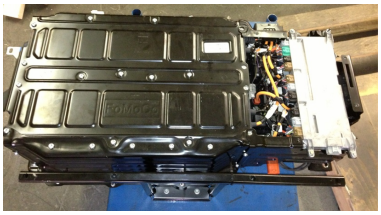
Battery Pack Laboratory Testing Results

2013 Ford C-Max Energi - VIN 0852



Vehicle Details and Battery Specifications[1,2]

Vehicle Details

Base Vehicle: 2013 Ford C-Max Energi	VIN: 1FADP5CUXDL530852
Architecture: Plug-In Hybrid Electric	

Battery Specifications

Manufacturer: Panasonic	Rated Pack Energy/Capacity: 7.6 kWh / 26.0 Ah
Type: Lithium-ion	Min/Max Cell Voltage: 3.00/4.20 V
Number of Cells: 84	Pack Mass/Volume[3]: 123.4 kg, 117.0 L
Nominal Cell/System Voltage: 3.7/310.8 V	Thermal Management: Active - Forced Air

[1] Vehicle details and battery specifications were either supplied by the manufacturer or derived from a literature review

[2] For full vehicle specifications, see the Baseline Performance Testing Results for this vehicle

[3] Battery pack volume is approximate and is based on the overall rectangular envelope less any significant voids

Battery Laboratory Test Results Summary

Test Number	Vehicle Odometer (Miles)	Date of Test	Measured Average Capacity (Ah)	Measured Average Energy Capacity (kWh)	CD Usable Energy Margin[4] (Wh)	CS Usable Energy Margin[4] (Wh)
Baseline	5,111	8/9/2013	25.1	7.7		
ICD 1	26,329	5/27/2014	24.4	7.5	246.8	246.8
ICD 2	71,478	5/3/2015	23.3	7.2	-383.0	-383.0
ICD 3	129,257	5/10/2016	21.9	6.7	-426.0	-426.0
End-of-Test						

[4] The CD and CS Usable Energy margins are defined as the difference between the battery usable energy values obtained from testing and the corresponding targets as defined in the Battery Test Manual for Plug-In Hybrid Electric Vehicles. A negative margin value indicates performance below the target, however it does not necessarily indicate any deficiency in the performance of the battery as it was designed to operate by the vehicle manufacturer.

PHEV Battery Test Results Analysis

Battery test results include those from the Static Capacity Test and the Hybrid Pulse Power Characterization (HPPC) Test, based on test procedures from the United States Advanced Battery Consortium Battery Test Manual For Plug-In Hybrid Electric Vehicles at the time of testing. These tests were performed for the US Department of Energy Vehicle Technology Office's Advanced Vehicle Testing Activity which is conducted by the Idaho National Laboratory and Intertek Testing Services, North America.

Static Capacity Test Results

The Static Capacity Test measures the charge and energy capacities of the battery between maximum and minimum pack voltages when discharged at a constant current calculated to approximate a 10 kW discharge rate.[5] Pack voltage versus capacity discharged during the Static Capacity Test is shown in Figure 1. Three iterations of the Static Capacity Test are performed at each interval, and the average results from each interval test are shown in the test results summary table on page 1.

