

APPENDIX F

GLOSSARY OF BATTERY AND BATTERY TESTING TERMINOLOGY FOR THE USABC BATTERY TEST PROCEDURES

Glossary of Battery and Battery Testing Terminology for the USABC Battery Test Procedures

acceleration power (kW)	The battery power required to accelerate an electric vehicle from zero to a specified speed in a specified time. The battery voltage must be maintained above a specified minimum. For example, 50 kW acceleration power may be required when a vehicle is accelerated from 0 to 80 km per hour in 20 seconds, with battery voltage maintained above 2/3 of the open-circuit voltage (highest open-circuit encountered through entire state of charge) during the 50-kW discharge.
active materials	The constituents of a cell that participate in the electrochemical charge/discharge reactions. Specifically, this normally does not include separators, current collectors, catalysts or supports.
active material area loading (g/cm ²)	The weight of active material per unit electrode area.
active material loading density (g/cm ³)	The weight of active material per unit electrode volume.
anode*	The electrode in an electrochemical cell at which oxidation takes place. During discharge, the negative terminal of the cell is the anode; however, during charge, the positive terminal of the cell is the anode. For rechargeable batteries, the electrodes are normally referred to according to the reactions that occur during discharge.
average power (kW)	Total energy withdrawn (or returned) from (or to) a battery divided by the time of discharge (or charge).
average voltage (V)	The ratio of the watt-hours delivered to the Ampere-hours delivered for a given discharge or charge. Not necessarily a simple average of voltage over time. Also known as <i>current weighted voltage</i> .
battery	Electrochemical cells electrically connected in a series and/or parallel arrangement.
battery cell	An assembly of at least one positive electrode, one negative electrode, and other necessary electrochemical and structural components. A cell is a self-contained energy conversion device whose function is to deliver electrical energy to an external circuit via a controlled internal chemical process. This chemical-to-electrical energy conversion process involves ionic transport between electrodes having different potentials.
battery module	The smallest grouping of physically and electrically connected cells that can be replaced as a unit. A module can be thought of as the smallest, repeating building block of a battery pack.
battery pack	An array of interconnected modules that has been configured for its intended energy storage application, that is, the configuration is application dependent.
battery system	Completely functional energy storage system consisting of the pack(s) and necessary ancillary subsystems for physical support, thermal management, and electronic control.

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battery system mass fraction	Ratio of battery system weight to gross vehicle weight.
battery volume (l)	The volume of the battery. Cell, module, pack, or system should be specified, and should include the usable volume displaced.
battery weight (kg)	The weight of the battery. Cell, module, pack, or system should be specified.
calendar life	The length of time a battery can undergo some defined operation before failing to meet its specified end-of-life criteria.
capacity {C} (Ah)	The total number of Ampere-hours that can be withdrawn from a fully charged battery under specified conditions. Also referred to as <i>coulombic capacity</i> .
available, or deliverable, capacity (Ah)	The total ampere-hours that can be withdrawn from a fully charged cell or battery for a specific set of operating conditions including discharge rate, temperature, age, stand time, and any discharge cutoff criteria specified by the battery manufacturer.
C_i (Ah)	The capacity in Ampere-hours obtained from a battery discharged at a constant current to an end-of-discharge condition (discharge cutoff voltage) in precisely i hours. C_i is established once and is not adjusted through the battery's life.
energy output, or energy capacity* (Wh)	The total watt-hours that can be withdrawn from a fully charged battery for a specific set of operating conditions including temperature, rate, age, stand time, and discharge cutoff criteria (specified by battery manufacturer).
rated capacity (Ah)	The developer's or manufacturer's specification for capacity. This single value is chosen by the manufacturer to best represent the expected performance of the item when tested under all the conditions of this manual.
residual capacity (Ah)	The Ampere-hours that can be discharged from a battery at a specified discharge rate and temperature after it has been exposed to specified conditions, such as driving-profile or open-circuit stand tests.
specific capacity (mAh/g)	Capacity per unit weight of active material. This term is usually applied to active materials and/or electrodes (that is, including current collectors).
theoretical capacity (Ah)	The capacity of a cell's active material, assuming 100% utilization.
capacity area density (mAh/cm ²)	The electrochemical capacity of active material per unit electrode area.
cathode*	The electrode in an electrochemical cell at which reduction takes place. During discharge, the positive terminal of the cell is the cathode; however, during charge, the negative terminal of the cell is the cathode. For rechargeable batteries, the electrodes are normally referred to according to the reactions that occur during discharge.
cell	See battery cell.

