inconsistent triggering of EOT criteria that can occur at high power-demand points when a BEV is following a dynamic drive schedule at low states-of-charge. Figure 4 illustrates how multiple drive cycles (UDDS, HFEDS, and CSC) are combined in the MCT test.

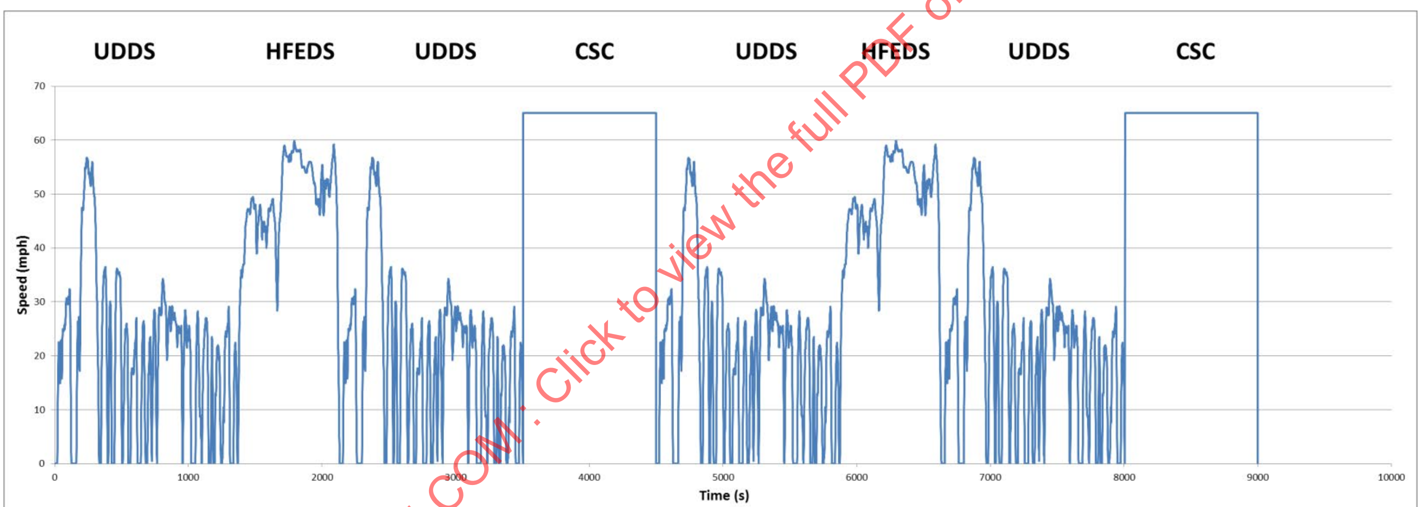

Figure 4 - Multi-cycle range test: speed versus time profile

In addition to measuring the cycle-specific energy consumption, the MCT also allows for the determination of cycle-specific range. Determining the range for a given cycle type requires knowledge of both the energy consumption for the drive cycle and the total energy content of the test vehicle's battery. The MCT method makes use of an in-situ determination of the battery's useable DC energy content (UBE) that—when combined with a drive cycle's DC energy consumption—can be used to determine the range for that cycle. The general equation describing this method is given in Equation 21.

$$R_{[cycle]} = \frac{Distance_{[cycle]}}{Edc_{[cycle]}} \times UBE = \frac{UBE}{ECdc_{[cycle]}} \quad \text{(Eq. 21)}$$

The UBE determined from the MCT may also be applicable to cycles listed in Section 6 for test temperatures ≥10 °C (50 °F), even though these cycles are not part of the MCT. The ability to use a single UBE value across multiple drive cycle types—thus eliminating the need to run a separate, full-depletion test for each drive cycle—is enabled by the fact that the total deliverable battery energy has been shown to be sufficiently robust with respect to the standard dynamometer drive schedules. This property enables range determinations for cycle types that are not included in the MCT sequence from which the UBE was derived, for example the US06 or SC03, thus minimizing the need to run additional full depletion tests for these cycles (see Appendix B for specific applications). This ability to use a single energy content value (within appropriate test temperature constraints) is applicable to lithium ion batteries and the existing standard drive cycles listed in Section 6. New battery technologies, new drive schedules, or significantly different vehicle designs should be evaluated to determine if this property remains applicable.

The AC energy consumption for each drive cycle included in the MCT is determined using the RAF and the cycle-specific DC energy consumption, per Equation 22. Note that, in some instances, AC energy measurement will be required before the MCT drive cycle.

$$ECac_{[cycle]} = \frac{FRE}{UBE} \times ECdc_{[cycle]} = RAF \cdot ECdc_{[cycle]} \quad \text{(Eq. 22)}$$

The AC energy allocated to each cycle type is effectively proportional to that cycle's DC discharge energy. The RAF determined from the MCT may also be applicable to cycles listed in Section 6 for test temperatures ≥10 °C (50 °F), even though these cycles are not part of the MCT. Test cycles performed at -7 °C (20 °F) may require UBE and FRE determinations that are performed at the actual test temperature.

8.3 Multi-Cycle Range and Energy Consumption Test

8.3.1 Dynamometer Test Preparation

The MCT is used to determine both the city and highway range and energy consumption values using a single, continuous full depletion test, and is to be conducted subject to the test conditions and data requirements of Sections 4 and 5.

8.3.1.1 Dynamometer Determination

See 7.2.1.1 for the procedure which is also applicable to this test cycle group.

8.3.2 Post-65 mph Recharge Process

See 7.2.1.2 and 7.2.2 for the procedure which is also applicable to this test cycle group for vehicles utilizing thermal conditioning.

8.3.3 Test Sequence

The MCT range test consists of four UDDS phases, two HFEDS phases, and two CSC phases. The test sequence, shown in Figure 5, is characterized by four distinct segments: (1) Sequence 1 (S_1), the initial UDDS-HFEDS-UDDS sequence; (2) the mid-test CSC depletion phase (CSC_M); (3) Sequence 2 (S_2), the second UDDS-HFEDS-UDDS sequence; and (4) the end-of-test CSC (CSC_E).

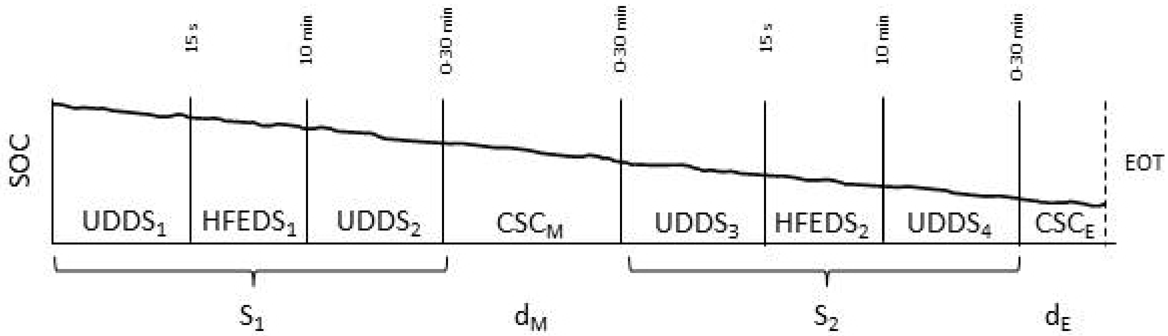

Figure 5 - Multi-cycle range test sequence

The UDDS and HFEDS cycles provide the cycle-specific DC energy consumption values (at both high and low states-of-charge) needed in order to calculate city and highway range and AC energy consumption. These dynamic drive cycles make up 81.31 km (50.52 miles) of driving distance; the remainder of the vehicle's UBE is depleted using CSC phases, which deplete battery energy more rapidly than UDDS or HFEDS cycles.

The CSC_M phase is located between S_1 and S_2. This placement enables—given a sufficiently long duration for the CSC_M—the vehicle's performance on the UDDS and HFEDS to be quantified for both high and low states of charge. Since the CSC_M distance (d_M) that is required to ensure that S_2 is conducted at a "substantially" lower SOC condition than S_1 will depend on the range capability of the test vehicle, good engineering judgment should be applied in order to select an appropriate CSC_M distance. In general, a d_M should be selected such that it will result in a CSC_E distance (d_E) that is 20% or less of the total driven distance for the MCT. Recommended methods for determining the length of d_M both prior to and during a test are given in Appendix A.

NOTE: The CSC_M may be omitted for vehicles that are projected to meet the maximum CSC_E distance recommendation without a CSC_M (i.e., vehicles with relatively short range capability).

The test is concluded with a CSC (CSC_E) to enable a more consistent triggering of the end-of-test criterion and to prevent step changes in the range determination that have been observed when dynamic cycles with varying power demands are used to end an FDT.

8.3.4 Dynamometer Test

The vehicle shall be operated over the test sequence described in 8.3.3. The required soak times (also shown in Figure 5) are as follows: 15 seconds key-on pause between $UDDS_1$ and $HFEDS_1$ and between $UDDS_3$ and $HFEDS_2$; 10 minutes (±1 minute) key-off soak between $HFEDS_1$ and $UDDS_2$ and between $HFEDS_2$ and $UDDS_4$; 0 to 30 minutes (±1 minute) optional soak preceding and following the CSC phases. The CSC_M and CSC_E portions of the test may be segregated into distinct sub-phases with associated soak periods as described in 6.6. During all soak periods, the key or power switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, and the brake pedal not depressed. Test site ambient temperature shall be maintained in accordance with 4.3.1. The test is terminated when end-of-test criteria in 7.2.4 have been satisfied during the CSC_E. Dynamometer coastdown "quick checks" are not required.

DC discharge A•h (C_D) must be measured during the entire dynamometer test procedure (driving phases and soaks).

For vehicles utilizing thermal conditioning: Post-dynamometer test charging is not required.

For vehicles not utilizing thermal conditioning: Within 3 hours of completing the test, the vehicle must be placed on-charge following the requirements specified in 7.2.6.

8.4 Phase Scaling Factors

The phase scaling factors determine the contribution of each phase's energy consumption value to the total energy consumption for a given drive cycle type. Application of the generic phase scaling factors given in Equations 23, 24, and 25 results in a cycle-specific energy consumption that is equivalent to the taking of an un-weighted average of the individual energy consumption values for each phase.

$$K_{[cycle]\_i} = \frac{1}{n_{[cycle]}} \quad \text{(Eq. 23)}$$

Where $n_{[cycle]}$ is the total number of measured test phases of a particular cycle type and the subscript "i" is the phase run order within a given cycle type. For the UDDS and HFEDS phases contained within the MCT sequence, the generic phase scaling factors are defined as follows:

$$K_{UDDS\_i} = \frac{1}{n_{UDDS}} = \frac{1}{4} (i = 1, 2, 3, 4) \quad \text{(Eq. 24)}$$

$$K_{HFEDS\_i} = \frac{1}{n_{HFEDS}} = \frac{1}{2} (i = 1, 2) \quad \text{(Eq. 25)}$$

8.4.1 SCT-Equivalent UDDS Phase Factors

It has been observed that in certain BEV applications the energy consumption of the first UDDS is significantly higher than that of subsequent UDDS phases, likely due to regenerative braking limitations at high states-of-charge and/or "cold start" parasitic losses. For the SCT, the relative impact of this effect is minimal because the contribution of the first UDDS to the overall test result is diluted by the inclusion of many additional UDDS phases (13+ for a vehicle with a 160 km [100 mile] range). However, for the MCT the vehicle's performance on first UDDS has a much greater impact on the total UDDS results since the test sequence includes only four UDDS phases. In order to make the city MCT results equivalent to those produced from the city SCT, the following SCT-equivalent cycle scaling factors are used in the city range and energy consumption equations:

$$K_{UDDS\_1\_e} = \frac{Edc_{UDDS\_1}}{UBE} \quad \text{(Eq. 26)}$$

$$K_{UDDS\_2\_e} = K_{UDDS\_3\_e} = K_{UDDS\_4\_e} = \frac{1 - K_{UDDS\_1\_e}}{3} \quad \text{(Eq. 27)}$$

Under this formulation, the relative contribution of first UDDS phase to the total UDDS energy consumption is proportional to its fraction of the total discharge energy (UBE), thus replicating the relative impact of the first phase that is inherent in the city SCT. Equal weightings are then assigned to UDDS phases 2, 3, and 4, as shown in Equation 27 (since the scaling factors are simply a normalized weighted average, they must have a sum equal to 1).

