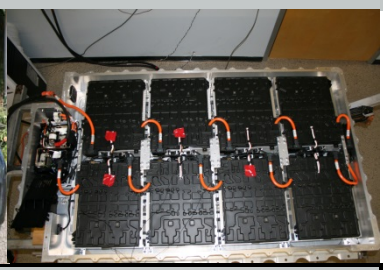
2014 BMW i3 – VINs 5486, 5626, 5655 & 5658

Advanced Vehicle Testing –DC Fast Charging at Temperature Test Results



VEHICLE, ENERGY STORAGE SYSTEM, AND DCFC DETAILS[1]

Vehicle Details

Base Vehicle: 2014 BMW i3
Vehicle Type: BEV
VINs: WBY1Z2C55EV285486; WBY1Z2C55EV285655; WBY1Z2C50EV285658; WBY1Z2C55EV285626

DCFC Details

Manufacturer: BTC Power
Model/Type: EVFC-5-1-B-1-1-480/SAE CCS+CHAdeMO
Rated DC Charge Power: 50 kW
Rated DC Current[2]: 100 A

Energy Storage System Specifications

Manufacturer: Samsung SDI
Type: Lithium-ion NMC
Rated Pack Energy/Capacity: 18.8 kWh/60.0 Ah
Thermal Management: Active – Refrigerant

Test Dates by VIN[3]

	5486	5655	5658	5626
0°C	9/12/2015	9/11/2015	10/25/2015	10/24/2015
25°C	9/15/2015	9/14/2015	10/28/2015	10/26/2015
50°C	N/A	N/A	N/A	N/A

TEST RESULTS SUMMARY

Test Temp. (°C)	Total Charge Duration (hh:mm:ss)	End of Charge Range (mi)	Total DC Charge Energy (kWh)	Initial Charge Start/End SOC[3,4] (%)	Top-Off Charge Start/End SOC[4] (%)	Initial/Top-Off Charge Avg. Power (kW)	ESS ΔT[5] (°C)	ESS Thermal Regulation Energy[6] (kWh)
VIN 5486 - Beginning-of-Test (at 8,201 miles)[7]								
0 °C	02:01:20	73	18.05	0.5 / 77.5	77.5 / 93.5	15.2 / 2.6	4.3	0.31
25 °C	01:16:01	Not Rec.	18.89	1.0 / 95.0	95.0 / 96.5	18.4 / 0.9	1.5	0.46
50 °C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Middle-of-Test								
0 °C								
25 °C								
50 °C								
End-of-Test								
0 °C								
25 °C								
50 °C								
VIN 5655 - Beginning-of-Test (at 8,407 miles)[7]								
0 °C	02:01:00	56	18.75	0.0 / 77.0	77.0 / 92.0	16.0 / 2.6	3.5	0.28
25 °C	01:18:57	67	19.07	0.0 / 95.5	95.5 / 97.0	18.6 / 0.8	1.8	0.57
50 °C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Middle-of-Test								
0 °C								
25 °C								
50 °C								
End-of-Test								
0 °C								
25 °C								
50 °C								

Test Temp. (°C)	Total Charge Duration (hh:mm:ss)	End of Charge Range (mi)	Total DC Charge Energy (kWh)	Initial Charge Start/End SOC[3,4] (%)	Top-Off Charge Start/End SOC[4] (%)	Initial/Top-Off Charge Avg. Power (kW)	ESS ΔT[5] (°C)	ESS Thermal Regulation Energy[6] (kWh)
VIN 5658 - Beginning-of-Test (at 9,532 miles)[7]								
0 °C	02:01:18	62	17.95	0.0 / 76.5	76.5 / 91.0	15.1 / 2.7	5.5	0.32
25 °C	01:15:16	72	18.77	1.5 / 95.0	95.0 / 96.5	18.3 / 1.0	1.4	0.51
50 °C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Middle-of-Test								
0 °C								
25 °C								
50 °C								
End-of-Test								
0 °C								
25 °C								
50 °C								
VIN 5626 - Beginning-of-Test (at 6,836 miles)[7]								
0 °C	02:01:12	57	18.01	1.0 / 77.0	77.0 / 91.5	15.1 / 2.7	2.7	0.42
25 °C	01:16:42	76	19.30	0.0 / 95.0	95.0 / 96.5	18.8 / 1.0	1.9	0.49
50 °C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Middle-of-Test								
0 °C								
25 °C								
50 °C								
End-of-Test								
0 °C								
25 °C								
50 °C								

