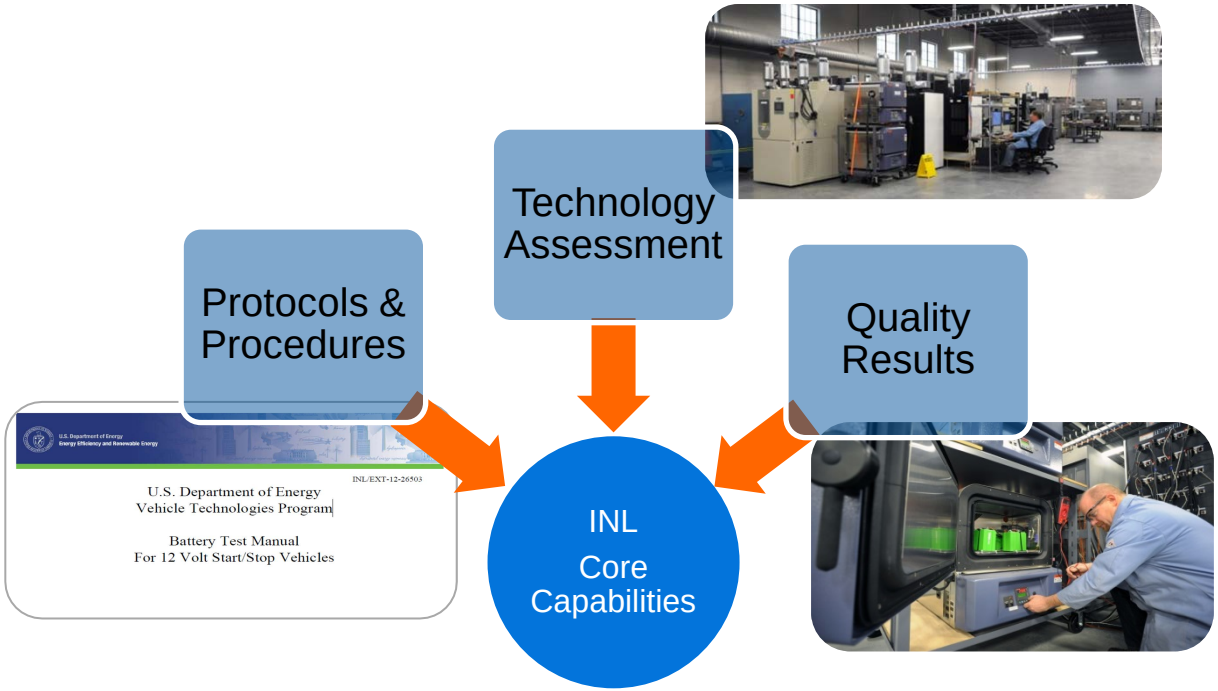
Data Analysis



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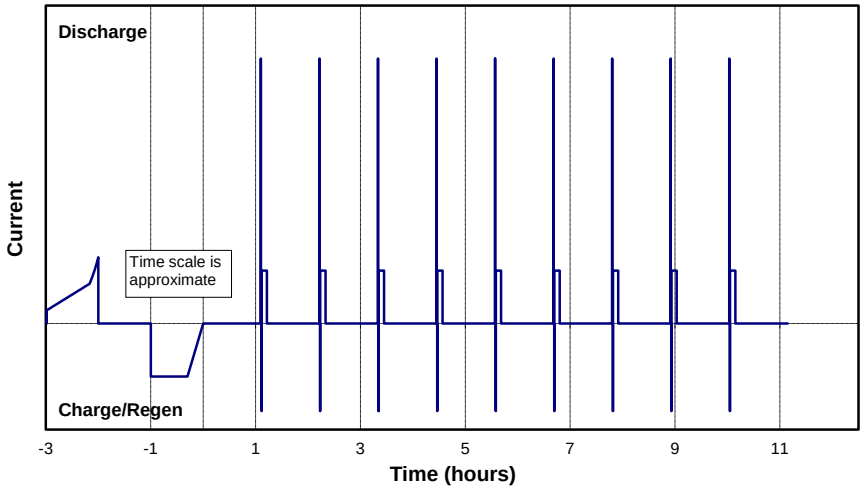
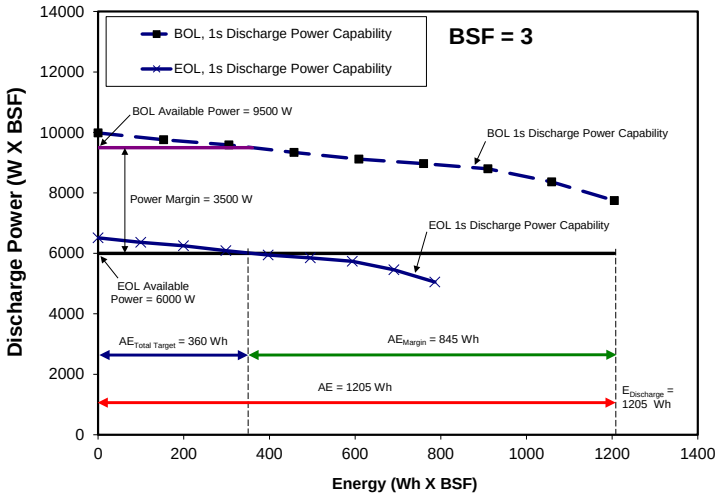
Data Analysis

- **New test data are generally processed every month after an RPT is completed.**
- **Degradation rates in capacity, energy, available power, and available energy are typically reported.**
- **The gap analysis chart is used to compare the device degradation with the established USABC targets.**





Data Analysis - Considerations

- **PHEV and 12V S/S**
  - Full charge is at $Vmax_{op}$
  - Testing is based on <u>rated</u> capacity
  - HPPC discharge pulses are performed based on the I_{HPPC} current rates: $I_{HPPC} = P_{CPD}/(V_{nominal} * BSF)$
  - HPPC tests are preceded by constant power discharges

- **EV**
  - Full charge is at $Vmax_{op}$, but $Vmax_{op}$ can equal $Vmax_{100}$.
  - Testing is based on <u>operating</u> capacity
  - HPPC discharge pulses are performed with at least a C/1 rate
  - HPPC tests are preceded by constant C/3 discharge
  - Peak Power testing is also conducted

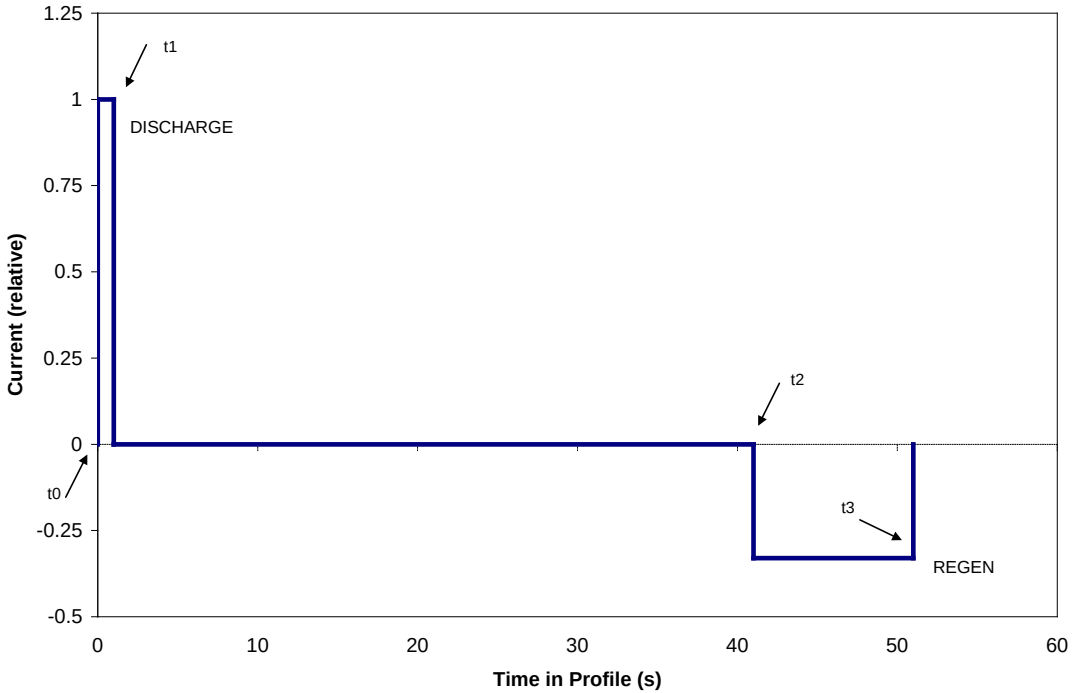
Data Analysis –12V S/S

- **The Gap Analysis chart is the standard communication tool for USABC Programs.**
  - Supports direct comparisons between programs and technologies.