8.5 DC Discharge Energy Consumption

DC discharge energy consumption is required in order to calculate range and AC energy consumption for the MCT. It is to be determined uniquely for each phase of the test—with phases of the same drive schedule differentiated by a subscript indicating relative phase order within the drive schedule type—and is defined as the ratio of discharge energy to distance traveled:

$$ECdc_{[phase]\_i} = \frac{Edc_{[phase]\_i}}{D_{[phase]\_i}} \quad \text{(Eq. 28)}$$

Where $D_{[phase]\_i}$ is the driven distance for the phase.

The total DC energy consumption for each drive cycle is calculated by summing the product of the phase scaling factor and the respective DC discharge energy consumption for all phases of a given cycle type.

$$ECdc_{[cycle]} = \sum [K_{[phase]\_i} \cdot ECdc_{[phase]\_i}] \quad \text{(Eq. 29)}$$

The city discharge energy consumption, using the SCT-equivalent scaling factors in 8.4.1, is then:

$$\begin{aligned} ECdc_{City} &= (K_{UDDS\_1\_e} \cdot ECdc_{UDDS\_1}) + (K_{UDDS\_2\_e} \cdot ECdc_{UDDS\_2}) \\ &\quad + (K_{UDDS\_3\_e} \cdot ECdc_{UDDS\_3}) + (K_{UDDS\_4\_e} \cdot ECdc_{UDDS\_4}) \end{aligned} \quad \text{(Eq. 30)}$$

The highway discharge energy consumption, using the generic scaling factors in 8.4, is then:

$$\begin{aligned} ECdc_{Highway} &= K_{HFEDS\_1} \cdot ECdc_{HFEDS\_1} + K_{HFEDS\_2} \cdot ECdc_{HFEDS\_2} \\ &= \frac{ECdc_{HFEDS\_1} + ECdc_{HFEDS\_2}}{2} \end{aligned} \quad \text{(Eq. 31)}$$

8.6 Range ($R_{[cycle]}$)

The range, measured in kilometers (miles), for a given drive cycle is calculated using the UBE and the total cycle DC discharge energy consumption:

$$R_{cycle} = \frac{UBE}{\sum K_i \cdot ECdc_{[phase]\_i}} = \frac{UBE}{ECdc_{cycle}} \quad \text{(Eq. 32)}$$

The city range, using Equation 33, is then:

$$R_{City} = \frac{UBE}{ECdc_{City}} \quad \text{(Eq. 33)}$$

The highway range, using Equation 34, is then:

$$R_{Highway} = \frac{UBE}{ECdc_{Highway}} \quad \text{(Eq. 34)}$$

8.6.1 AC Energy Consumption

AC energy consumption is determined by multiplying the DC discharge energy consumption for a given drive cycle by the recharge allocation factor. If the vehicle utilized thermal conditioning prior to the test cycle, the pre-test recharge energy must be used to define RAF. Alternatively, if thermal conditioning was not utilized, the post-test recharge energy may be used to define RAF.

$$ECac_{cycle} = RAF \cdot \sum K_i \cdot ECdc_{phase\_i} = RAF \cdot ECdc_{cycle} \quad \text{(Eq. 35)}$$

The city AC energy consumption, using Equation 36, is then:

$$ECac_{City} = RAF \cdot ECdc_{City} \quad \text{(Eq. 36)}$$

The highway AC energy consumption, using Equation 37, is then:

$$ECac_{Highway} = RAF \cdot ECdc_{Highway} \quad \text{(Eq. 37)}$$

9. SHORT MULTI-CYCLE RANGE AND ENERGY CONSUMPTION TEST (SMCT)

9.1 Purpose of Test

The purpose of this test is the determination of multiple range and energy consumption values using a full discharge test procedure where a vehicle is operated on a chassis dynamometer over repeated driving schedules. This is an FDT where the vehicle is driven until the prescribed cycle is completed and then followed by a separate discharge procedure to fully deplete the vehicle's battery. Each vehicle will drive a fixed distance, regardless of battery size or range capability, starting will a full state of charge (SOC). The remaining useable energy content of the battery is determined using a separate procedure, denoted as "DC discharge test procedure." It is the intent of this section to provide alternative procedures for testing BEVs in an effort to reduce test burden, particularly for long-range BEVs.

Vehicles must be capable of discharging either DC or AC energy out of the vehicle through the charge port connections or other approved means to test with the SMCT method. The vehicle may need to enter a dyno mode to perform this procedure and this dyno mode must be approved by the administrator prior to test. If the vehicle has auxiliary loads that are not captured through the discharge measurement process, additional measurements should be used to capture this energy and summed with the DC discharge energy as measured at the charge port connection or other approved means. For an alternative procedure not requiring charge port discharging, see Section 10 (SMCT+).

9.2 Test Methodology

The SMCT consists of seven phases of standard dynamic drive cycles. The fixed drive cycles are used to determine the energy consumption associated with specific and established driving patterns. Figure 6 illustrates how multiple drive cycles (UDDS, HFEDS, US06) are combined in the SMCT test.

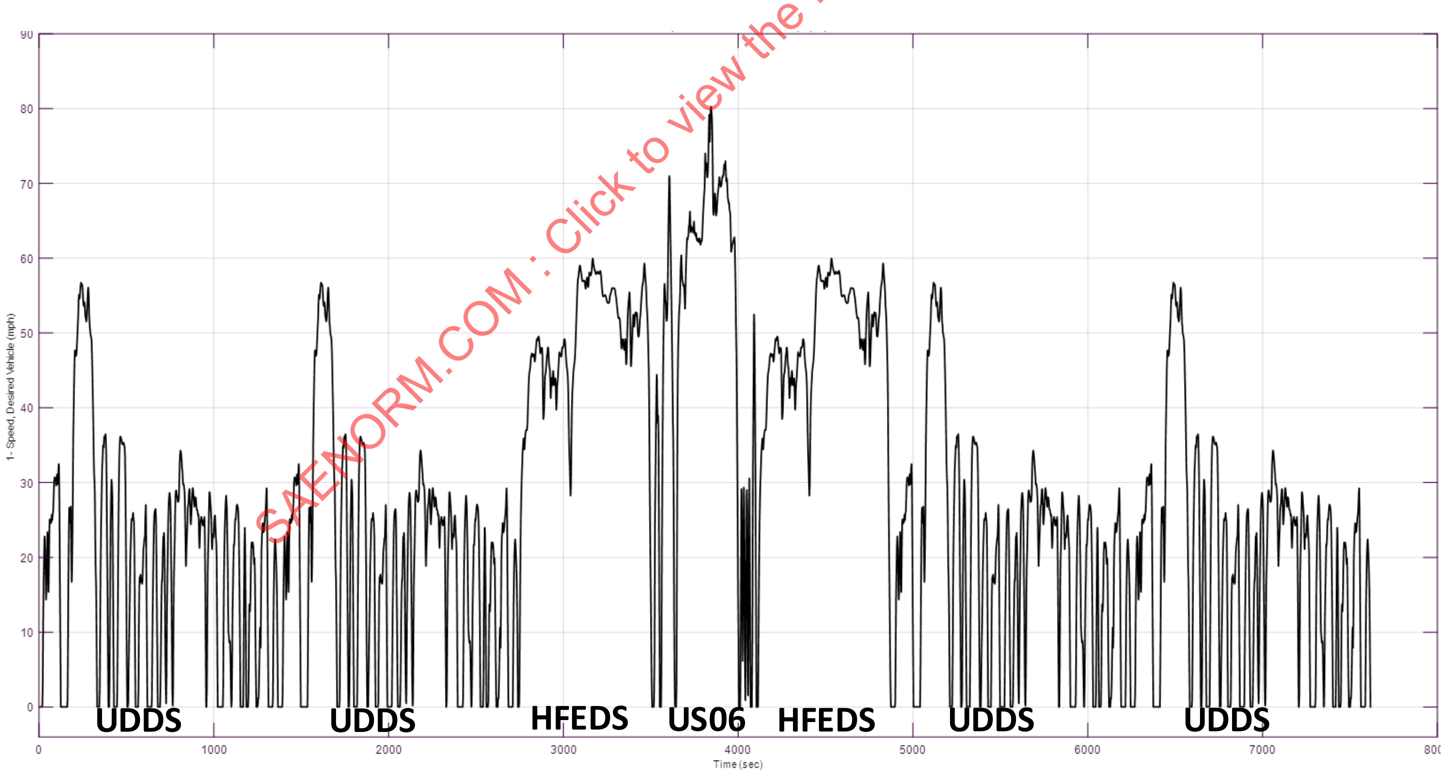

Figure 6 - Short multi-cycle range test

9.2.1 Test Procedure

The SMCT is used to determine both the city and highway range and energy consumption values using a partial depletion dynamometer test in combination with the DC discharge test procedure and is to be conducted subject to the test conditions and data requirements of Sections 4 and 5. The SMCT can also be used to satisfy five-cycle data requirements for UDDS, HFEDS, and US06. However, SC03 and cold FTP testing are still required for a complete five-cycle analysis.

9.2.2 Determination of Estimated Constant Discharge Rate

The constant discharge rate at 20 °C ambient is determined by means of the estimated useable energy ($UBE_{estimated}$) available for discharge and the estimated total duration of time taken to run either the MCT test (Section 8) or SMCT+ test (Section 10) at 20 to 30 °C ambient, including soak times during testing.

A manufacturer should provide prior evidence indicating the $y_{estimated}$ duration at which it takes to complete the traditional MCT or SMCT+ test at the respective temperatures. A prior test on a representative vehicle is recommended to determine these values. The administrator may also request additional data including UBE, AC recharge energy, and DC energy consumption from the prior testing on a representative vehicle. In the event this data has not been determined with a prior vehicle test, good engineering judgment should be used to estimate $y_{estimated}$ to gain agreement with the appropriate administrator as to its value.

A constant power load, as programmed at the load bank or power accepting device to discharge the battery during the E/y phase, can be determined by the following:

$$\text{Estimated Constant Discharge Rate (Watts) @ 20°C} = \frac{E}{y} = \frac{UBE_{estimated}}{y_{estimated}} \quad \text{(Eq. 38)}$$

Alternatively, a constant current load, as programmed at the load bank or power accepting device, can be applied:

$$\text{Constant Discharge Rate Estimate (amps)} = CDR_A = \frac{\text{Est.Constant Discharge Rate (Watts)}}{\text{HV Battery Nominal Voltage } (V_{nom})} \quad \text{(Eq. 39)}$$

$UBE_{estimated}$, $y_{estimated}$, HV battery nominal voltage shall be furnished from a previous MCT test (Section 8) or SMCT+ test (Section 10) at 20 to 30 °C for use with Equations 38 and 39. HV battery nominal should represent the open circuit voltage (OCV) of the high voltage battery at 50% state of charge. The values can also be determined using good engineering judgement and gain agreement with the appropriate administrator as to its value.

9.2.3 Constant Discharge Rate Equivalency

The constant discharge rate shall remain equivalent for all constant discharge phases used at an ambient temperature of 20 to 30 °C.

9.3 Test Sequence

9.3.1 Dynamometer Test Preparation

9.3.1.1 Dynamometer Determination

Prior to dynamometer testing, a dynamometer determination should be performed as described in 40 CFR § 1066.305.

For vehicles not utilizing thermal conditioning: See 7.2.1.1 for the procedure which is also applicable to this test cycle group.

For vehicles utilizing thermal conditioning: Before proceeding with the dynamometer determination, ensure that battery state of charge (SOC) is 50% or greater. This will ensure accurate AC recharge energy measurement. Follow 9.3.1.2 and 9.3.2.

9.3.1.2 Prep DC Discharge Procedure

The prep DC discharge procedure should consist of performing the DC discharge test procedure at rate E/y (20 to 30 °C ambient) until the vehicle's battery is fully depleted.