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cell, secondary	A cell, as described herein (see battery cell), with two additional attributes: rechargeability and energy storage. Rechargeability is the application of electricity in order to repeatedly reverse the internal chemical process once the chemical energy has been discharged. Energy storage is the retention of recharged chemical energy with minimal losses during periods when the cell is not in use.
charge	Conversion of electrical energy into chemical potential energy within a cell by the imposed passage of a direct current.
charge profile	Schedule used for charging a battery. For example:
constant current charging {CI}	Charging of a battery at a controlled, constant rate of electron flow (normally applied with a maximum voltage limit).
constant voltage (potential) charging {CV}	Charging of a battery by applying a constant voltage while allowing the current to vary (normally applied with a maximum current limit).
CI/CV	A constant current charge followed by a constant-voltage charge. See also finishing charge rate, float charge, and trickle charge.
charge rate {C _i /X} (A)	The current applied to a battery to restore its available capacity. The current can be expressed in amperes, but more commonly it is normalized to the rated capacity (C) of the battery, and expressed as C _i /X, where i is the hour rate for the rated capacity, and X is a time specification, usually in hours. If i is not given, it is assumed to be the same as X. For example, the 10-hour charge rate of a 500-ampere-hour battery (rated at the 5-hour discharge rate) is expressed as <div style="text-align: center;"> $\frac{\text{rated capacity}}{\text{charge time}} = \frac{500 \text{ ampere-hours}}{10 \text{ hours}}$ $= 50 \text{ amperes} = C_5/10 \text{ rate.}$ </div> <p>In contrast, the capacity of the same battery rated at the 3-hour discharge rate might be 450 Ampere-hours, giving a 10-hour charge rate of</p> $450/10 = 45A = C_3/10 \text{ rate.}$
core performance tests	The minimal set of tests that must be initially performed on every USABC test unit, and which is a subset of the general performance characterization tests. Refer to Figure 1. Outline of USABC Laboratory Battery Testing Process in this manual for a list of included tests.
current {I} (A)	The rate of flow of electricity in a circuit.
current collector	A part of an electrode that conducts electrons. It may also serve as a structural support for the electrode.
current density (mA/cm ²)	The current per unit electrode area. Determined by dividing the charge or discharge current by the total geometric (projected) area of the positive or negative electrode.
cutoff voltage (V)	The battery voltage at which charge or discharge is terminated.

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cycle	The period commencing from the start of one charge/discharge to the start of the next charge/discharge where said period includes discharge time, open-circuit time, and charge time. The depth of discharge (or percentage of capacity) associated with each cycle must be specified.
cycle life	The number of cycles, each to specified discharge and charge termination criteria, such as depth-of-discharge, under a specified charge and discharge regime, that a battery can undergo before failing to meet its specified end-of-life criteria.
deep discharge	A qualitative term indicating the withdrawal of a significant percentage of capacity (typically, 80 percent or more).
depth-of-discharge {DOD} (%)	The ratio of the net Ampere-hours discharged from a battery at a given rate to the rated capacity.
discharge	Spontaneous conversion of chemical potential energy into electrical energy within a cell, which results from allowing the passage of direct current.
discharge regime	Schedule used for battery discharge that follows a particular current (or power) versus time sequence. Recharge segments may be included. The USABC's Dynamic Stress Test (DST) is a discharge regime commonly used to evaluate the service life of EV batteries.
discharge profile	The longest, unique repeating unit of a discharge regime (specifically, 360 sec for the DST; 1372 seconds for the FUDS)
discharge segment	A subsection of a profile. A convenient, contiguous grouping of specific steps in a profile.
discharge step	A change from one power level to another in a discharge profile.
discharge rate {C _i /X} (A)	<p>The current during discharge of a battery. The current can be expressed in amperes, but more commonly it is normalized to the rated capacity (C) of the battery, and expressed as C_i/X, where <i>i</i> is the hour rate for the rated capacity, and X is a time specification, usually in hours. If <i>i</i> is not given, it is assumed to be the same as X. For example, the 10-hour discharge rate of a 500-ampere-hour battery (rated at the 5-hour discharge rate) is expressed as</p> $\frac{\text{rated capacity}}{\text{discharge time}} = \frac{500 \text{ ampere-hours}}{10 \text{ hours}}$ <p>= 50 amperes = C₅/10 rate.</p> <p>In contrast, the capacity of the same battery rated at the 3-hour discharge rate might be 450 Ampere-hours, giving a 10-hour discharge rate of</p> $450/10 = 45\text{A} = C_3/10 \text{ rate.}$
Discharge Voltage Limit	The minimum voltage under load permitted during performance of the Peak Power Test and other performance tests. It is equal to 2/3 of the open circuit voltage at 80% DOD at beginning of life, unless the manufacturer specifies a more restrictive (higher) value.
DOD	See depth-of-discharge.