Characteristics	Units	EOL Targets	Not Under Hood	
			RPT0	RPT##
Discharge Pulse (1s)	kW	6		9.5
Max discharge current, 0.5s	A	900		
Cold cranking power at -30 °C	kW, 0.5s	6	TBD	
	kW, 4.0s	4	TBD	
Available Energy (750 W)	Wh	360		1205

Data Analysis – HPPC (12V S/S)

- **Step 1 – Calculate resistances.**



$$\text{Discharge Resistance} = \frac{\Delta V_{discharge}}{\Delta I_{discharge}} = \left| \frac{V_{t1} - V_{t0}}{I_{t1} - I_{t0}} \right|$$

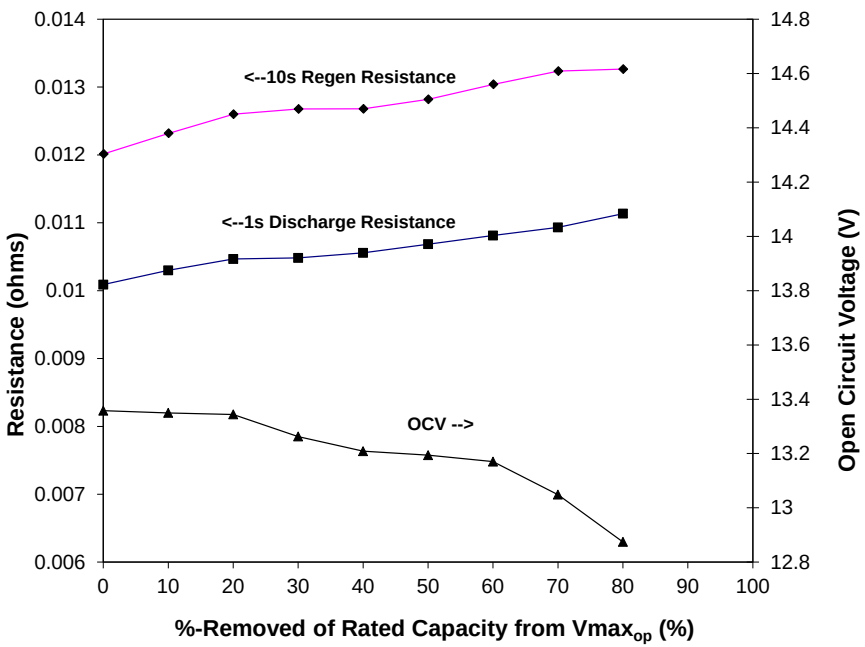
$$\text{Regen Resistance} = \frac{\Delta V_{regen}}{\Delta I_{regen}} = \left| \frac{V_{t3} - V_{t2}}{I_{t3} - I_{t2}} \right|$$

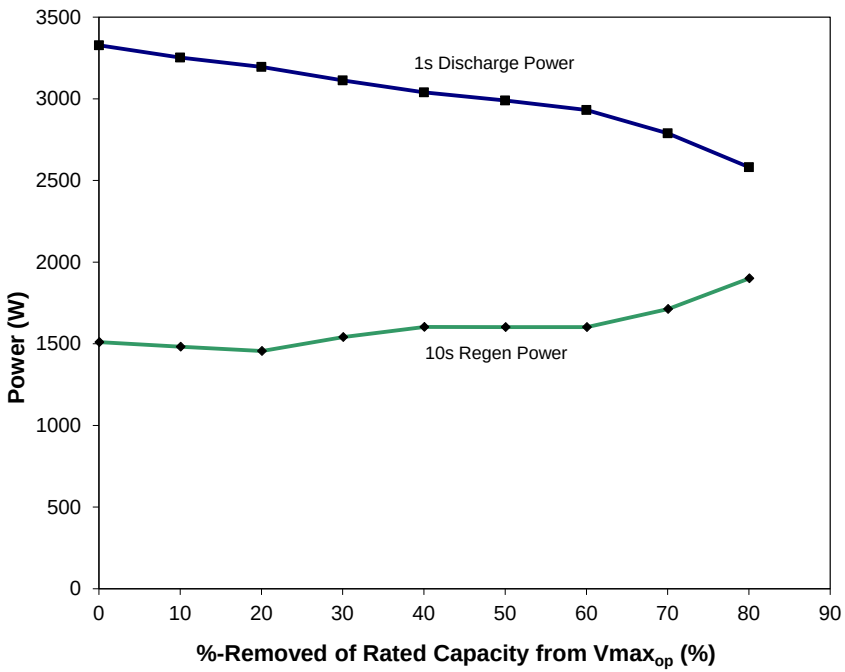
Data Analysis – HPPC (12V S/S)

- **Step 2 – Calculate power capability.**

$$Discharge\ Pulse\ Power\ Capability = Vmin_{pulse} \bullet (OCV_{dis} - Vmin_{pulse}) \div R_{discharge}$$

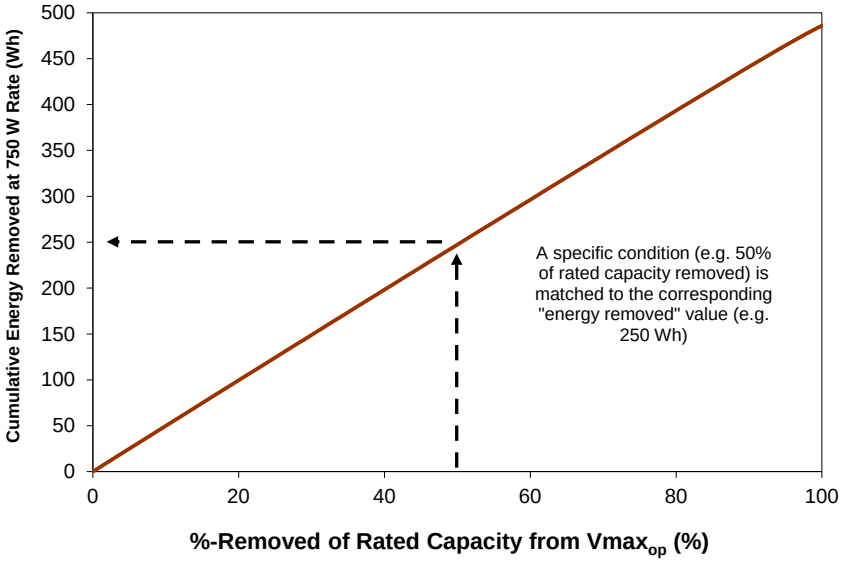
$$Regen\ Pulse\ Power\ Capability = Vmax_{pulse} \bullet (Vmax_{pulse} - OCV_{regen}) \div R_{regen}$$