9.3.2 Prep DC Discharge Process End Criteria

It is recommended that the vehicle end the prep DC discharge process by opening the DCFC contactors to stop the discharge process or communicating to the load device to stop the discharge load and open contactors. However, ensure that there is a redundancy check (SOC, cell voltage, battery power, and/or thermal limit) broadcasted to the load device from the vehicle to allow a secondary means of stopping power-flow between the vehicle and the load device. During the prep DC discharge process, DC energy should not be recorded.

Following the prep DC discharge process, the vehicle, battery, and thermal management system, if any, shall be soaked for at least 12 hours and not more than 36 hours. Within 3 hours of completing the DC discharge process, the vehicle shall be placed on charge at the beginning of the soak period and the soak shall not end before full charge is reached. Once connected, the vehicle shall begin AC charging. Full AC recharge energy shall be measured during the soak period for a minimum of 12 hours or until the vehicle completes the charge event and post-charge thermal conditioning, whichever is longest in duration. Charge energy is denoted as full recharge energy (FRE) for 20 to 30 °C ambient.

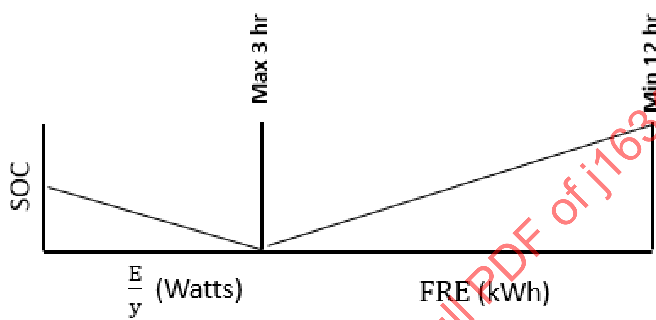

Figure 7 - Prep DC discharge process at 20 to 30 °C and measured charge

Upon completion of the charge and soak, the vehicle shall be moved (pushed or towed—not driven) into position on the chassis dynamometer in order to complete the SMCT test sequence at 20 to 30 °C ambient. 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 charge/soak period and the start of this test. The dynamometer test must begin no more than 1 hour after the vehicle is taken off charge.

9.3.3 SMCT Test Sequence

The SMCT range test consists of four UDDS phases, two HFEDS phases, and one US06 phase. The test sequence, shown in Figure 8, is characterized by three distinct segments: (1) Sequence 1 (S_1), the initial UDDS-UDDS-HFEDS sequence; (2) the US06 cycle ($US06_1$); and (3) Sequence 2 (S_2), the final HFEDS-UDDS-UDDS sequence.

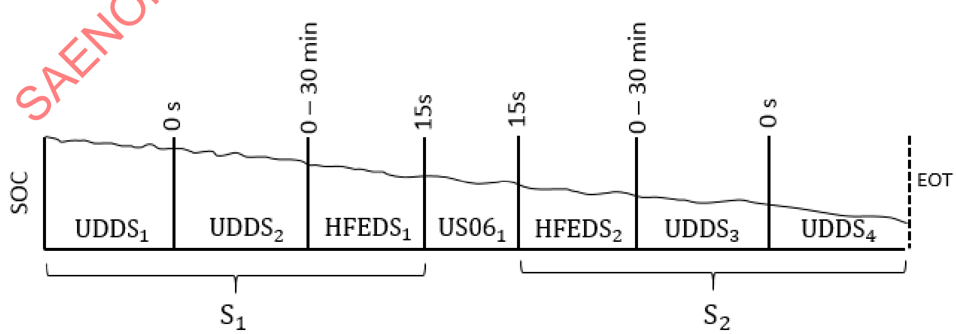

Figure 8 - SMCT test sequence

The UDDS and HFEDS cycles provide the cycle-specific DC energy consumption values needed in order to calculate city and highway range and AC energy consumption. These dynamic drive cycles make up 81.31 km (50.52 miles) of driving distance. The US06 phase allows for capturing the final portion of the five-cycle data as measured at standard conditions.

The US06 phase is located between S_1 and S_2.

The SMCT partial discharge is concluded with the $UDDS_4$ phase. The vehicle must then be moved (pushed or towed—not driven) from the dynamometer and placed in a soak area; begin the DC discharge test procedure within 1 hour of SMCT test completion.

9.3.4 Dynamometer Test

The vehicle shall be operated over the test sequence described in 9.3.3. The required soak are as follows: 0 seconds key-on pause between $UDDS_1$ and $UDDS_2$ and between $UDDS_3$ and $UDDS_4$; 0 to 30 minutes (±1 minute) optional soak preceding $HFEDS_1$ and $UDDS_3$, 15 second key-on pause between $HFEDS_1$ and $US06_1$, 15 second key-on pause between $US06_1$ and $HFEDS_2$. During all optional soak periods (if exercised), the key or power switch must be in the "off" position, the hood must be closed, the test cell fan(s) must be off, and the brake pedal not depressed. Test site ambient temperature shall be maintained in accordance with 4.3.1. The dynamometer test is terminated when $UDDS_4$ is completed. Dynamometer coastdown "quick checks" are not required.

DC discharge A•h (C_D) must be measured during the entire dynamometer test procedure (driving phases and soaks).

For vehicles utilizing thermal conditioning: Post-DC discharge test procedure charging is not required.

Within 1 hour of completing the dynamometer test, the vehicle must perform the DC discharge test procedure specified in 9.3.6. DC discharge energy ($Edc_{discharge}$) and DC discharge ampere-hours (C_D) will be measured during the DC discharge test procedure in a soak room environment.

9.3.5 Phase Scaling Factors

The SMCT uses the same scaling factors as the MCT test, as defined in 8.4 and 8.4.1.

9.3.6 DC Discharge Test Procedure

The vehicle shall perform the DC discharge test procedure to assist in determining UBE for 20 to 30 °C ambient (when required). Alternatively, the DC energy (kWh) may be measured at the battery terminals if it is not possible to measure DC energy outside of the vehicle, or if the vehicle will discharge AC power. In the event the vehicle must remain in an "on" state, the powerflow from the battery to other devices on the vehicle must be measured and recorded at the same time with the equivalent sample rate as the energy discharged through the charge port or other means (e.g., battery cable). This parasitic energy will then be added to the energy discharged during the SMCT and the energy discharge at the charge port (or battery cable).

The remaining DC energy in the battery after the applicable SMCT drive cycle shall be discharged and measured at the rate E/y for tests at 20 to 30 °C.

Before beginning this test, the vehicle must be placed in a soak room with an ambient temperature matching the ambient temperature of the drive cycle. The test begins by discharging to a load bank or other power accepting device by means of DC power using the discharge rate defined in 9.2.2. If the vehicle will have aux loads present that may not be captured through the charge port discharge process, other current and voltage measurements of such loads should be measured. If the vehicle will discharge AC power, the vehicle must have a means to measure DC energy out of the vehicle through an alternative method.

The discharge ends (EOT_dc) when the battery discharge power required to maintain 61 mph at the vehicle's stated roadload is no longer available. It is recommended that the vehicle end the test by stopping the discharge applied to the vehicle (through communication to the cycler) and opening DCFC contactors. However, ensure that there is a redundancy check (SOC, cell voltage, battery power, and/or thermal limit) broadcasted to the load device from the vehicle to allow a secondary means of stopping power-flow between the vehicle and the load device.

If additional fan cooling is needed during the discharge process, follow 40 CFR § 1066.105 and use good engineering judgement to select the appropriate cooling.

For vehicles not utilizing thermal conditioning: When the discharge is complete, the vehicle shall then be connected to AC measurement equipment so as to measure the wall energy during charging. Once connected, the vehicle shall begin AC charging, denoted by phase Eac_{post}, within 3 hours of completion of the DC discharge process. The vehicle shall remain on charge and re-charge energy shall be measured during the soak period for a minimum of 12 hours or until the vehicle completes the charge event, whichever is longest in duration.

After 12 hours or the charge complete criteria is reached (whichever is longest), stop the charge measurement process. Record the final charge energy (in AC kWh), denoted as Eac_{post}.

For vehicles utilizing thermal conditioning: Post-dynamometer test charging is not required.

9.3.7 Determination of UBE and FRE

SMCT useable battery energy is the sum of DC energy consumed during the SMCT and DC discharge procedure, along with any parasitic energy measured during the DC discharge procedure.

$$\mathrm{UBE} = \mathrm{Edc}_{\mathrm{total}}|_{\mathrm{PDT}} + \mathrm{Edc}_{\mathrm{discharge}} + \mathrm{Edc}_{\mathrm{parasitic}} \quad \text{(Eq. 40)}$$

The final AC charge energy for vehicles utilizing thermal conditioning on the SMCT will be calculated as:

$$\mathrm{FRE}_{\mathrm{SMCT}} = \mathrm{Eac\_pre}|_{\mathrm{FDT}} \quad \text{(Eq. 41)}$$

The final AC charge energy for vehicles not utilizing thermal conditioning on the SMCT will be calculated as:

$$\mathrm{FRE}_{\mathrm{SMCT}} = \mathrm{Eac\_post}|_{\mathrm{FDT}} \quad \text{(Eq. 42)}$$

9.3.8 Verification of y_{ACTUAL}

The measured value of y, as demonstrated during the cumulative time measurement of SMCT testing and the DC discharge test procedure, denoted as y_{ACTUAL}, should be within ±5% of the $y_{estimated}$ value provided by the OEM for 20 to 30 °C ambient. y_{ACTUAL} should be calculated as the time from the start of the MCT or SMCT+ test cycle, including test cycle soaks and excluding vehicle move soaks, until the end-of-test criteria (EOT_dc) has been reached.

$$0.95 \cdot y_{\mathrm{estimated}} < y_{\mathrm{ACTUAL}} < 1.05 \cdot y_{\mathrm{estimated}} \quad \text{(Eq. 43)}$$

In the event y_{ACTUAL} does not satisfy Equation 43, 9.3 must be repeated until Equation 43 is satisfied by changing the value of $y_{estimated}$ before the test begins. The value $y_{estimated}$ must be changed if Equation 43 is not satisfied, regardless of its original source being test data or engineering judgement.