Test Results Analysis

DC fast charging at temperature testing includes tests that measure the charge duration, energy transfer, and energy used to thermally regulate the energy storage system (ESS) for charge events at 0, 25 and 50 °C.[8] The objective of this testing is to provide analysis about the effects of ambient temperature on DC fast charge-capable vehicles. These tests were performed as part of the US Department of Energy Advanced Vehicle Testing Activity, which is conducted by Idaho National Laboratory and the Intertek Center for Evaluation of Clean Energy Technology (CECET).

Test Results: Energy and SOC

Figures 1a and 1b show the energy transferred to each vehicle and the change in state of charge (SOC) over the duration of each charge event for each of the specified temperatures. Each DC fast charge event consists of an initial charge event and a top-off charge event.[9,10] The end of the initial charge is denoted by a dashed oval. During testing, fast charging at 50 °C DC was not able to be conducted due to the vehicle preventing the charge event from occurring. Many vehicle manufacturers report the time required for a charge of the ESS to 80% SOC as being 30 minutes. For VIN 5486, the SOCs recorded at the 30-minute mark for the 0 and 25 °C tests were 42.0% and 82%, respectively. For VIN 5655, the SOCs recorded at the 30-minute mark for the 0 and 25 °C tests were 38.5% and 82.5%, respectively. For VIN 5658, the SOCs recorded at the 30-minute mark for the 0 and 25 °C tests were 42.0% and 81.5%, respectively. For VIN 5626, the SOCs recorded at the 30-minute mark for the 0 and 25 °C tests were 43.0% and 79.0%, respectively.

