US Battery Performance and Durability Testing

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Battery Testing in the US

- Battery performance and life testing in the US is application-driven
- Current focus is on HEVs, PHEVs and EVs
- For simplicity, this presentation will be focused on test methods for PHEVs and EVs at the pre-competitive stage
- General testing philosophy
  - Obtain sufficient information in a limited amount of time to gauge the performance of a battery without exhausting it
  - The test procedures employ accelerated aging techniques
  - The test procedures used are applicable to cells, modules and complete battery systems
- Anatomy of battery testing
  - Characterize the performance of a battery
  - Age it under controlled conditions
  - Measure changes in performance by repeating portions of the characterization tests
    - A reference performance test

PHEV Battery Testing

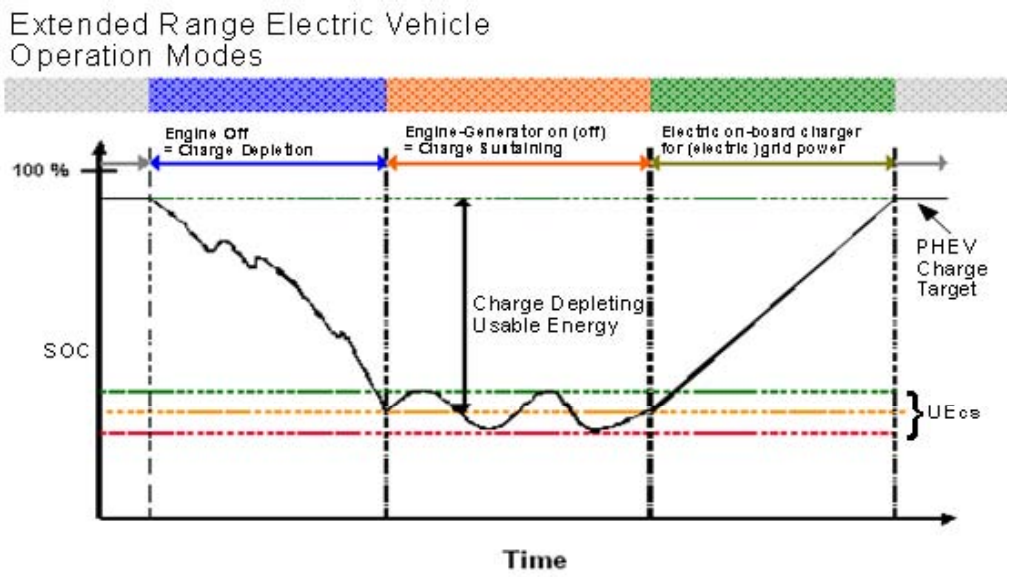
- The US Advanced Battery Consortium (USABC) has established performance and life targets for PHEVs
- Intended vehicle platforms
  - Minimum PHEV battery target: a sport utility vehicle with a mass of 2000 kg and with an equivalent electric range of 10 miles (16 km)
  - Medium PHEV battery target: a passenger car with a mass of 1600 kg and with an equivalent electric range of 20 miles (32 km)
  - Maximum PHEV battery target: a passenger car with a mass of 1500 kg and with an equivalent electric range of 40 miles (64 km)
- The goals are directly applicable to complete battery systems; most can be applied to the testing of modules, cells or sub-scale cells with appropriate scaling (battery scale factor)

Selected Energy Storage System Target Values

Characteristics at EOL (End-of-Life)	Unit	Min PHEV Battery	Med PHEV Battery	Max PHEV Battery
Equivalent Electric Range	Miles (km)	10 (16)	20 (32)	40 (64)
Peak Discharge Pulse Power (2 sec /10 s)	kW	50/45	45/37	46/38
Peak Regen Pulse Power (10 s)	kW	30	25	25
Max. Current -10s	A	300	300	300
Available Energy for CD Mode, 10-kW Rate	kWh	3.4	5.8	11.6
Available Energy for CS Mode, 10-kW Rate	kWh	0.5	0.3	0.3
Minimum Efficiency	%	90	90	90
Cold cranking power at -30°C	kW	7	7	7
CD Life	Cycle	5,000	5,000	5,000
CS HEV Cycle Life, 50 Wh Profile	Cycles	300,000	300,000	300,000
Calendar Life, 35°C	Year	15	15	15