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driving profile	A schedule of vehicle speed versus time that is used to test vehicle and battery characteristics.
Dynamic Stress Test (DST)	A variable-power discharge regime, developed by USABC to simulate expected demands of an EV battery. This specific regime can effectively simulate dynamic discharging and can be implemented with equipment at most test laboratories and developers.
DST _n	A label for reporting DST test results which indicates that the data result from a DST scaled to a peak power value of n W/kg.
efficiency (%)	The ratio of the useful output to the input:
coulombic (Ah-) (%)	The ratio of the Ampere-hours removed from a battery during a discharge to the Ampere-hours required to restore the battery to the state of charge before the discharge was started: <div style="text-align: center; margin: 10px 0;"> $\frac{\text{ampere-hours discharged}}{\text{ampere-hours charged}} = \frac{\int_0^{t_d} i_d dt}{\int_0^{t_c} i_c dt}$ </div> <p>where i_d and i_c are the discharge and charge currents, respectively, and t_d and t_c are the discharge and charge times, respectively.</p>
energy (watt-hour, round trip) efficiency (%)	The ratio of the net DC energy delivered by a battery during a discharge to the total DC energy required to restore the initial state-of-charge: <div style="text-align: center; margin: 10px 0;"> $\frac{\text{watt-hours discharged}}{\text{watt-hours charged}} = \frac{\int_0^{t_d} i_d v_d dt}{\int_0^{t_c} i_c v_c dt}$ </div> <p>where v_d and v_c are the discharge and charge voltages, respectively, i_d and i_c are the discharge and charge currents, respectively, and t_d and t_c are the discharge and charge times, respectively. The watt-hour efficiency is equal to the product of the voltaic and coulombic efficiencies.</p>
voltaic (%)	The ratio of average voltage during discharge of a battery to the average voltage during charge with the prior or subsequent restoration of an equivalent capacity.
battery system energy efficiency (%)	Round trip <i>battery system</i> energy efficiency should be distinguished from general energy efficiency as defined above. It must include energy losses resulting from self-discharge, cell equalization, thermal loss compensation, and all battery-specific auxiliary equipment.
electrode	The conducting body that contains active materials and through which current enters or leaves a cell.
electrolyte	The medium that provides ion transport between the positive and negative electrodes of a cell. It may participate directly in the charge/discharge reactions.