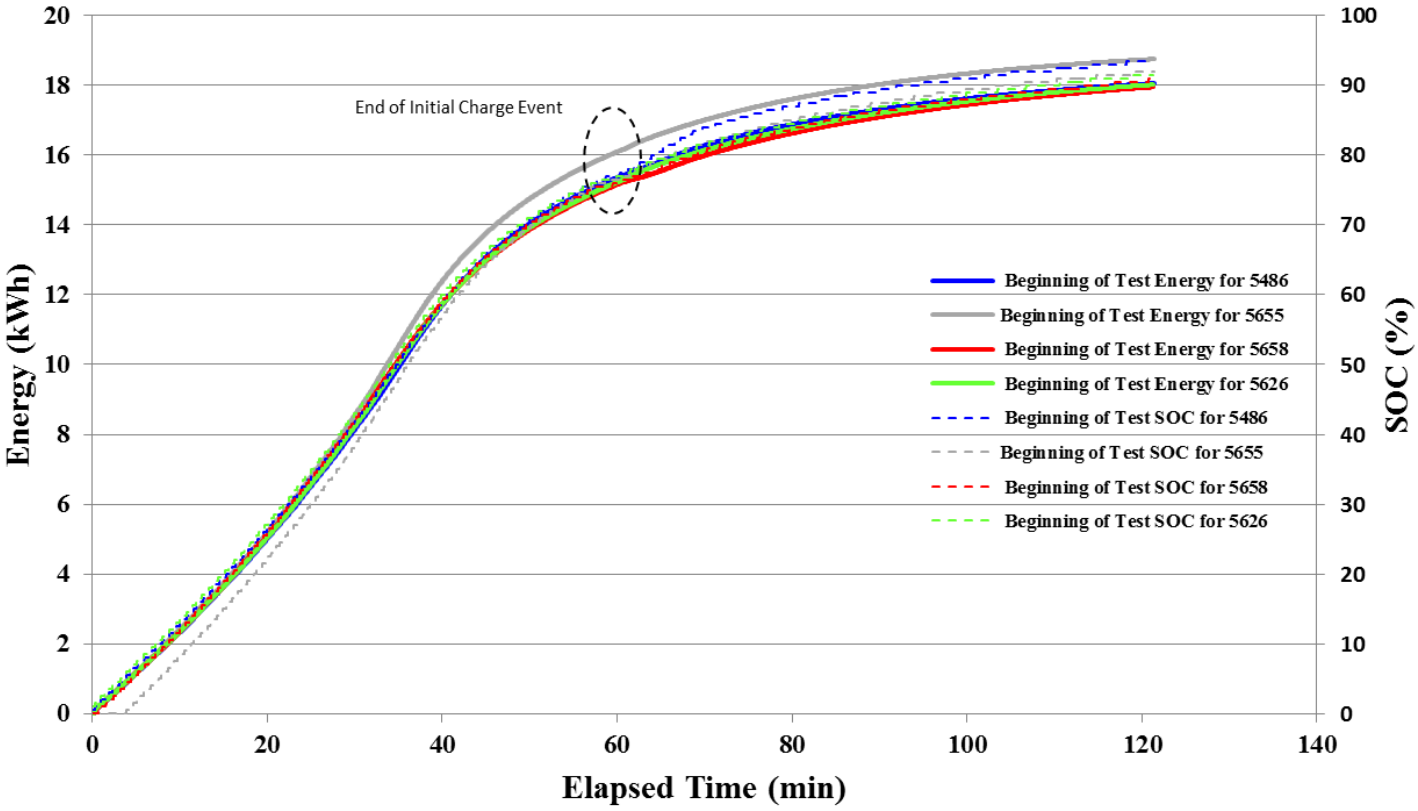


Figure 1a. 0 °C charge energy and SOC versus time

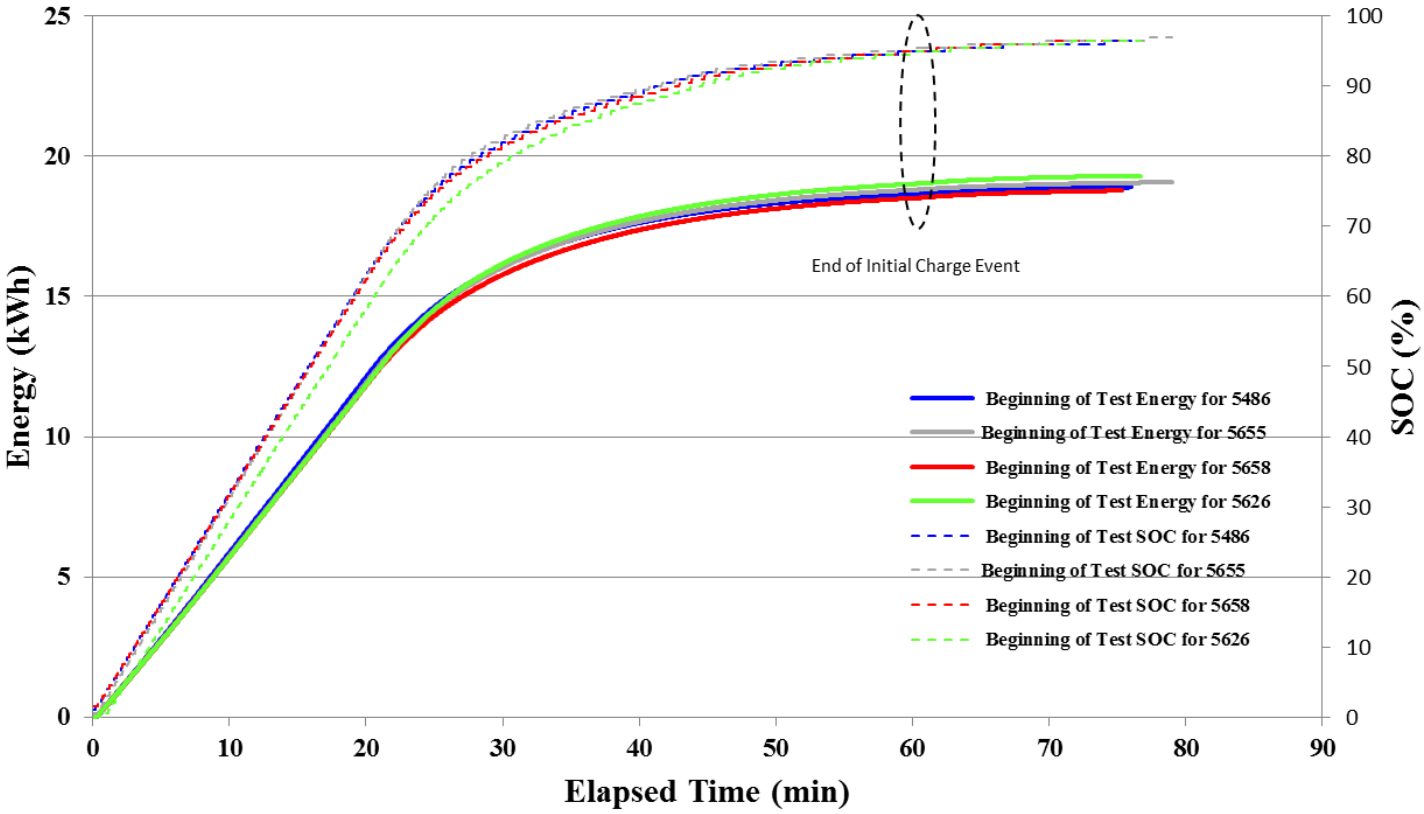


Figure 1b. 25 °C charge energy and SOC versus time

Test Results: Temperatures

Tables 1,2,3 and 4 show the initial, final, and maximum ESS enclosure temperatures of each vehicle's ESS during charging events.

Table 1. VIN 5486 ESS enclosure temperature during BOT test

Test Temperature (°C)	ESS Enclosure Initial Temp. (°C)	ESS Enclosure Final Temp. (°C)	ESS Enclosure Maximum Temp. (°C)
0 °C	-1.8	2.4	2.6
25 °C	25.7	27.2	27.3
50 °C	N/A	N/A	N/A

Table 2. VIN 5655 ESS enclosure temperature during BOT test

Test Temperature (°C)	ESS Enclosure Initial Temp. (°C)	ESS Enclosure Final Temp. (°C)	ESS Enclosure Maximum Temp. (°C)
0 °C	-1.6	1.9	4.8
25 °C	25.9	27.6	27.8
50 °C	N/A	N/A	N/A

Table 3. VIN 5658 ESS enclosure temperature during BOT test

Test Temperature (°C)	ESS Enclosure Initial Temp. (°C)	ESS Enclosure Final Temp. (°C)	ESS Enclosure Maximum Temp. (°C)
0 °C	-1.5	4.0	6.1
25 °C	25.4	26.9	27.1
50 °C	N/A	N/A	N/A

Table 4. VIN 5626 ESS enclosure temperature during BOT test

Test Temperature (°C)	ESS Enclosure Initial Temp. (°C)	ESS Enclosure Final Temp. (°C)	ESS Enclosure Maximum Temp. (°C)
0 °C	-1.7	1.0	1.4
25 °C	24.5	26.4	26.7
50 °C	N/A	N/A	N/A

Test Results: Charge Power[11,12]

Figures 2a and 2b show the power at which each vehicle's ESS was being charged for each of the specified temperatures. As before, the end of the initial charge event is denoted by a dashed oval.