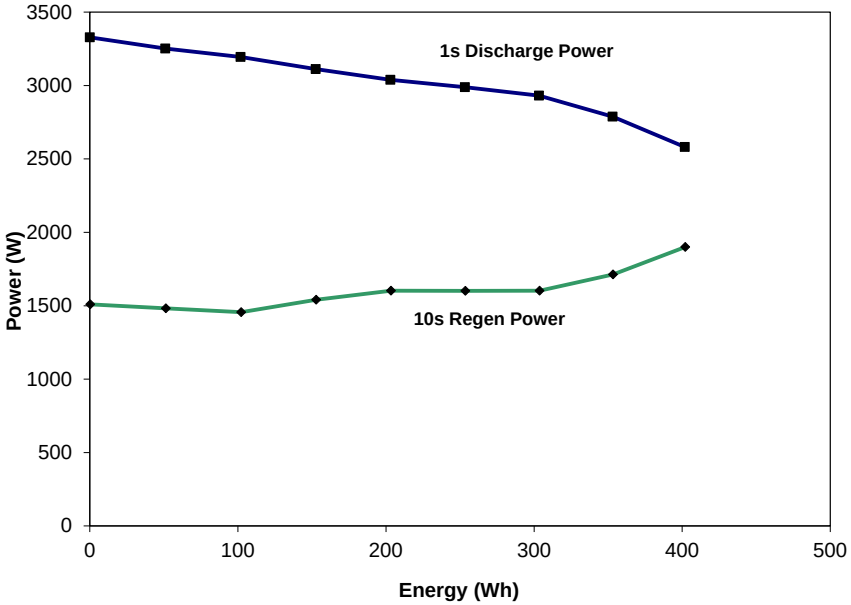




Data Analysis – HPPC (12V S/S)

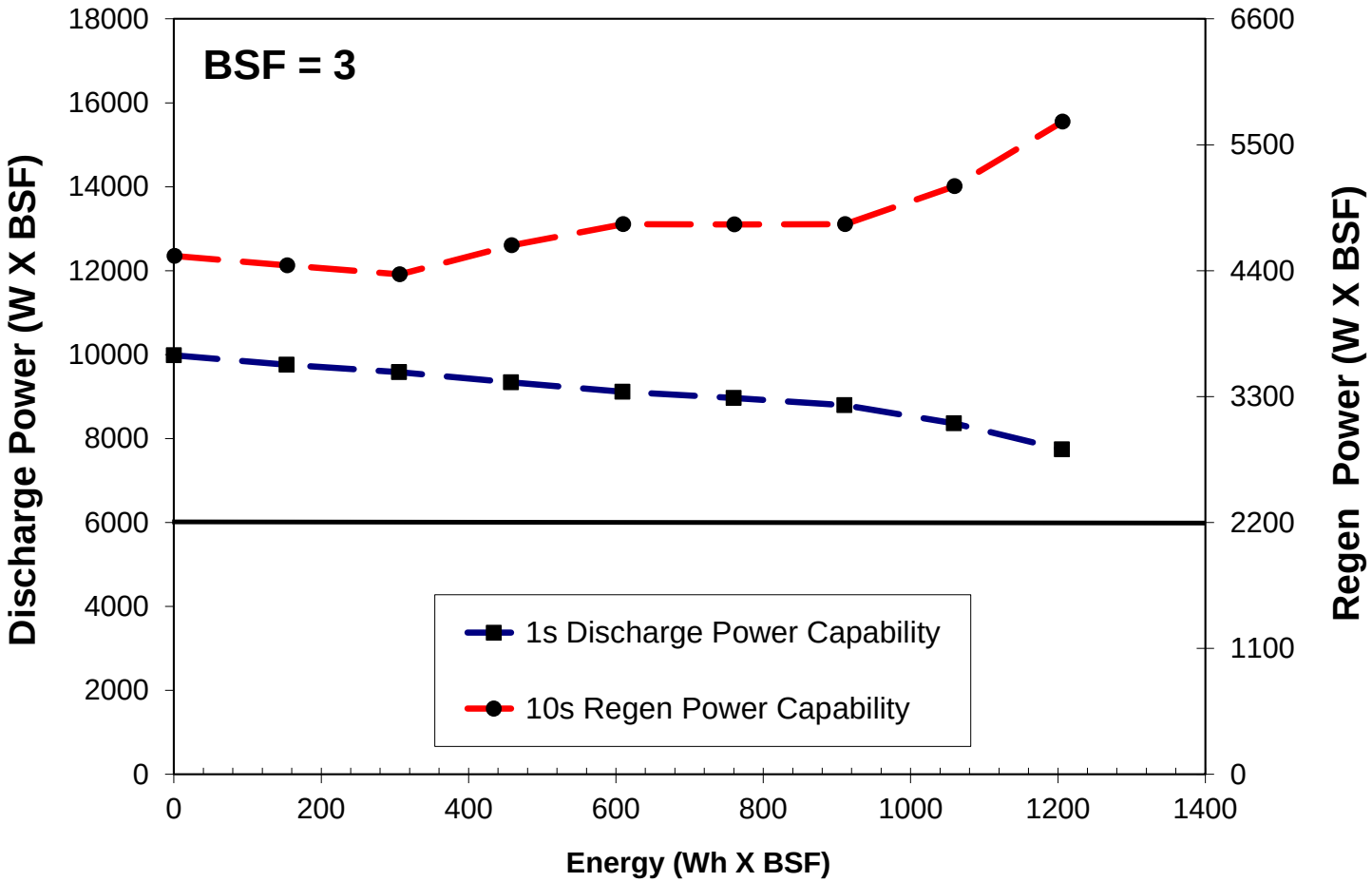
- **Step 3 – Correlate %-removed of rated capacity with energy removed at a 750-W rate.**





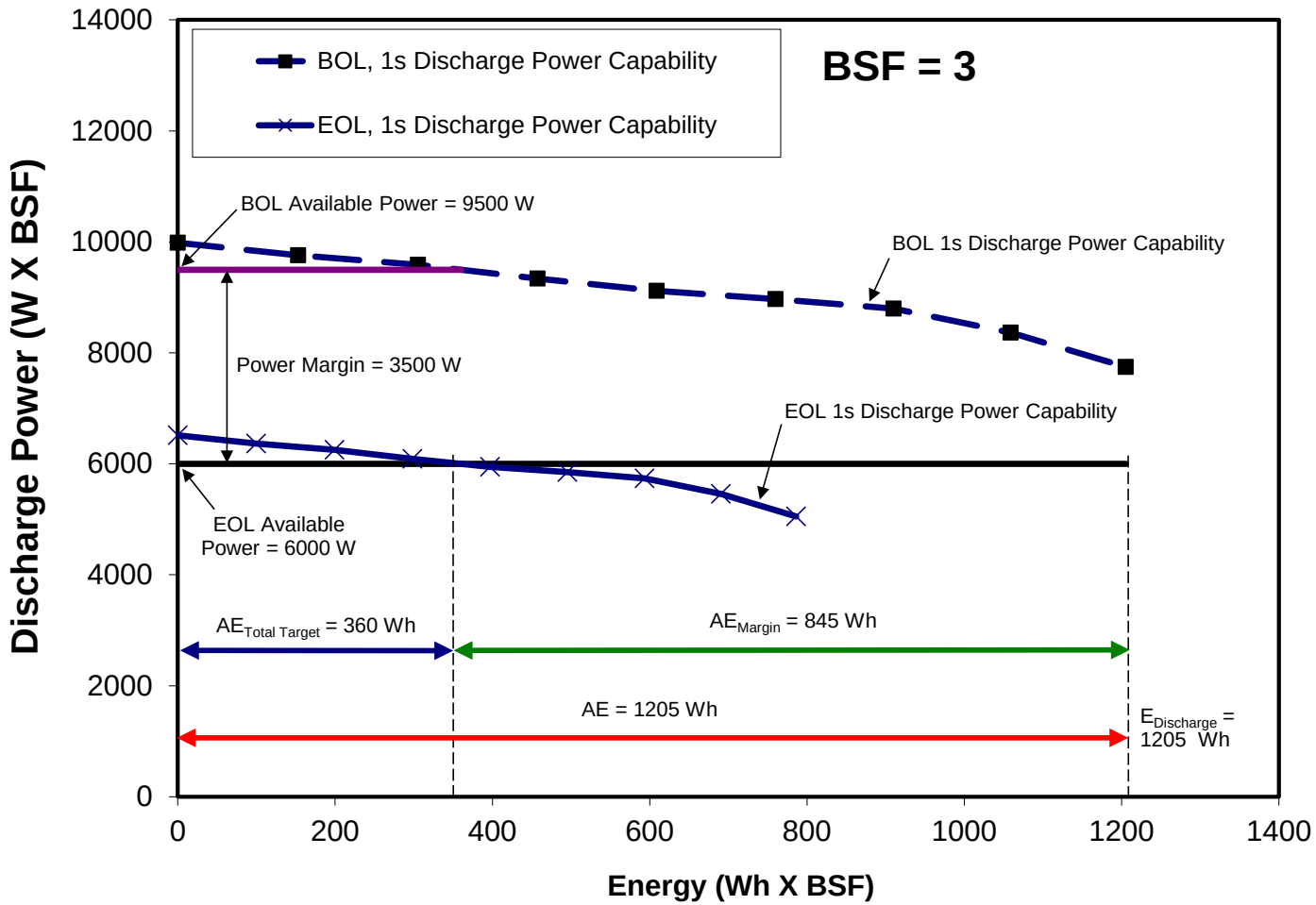
Data Analysis – HPPC (12V S/S)