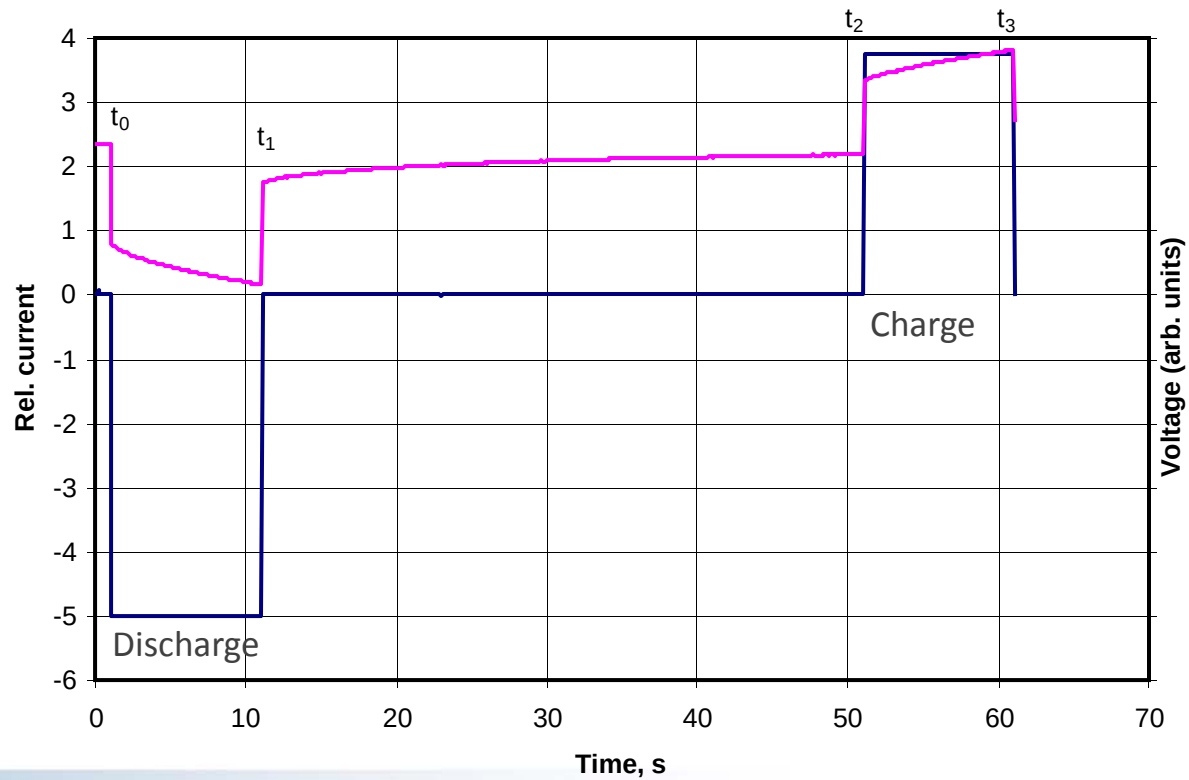
Test Procedures Are Derived From Goals

- The principle objective of the procedures in the test manual is to provide a means to compare battery performance and life to the targets
- For a PHEV, there are two modes of operation
  - Charge-depleting
    - Electric propulsion only
    - Discharges the battery
  - Charge-sustaining
    - Hybrid gasoline-electric propulsion
    - Maintains a relatively constant state-of-charge
  - Procedures allow the effect of each mode of operation on battery life to be characterized