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end-of-charge voltage {EOCV} (V)	The battery voltage when charge is terminated.
end-of-discharge voltage {EODV} (V)	The battery voltage when discharge is terminated.
end-of-life	The stage at which the battery meets specific failure criteria (e.g., capacity and/or power degradation). Specifically, when either: <ul style="list-style-type: none"> (1) the net delivered capacity of a cell, module, or battery is less than 80% of its rated capacity when measured on the DST (Reference Performance Test); or (2) the peak power capability (determined using the Peak Power Test) is less than 80% of the rated power at 80% DOD.
end of (life cycle) test	The condition that occurs when the actual performance of the test unit degrades to a level defined in the test plan and life-cycle testing is to be terminated. This end-of-test condition may or may not be related to end-of-life depending on test plan objectives.
energy density (Wh/l)	The rated energy of a battery (Wh) divided by the total battery volume (l). Also referred to as volumetric energy density.
equalization	The process of restoring all cells in a battery to an equal state-of-charge. This can consist of a prolonged charge or a complete discharge to a shorted condition, depending on the battery technology.
failure criteria	Specific battery performance characteristics that, when reached, indicate the battery can no longer perform its intended duty cycle.
finishing charge rate (A)	The current specified for completing the charging of a battery that is nearing 100% state of charge.
float charge	Charging a battery at a fixed voltage for extended periods of time to obtain or maintain the fully charged condition.
FUDS	Federal Urban Driving Schedule. The Environmental Protection Agency (EPA) urban dynamometer driving schedule, as defined in 40 CFR (Code of Federal Regulations), paragraph 86.115-78. A velocity-versus-time profile defined by the EPA to test for vehicle emissions and city fuel economy. When used as a laboratory battery test, a vehicle must be specified to derive a scaleable, power-versus-time profile from the velocity profile.
gassing	The evolution of gas at the interface between the electrolyte and the surface of an electrode (or both electrodes) in a cell.
grid	The framework for a plate or electrode that supports or retains the active materials and acts as a current collector. It is also known as the substrate.
high-rate discharge	A qualitative term indicating a discharge rate that is usually greater than the $C_i/1$ rate, e.g., $2C_i$ rate, where i is an integer denoting the rate at which C was determined. See discharge rate (C_i/X)

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hour rate (h)	The charge or discharge current of a battery expressed in terms of the length of time a new, fully charged battery can be discharged at a specific current before reaching a specified end-of-discharge voltage. For example, the 10-hour rate for discharging a 500-ampere-hour cell (rated at the 5-hour rate) would be 50 amperes. See charge rate or discharge rate.
internal impedance (ohm)	Opposition to the flow of an alternating current at a particular frequency in a battery at a specified state-of-charge and temperature.
internal resistance (ohm)	Opposition to direct current flow in a battery. Its value may vary with the current, state-of-charge, age, and temperature. It is the sum of the ionic and electronic resistances of the cell components.
long-term	Design feasibility and performance benefits demonstrated by vehicle tests of full-scale experimental batteries by mid-year 1995.
memory effect	A temporary loss of available battery capacity because of repetitive cycling to less than 100% DOD.
mid-term	Performance demonstrated by vehicle road-test of full-scale experimental batteries. Volume production and processing capability demonstrated by limited-run prototype production in a pilot plant by mid-year 1995.
minimum discharge voltage*	See Discharge Voltage Limit
negative electrode	Of the two electrodes comprising a cell, the electrode at which the associated half-cell reaction has the lower potential. It is negative in voltage relative to the other electrode of the cell. It is the electrode at which oxidation occurs during (spontaneous) discharge of the cell.
net Ampere-hours (Ah)	For a discharge test including both negative (discharge) and positive (regen) current or power steps, the difference between the Ah removed from the battery during discharge steps and the Ah returned to the battery during regen steps, regardless of battery charge acceptance.
nominal operating voltage (V)	The voltage of a battery, as specified by the manufacturer, discharging at a specified rate and temperature.
nonaqueous batteries	Batteries that do not contain water, such as those with molten salt, organic liquid, organic solid, or inorganic solid electrolytes.
open-circuit, IR-free, voltage { V_{IRFree} OCV} (V)	The voltage of a battery (at a specified state-of-charge and temperature) in the absence of charge or discharge current. It varies during the period following a charge or discharge and with state-of-charge. Also known as <i>no-load voltage</i> , it is a dynamic, derived value. At steady-state (with no current), the IR-free OCV approaches the true open-circuit voltage
overcharge (Ah)	The amount by which the charge Ampere-hours exceed the Ampere-hours removed on the previous discharge, sometimes reported as a percentage. Occasionally, this excess is normalized to the rated capacity.