- **Step 4 – Scale power vs. energy curves by the BSF**



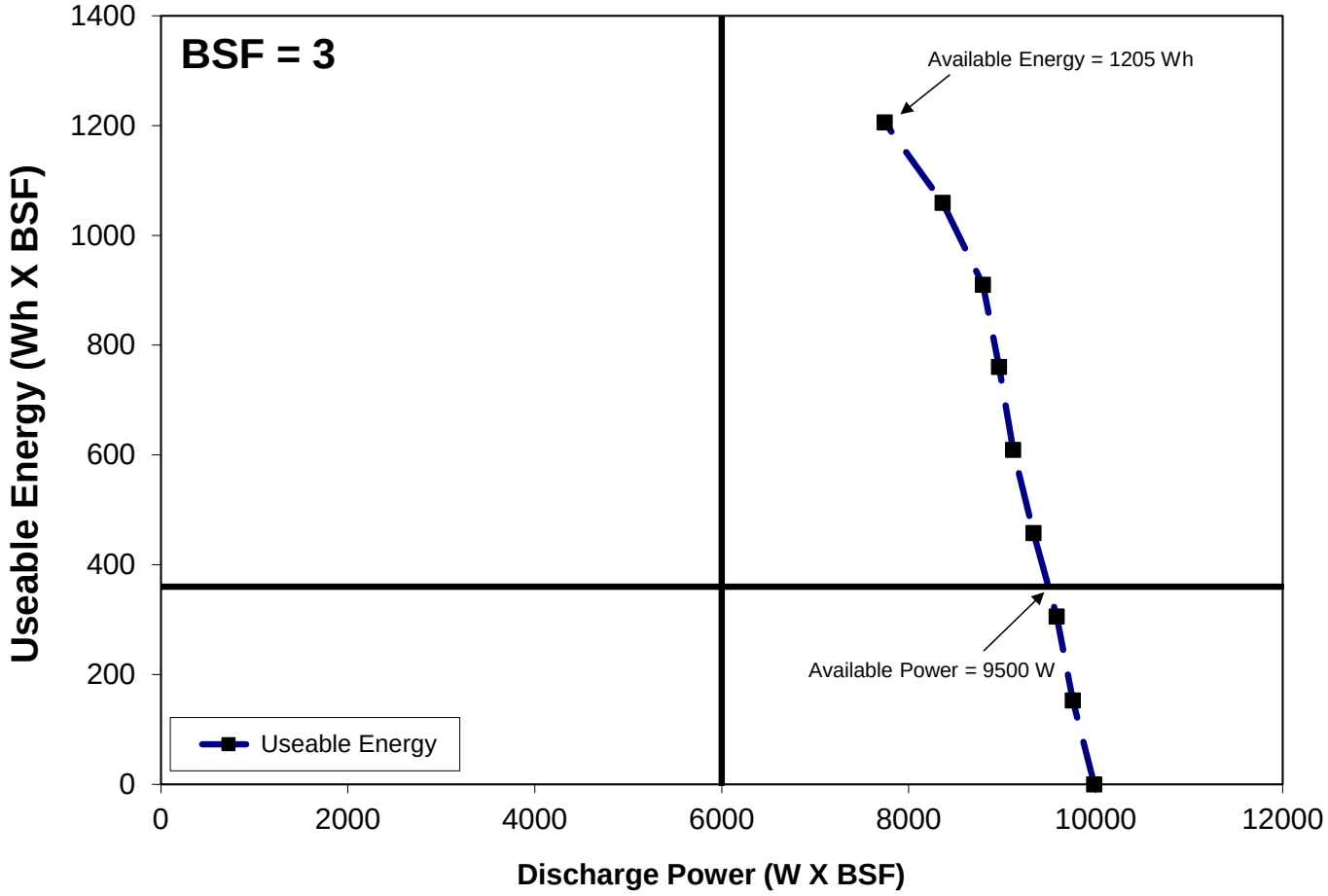
Data Analysis – HPPC (12V S/S)

- **Step 5 – Find Available Power and Available Energy.**



Data Analysis – HPPC (12V S/S)

- **Step 5 (alternative) – Generate Useable Energy curve to find power and energy.**



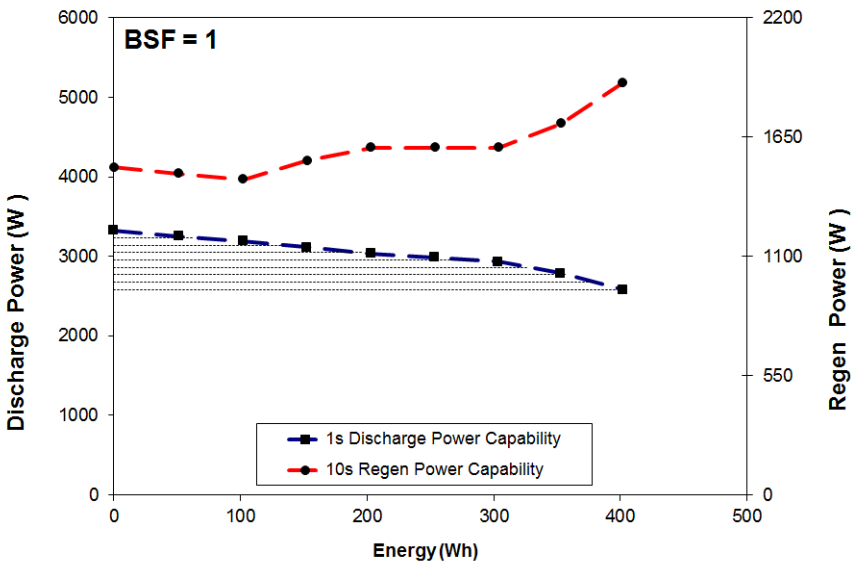
Data Analysis –12V S/S

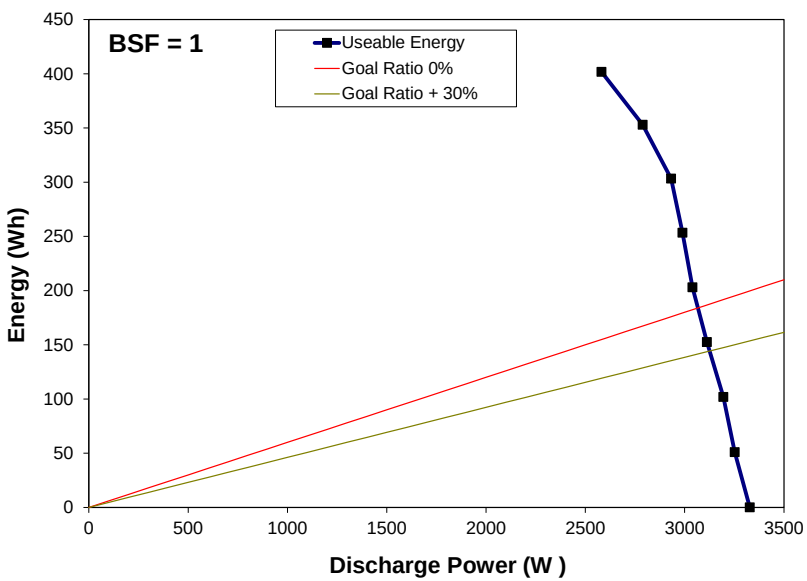
- **The data collected from the HPPC power and energy assessment are used for the Gap Analysis.**
  - If value is greater than the target, highlight in green
  - If value is less than the target but within 15%, highlight in yellow.
  - Otherwise, highlight in red

Characteristics	Units	EOL Targets	Not Under Hood	
			RPT0	RPT##
Discharge Pulse (1s)	kW	6		9.5
Max discharge current, 0.5s	A	900		
Cold cranking power at -30 °C	kW, 0.5s	6	TBD	
	kW, 4.0s	4	TBD	
Available Energy (750 W)	Wh	360		1205

Data Analysis – HPPC (12V S/S)

- **BSF Calculations:**
  - Assume a 30% power margin.
  - Where the Goal Ratio intersects the useable energy curve, find the BSF based on the targets (e.g., 360 Wh / energy or 6 kW * 1.3 / power).