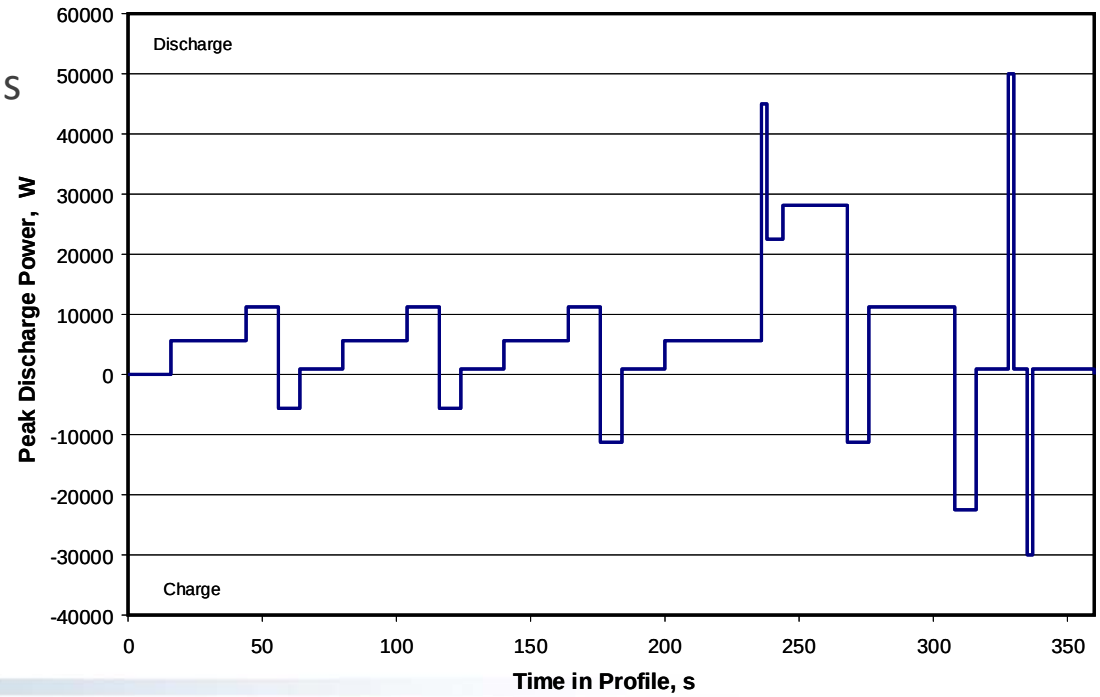
PHEV Test Procedures: Characterize Battery Performance

- Batteries are characterized in terms of constant-current capacity, self-discharge, hybrid pulse-power capability (HPPC), cold cranking (5 kW at -30°C), thermal performance and energy efficiency
- HPPC Test: Measure battery impedance and power/energy characteristics
- $R_d = \Delta V / \Delta I = (V_{t1} - V_{t0})/(I_{t1} - I_{t0})$; $R_r = (V_{t3} - V_{t2})/(I_{t3} - I_{t2})$
- End-of-test: Power or energy values are less than target values



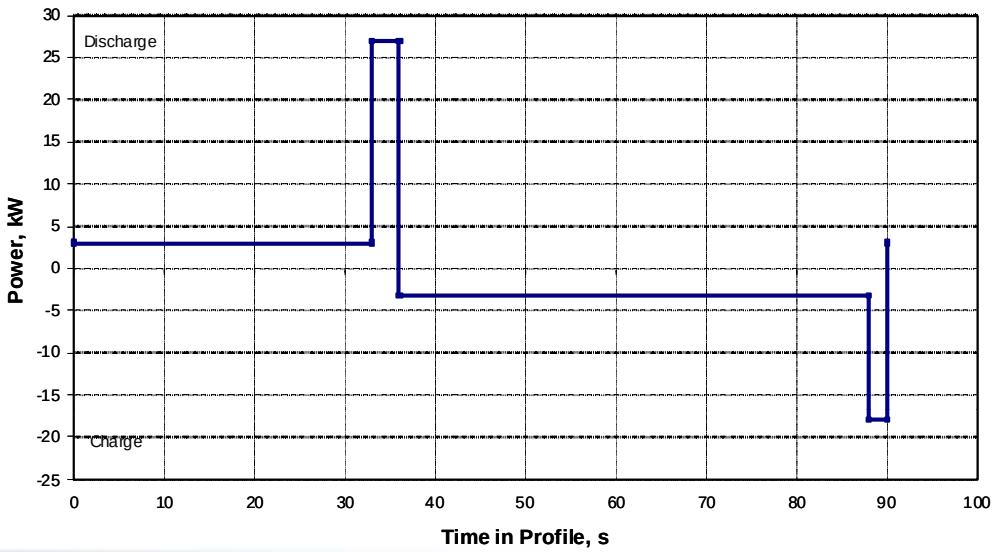
PHEV Test Procedures: Three Battery Life/Aging Tests (1)