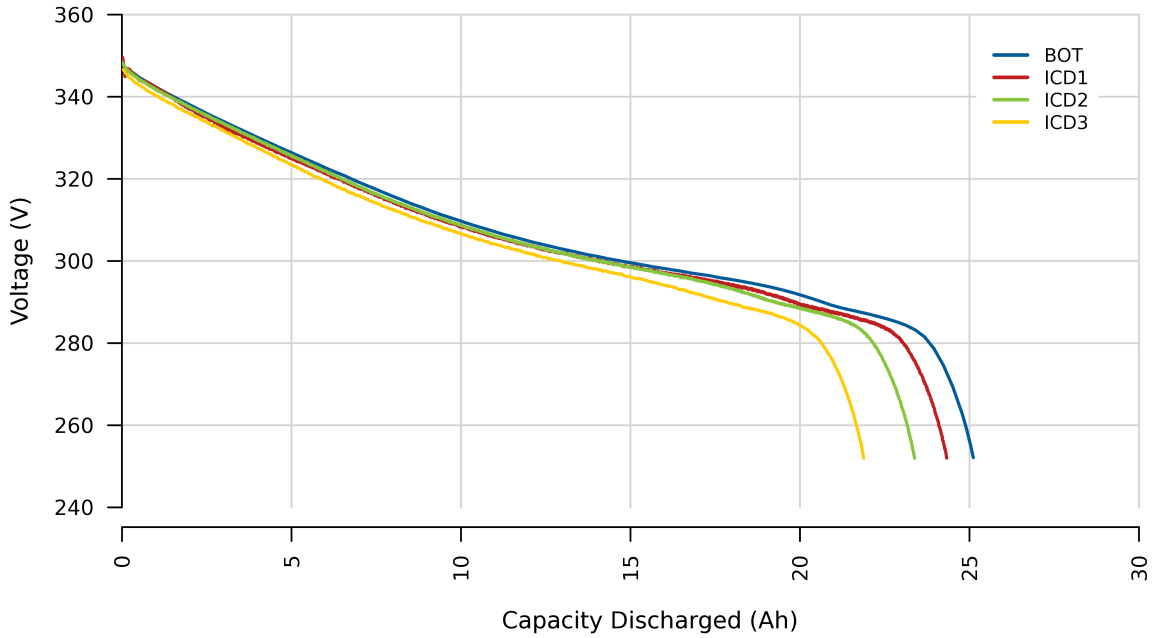


Figure 1. Voltage versus capacity discharged during the static capacity test

Hybrid Pulse Power Characterization Test Results

The HPPC test is performed to characterize the discharge and charge pulse power capability of the battery at each 10-percent depth-of-discharge interval. Numerical results derived from the HPPC test results are summarized in the table on page 1, including comparison of the measured results to the United States Advanced Battery Consortium goals for PHEV batteries. The results from these tests are in relation to the targets for a Medium PHEV Battery, having an equivalent electric range of 20 miles.

[5] Discharge rate is determined by taking the average of the maximum and minimum voltage values for a particular pack and dividing that value into 10 kW, per the PHEV manual. For this vehicle, the value is 10kW / 302.4 V = 33.07 A.

Figures 2 and 3 illustrate the battery charge and discharge calculated pulse resistance, which indicate internal resistance at each 10-percent depth-of-discharge interval.