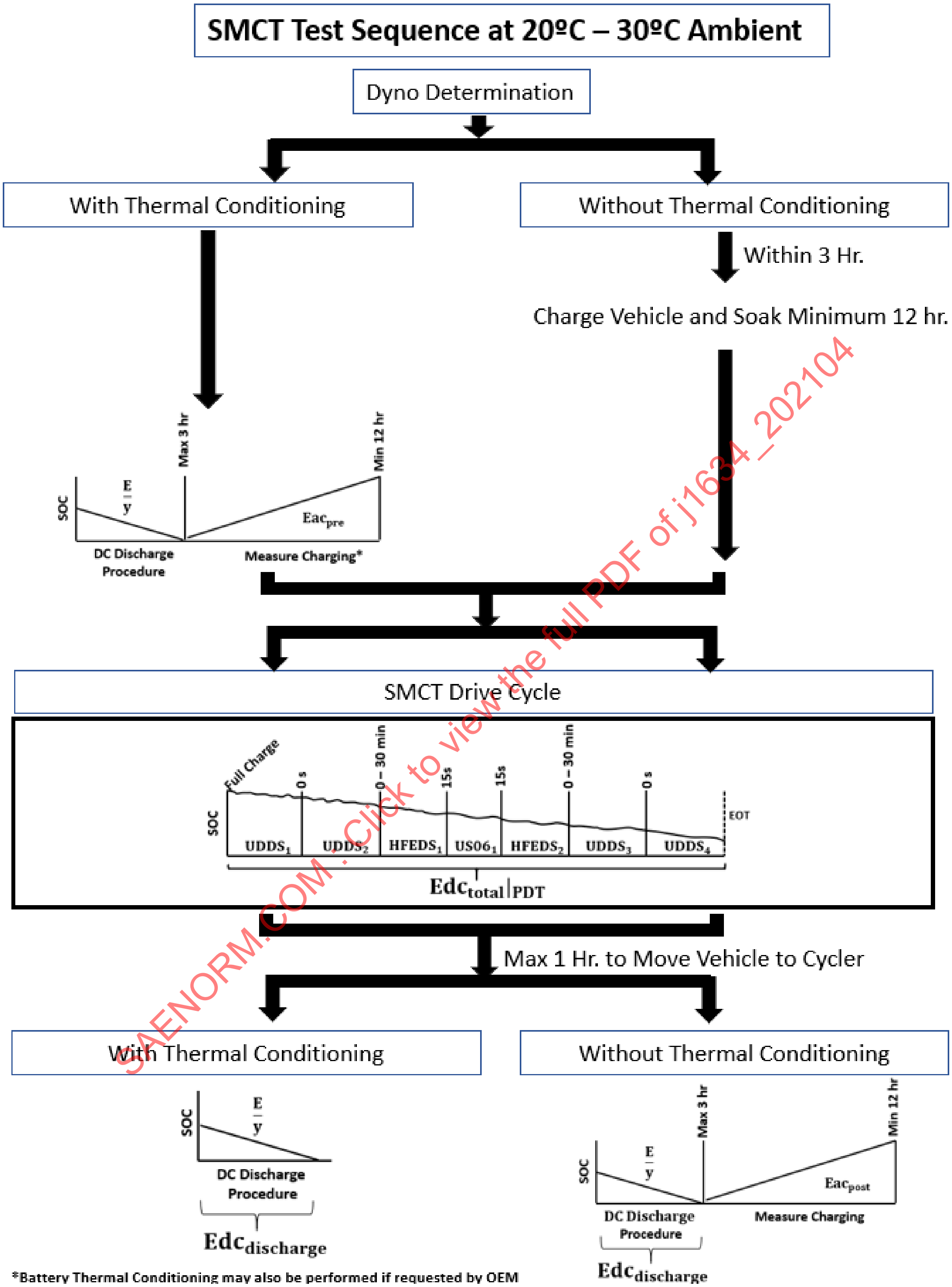

Figure 9 - Complete SMCT test sequence

9.4 DC Discharge Energy Consumption (SMCT Cycle)

DC discharge energy consumption should follow the equations as outlined in 8.5.

9.4.1 Range ($R_{[cycle]}$)

The range, measured in kilometers (miles), for a given drive cycle is calculated using the UBE and the total cycle DC discharge energy consumption:

$$R_{cycle} = \frac{UBE}{\sum K_i \cdot ECdc_{[phase]\_i}} = \frac{Edc_{total|PDT} + Edc_{discharge} + Edc_{parasitic}}{ECdc_{cycle}} \quad \text{(Eq. 44)}$$

Where $Edc_{parasitic}$ is the DC energy measured during the DC discharge test procedure that was consumed on-board the vehicle and not measured through the charging port. In some cases, this value may be 0, or may be already accounted for in the $Edc_{discharge}$ measurement.

The city range, using Equation 45, is then:

$$R_{city} = \frac{UBE}{ECdc_{City}} = \frac{Edc_{total|PDT} + Edc_{discharge} + Edc_{parasitic}}{ECdc_{City}} \quad \text{(Eq. 45)}$$

The highway range, using Equation 46, is then:

$$R_{highway} = \frac{UBE}{ECdc_{Highway}} = \frac{Edc_{total|PDT} + Edc_{discharge} + Edc_{parasitic}}{ECdc_{Highway}} \quad \text{(Eq. 46)}$$

9.4.2 AC Energy Consumption

AC energy consumption is determined by multiplying the DC discharge energy consumption for a given drive cycle by the recharge allocation factor:

$$ECac_{cycle} = RAF \cdot \sum K_i \cdot ECdc_{phase_i} = RAF \cdot ECdc_{cycle} \quad \text{(Eq. 47)}$$

The city AC energy consumption, using Equation 48, is then:

$$ECac_{city} = RAF \cdot ECdc_{City} \quad \text{(Eq. 48)}$$

The highway AC energy consumption, using Equation 49, is then:

$$ECac_{highway} = RAF \cdot ECdc_{Highway} \quad \text{(Eq. 49)}$$

10. SHORT MULTI-CYCLE RANGE AND ENERGY CONSUMPTION TEST PLUS STEADY STATE (SMCT+)

10.1 Purpose of Test

The purpose of this test is the determination of multiple range and energy consumption values using a full discharge test procedure where a vehicle is operated on a chassis dynamometer over a fixed set of cycles to calculate efficiency in the beginning of the test while the last phase of the test finalizes the UBE measurement. This is an FDT where the vehicle is driven until the useable energy content of the vehicle's battery is completely exhausted. Each vehicle will drive a fixed distance using the SMCT, regardless of battery size or range capability, starting will a full state of charge (SOC). The remaining useable energy content of the battery is determined using a constant speed 65 mph drive cycle after the SMCT is completed, denoted as CSC. The CSC is of variable length and is driven until the end-of-test criteria is met, per 7.2.4. This test provides an alternative procedure for vehicles unable to perform the SMCT test as outlined in Section 9.

10.2 Test Methodology

The SMCT+ consists of seven phases of standard dynamic drive cycles from the SMCT cycle and a variable length steady state driving profile at 65 mph. The fixed drive cycles are used to determine the energy consumption associated with specific and established driving patterns. Figure 10 illustrates how multiple drive cycles (UDDS, HFEDS, US06) are combined in the SMCT+ test with a variable length CSC. This test also provides UDDS, HFEDS, and US06 data applicable to calculating an optional five-cycle adjustment factor, outlined in Appendix B.

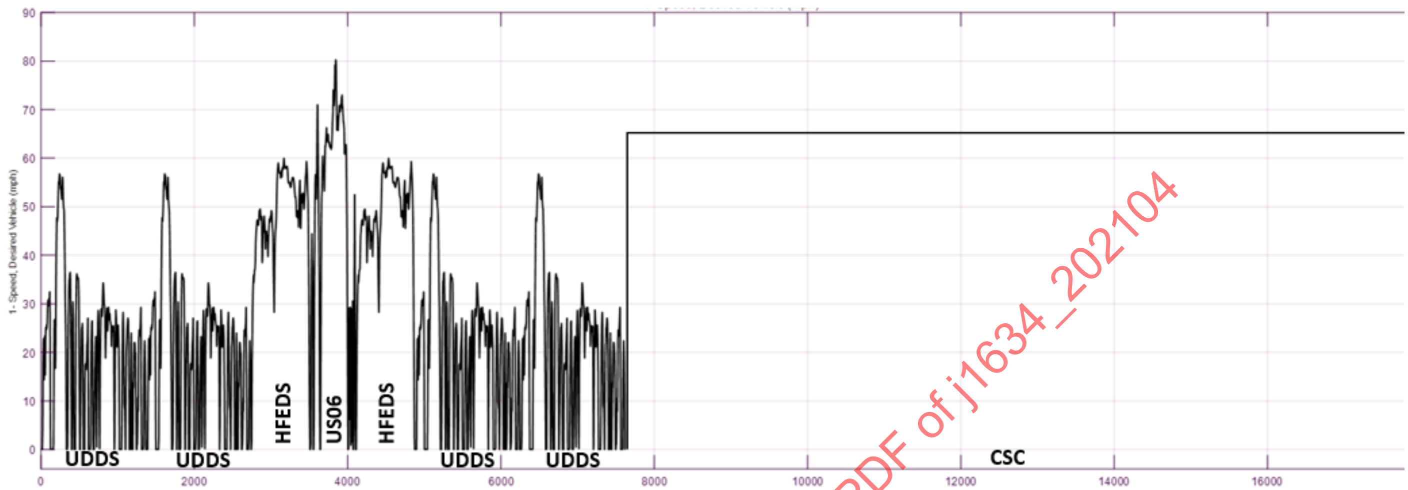

Figure 10 - Short multi-cycle range test plus steady state (CSC length varies by vehicle)

10.2.1 Test Procedure

The SMCT+ is used to determine both the city and highway range and energy consumption values using a full depletion test in combination with a steady state discharge "CSC" to determine UBE and is to be conducted subject to the test conditions and data requirements of Sections 4 and 5. The SMCT+ can also be used to satisfy five-cycle data requirements for UDDS, HFEDS, and US06. However, SC03 and cold FTP testing is still required for complete five-cycle analysis.

10.3 Test Sequence

10.3.1 Dynamometer Determination

Prior to dynamometer testing, a dynamometer determination should be performed as described in 40 CFR § 1066.305.

For vehicles not utilizing thermal conditioning: See 7.2.1.1. for the procedure which is also applicable to this test cycle group.

For vehicles utilizing thermal conditioning: Before proceeding with the dynamometer determination, ensure that battery state of charge (SOC) is 50% or greater. This will ensure accurate AC recharge energy measurement. Follow 10.3.1.1 and 10.3.2.

10.3.1.1 Dynamometer Determination

See 7.2.1.1. for the procedure which is also applicable to this test cycle group.

10.3.2 Post-65 mph Recharge Process

See 7.2.1.2 and 7.2.2 for the procedure which is also applicable to this test cycle group for vehicles utilizing thermal conditioning.

10.3.3 SMCT+ Test Sequence

The SMCT+ range test consists of four UDDS phases, two HFEDS phases, one US06 phase, and one constant speed phase. The test sequence, shown in Figure 11, is characterized by four distinct segments: (1) Sequence 1 (S_1, the initial UDDS-UDDS-HFEDS sequence); (2) the US06 cycle ($US06_1$); (3) Sequence 2 (S_2, the final HFEDS-UDDS-UDDS sequence); and (4) the final constant speed segment (CSC). As an option, the manufacturer may follow an optional soak procedure during the CSC as defined in 6.6.

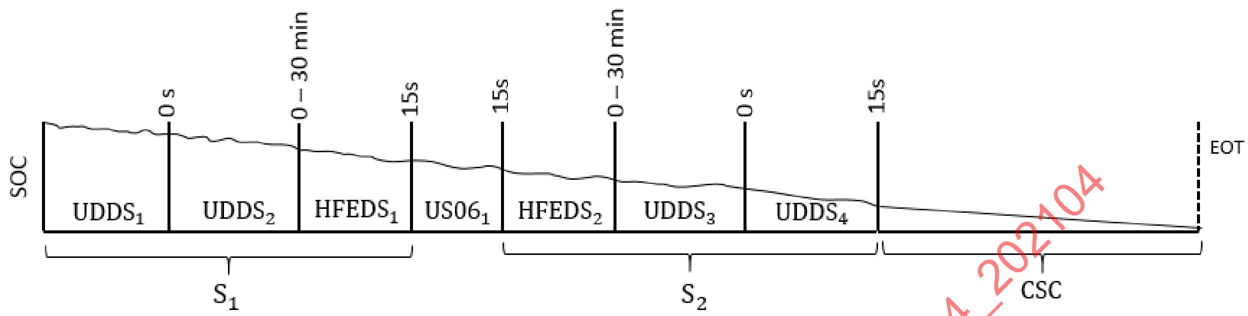

Figure 11 - SMCT+ test sequence

The UDDS and HFEDS cycles provide the cycle-specific DC energy consumption values needed in order to calculate city and highway range and AC energy consumption. These dynamic drive cycles make up 81.31 km (50.52 miles) of driving distance. The US06 phase allows for capturing the final portion of the five-cycle data as measured at standard conditions.

The US06 phase is located between S_1 and S_2.

10.3.4 Dynamometer Test

The vehicle shall be operated over the test sequence described in 10.3.3. The required soak are as follows: 0 second key-on pause between $UDDS_1$ and $UDDS_2$ and between $UDDS_3$ and $UDDS_4$; 0 to 30 minutes (±1 minute) optional soak preceding $HFEDS_1$ and $UDDS_3$, 15 second key-on pause between $HFEDS_1$ and $US06_1$, 15 second key-on pause between $US06_1$ and $HFEDS_2$. During all optional soak periods (if exercised), the key or power switch must be in the “off” position, the hood must be closed, the test cell fan(s) must be off, and the brake pedal not depressed. Test site ambient temperature shall be maintained in accordance with 4.3.1. The dynamometer test is terminated when CSC is completed, per the end-of-test criteria defined in 7.2.4. Dynamometer coastdown “quick checks” are not required.

DC discharge A•h (C_D) must be measured during the entire dynamometer test procedure (driving phases and soaks).

For vehicles utilizing thermal conditioning: Post-dynamometer test charging is not required.