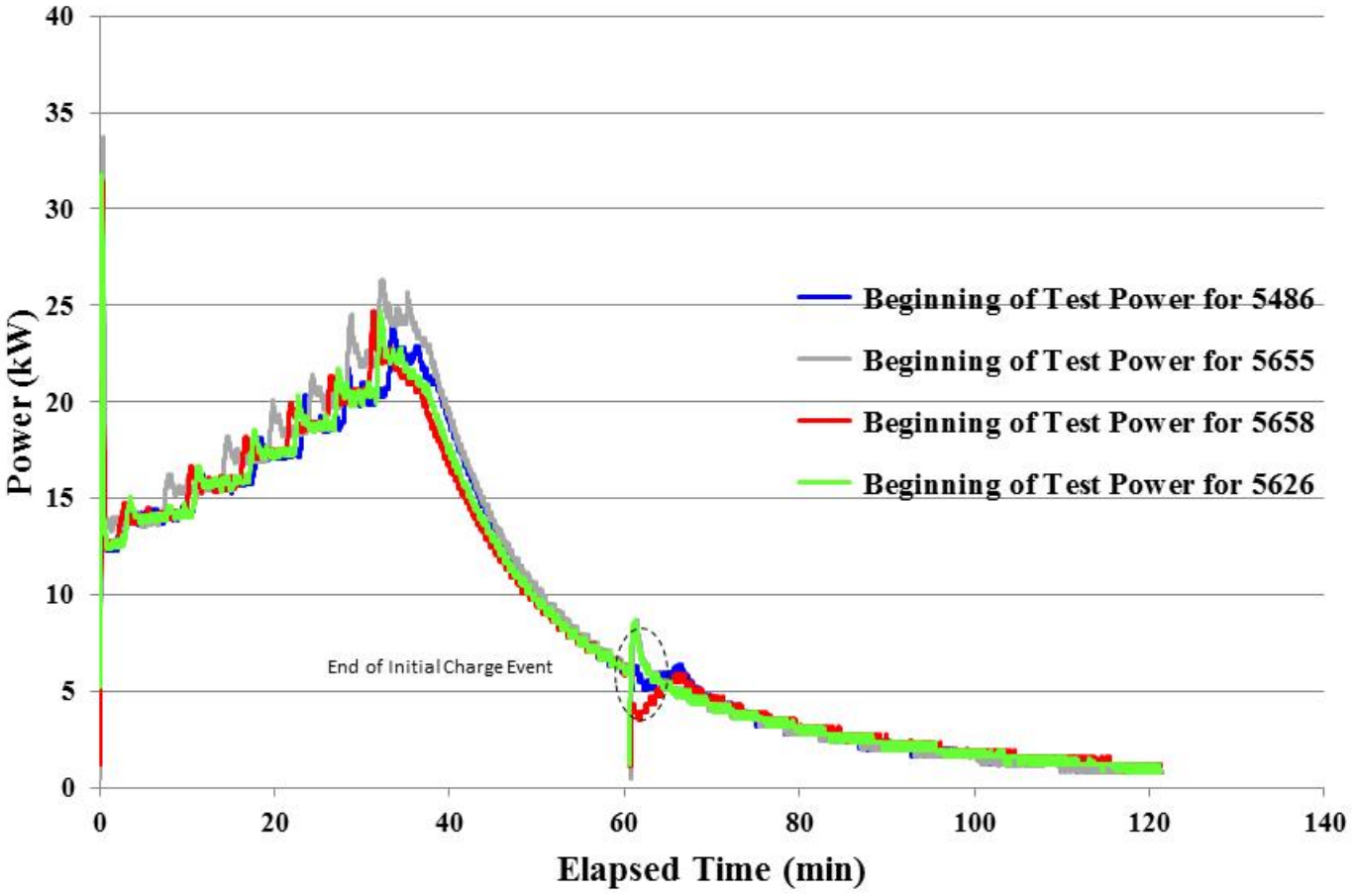


Figure 2a. 0 °C charge power profiles

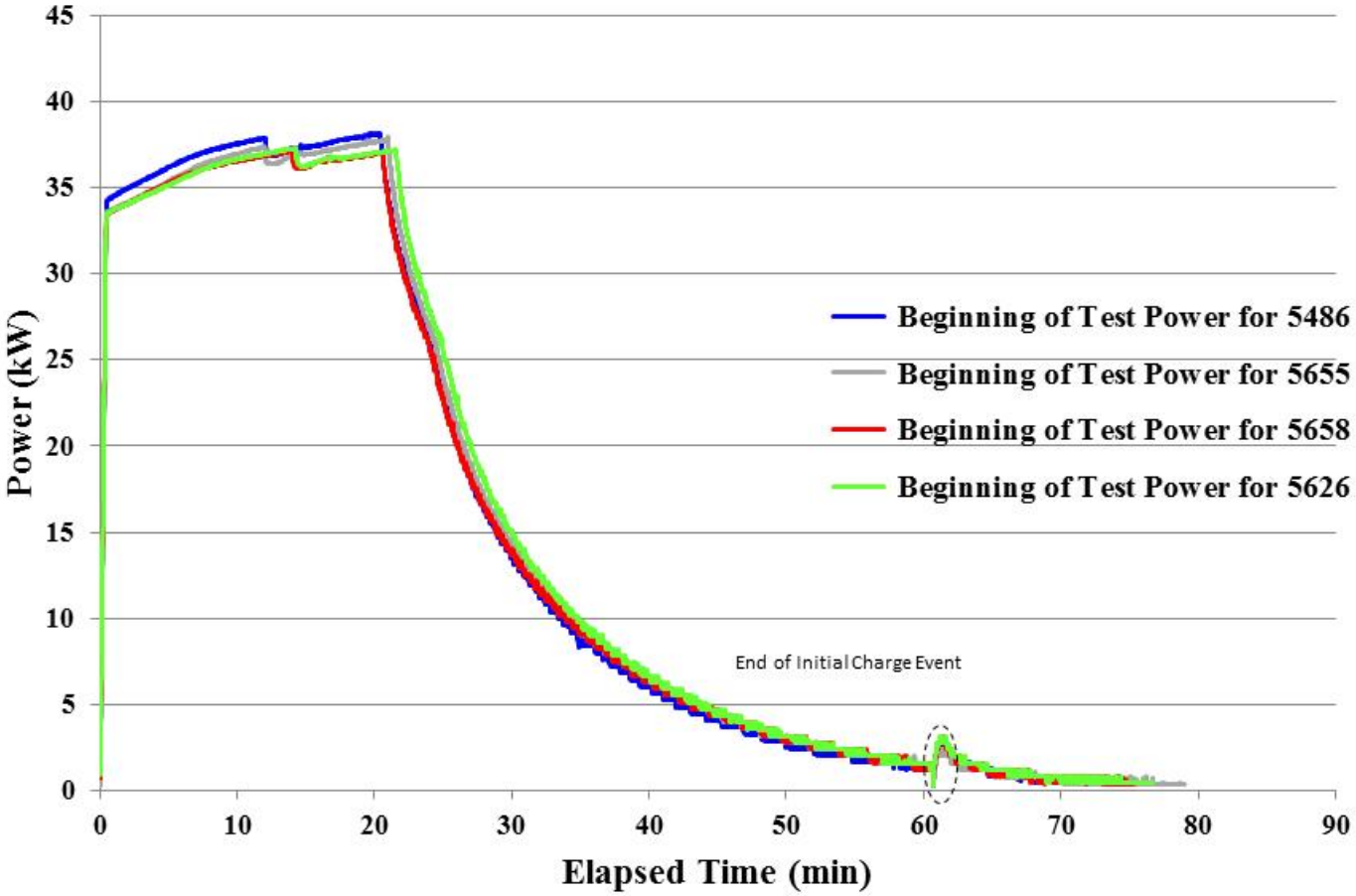


Figure 2b. 25 °C charge power profiles

NOTES:

1. Vehicle, ESS, and DCFC details were either supplied by the manufacturer or derived from a literature review.
2. The BTC DCFC has a maximum current output of 100 A.
3. The BMW i3 did not take a charge after repeated attempts at 50 °C. Attempts were made at 0%, 5% and 50% SOC. The charge was accepted once pack temperature dropped.
4. The ESS SOC is recorded from the vehicle controller area network (CAN) bus. The SOC displayed on the dashboard is also recorded for comparison and corroboration when available. In the case of the BMW i3, the CAN SOC correlates with the SOC revealed by a diagnostic scan tool. Refer to Note 9 for details concerning top-off charge events.
5. The "ESS ΔT During Test" is the difference in the temperature of the ESS between start and end of test. This parameter is calculated using the vehicle CAN message for battery temperature when available. When the CAN message is not available, the ESS enclosure temperature is measured by placing a thermocouple on the battery pack enclosure. In the case of the BMW i3, ESS temperature is not reported via CAN and the pack thermocouple was placed at the rear passenger side corner of the pack near the coolant lines.
6. The thermal regulation load is an approximate calculation of the amount of energy used by the vehicle to regulate ESS temperature, where applicable. This is calculated by subtracting the amount of energy into the ESS from the amount of energy output by the DCFC; the calculated value also includes resistive and conversion electrical losses. In the case of the BMW i3, it is possible that the energy values noted for the 0 °C and 25 °C tests are due to parasitic losses or powering of the vehicle fast charging system. There are three possibilities for how the onboard vehicle electronics receive power during a fast charge: 1) 12 V interface on the SAE Combo fast charger, 2) DC-to-DC converter steps high voltage down to 12 V, or 3) the system could be powered directly from the 12 V battery of the vehicle. Also, it is noteworthy that thermal regulation power became slightly negative during the top-off charge causing the overall energy level to decrease slightly from its peak value. This is likely due to the difference in the resolution of the energy meter in the vehicle and the BTC fast charger. The peak thermal regulation energy before the decrease occurred is listed below for each charge:

   VIN 5486:
   - 0 °C: 0.60 kWh
   - 25 °C: 0.67 kWh
   - 50 °C: N/A

   VIN 5655:
   - 0 °C: 0.56 kWh
   - 25 °C: 0.76 kWh
   - 50 °C: N/A

   VIN 5658:
   - 0 °C: 0.58 kWh
   - 25 °C: 0.66 kWh
   - 50 °C: N/A

   VIN 5626:
   - 0 °C: 0.69 kWh
   - 25 °C: 0.66 kWh
   - 50 °C: N/A

7. Each fast charge-capable vehicle is chamber tested three times over the course of its test life. Under normal circumstances for EVs, the temperature chamber testing will take place at the same mileage target as the ESS Beginning of Test (BOT) test at 400 miles. The Middle of Test (MOT) takes place at the same mileage target as the ESS Interim Component Durability 3 (ICD3) test that is conducted at 24,000 miles. Finally, the End of Test (EOT) is conducted at the same mileage target as the ESS EOT test that is conducted at 36,000 miles. In the case of the BMW i3, the procurement of an SAE CCS fast charger was made after the vechiles had reached BOT mileage.
8. Each test consists of a soak period deemed sufficient to ensure the vehicle ESS is at the target test temperature; the soak period is a minimum of 21 hours.
9. One top-off charge is conducted per test regardless of the ESS SOC reading at the end of the initial and top-off charge events. The battery management system (BMS) determines the stopping point of the initial and top-off charge events. The dashboard Vehicle Energy Indicator (VEI) for each vehicle at the start/end of each test was as follows:

   VIN 5486:
   - 0 °C: 1 / 4 bars
   - 25 °C: 1 / 5 bars
   - 50 °C: N/A

   VIN 5655:
   - 0 °C: 1 / 5 bars
   - 25 °C: 1 / 5 bars
   - 50 °C: N/A

   VIN 5658:
   - 0 °C: 1 / 5 bars
   - 25 °C: 1 / 5 bars
   - 50 °C: N/A

   VIN 5626:
   - 0 °C: 1 / 5 bars
   - 25 °C: 1 / 5 bars
   - 50 °C: N/A

10. Time (mm:ss) between the end of the initial charge and beginning of the top-off charge is collected for each test. This delay has not been included in the figures. There were a number of instances where the time delay between charges was in excess of five minutes. This occurred because in some cases it took multiple charge attemps for the top-off charge to be initiated.

    VIN 5486:
    - 0 °C: 07:27
    - 25 °C: 06:11
    - 50 °C: N/A

    VIN 5655:
    - 0 °C: 01:00
    - 25 °C: 02:24
    - 50 °C: N/A

    VIN 5658:
    - 0 °C: 01:47
    - 25 °C: 05:15
    - 50 °C: N/A

    VIN 5626:
    - 0 °C: 01:20
    - 25 °C: 05:24
    - 50 °C: N/A

11. Maximum charge power for initial and top-off charges:

    VIN 5486:
    - 0 °C: 31.3 / 6.4 kW
    - 25 °C: 38.2 / 2.8 kW
    - 50 °C: N/A

    VIN 5655:
    - 0 °C: 33.7 / 8.7 kW
    - 25 °C: 37.9 / 2.4 kW
    - 50 °C: N/A

    VIN 5658:
    - 0 °C: 31.4 / 5.9 kW
    - 25 °C: 37.1 / 3.2 kW
    - 50 °C: N/A

    VIN 5626:
    - 0 °C: 31.7 / 8.7 kW
    - 25 °C: 37.3 / 3.2 kW
    - 50 °C: N/A

12. Voltage at end of initial charge / voltage at end of top-off charge / maximum charge voltage / voltage at initial current drop off:

    VIN 5486:
    - 0 °C: 392.9 / 393.1 / 393.2 / 392V
    - 25 °C: 393.3 / 393.3 / 393.4 / 392 V
    - 50 °C: N/A

    VIN 5655:
    - 0 °C: 393.1 / 393.3 / 393.4 / 392.5 V
    - 25 °C: 393.3 / 393.4 / 393.5 / 392.1 V
    - 50 °C: N/A

    VIN 5658:
    - 0 °C: 392.9 / 393.2 / 393.3 / 392.6 V
    - 25 °C: 393.4 / 393.3 / 393.5 / 392.2 V
    - 50 °C: N/A

    VIN 5625:
    - 0 °C: 393.1 / 393.2 / 393.3 / 392.9 V
    - 25 °C: 393.2 / 393.2 / 393.4 / 392.3 V
    - 50 °C: N/A

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