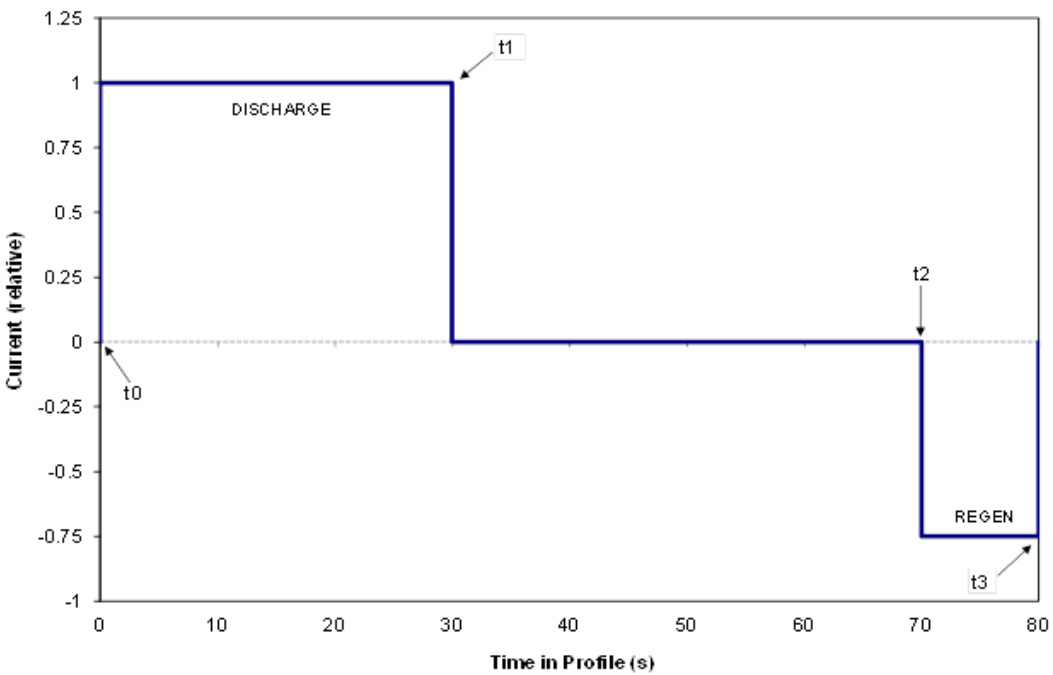
Data Analysis –EV

- **For EV applications, both the HPPC and Peak Power test results are reported in the Gap Analysis chart.**
  - The Peak Power test provides information on the discharge power capability.

Characteristics	Units	EOL Targets	Cell Level			
			RPT0		RPT##	
			HPPC	Peak Power	HPPC	Peak Power
Peak Discharge Power Density (30 sec)	W/L	1500	##	##	2695	3563
Peak Specific Discharge Power (30 sec)	W/kg	700	##	##	1280	1693
Peak Specific Regen Power (10 sec)	W/kg	300	##		670	
Available Energy Density @ C/3 Discharge Rate	Wh/L	750	##		784	
Available Specific Energy @ C/3 Discharge Rate	Wh/ kg	350	##		373	

Data Analysis – HPPC (EV)

- **Step 1 – Calculate resistances.**



$$\text{Discharge Resistance} = \frac{\Delta V_{discharge}}{\Delta I_{discharge}} = \left| \frac{V_{t1} - V_{t0}}{I_{t1} - I_{t0}} \right|$$

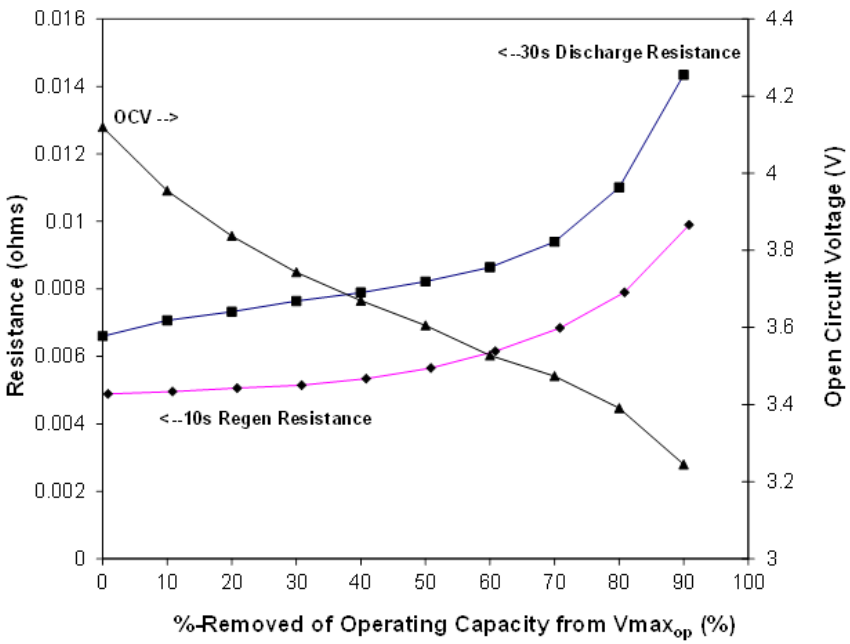
$$\text{Regen Resistance} = \frac{\Delta V_{regen}}{\Delta I_{regen}} = \left| \frac{V_{t3} - V_{t2}}{I_{t3} - I_{t2}} \right|$$

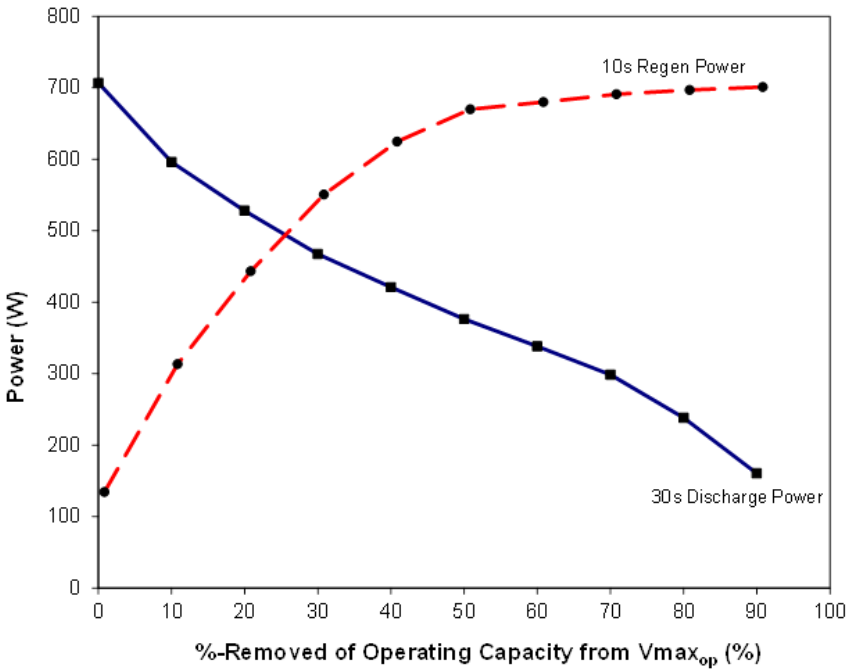
Data Analysis – HPPC (EV)