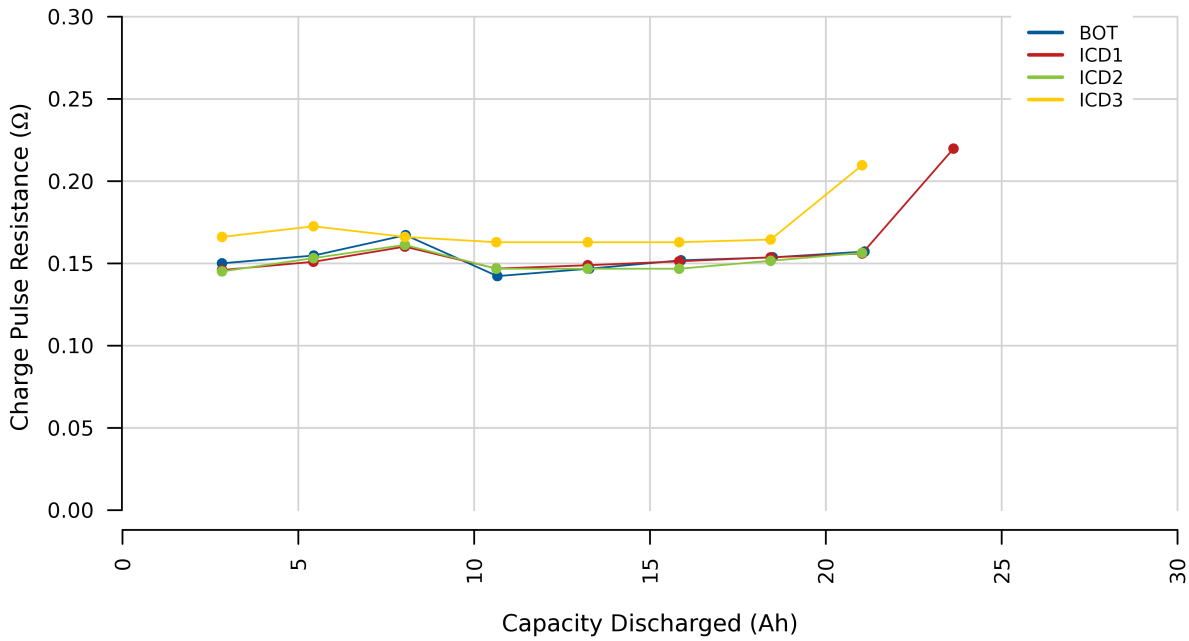


Figure 2. Ten-second charge pulse resistance versus capacity discharged

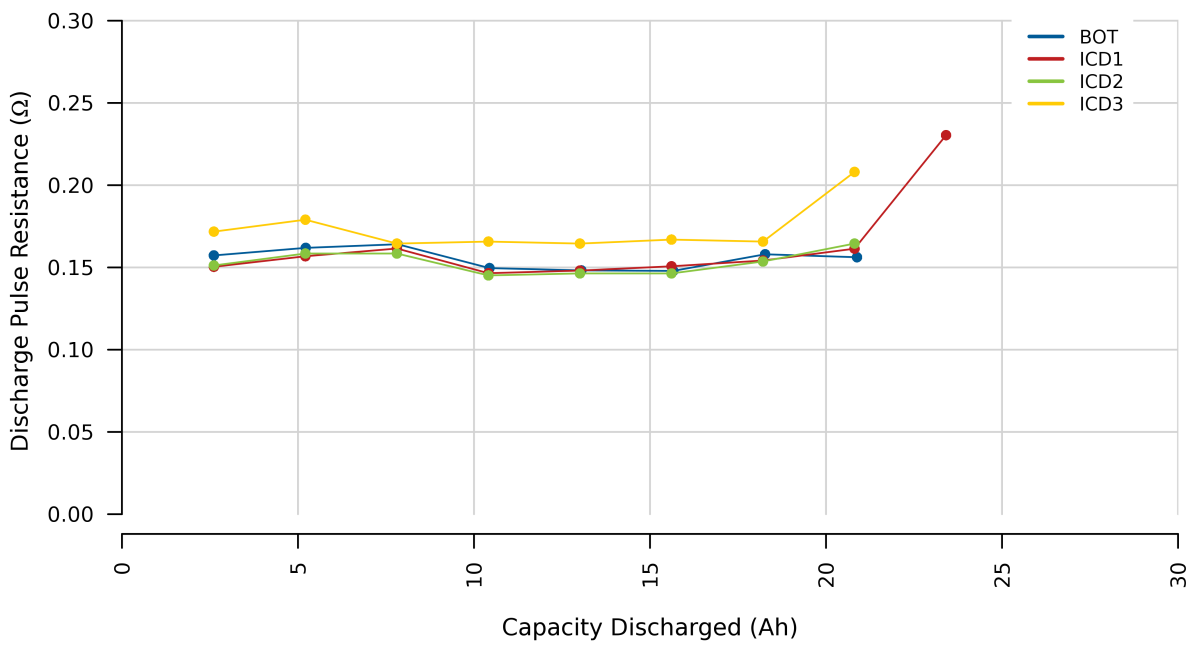


Figure 3. Ten-second discharge pulse resistance versus capacity discharged

Figure 4 shows the battery's 10-second charge and discharge pulse power capabilities as a function of energy discharged. The Medium PHEV battery target performance goals of 37 kW discharge power and 25 kW charge power are shown as a dashed line. Note that the axes are scaled such that the charge and discharge pulse power goals align.

