DC Fast Charging Effects on Battery Life and EVSE Efficiency and Security Testing

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Advanced Vehicle Testing Activity (AVTA)

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Project ID: VSS131
INL/MIS-14-31708

Idaho National Laboratory

Overview

Timeline

- Start Date: 10/2012
- End Date: 9/2014
- Percent Complete: 60%

Barriers

- Cost
- Infrastructure
- Constant Advances in Technology

Budget

- FY13 – $ 1.4M
- FY14 – $ 0.9M

- Spent to Date: $ 1.15M

Partners

- Intertek Testing Services
- DOE Office of Energy Efficiency and Renewable Energy (EERE)
- DOE Office of Electricity Delivery and Energy Reliability (OE)
- Industry partners
  - Delta, Eaton, General Electric, Siemens
- Idaho National Laboratory (INL) - Lead

Idaho National Laboratory

Objectives/Relevance

- Minimize uncertainty by quantifying the impacts of DC Fast Charging on EV battery capacity (range) and power capability (performance)
  - Barrier addressed: Cost, Infrastructure
    - Provide information to model cost-benefit of fast charging
    - PEV consumers, infrastructure providers
- Support modeling and research efforts among VSST labs by collecting and analyzing driving, charging, and battery lab data
  - Barrier addressed: Constant advances in technology
    - Develop test methods to characterize new technologies
    - Results data to support modeling/simulation for current study, future work
- Enable informed investments in advanced infrastructure development that address barriers to PEV adoption
  - Barriers addressed: Cost, Infrastructure
    - Providing independent, common reporting to DOE on efficiency using standardized testing methods
    - Vulnerability assessments to advanced technology developers

Milestones

Date	Milestone	Status
12/31/2013	Post testing reports and fact sheets on AVTA website, report status	Complete
12/31/2013	Conduct operational/efficiency testing and cyber security vulnerability assessment of one EVSE provided by FOA awardees	Complete
3/31/2014	Post testing reports and fact sheets on AVTA website, report status	Complete
3/31/2014	Conduct operational/efficiency testing and cyber security vulnerability assessment of one EVSE provided by FOA awardees	Pending delivery
6/30/2014	Post testing reports and fact sheets on AVTA website, report status	On-Track
6/30/2014	Conduct operational/efficiency testing and cyber security vulnerability assessment of one EVSE provided by FOA awardees	On-Track, pending delivery
9/30/2014	Post testing reports and fact sheets on AVTA website, report status	On-Track
9/30/2014	Conduct operational/efficiency testing and cyber security vulnerability assessment of one EVSE provided by FOA awardees	On-Track, pending delivery

Approach – DC Fast Charge Effects

- Accumulate comparable on-road mileage on dedicated vehicles
  - Two 2012 Nissan Leafs exclusively DC Fast Charged (50 kW)
  - Two 2012 Nissan Leafs exclusively AC Level 2 Charged (3.3 kW)
  - Same route twice daily (AM, PM), in pairs (DCFC car, AC L2 car)
  - Minimize effects by rotating drive pairing, drivers, order
- Characterize vehicle performance when new, and at conclusion of testing
  - Track testing – constant speed range, acceleration
- Measure battery capacity, characterize internal resistance and power capability when new, at 10,000 mile intervals
  - Lab testing – constant current C_3 capacity, pulse power and low peak power tests (USABC procedures)

- Laboratory cycling and testing
  - 2012 Nissan Leaf battery packs (2)
  - Constant temp (30° C)
  - Same 'drive' cycle, only charge differs between packs (50kW, 3.3kW)

Approach – EVSE Testing

- Conduct functionality, efficiency, and cyber security testing of Smart Grid Capable EVSE in support of FOA-554
  - Functionality and efficiency tests
    - Stand-by power consumption
    - Power consumption during charging
    - On-board energy meter accuracy
    - Functionality per J1772 standard
      - Emulated J1772 communications
      - Production PEV functionality
  - Cyber Security testing
    - Identify severity and cause of vulnerabilities
      - Hardwired connection
      - Wireless communication
      - Invasive investigation
      - Firmware and back-office vulnerability testing