- There are three battery life/aging tests: calendar, charge-depleting cycling and charge-sustaining cycling
- Calendar life: Similar to a storage experiment, where the battery is idle most of the time. A daily pulse is performed to gauge the health of the battery. These tests are performed at specific temperatures and a range of temperatures is typically used
- Charge-depleting (CD) cycling: Emulates electric propulsion in a prototypical vehicle. Starting from about 90% SOC, the cycle life profile is repeated until the scaled, goal CD energy is removed

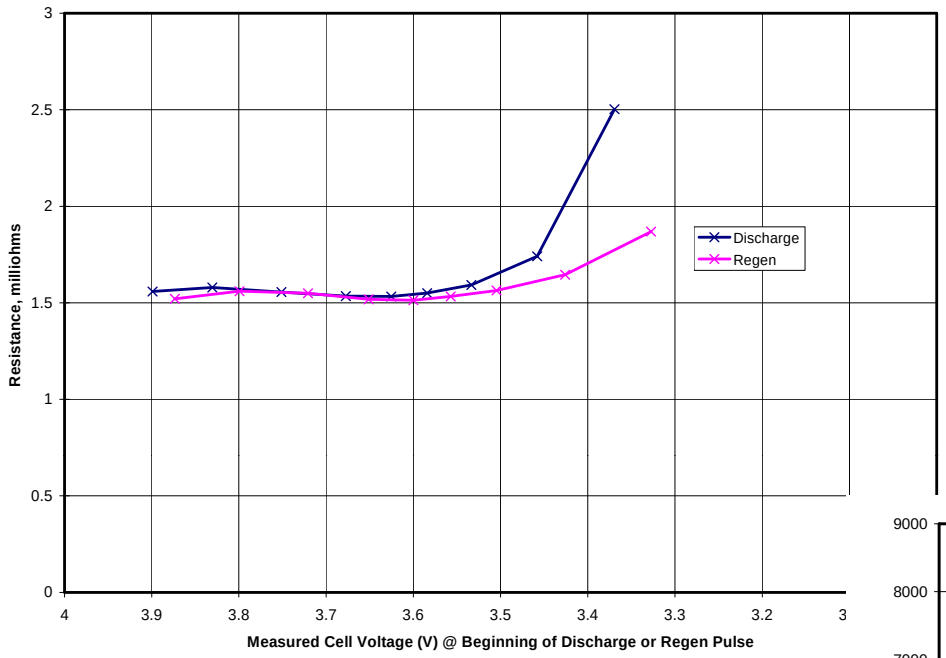


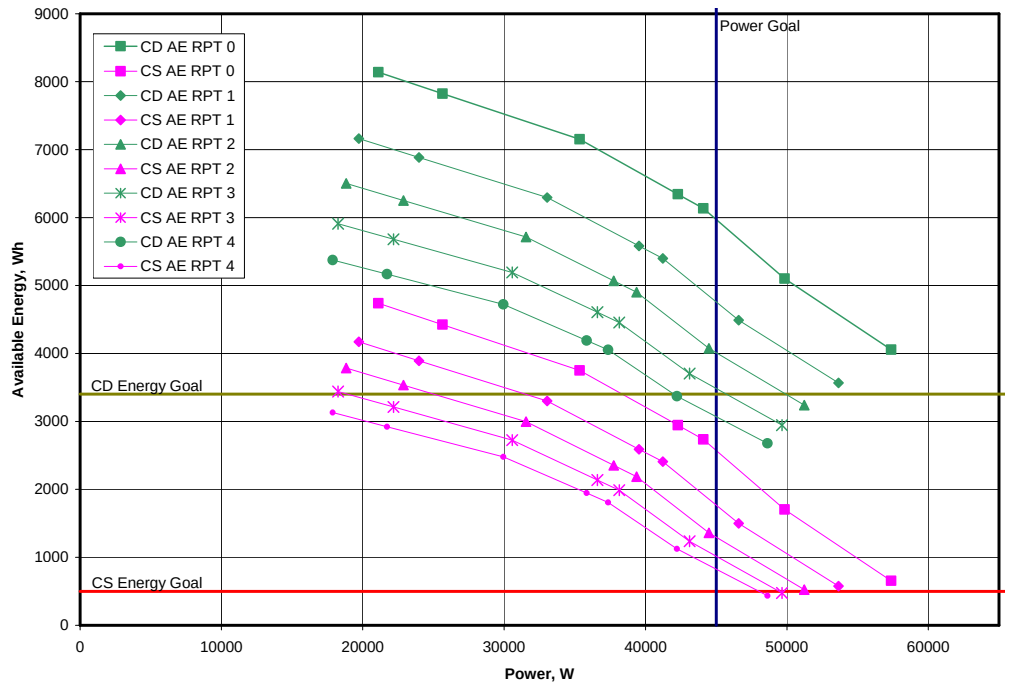
PHEV Test Procedures: Three Battery Life/Aging Tests (2)