- **Step 2 – Calculate power capability.**

$$Discharge\ Pulse\ Power\ Capability = Vmin_{pulse} \bullet (OCV_{dis} - Vmin_{pulse}) \div R_{discharge}$$

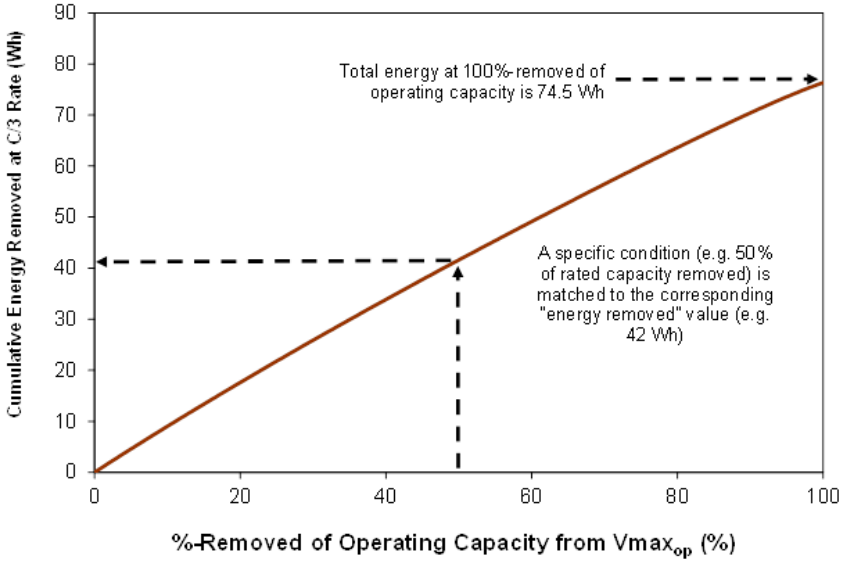
$$Regen\ Pulse\ Power\ Capability = Vmax_{pulse} \bullet (Vmax_{pulse} - OCV_{regen}) \div R_{regen}$$

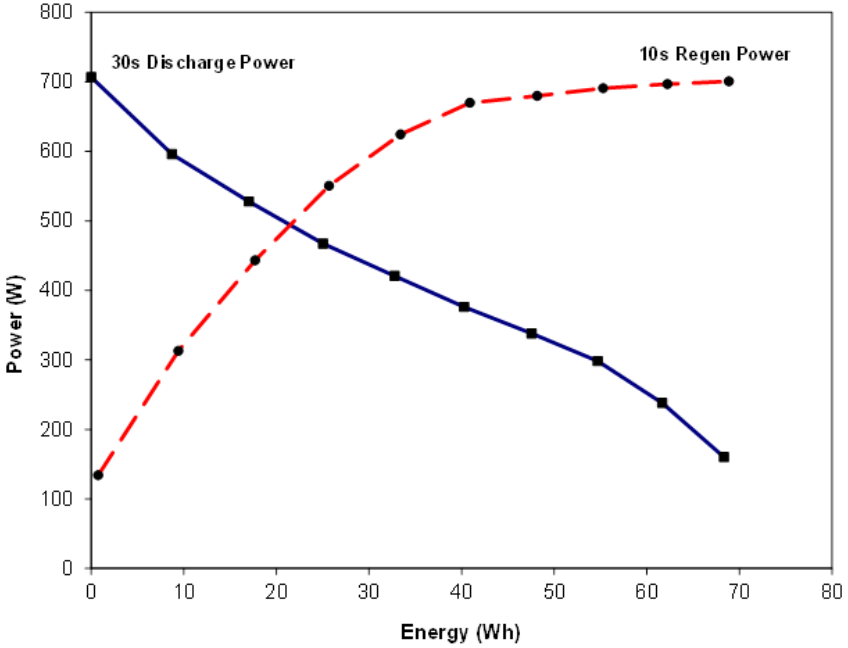




Data Analysis – HPPC (EV)

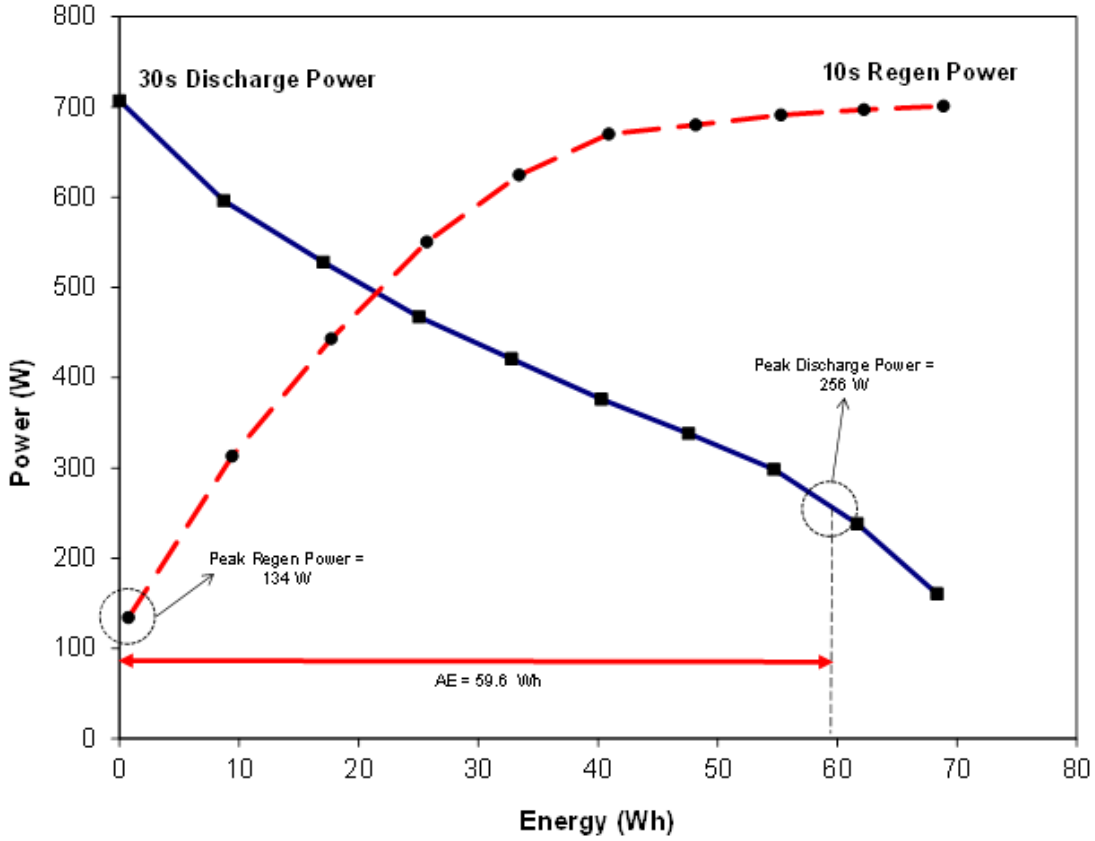
- **Step 3 – Correlate %-removed of rated capacity with energy removed at a C/3 rate.**
  - Note that the total energy removed corresponds to the Available Energy.