Technical Accomplishments – DCFC Effects

- Interim lab battery tests at 10k mile intervals - Static Capacity, HPPC, LPP
- Results-to-date reporting on battery capacity changes on AVTA website
- INL Lab cycling and testing underway
  - Bitrode FTF power processing machines
  - Cincinnati SubZero walk-in thermal chambers

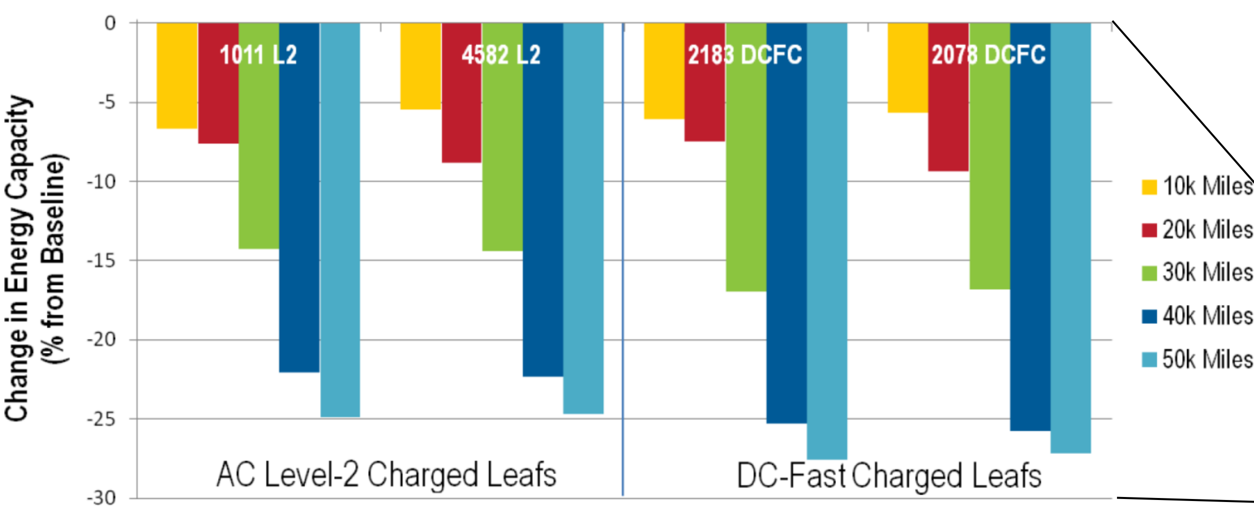
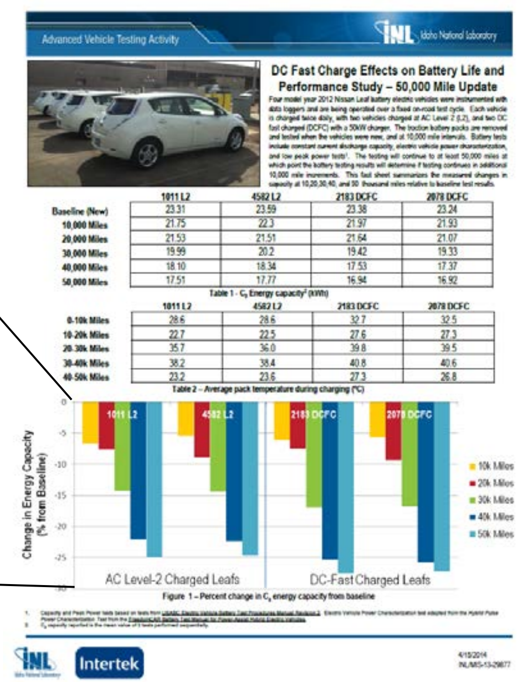


Figure 1 – Percent change in C_3 energy capacity from baseline



Advanced Vehicle Testing Activity

INL Idaho National Laboratory

DC Fast Charge Effects on Battery Life and Performance Study – 50,000 Mile Update

Four model year 2012 Nissan Leaf battery electric vehicles were instrumented with data loggers and are being operated over a fixed on-road test cycle. Each vehicle is charged twice daily, with two vehicles charged at AC Level 2 (L2), and two DC fast charged (DCFC) with a 50kW charger. The traction battery packs are removed and tested when the vehicles were new, and at 10,000 mile intervals. Battery tests include constant current discharge capacity, electric vehicle power characterization, and low peak power tests[1]. The testing will continue to at least 50,000 miles at which point the battery testing results will determine if testing continues in additional 10,000 mile increments. This fact sheet summarizes the measured changes in capacity at 10,20,30,40, and 50 thousand miles relative to baseline test results.