For vehicles not utilizing thermal conditioning: Within 3 hours of completing the test, the vehicle must be placed on-charge following the requirements specified in 7.2.6.

10.3.5 Phase Scaling Factors

The SMCT+ test uses the same scaling factors as the MCT test, as defined in 8.4 and 8.4.1.

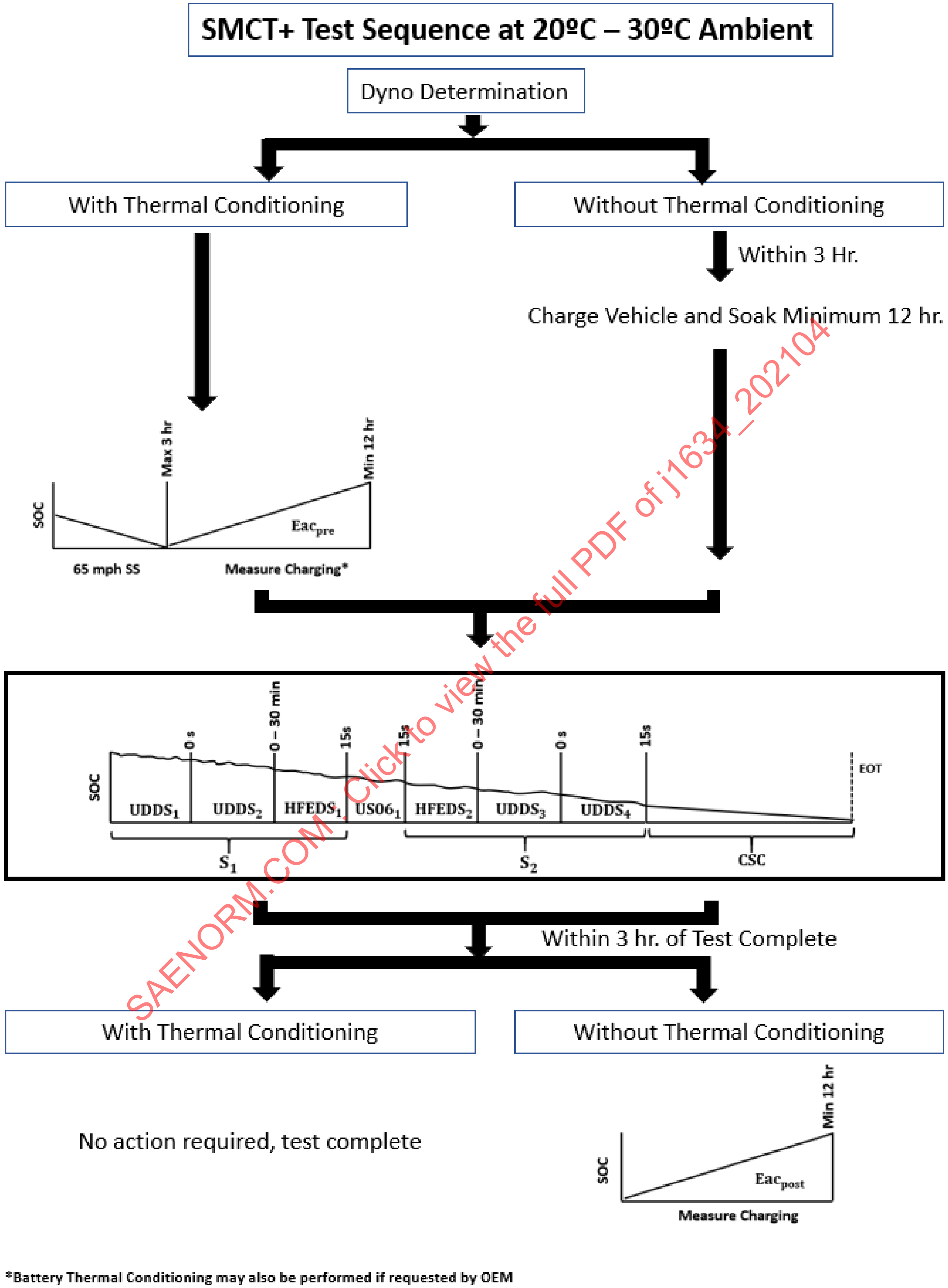

Figure 12 - Complete SMCT+ test sequence

10.4 DC Discharge Energy Consumption (SMCT+ Cycle)

DC discharge energy consumption should follow the equations as outlined in 8.5.

10.4.1 Range ($R_{[cycle]}$)

The range, measured in kilometers (miles), for a given drive cycle should follow the equations as outlined in 8.6.

10.4.2 AC Energy Consumption

AC energy consumption should follow the equations as outlined in 8.6.1.

11. ADDITIONAL TEST CYCLES

11.1 General

It is generally recognized that the on-road performance of BEVs can be significantly impacted by operating conditions that are not fully represented in a testing methodology consisting of only UDDS and HFEDS test cycles conducted between 20 to 30°C ambient (68 to 86 °F). The effects of cold ambient temperatures and heating/cooling accessory loads on range capability are particularly important to understand. To address these and other related concerns, Appendix B provides a detailed BEV five-cycle test procedure.

12. NOTES

12.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE LIGHT DUTY VEHICLE PERFORMANCE AND ECONOMY MEASURE COMMITTEE

APPENDIX A - METHODS FOR ESTIMATING LENGTH OF CSC_M (d_M)

In order to perform the MCT, the distance to run during the CSC_M must be determined. Two possible methods are given in this section: (1) using a combination of data taken before and/or during the test, or (2) using the vehicle's projected range.

A.1 METHOD 1: DC RECHARGE ENERGY METHOD

This method requires data from the recharge event preceding the test (or known UBE), cycle DC discharge energy, and DC energy consumption rates measured either before or during the MCT. It is assumed that the vehicle's useable battery energy is completely depleted prior to initiation of the pre-test recharging event (it is generally recommended to fully discharge the vehicle using CSC and/or standard drive cycles prior to the SCT or MCT charge/soak period). If a reasonable estimate of the vehicle's useable battery energy is not available, use the following equation to estimate UBE:

$$UBE_{est} = 0.95 * Edc_{recharge}$$

Where $Edc_{recharge}$ is the DC recharge energy measured during the pre-test recharging event. The 0.95 factor is used as an estimate for battery efficiency. Use better data if it exists. If DC recharge energy is not available, use Eac and define a suitable (lower) battery plus charger efficiency factor to calculate UBE_{est}.

Using the known or estimated UBE, the length of CSC_M (d_M) is calculated by:

$$d_M = \frac{0.9 \cdot UBE_{est} - 4 \cdot Edc_{UDDS} - 2 \cdot Edc_{HFEDS}}{EC_{CSC}} \qquad \text{(Eq. A1)}$$

where:

Edc_{UDDS} = discharge energy of UDDS #2 of the MCT (or "warm" UDDS phase of a previous test)

Edc_{HFEDS} = discharge energy from HFEDS #1 of the MCT (or HFEDS phase of a previous test)

EC_{CSC} = DC energy consumption from a previously run CSC, most commonly a CSC used to deplete the vehicle the day before the test; it is recommended that the CSC phases be at least 5 minutes long to remove effects of acceleration and braking

The 0.9 factor is intended to leave 10% of the total energy for CSC_E. If more uncertainty exists, use a smaller factor, but target no more than 20% of the total energy for the CSC_E as per 8.3.3.

A.2 METHOD 2: PROJECTED BEV RANGE METHOD

In the case where the DC cycle discharge energy and DC recharge energy are unknown, an appropriate duration for the CSC_M can be determined using the vehicle's projected range on one or more of the following cycles: UDDS, HFEDS, or CSC.

NOTE: These range projections should be intended to reflect the expected unadjusted dynamometer range values; using adjusted range values, such as those listed on fuel economy labels, will significantly reduce the accuracy of this method.

Using the vehicle's projected range on the UDDS, HFEDS, and 65 mph CSC, along with the scheduled UDDS and HFEDS distances prescribed in the MCT, the distance of CSC_M is found by:

$$d_M = 0.8 * (R_{CSC_{est}} - 4 * d_{UDDS} * \frac{R_{CSC}}{R_{UDDS}} - 2 * d_{HFEDS} * \frac{R_{CSC}}{R_{HFEDS}} - 0.2 * R_{CSC_{est}}) \quad \text{(Eq. A2)}$$

where:

R_{UDDS_est} = estimated range on repeated UDDS cycles

R_{HFEDS_est} = estimated range on repeated HFEDS cycles

R_{CSC_est} = estimated range on CSC cycles

d_{UDDS}= driving distance (scheduled) of one UDDS cycle: 12 km (7.45 miles)

d_{HFEDS} = driving distance (scheduled) of one HFEDS cycle: 16.5 km (10.26 miles)

0.2 factor = 20% of total CSC range reserved for CSC_E (use smaller factor if accuracy of range estimates allow)

0.8 factor = 20% reduction in expected range due the increased energy consumption of 65 mph cruise relative to HWFET cycle

If one or more of the above cycle range estimates are unknown, then the following generic range relationships may be used to determine the unknown range quantities (use vehicle-specific estimates if available):

$$R_{CSC\_est} = R_{HFEDS\_est} = 0.9 \times R_{UDDS\_est} \quad \text{(Eq. A3)}$$

Finally, the duration of the CSC_M is found using the estimated distance (d_M):

$$\text{Duration of } CSC_M = \frac{d_M}{105 \text{ km/h (65 mph)}} \quad \text{(Eq. A4)}$$

APPENDIX B - BEV FIVE-CYCLE TEST PROCEDURES

B.1 SCOPE

EPA regulations allow BEV manufacturers to generate and use five-cycle data (40 CFR § 600.210-12(d)(3)(i)) for fuel economy labeling. This appendix describes a method for calculating BEV five-cycle fuel economy (mile/kWh). The resulting five-cycle fuel economy can then be used to determine a five-cycle adjustment factor by comparing the value to the two-cycle fuel economy, derived from the SCT, MCT, SMCT, or SMCT+ drive cycles.

Five-cycle fuel economy is determined by performing five-cycle tests on a BEV and measuring DC discharge energy (Edc) for vehicles not utilizing thermal conditioning and measuring both DC discharge energy (Edc) and AC re-charge energy (Eac_{pre}) for vehicles utilizing thermal conditioning. If there is no evidence of thermal conditioning during these periods, or the manufacturer attests that there is no thermal conditioning, the equations may be used following vehicles not utilizing thermal conditioning. For vehicles that use thermal conditioning on any of the five-cycle tests, this requires the use of thermal conditioning equations for all five-cycle tests.

The adjustment factor for vehicles not utilizing thermal conditioning is calculated by dividing the combined five-cycle DC discharge fuel economy ($mile/kWh_{DC}$) by the combined two-cycle DC discharge fuel economy ($mile/kWh_{DC}$).

The adjustment factor for vehicles utilizing thermal conditioning is calculated by dividing the combined five-cycle AC discharge fuel economy ($mile/kWh_{AC}$) by the combined two-cycle AC discharge fuel economy ($mile/kWh_{AC}$).

The two-cycle DC or AC discharge fuel economy is measured during charge depletion testing (UDDS and highway) and the results shall be obtained from either single-cycle tests (UDDS and HFEDS SCT), multi-cycle test (MCT), short multi-cycle test (SMCT), or short multi-cycle test plus steady state (SMCT+).

For vehicles not utilizing thermal conditioning: The five-cycle BEV AC fuel economy value ($mile/kWh_{AC}$) is calculated by multiplying the adjustment factor (based on $mile/kWh_{DC}$) by the calculated combined two-cycle AC fuel economy ($mile/kWh_{AC}$).

For vehicles utilizing thermal conditioning: The five-cycle BEV AC fuel economy value ($mile/kWh_{AC}$) is calculated by multiplying the adjustment factor (based on $mile/kWh_{AC}$) by the calculated combined two-cycle AC recharge fuel economy ($mile/kWh_{AC}$).

B.2 DEFINITIONS

B.2.1 Useable Battery Energy Requirements for -7 °C (UBE_{N7C}) and 35 °C (UBE_{35C})

UBE for a test conducted at -7 °C (20 °F) is designated by UBE_{N7C} and may be required for vehicles that utilize thermal conditioning during any of the five-cycle testing.