- Charge-sustaining (CS) cycling: Emulates the operation of a PHEV in hybrid electric vehicle mode. This profile is performed continuously and at low SOC
- CD and CS cycle profiles can be combined to better capture the operation of a PHEV
  - Perform CD profile to removed scaled amount of energy then perform 50 CS profiles
- Reference performance tests (RPTs) are performed every 32 days, 400 cycles and 30,000 cycles for calendar, CS cycle and CD cycle life, respectively
  - RPTs consist of constant-current capacity measurement and HPPC test at 30°C



PHEV Test Procedures: Calculated Results





Energy or power can determine BSF. In the example to the right, power determined the BSF

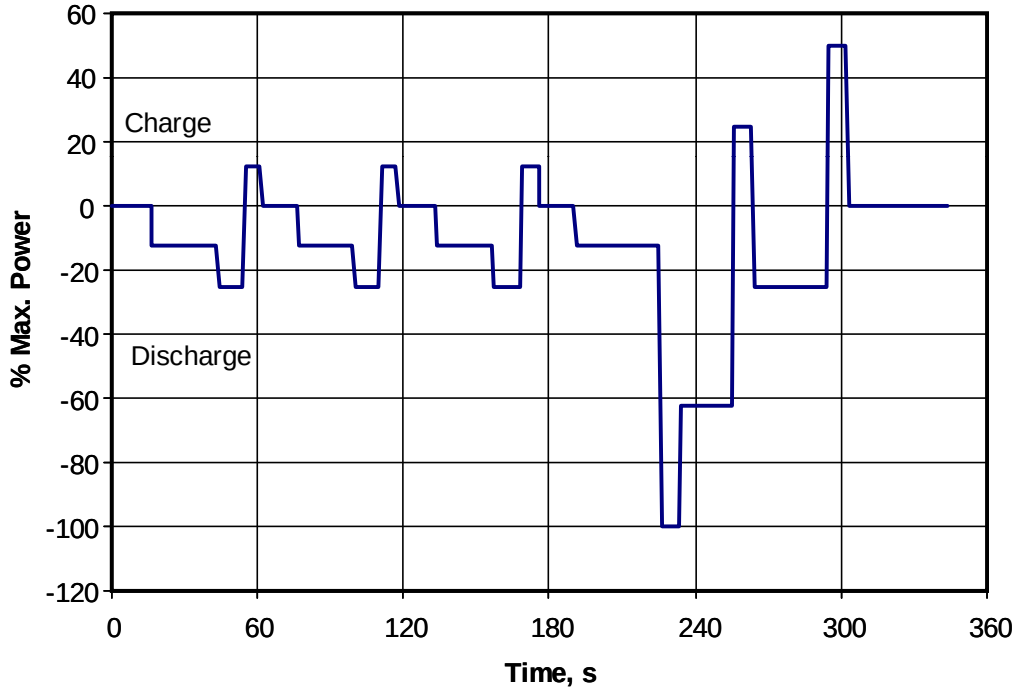
EV Battery Testing

- The USABC has established performance and life targets for EVs
- Intended platform is a four-passenger, car which weighs about 1800-2000 kg and has a driving range of ~100 mi (160 km)
- Goals are based on battery weight and volume

Parameter	Target	
	Mid-Term	*Long Term*
Power density, W/L	460	600
Specific power (discharge; 80% DOD for 30 sec), W/kg	300	400
Specific power (regen; 20% DOD for 10 sec), W/kg	150	200
Energy density at C/3 rate, Wh/L	230	300
Specific energy at C/3 rate, Wh/kg	150	200
Specific Energy:Specific Power ratio	2:1	2:1
Total pack size, kWh	40	40
Life, years	10	10
Cycle life (80% DOD), cycles	1,000	1,000
Power and capacity degradation, % of rated	20	20
Operating environment	-40 to 50°C (20% performance loss; 10% desired)	-40 to 85°C
Normal recharge time, h	6	3 to 6
Fast recharge time	20-70% SOC in <30 min	40-80% SOC in 15 min