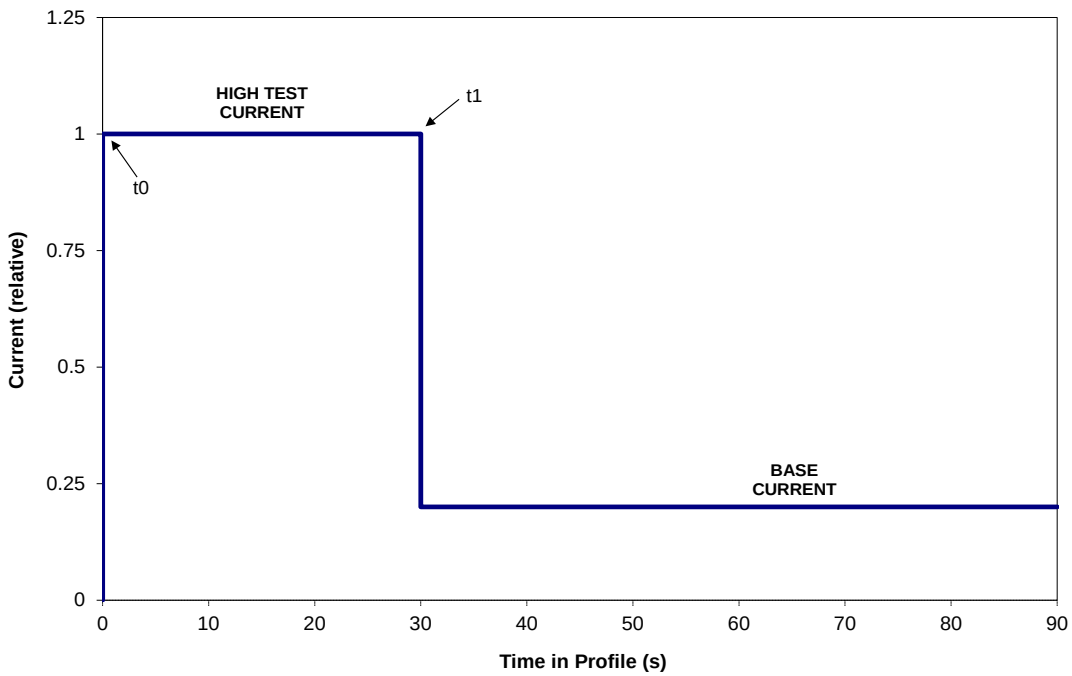
Data Analysis – HPPC (EV)

- **Step 4 – Identify discharge and regen power capability.**
  - Discharge power is at the Available Energy target, fixed at BOL.



Data Analysis – Peak Power (EV)

- **Step 1 – Calculate resistances.**



$$\text{Discharge Resistance} = \frac{\Delta V_{discharge}}{\Delta I_{discharge}} = \left| \frac{V_{t1} - V_{t0}}{I_{t1} - I_{t0}} \right|$$

$$\text{Regen Resistance} = \frac{\Delta V_{regen}}{\Delta I_{regen}} = \left| \frac{V_{t3} - V_{t2}}{I_{t3} - I_{t2}} \right|$$

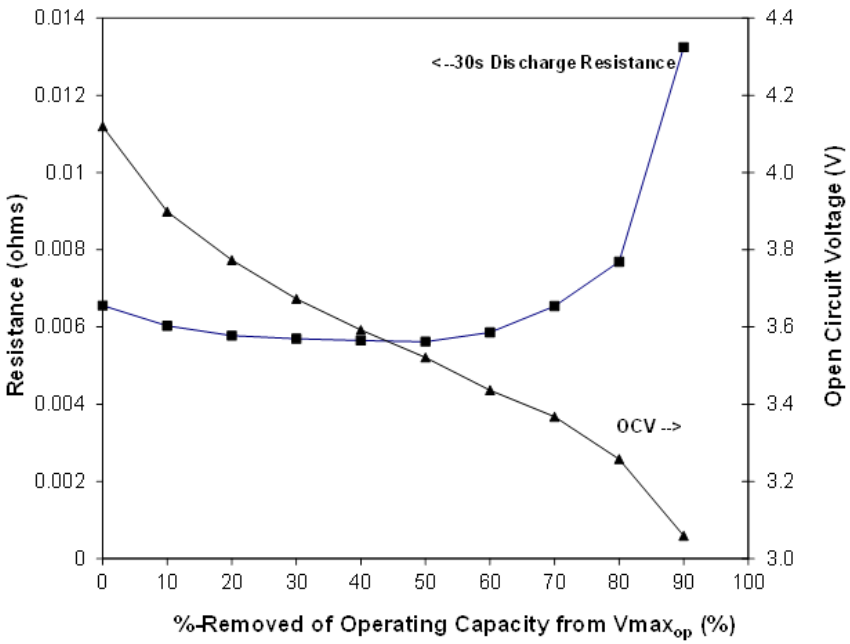
Data Analysis – Peak Power (EV)

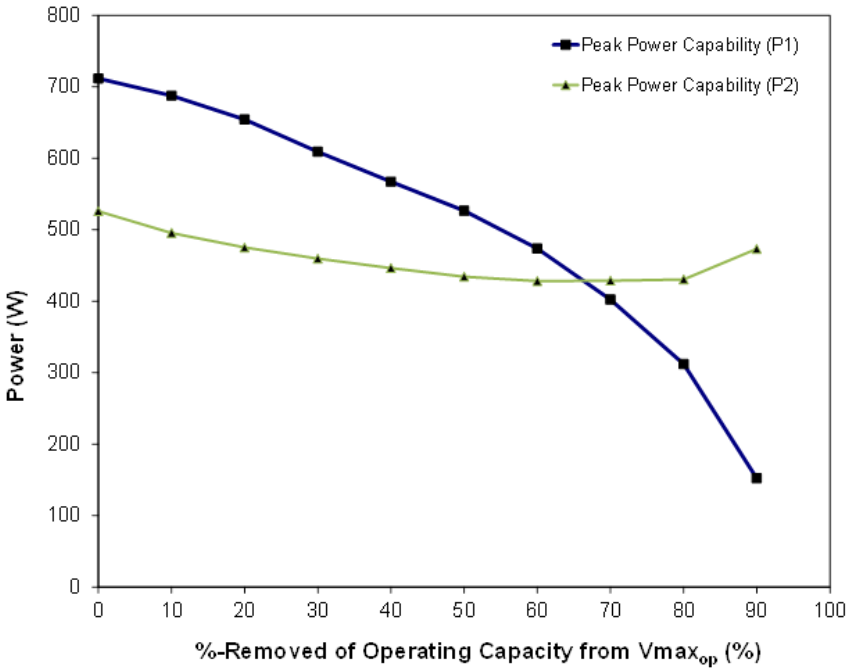
- **Step 2 – Calculate power capability.**

$$V_{IRFree} = V_{t_0} + I_{t_0} R_{discharge}$$

$$Discharge\ Pulse\ Power\ Capability\ (P1) = \frac{V\min_{pulse}\left(V_{IRFree} - V\min_{pulse}\right)}{R_{discharge}}$$

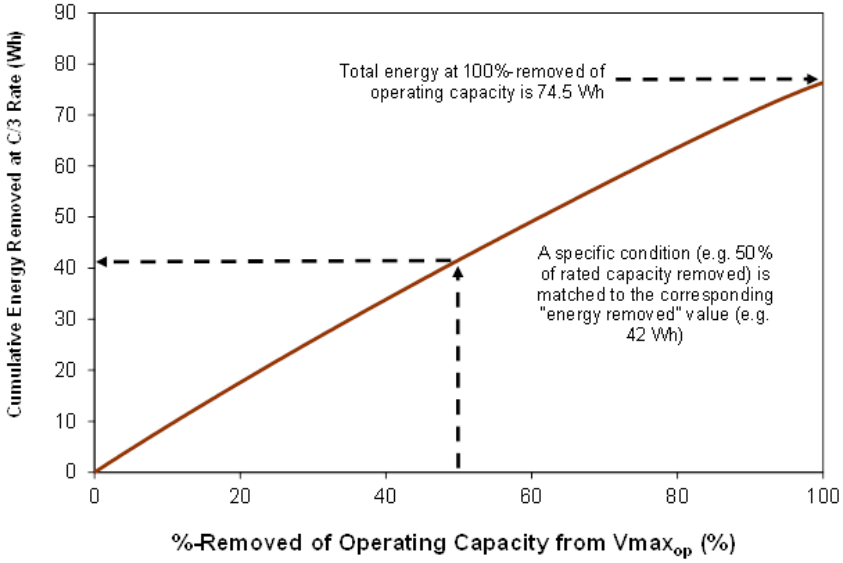
$$Discharge\ Pulse\ Power\ Capability\ (P2) = I_{MAX}\left[V_{IRFree} + \left(R_{discharge} \cdot I_{MAX}\right)\right]$$