For -7 °C (20 °F) ambient testing utilizing thermal conditioning, if the battery pack bulk initial average temperature is within the limits -4 °C < x < 20 °C as measured by on-board data or actual measurement prior to the cold start of the drive cycle, the UBE must be measured separately unless it can be shown that Equation B1 is satisfied through previous testing of the Modified cold FTP cycle, the cold FTP depletion in combination with the DC discharge procedure, the cold FTP full charge depletion test or good engineering judgement when the reference UBE data is SCT, MCT, SMCT, or SMCT+:

$$0.95 * \mathrm{UBE} < \mathrm{UBE}_{N7C} \quad \text{(Eq. B1)}$$

For -7 °C (20 °F) ambient testing utilizing thermal conditioning when the battery pack bulk initial average temperature is exceeding 20 °C, satisfying Equation B1, or not using any thermal conditioning, the vehicle test is allowed a carry-over UBE per Equation B2 from SCT, MCT, SMCT, or SMCT+:

$$\mathrm{UBE}_{N7C} = \mathrm{UBE} \quad \text{(Eq. B2)}$$

For vehicles not utilizing thermal conditioning: The UBE carry-over shall only apply to RAF calculation and cannot be used to determine -7 °C (20 °F) cold FTP full depletion vehicle range. Vehicles that satisfy Equations B1 or B2 may also optionally determine UBE_{N7C} through cold FTP full charge depletion testing if electing to perform a full depletion test in this condition.

For -7 °C (20 °F) ambient testing utilizing thermal conditioning not satisfying Equations B1 or B2, or if the battery pack bulk initial average temperature is below -4 °C at the start of the drive cycle, the UBE_{N7C} must be measured separately by means of the modified cold FTP cycle (see Section C.9), cold FTP full charge depletion test, or the cold FTP depletion in combination with the DC discharge procedure:

$$UBE_{N7C} = Edc_{totalN7C} \quad \text{(Eq. B3)}$$

For 35 °C (95 °F) ambient testing utilizing thermal conditioning, the UBE shall carry-over per Equation B4 from the SCT, MCT, SMCT, or SMCT+ cycle:

$$UBE_{35C} = UBE \quad \text{(Eq. B4)}$$

B.2.2 Energy Consumption (ECac, ECdc)

Energy consumption is the energy used by the vehicle per unit of distance traveled. Two types of energy consumption are used in this procedure: (1) AC energy consumption (ECac) calculated using the AC recharge energy and expressed in AC Wh/km (or AC Wh/mile), and (2) DC discharge energy consumption (ECdc) calculated using the DC discharge energy and expressed in DC Wh/km (or DC Wh/mile).

In the case of test cycles performed at 10 to 35 °C ambient not utilizing thermal conditioning and with carry over UBE (SCT, MCT, SMCT, or SMCT+ as the reference cycle), the general Equations B5 and B6 may be followed if requested by the manufacturer:

$$ECac = \frac{Eac_{pre}}{\text{distance travelled}} \quad \text{(Eq. B5)}$$

$$ECdc = \frac{Edc}{\text{distance travelled}} \quad \text{(Eq. B6)}$$

In the case of test cycles performed at 10 to 35 °C ambient not utilizing thermal conditioning and with carry over UBE (SCT, MCT, SMCT, or SMCT+ as the reference cycle), the general Equations B7 and B8 should be followed:

$$ECac = \frac{Eac_{post}}{\text{distance travelled}} \quad \text{(Eq. B7)}$$

$$ECdc = \frac{Edc}{\text{distance travelled}} \quad \text{(Eq. B8)}$$

In the case of test cycles performed at -7 °C ambient utilizing thermal conditioning not satisfying Equations B1 or B2, or if the battery pack bulk initial average temperature is below -4 °C (no thermal conditioning):

$$ECac = \frac{Eac_{preN7C}}{\text{distance travelled}} \quad \text{(Eq. B9)}$$

$$ECdc = \frac{Edc_{totalN7C}}{\text{distance travelled}} \quad \text{(Eq. B10)}$$

In the case of test cycles performed at -7 °C ambient with vehicles utilizing thermal conditioning with carry over UBE (SCT, MCT, or SMCT as the reference cycle):

$$ECac = \frac{Eac_{preN7C}}{\text{distance travelled}} \quad \text{(Eq. B11)}$$

$$ECdc = \frac{Edc_{total}}{\text{distance travelled}} \quad \text{(Eq. B12)}$$

In the case of test cycles performed at 35 °C ambient with vehicles utilizing thermal conditioning with carry over UBE (SCT, MCT, or SMCT as the reference cycle):

$$ECac = \frac{Eac_{pre35C}}{\text{distance travelled}} \quad \text{(Eq. B13)}$$

$$ECdc = \frac{Edc_{total}}{\text{distance travelled}} \quad \text{(Eq. B14)}$$

B.2.3 Test Discharge Energy (Edc_{total})

The sum of the discharge energies, measured in DC Wh, for all phases of a test at -7 °C ambient requiring unique energy measurement for vehicles utilizing thermal conditioning:

$$Edc_{total_{N7C}} = Edc_{modified_{N7C}} = Edc_{total_{N7C}}|_{FDT} = \sum^{\text{all test phases}} Edc_{[phase]} + \sum^{\text{all test soaks}} Edc_{[soak]} \quad \text{(Eq. B15)}$$

B.2.4 DC Discharge Test Procedure - Total Discharge Energy ($Edc_{dischargeN7C}$)

If the DC discharge test procedure is performed at -7 °C (20 °F) ambient:

$$Edc_{discharge_{N7C}} = \sum Edc_{DTP_{N7C}} \quad \text{(Eq. B16)}$$

$$Edc_{total_{N7C}} = \sum Edc_{totalN7C}|_{PDT} + \sum Edc_{discharge_{N7C}} + \sum Edc_{parasitic} \quad \text{(Eq. B17)}$$

Where $Edc_{parasitic}$ is the DC energy measured during the DC discharge test procedure that was consumed on-board the vehicle and not measured through the charging port. In some cases, this value may be 0 or may be already accounted for in the $Edc_{dischargeN7C}$ measurement.

B.2.5 Full Recharge Energy (FRE)

The full recharge energy is the AC recharge energy, measured in AC Wh, needed to return the battery to FC in the recharging period.

In the case where a PDT is performed at 10 to 35 °C that does not utilize thermal conditioning:

$$FRE_{post} = Eac_{post} \quad \text{(Eq. B18)}$$

Alternatively, if the vehicle is performing PDTs between 20 to 30 °C ambient and the vehicle utilizes thermal conditioning, the FRE will be determined before the drive cycle is completed:

$$FRE_{pre} = Eac_{pre}|_{PDT} \quad \text{(Eq. B19)}$$

FRE for a vehicle performing testing at -7 °C (20 °F) and utilizes thermal conditioning is designated by FRE_{N7C}. FRE measured at -7 °C (20 °F) must include all thermal conditioning energy used during plug in charging.

$$FRE_{N7C} = Eac_{preN7C} \quad \text{(Eq. B20)}$$

FRE for a vehicle performing testing at 35 °C (95 °F) and utilizes thermal conditioning is designated by FRE_{35C}. FRE measured at 35 °C (95 °F) must include all thermal conditioning energy used during plug in charging.

$$FRE_{35C} = Eac_{pre35C} \quad \text{(Eq. B21)}$$

In the case where a vehicle performing testing at -7 °C (20 °F) or 35 °C (95 °F) and does not utilize thermal conditioning, the FRE values may be carried over or can be uniquely determined if desired. Equation B22 should be used for vehicles that do not utilize thermal conditioning on the SCT, MCT, SMCT, or SMCT+ tests and perform measured charging after the test cycle. Equation B23 should be used for vehicle that do not utilize thermal conditioning on the SCT, MCT, SMCT, or SMCT+ tests and optionally perform measured charging before the test cycle.

$$\mathrm{FRE_{35C}} = \mathrm{FRE_{N7C}} = \mathrm{FRE_{post}} \tag{Eq. B22}$$

$$\mathrm{FRE_{35C}} = \mathrm{FRE_{N7C}} = \mathrm{FRE_{pre}} \tag{Eq. B23}$$

B.2.6 Recharge Allocation Factor (RAF)

The ratio of the full depletion AC recharge energy (FRE) and the full depletion DC discharge energy (UBE). The RAF is used to allocate the measured AC recharge energy to the individual test phases based on the DC discharge energy expended in each phase. This factor enables AC energy consumption determinations for multiple drive cycle phases using a single recharging event.

For vehicles that utilize thermal conditioning before a drive cycle at -7 °C (20 °F) ambient and are allowed a carry-over UBE:

$$\mathrm{RAF_{N7C}} = \frac{\mathrm{Eac_{preN7C}}}{\mathrm{Edc_{total}}} = \frac{\mathrm{FRE_{N7C}}}{\mathrm{UBE}} \left(\frac{\mathrm{AC, W \cdot hr}}{\mathrm{DC, W \cdot hr}}\right) \tag{Eq. B24}$$

For vehicles that utilize thermal conditioning and are required to measure UBE at -7 °C (20 °F) using the modified cold FTP, cold FTP full depletion test, or cold FTP depletion test in combination with the DC discharge test procedure:

$$\mathrm{RAF_{N7C}} = \frac{\mathrm{Eac_{preN7C}}}{\mathrm{Edc_{total_{N7C}}}} = \frac{\mathrm{FRE_{N7C}}}{\mathrm{UBE_{N7C}}} \left(\frac{\mathrm{AC, W \cdot hr}}{\mathrm{DC, W \cdot hr}}\right) \tag{Eq. B25}$$

For vehicles that utilize thermal conditioning before a drive cycle at 35 °C (95 °F) ambient:

$$\mathrm{RAF_{35C}} = \frac{\mathrm{Eac_{pre35C}}}{\mathrm{Edc_{total_{35C}}}} = \frac{\mathrm{FRE_{35C}}}{\mathrm{UBE_{35C}}} \left(\frac{\mathrm{AC, W \cdot hr}}{\mathrm{DC, W \cdot hr}}\right) \tag{Eq. B26}$$

In the case where a vehicle performing testing at -7 °C (20 °F) or 35 °C (95 °F) and does not utilize thermal conditioning, the RAF values may be carried over or can be uniquely determined if desired:

$$\mathrm{RAF_{N7C}} = \mathrm{RAF_{35C}} = \mathrm{RAF} \tag{Eq. B27}$$

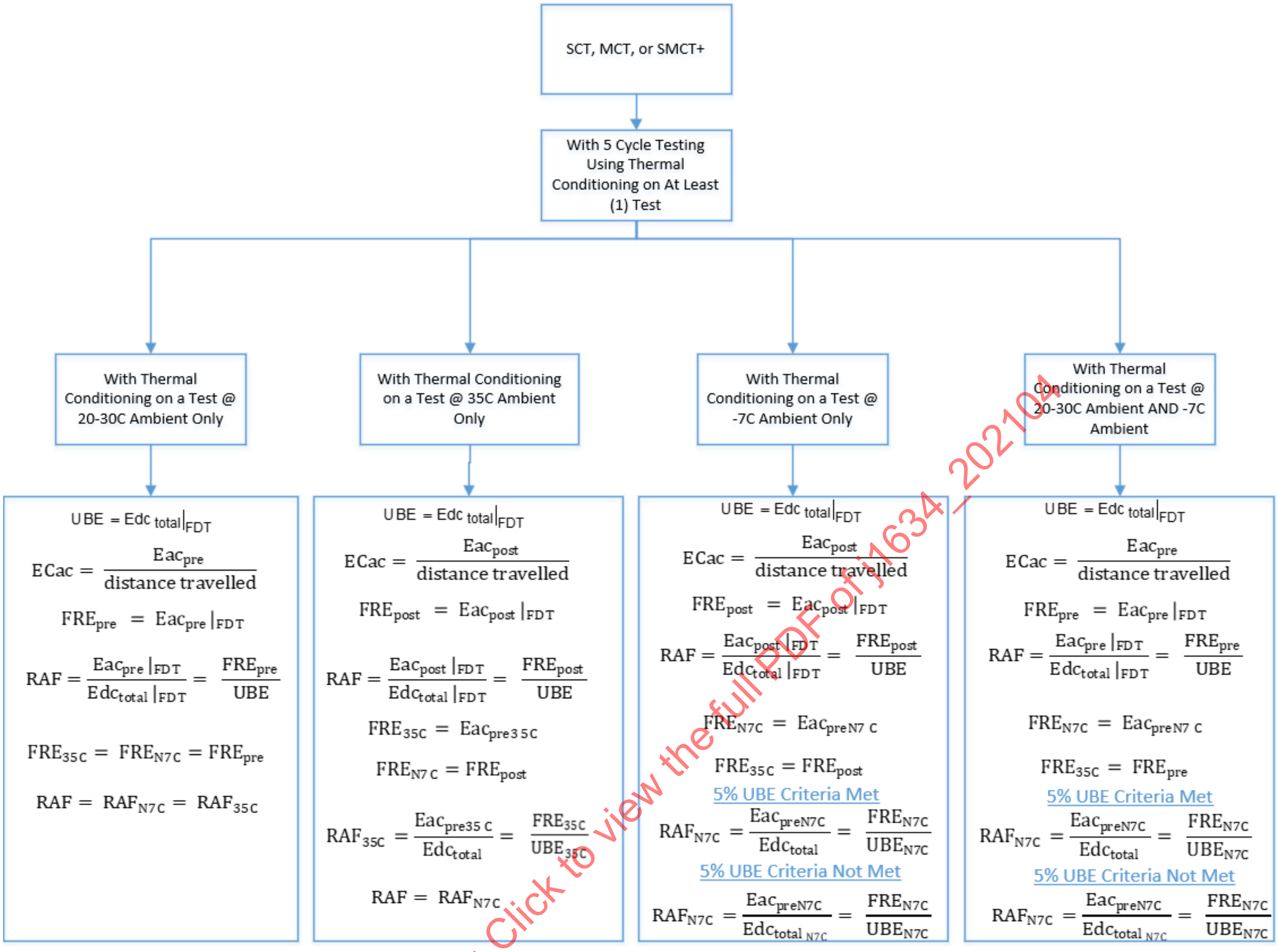

Figure B1 - Examples - equation criteria flow chart: SCT, MCT, SMCT+ utilizing thermal conditioning

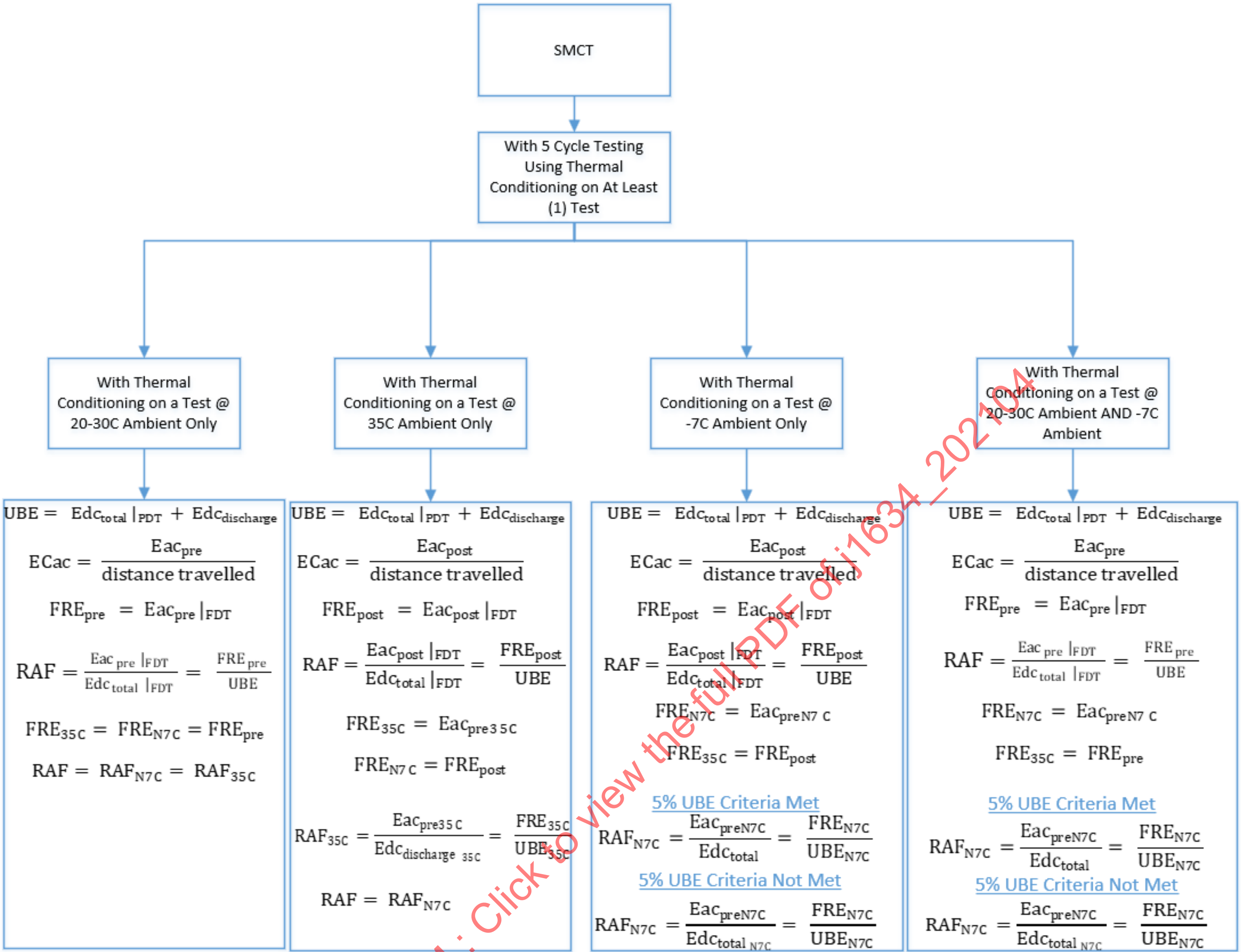

Figure B2 - Examples - equation criteria flow chart: SMCT utilizing thermal conditioning

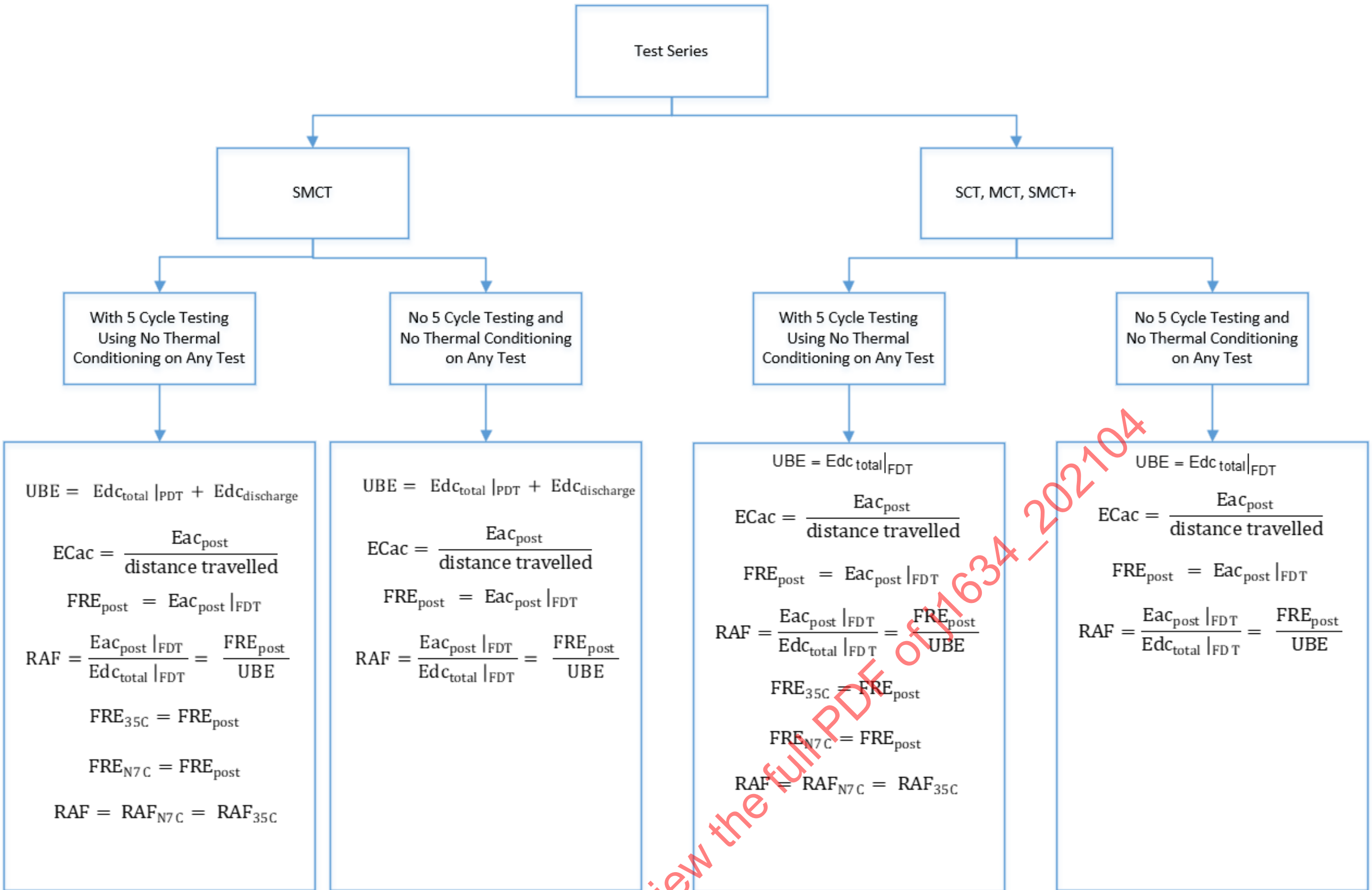

Figure B3 - Examples - equation criteria flow chart: not utilizing thermal conditioning

B.3 TEST PROCEDURES

The five test cycles are (1) the federal test procedure (UDDS), (2) the highway fuel economy test (HFEDS), (3) the US06 test, (4) the SC03 test, and (5) the -7 °C cold temperature federal test procedure (UDDS). The five-cycle fuel economy equations (40 CFR § 600.114-12) require "bag" specific fuel economy data; e.g., Bag1 FE results from the FTP and -7 °C cold temperature FTP. "Bag" data from the FTP, the -7 °C cold temperature FTP, and the US06 are subsets of the UDDS and US06 cycles and are defined in the CFR. Therefore, for the five-cycle calculation the DC discharge energy measurements and cycle distance measurements need to be integrated and recorded according to the FTP, the -7 °C cold temperature FTP, and the US06 bag definitions and not the UDDS and US06 cycle definitions. The SC03 and HFEDS are single bag tests and the complete SC03 and HFEDS test results are used in the five-cycle fuel economy calculation.

The UDDS is defined in 40 CFR § 86, Appendix 1, Paragraph (a). The individual UDDS bags are defined in 40 CFR § 86.137-94(a) and include the cold transient bag (Bag 1), the stabilized bag (Bag 2), and the hot transient bag (Bag 3). The HFEDS is defined in 40 CFR § 600, Appendix 1 and is a single bag test. The US06 is defined in 40 CFR § 86, Appendix 1, Paragraph (g). The US06 consists of two bags, a city bag and a highway bag, which are defined in 40 CFR § 1066.801. The SC03 is also a single bag test like the HFEDS and the SC03 is defined in 40 CFR § 86, Appendix 1, Paragraph (h).

B.3.1 Five-Cycle DC Discharge Test Procedures

For vehicles not utilizing thermal conditioning: DC discharge data values are needed on each of the five-cycle test procedures to create DC consumption values which are then used in the five-cycle fuel economy equations found in 40 CFR § 600.114-12. If no thermal conditioning is used for SC03, the Section 8 (MCT), Section 9 (SMCT) or Section 10 (SMCT+) RAF may be used for SC03.