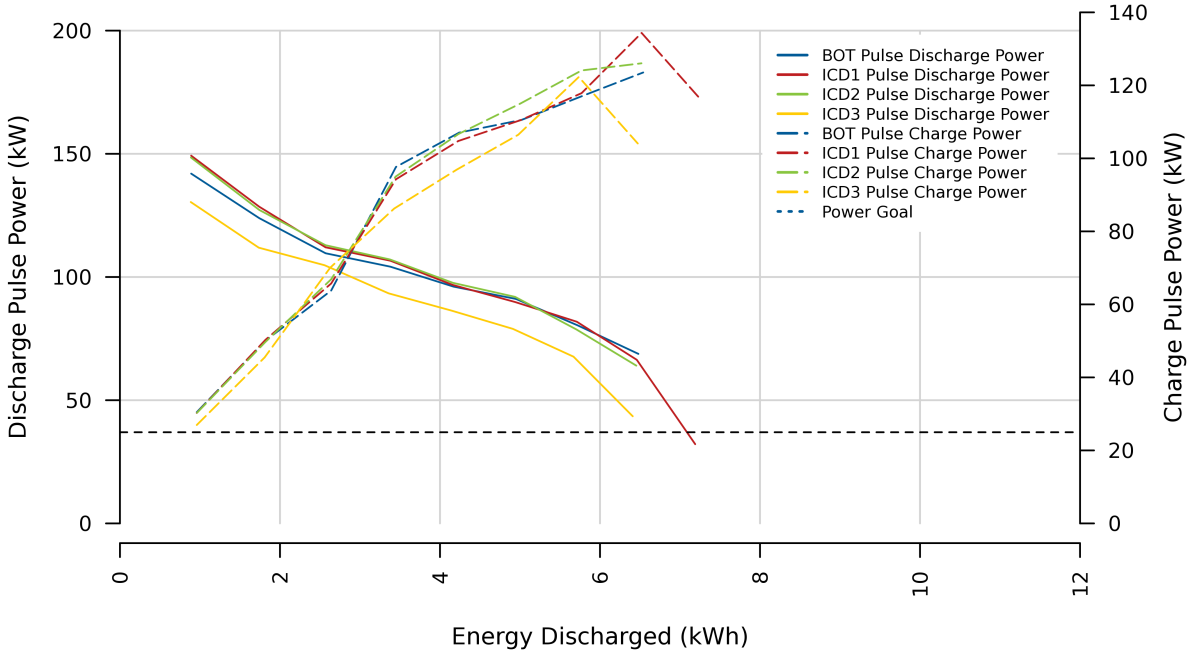


Figure 4. Discharge and charge power capability versus energy discharged

Figure 5 shows the charge-depleting (CD) and charge-sustaining (CS) Usable Energy curves, calculated using the methods from the PHEV battery test manual. The curves indicate the Usable Energy as a function of discharge power. The two dotted horizontal lines show the USABC Medium PHEV battery Available Energy goals for CS and CD modes of 0.3 kWh and 5.8 kWh, respectively. The dotted vertical line shows the Medium PHEV battery CS power target of 37 kW. CS and CD Available Energies are defined as the Usable Energy points, on the y-axis, where each respective curve crosses the discharge power goal line. CS Available Power is defined as the discharge power point, on the x-axis, where the CS Usable Energy curve crosses the CS energy goal line.

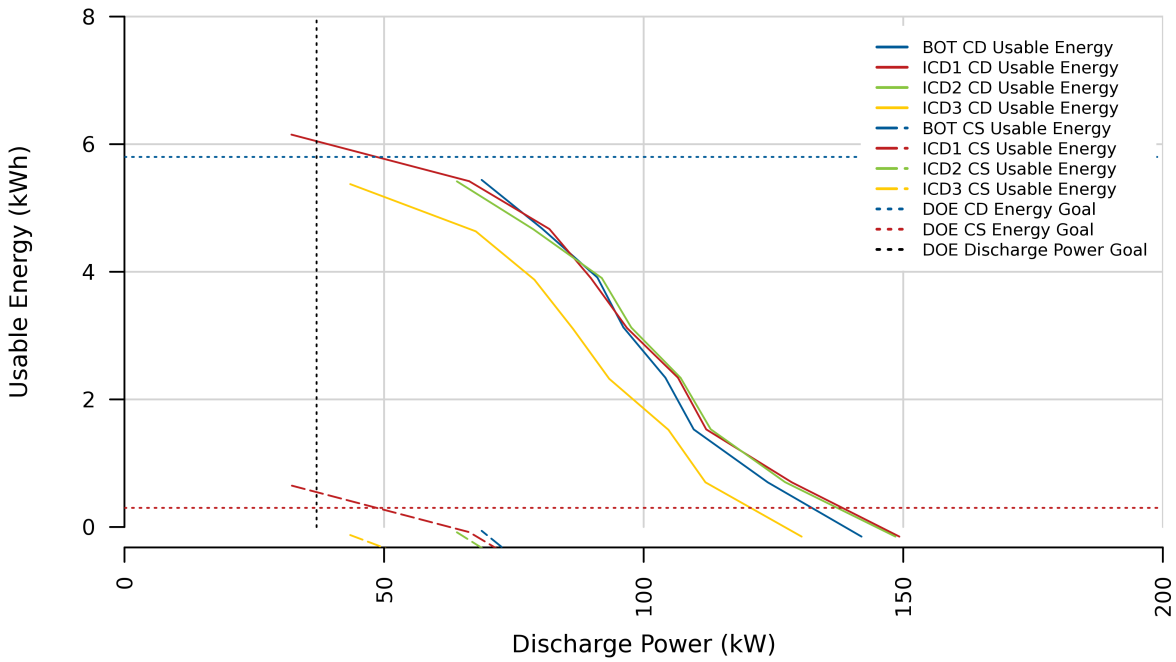


Figure 5. Usable energy versus power