EV Test Procedures: Characterize Battery Performance(1)

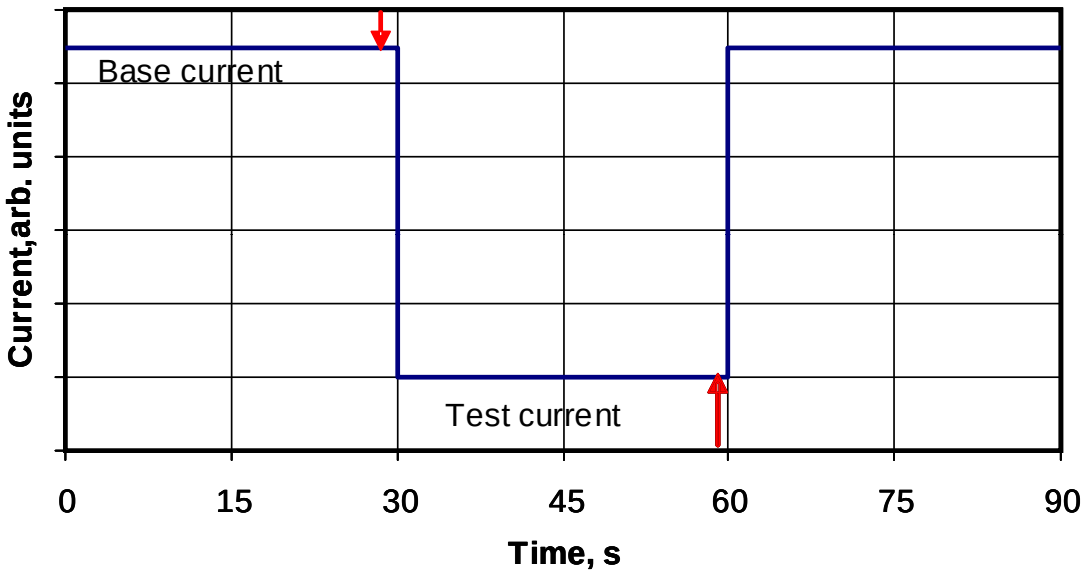
- Batteries are characterized in terms of constant-current capacity (e.g., C/1, C/2 and C/3), dynamic stress test capacity, self-discharge, peak-power capability, thermal performance and energy efficiency



- Dynamic Stress Test Profile. The maximum discharge power peak is scaled to 80% of the peak power available at 80% depth of discharge.

EV Test Procedures: Characterize Battery Performance (2)

- Peak power test profile used to measure peak power at every 10%DOD



- The arrows indicate the points for measuring voltage (V) and current (I). From these points, $R=\Delta V/\Delta I$

EV Test Procedures: Characterize Battery Performance (3)

- Using the results from the peak-power test, the power capability at each %DOD is calculated using Equations (1), (2) and (3)