For vehicles utilizing thermal conditioning: DC discharge data and cycle specific RAF values are needed on each of the five-cycle test procedures to create AC consumption values which are then used in the five-cycle fuel economy equations found in 40 CFR § 600.114-12. In some cases, the RAF may carry over between cycles if the cycle specific criteria is met.

For vehicles utilizing thermal conditioning at 20 to 30 °C ambient: The cycle specific RAF value shall be determined. If performing the drive cycle in Section 8 (MCT), Section 9 (SMCT), or Section 10 (SMCT+), RAF from this section may be used for UDDS/HFEDS/US06. The cold temperature FTP test must furnish a unique RAF, denoted RAF_{N7C}. SC03 tests utilizing thermal conditioning must furnish a unique RAF, denoted RAF_{35C}.

For vehicles utilizing thermal conditioning at -7 °C ambient: It is recommended that RAF_{N7C} is determined by Eac_{pre} and Edc_{total}. For vehicles with battery pack bulk average temperatures in excess of 20 °C prior to cold FTP dynamometer cycle, UBE may be carried over from Section 8 (MCT), Section 9 (SMCT), or Section 10 (SMCT+) testing for use at -7 °C ambient. Likewise, vehicles with battery pack bulk initial average temperature within -4 °C < x < 20 °C are able to carry over UBE if data or good engineering judgment can show UBE with 5% of the UBE declared for Sections 8, 9, or 10. If neither can be shown, UBE must be determined for -7 °C. Several options are provided to determine UBE for -7 °C, including the use of the cold FTP full depletion cycle in this appendix. Alternatively, the modified cold FTP cycle or cold FTP in combination with the DC discharge procedure can be used to determine UBE at -7 °C using Appendix C.

B.3.2 Five-Cycle Testing Overview

DC discharge data are measured on a single FTP, HFEDS, and US06 or combination tests. DC discharge energy and distance are measured and recorded for each bag of the FTP (Bag 1, Bag 2, and Bag 3), each bag of the US06 (city bag and highway bag) and for the HFEDS.

B.3.2.1 Battery Charge Condition

For all five-cycle tests (except cold FTP) with vehicles not utilizing thermal conditioning, the BEV shall be re-charged to a minimum 50% state of charge up to full charge condition prior to test. For all five-cycle tests utilizing thermal conditioning or any cold FTP tests (with or without thermal conditioning), the BEV shall be re-charged to full charge condition prior to test. Vehicles that do not use thermal conditioning on a specific test cycle must be unplugged for the remainder of the soak period after 12 hours or charge complete, whichever is longest, up until the point of moving the vehicle to the dynamometer to begin the drive cycle. Vehicles that do not use thermal conditioning from wall energy sources cannot provide thermal conditioning with on-board vehicle energy during the soak period prior to the drive cycle. Vehicles that use thermal conditioning on a specific test cycle must remain plugged in and AC energy shall be recorded during soak up until the point of moving the vehicle to the dynamometer to begin the drive cycle.

Perform the FTP test using the procedures as described in 40 CFR § 1066.810 through 1066.820. Perform the HFEDS test using the procedures as described in 40 CFR § 1066.840. Perform the US06 test using the procedures described in 40 CFR § 1066.830 and 40 CFR § 1066.831. As an alternative, SMCT data for FTP, HFEDS, and US06 may be used for five-cycle calculations from Sections 9 or 10 of this standard.

B.3.2.2 Special Test Considerations - SC03 Test

For vehicles not utilizing thermal conditioning: Set the BEV to the battery state of charge condition described in B.3.2.1. The vehicle must be unplugged after 12 hours or charge complete, whichever is longest. Vehicles that do not use thermal conditioning from wall energy sources cannot provide thermal conditioning with on-board vehicle energy during the soak period. A vehicle preconditioning cycle is performed prior to the measured SC03 cycle as described in 40 CFR § 1066.835. DC discharge energy and distance are measured and recorded during the SC03 test. Perform the SC03 test as described in 40 CFR § 1066.830 and 40 CFR § 1066.835.

For vehicles utilizing dynamometer thermal conditioning: Set the BEV to the battery state of charge condition described in B.3.2.1. Plug in vehicle and record the charge energy for a minimum of 12 hours or up until the point of moving the vehicle to the dynamometer to begin the drive cycle. Use a soak room at 20 to 30 °C with no solar load. Within 1 hour after un-plugging vehicle, load vehicle onto dyno site and perform actions necessary for a "test-ready" site. Begin site prep to 35 °C and 850 W/m[2] solar load. As the site temperature begins to stabilize at 35 °C, plug in vehicle, and initiate thermal conditioning and record the wall energy for the thermal conditioning event, denoted as "dynamometer thermal conditioning" in Eq. B28 (AC kWh).Immediately upon plugging in vehicle, begin thermal conditioning of vehicle either through the vehicle's remote, phone app, or inside vehicle. If activated inside vehicle, leave vehicle immediately upon enabling. Do not start the vehicle.

Apply thermal conditioning to the cabin or battery systems for the prescribed time as recommended by the vehicle manufacturer up to a maximum of 1 hour. Ensure this is no leak path to the dynamometer ambient air from the vehicle during thermal conditioning. If an interior access point (Hioki cable, other measurement equipment, etc.) is necessary ensure to keep it as small as possible. Once complete, record the final charge energy value. Unplug vehicle and begin SC03 test immediately, ensuring quick entry into the vehicle to avoid heat transfer from the cabin to the dynamometer cell ambient air. Total Eac_{pre35C} AC charge energy is thus the summation of battery charging energy from the soak room and thermal conditioning energy used at the dyno prior to the drive cycle.

$$\mathrm{Eac_{pre35C}} = \mathrm{Eac_{pre}} + \text{dynamometer thermal conditioning} \qquad \text{(Eq. B28)}$$

A prepatory drive cycle is performed prior to the measured SC03 cycle as described in 40 CFR § 1066.835. DC discharge energy and distance are measured and recorded during the SC03 test. Perform the SC03 test as described in 40 CFR § 1066.830 and 40 CFR § 1066.835.

B.3.2.3 Special Test Considerations - Cold FTP

Instead of performing a single -7 °C cold temperature FTP, a charge depleting -7 °C cold temperature FTP is performed. After soaking for the specified time after charge completion, a charge depleting test is performed in the -7 °C cold FTP test cell and the DC discharge energy is measured for each bag of the -7 °C cold temperature FTP discharge test. DC discharge and distance data from Bag 1 of the first charge depleting UDDS and from Bag 3 of the second charge depleting UDDS are then recorded. The total DC discharge energy and measured distance for the charge depleting -7 °C cold temperature FTP shall also be recorded.

For vehicles not utilizing thermal conditioning: Prior to the start of the cold soak period the BEV shall be recharged, without measurement, to FC condition at either ambient or cold soak conditions. The vehicle must remain unplugged during the cold soak period prior to UDDS testing and after battery charging is complete or 12 hours have elapsed, whichever is longer.

For vehicles utilizing thermal conditioning: Prior to the start of the cold soak period the BEV shall be recharged, with AC energy measurement, to FC condition at cold soak conditions. the vehicle must remain on charge during the cold soak period prior to UDDS testing and after battery charging is complete. AC recharge energy shall be recorded during the entire soak period. RAF_{N7C} must be calculated by using measured charge and thermal conditioning energy prior test as well as UBE_{N7C}. Determination of the source of UBE_{N7C} must be identified prior to the start of test to determine the test length.

For vehicles utilizing dynamometer thermal conditioning: Vehicle should begin procedure with a fully depleted battery. Plug in vehicle and record the charge energy for a minimum of 12 hours or up until the point of moving the vehicle to the dynamometer to begin the drive cycle. Use a soak room at -7 °C with no solar load. Remove vehicle from soak room and place in -7 °C dyno cell. It is preferred that the soak room and dyno are in the same location to avoid temperature changes to the vehicle during vehicle movement. Load vehicle onto dyno site and perform actions necessary for a "test-ready" site. Plug in vehicle and record the wall energy (AC kWh) for the thermal conditioning event. Immediately upon plugging in vehicle, begin thermal conditioning of vehicle either through the vehicle's remote, phone app, or inside vehicle. If activated inside vehicle, leave vehicle immediately upon enabling. Do not start the vehicle.

Apply thermal conditioning to the cabin or battery systems for the prescribed time as recommended by the vehicle manufacturer up to a maximum of 1 hour. Ensure this is no leak path to the dynamometer ambient air from the vehicle during thermal conditioning. If an interior access point (Hioki cable, other measurement equipment, etc.) is necessary ensure to keep it as small as possible. Once complete, record the final charge energy value. Unplug vehicle and begin -7 °C cold FTP test immediately, ensuring quick entry into the vehicle to avoid heat transfer from the cabin to the dynamometer cell ambient air. Total Eac_{preN7C} AC charge energy is thus the summation of battery charging energy from the soak room and thermal conditioning energy used at the dyno prior to the drive cycle.

$$\mathrm{Eac_{preN7C}} = \mathrm{Eac_{pre}} + \text{dynamometer thermal conditioning} \qquad \text{(Eq. B29)}$$

Perform the -7 °C cold temperature FTP as described in 40 CFR § 1066, Subpart H.

B.3.3 Two-Cycle Charge Depletion Testing

Full charge depleting UDDS and HFEDS tests are performed while measuring DC discharge energy and AC recharge energy according to the procedures in Sections 7, 8, 9, or 10. A two-cycle AC fuel economy (mile/kWh_{AC}) is calculated by harmonically averaging the charge depleting UDDS and HFEDS AC fuel economy results. The harmonic average calculation is described in 40 CFR § 600.206-12(a)(3)(i).

B.3.4 BEV Five-Cycle Adjustment Factor Calculation

For non-thermally conditioned vehicles: The BEV five-cycle adjustment factor is calculated by dividing the five-cycle DC mile/kWh_{DC} by the two-cycle charge depleting DC mile/kWh_{DC}. The five-cycle DC mile/kWh_{DC} is calculated by entering the DC consumption values measured and substituting mile/kWh_{DC} into the five-cycle equations found in 40 CFR § 600.114-12. If any test within the five-cycle calculation utilizes thermal conditioning, this method shall not be used.

For thermally conditioned vehicles: The BEV five-cycle adjustment factor is calculated by dividing the five-cycle AC mile/kWh_{AC} by the two-cycle charge depleting AC mile/kWh_{AC}. The five-cycle AC mile/kWh_{AC} is calculated by entering the AC consumption values measured and substituting mile/kWh_{AC} into the five-cycle equations found in 40 CFR § 600.114-12.

To determine the equivalent mile/kWh_{AC}, the following equations shall be used for each of the five-cycles:

For UDDS/HWFEDS/US06/SC03 cycles not utilizing thermal conditioning:

$$\mathrm{mile/kWh_{AC}} = \left(\frac{1}{\mathrm{RAF_{post}}}\right) \cdot \mathrm{mile/kWh_{DC}} \qquad \text{(Eq. B30)}$$

Manufacturers may elect to use pre-test charging energy if equivalent to post-test charging results.

Alternatively, if the SCT, MCT, SMCT, or SMCT+ are performed utilizing thermal conditioning:

$$\mathrm{mile/kWh_{AC}} = \left(\frac{1}{\mathrm{RAF_{pre}}}\right) \cdot \mathrm{mile/kWh_{DC}} \qquad \text{(Eq. B31)}$$

For the cold FTP cycle utilizing thermal conditioning:

$$\text{Cold FTP } \mathrm{mile/kWh_{AC}} = \left(\frac{1}{\mathrm{RAF_{N7C}}}\right) \cdot \mathrm{mile/kWh_{DC}} \qquad \text{(Eq. B32)}$$

For SC03 utilizing thermal conditioning:

$$\text{SC03 } \mathrm{mile/kWh_{AC}} = \left(\frac{1}{\mathrm{RAF_{35C}}}\right) \cdot \mathrm{mile/kWh_{DC}} \qquad \text{(Eq. B33)}$$

The numerator used for the BEV calculations in the city and highway fuel economy equations is 0.92 instead of 0.905 as shown in 40 CFR § 600.114-12. The numerator value is revised to remove the gasoline ethanol-content correction factor from the five-cycle equation.