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performance degradation	The extent to which the battery system is unable to meet the original performance specification or rating established for the battery. Performance characteristics of interest include capacity and power requirements, as well as other standards, such as, energy efficiency and charge retention. See end-of-life.
Peukert curve	Plot of the logarithm of the discharge rate versus the logarithm of discharge time to a specified end-of-discharge voltage.
polarization (V)	The voltage deviation from equilibrium open-circuit voltage caused by the flow of current in a battery.
positive electrode	Of the two electrodes comprising a cell, the electrode at which the associated half-cell reaction has the higher potential. It is positive in voltage relative to the other electrode of the cell. It is the electrode at which reduction occurs during (spontaneous) discharge of the cell.
power	
continuous (W)	A power level characteristic of a battery providing constant power for constant speed vehicle operation. Nominally, the power level required to remove 75% of the rated energy from the battery in 1 hour. Refer to <u>Procedure #4</u> , for details.
peak (W)	The 30s sustained pulse power obtainable from a battery under specified conditions. The peak power (at a given DOD) can be calculated by deriving the battery resistance and equivalent IR-free voltage from measured changes in battery voltage and current (at the given DOD). Refer to <u>Procedure #3</u> for details.
rated (W)	The manufacturer's specification of the discharge power capability of a battery.
regen (W)	The power delivered to a battery during regenerative braking.
power density (W/l)	The rated power of the battery (W) divided by the total volume of the battery (l). Also referred to as volumetric power density. Other common (and similarly derived) terms include peak power density and continuous power density.
power-to-energy ratio {P/E} (h ⁻¹)	Ratio of the peak power obtained under specified conditions, such as depth-of-discharge, to the energy output obtained under specified discharge conditions.
Ragone curve	Plot of the specific energy as a function of the continuous specific power at which the battery is discharged. Originally defined as the set of curves ranging between the high-power design and the high-energy design for a particular technology.
recharge factor	The inverse of the coulombic efficiency, expressed as a ratio, for a cycle.
reference performance test (RPT)	The set of tests to be performed periodically to monitor performance degradation during life-cycle testing. Refer to <u>Procedure #14C</u> for details.

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regenerative braking	The recovery of some fraction of the energy normally dissipated in friction braking into energy to be stored in an energy storage device. Also referred to as regen braking.
reversal	Forced discharge of a battery cell voltage below zero, that is, to the point that the cell's electrical terminals change polarity.
self-discharge	The process by which the available capacity of a battery is spontaneously reduced by undesirable chemical reactions or electronic short circuits within the cell.
separator	A cell component placed between the negative and positive electrodes that acts as an electronic insulator and physical separator. The electrolyte (ionic conductor) may also act as a separator.
service life	A general term that describes the length of time a battery can remain in service. Normally, the service life consists of calendar and/or cycle life.
short-circuit current (A)	That current delivered when a battery is short-circuited (i.e., the positive and negative terminals are directly connected with a low-resistance conductor).
specific energy (Wh/kg)	The discharge energy capacity of the battery divided by the total battery weight. Varies with discharge conditions.
specific peak power (W/kg)	The peak power of the battery divided by the total battery weight. Other common (and similarly derived) terms include specific peak power and specific continuous power.
specific power (W/kg)	The rated power of the battery divided by the total battery weight. Occasionally, referred to as gravimetric power density.
state-of-charge {SOC} (%)	The ratio of the Ampere-hours remaining in a battery at a given rate to the rated capacity under the same specified conditions (SOC = 100% – DOD).
temperature coefficient of capacity	The ratio of the change in available capacity because of a battery temperature change relative to the available capacity at a specified temperature.
thermal loss (W/kWh)	The power required to maintain a battery at its specified operating temperature, normalized by the battery's rated energy capacity.
throughput (Wh)	Cumulative, net energy output provided by a battery over its service life. It is the sum of all the energy delivered over all the discharges that the battery has provided.
trickle charge	Low-rate charging current applied to a battery to maintain full charge.
utilization (%)	The percentage by weight of the limiting active material present in an electrode that is electrochemically available for discharge at useful voltages. It is equal to the actual capacity divided by the theoretical capacity.

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