$$P_n = -\frac{2}{9}\frac{V_{IR-free}^{\ 2}}{R} \qquad (1)$$

$$P_n = -V_{\lim}\frac{V_{IR-free} - V_{\lim}}{R} \qquad (2)$$

$$P_n = -I_{\max}(V_{IR-free} + R \times I_{\max}), \qquad (3)$$

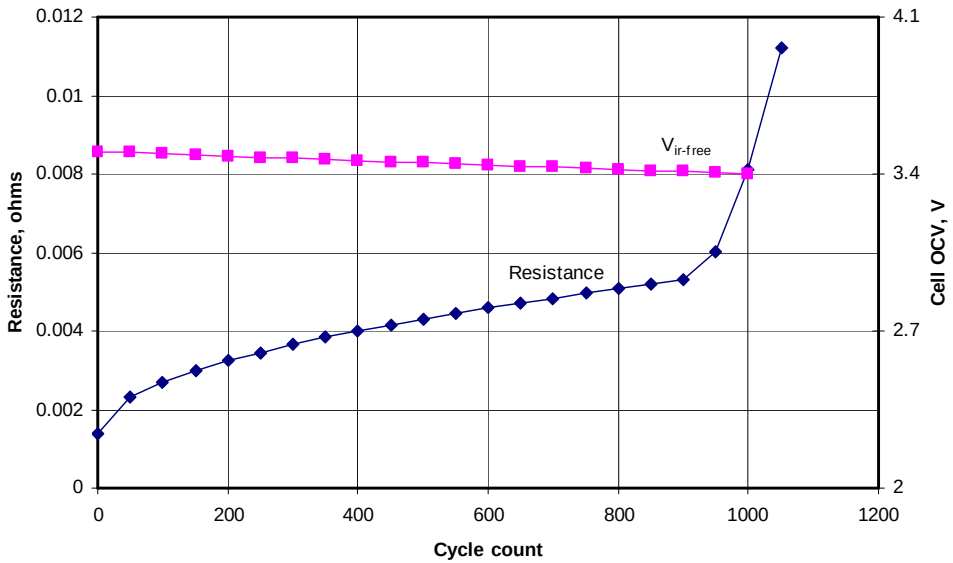
where P_n is peak power at n% DOD, $V_{iR\text{-}free}$ is the iR-corrected voltage at a given %DOD, R is resistance, V_{lim} is the limiting discharge voltage and I_{max} is the maximum current for the battery

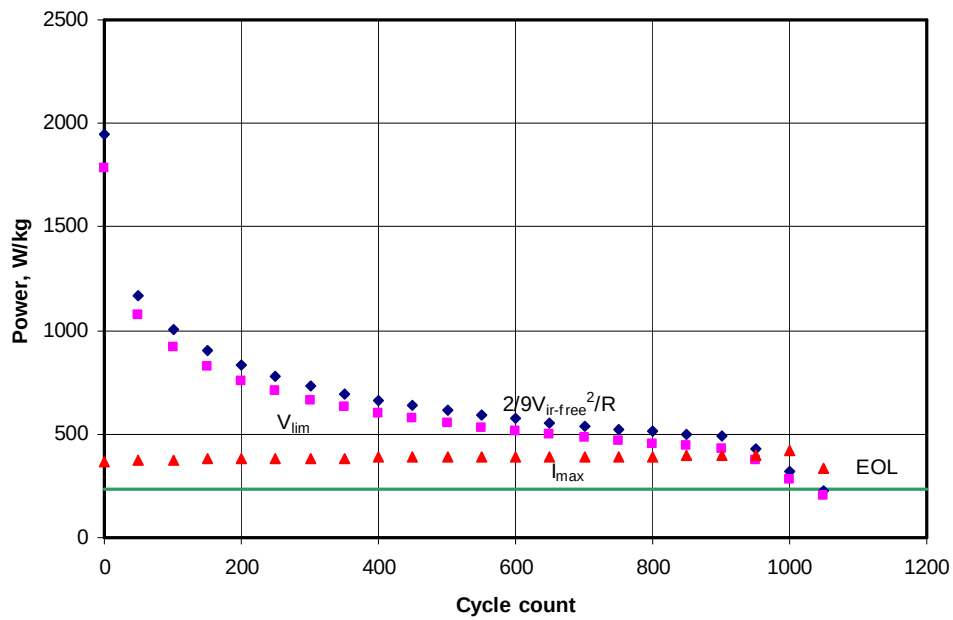
- Report the minimum power value calculated

EV Test Procedures: Two Life/Aging Tests

- There are two life/aging tests, calendar life and cycle life
- Calendar life: This test is similar to a storage test and can be performed at many different %DOD and temperatures. Typically, it is performed at low %DOD and in the temperature range of 25 to 60°C. RPTs are performed every 28 days at 25°C
- Cycle life: This test uses the DST profile, scaled for the power characteristics and repeated many times, to discharge the battery from 0 to 80% DOD, followed by recharging it according to the developers recommendations. Increasing the temperature at which the battery is cycled will further increase the rate of performance decline. RPTs are conducted every 50 cycles at 25°C
- RPTs consist of C/3 constant-current capacity, DST-discharge capacity and the peak power test

EV Test Procedures: Calculated Results





Summary

- Pre-competitive battery testing in the US is application-based and, thus, has many targets and procedures
- The test procedures can be used on any size cell, module or battery and on battery technologies at different levels of maturity
- The results of testing provide a guide to actual battery performance in the vehicle

- This area would be suitable for international collaboration

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