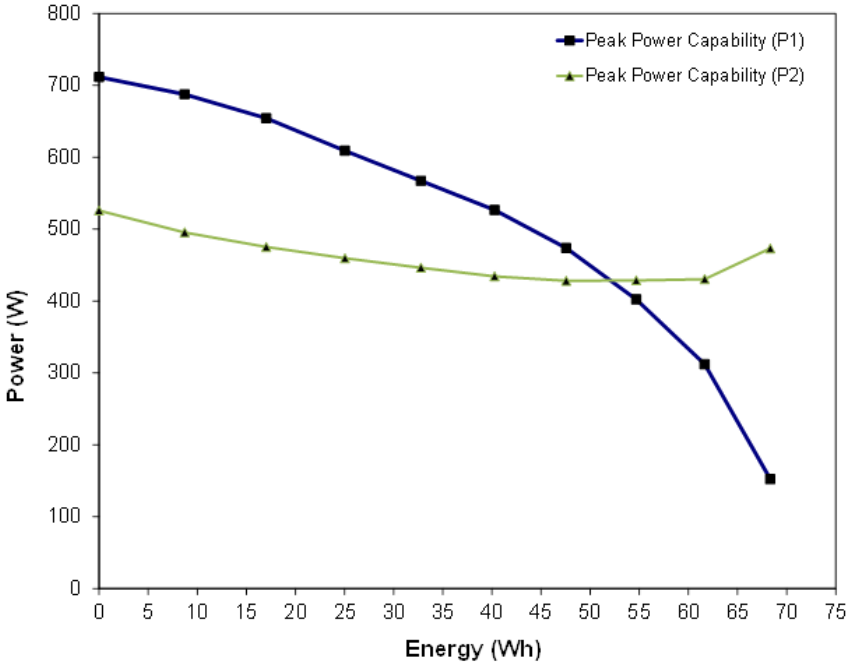




Data Analysis – Peak Power (EV)

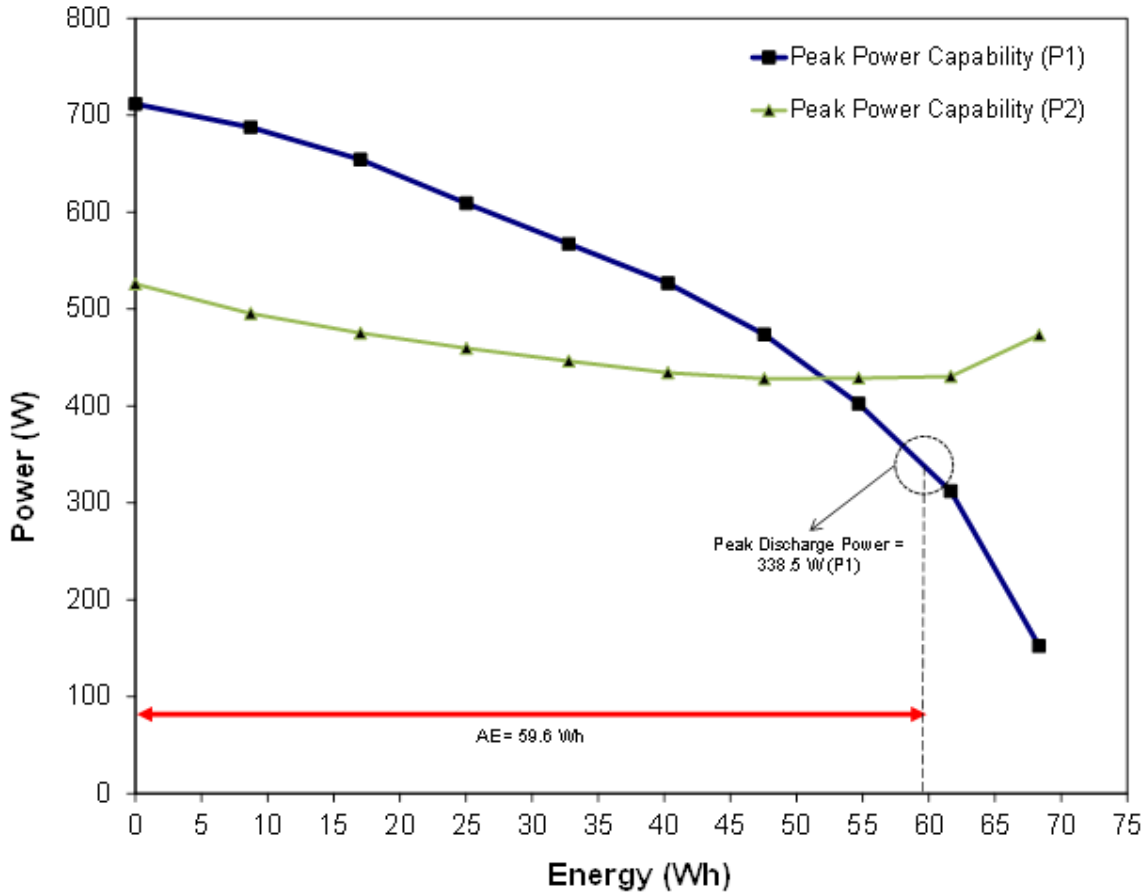
- **Step 3 – Correlate %-removed of rated capacity with energy removed at a C/3 rate.**
  - Use the same C/3 discharge as used for the HPPC test.





Data Analysis – Peak Power (EV)

- **Step 4 – Identify discharge power capability at the target Available Energy (fixed at BOL).**



Data Analysis –EV

- **The data collected from the HPPC and Peak Power tests are used for the Gap Analysis.**
  - The measured values must be scaled by the weight or volume.

Characteristics	Units	EOL Targets	Cell Level			
			RPT0		RPT##	
			HPPC	Peak Power	HPPC	Peak Power
Peak Discharge Power Density (30 sec)	W/L	1500	##	##	2695	3563
Peak Specific Discharge Power (30 sec)	W/kg	700	##	##	1280	1693
Peak Specific Regen Power (10 sec)	W/kg	300	##		670	
Available Energy Density @ C/3 Discharge Rate	Wh/L	750	##		784	
Available Specific Energy @ C/3 Discharge Rate	Wh/ kg	350	##		373	

Data Analysis – HPPC and Peak Power (EV)

- **BSF Calculations:**
  - Manufacturer should provide a BSF.
  - If not, use the manufacturer-provided margin and the BOL discharge energy.
  - For example, assume 20% energy margin:
    - BSF = 45 kWh / (80% * 74.5 Wh) = 755

Data Analysis – Other Reporting Parameters

- **Static capacity / Constant Power**
  - Report capacity (Ah) and energy (Wh) at the specified rates.

- **Capacity and energy fade can also be reported:**
  - $$Capacity\ Fade\,(\%) = 100 \times \left(1 - \frac{Capacity_{t1}}{Capacity_{t0}}\right)$$
  - $$Energy\ Fade\,(\%) = 100 \times \left(1 - \frac{Energy_{t1}}{Energy_{t0}}\right)$$

Data Analysis – Other Reporting Parameters

- **Power and energy fade can also be reported:**
  - $$\text{Power Fade}\,(\%) = 100 \times \left(1 - \frac{\text{Available Power}_{t1}}{\text{Available Power}_{t0}}\right)$$
  - $$\text{Energy Fade}\,(\%) = 100 \times \left(1 - \frac{\text{Available Energy}_{t1}}{\text{Available Energy}_{t0}}\right)$$

Data Analysis – Other Reporting Parameters

- **Other reporting parameters include:**
  - Self-discharge
  - Cold crank
  - Thermal performance
  - Energy efficiency
  - # of cycles/days on life testing

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