	1011 L2	4582 L2	2183 DCFC	2078 DCFC
Baseline (New)	23.31	23.59	23.38	23.24
10,000 Miles	21.75	22.3	21.97	21.93
20,000 Miles	21.53	21.51	21.64	21.07
30,000 Miles	19.99	20.2	19.42	19.33
40,000 Miles	18.10	18.34	17.53	17.37
50,000 Miles	17.51	17.77	16.94	16.92

Table 1 - C_3 Energy capacity[2] (kWh)

	1011 L2	4582 L2	2183 DCFC	2078 DCFC
0-10k Miles	28.6	28.6	32.7	32.5
10-20k Miles	22.7	22.5	27.6	27.3
20-30k Miles	35.7	36.0	39.8	39.5
30-40k Miles	38.2	38.4	40.8	40.6
40-50k Miles	23.2	23.6	27.3	26.8

Table 2 – Average pack temperature during charging (°C)

Figure 1 – Percent change in C_3 energy capacity from baseline

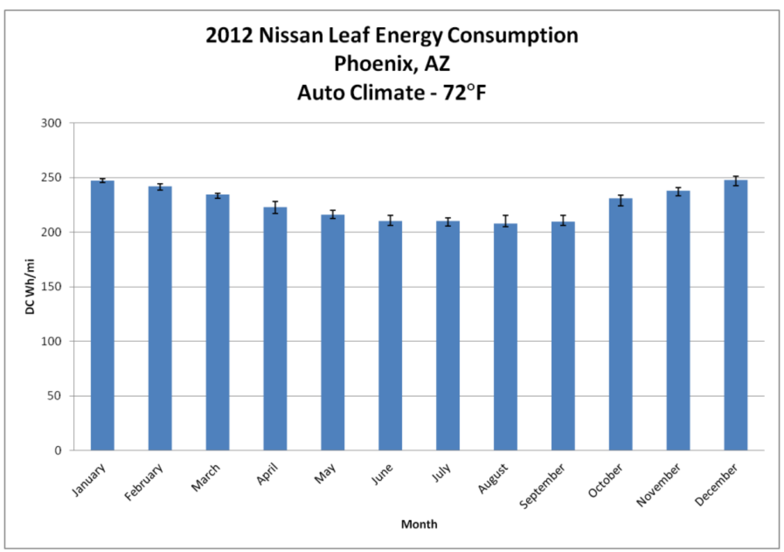
INL Intertek

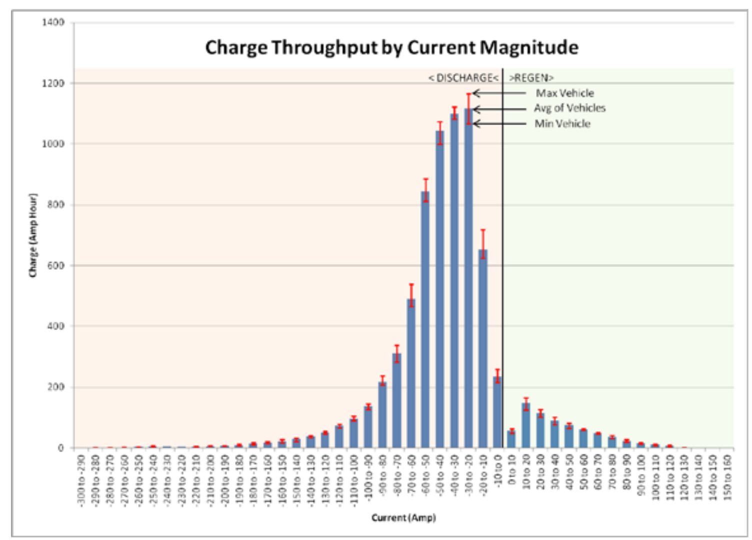
@50k 24.6% Capacity Loss vs 27.6% Capacity Loss

~3miles range difference between DCFC, AC L2

Technical Accomplishments – DCFC Effects continued

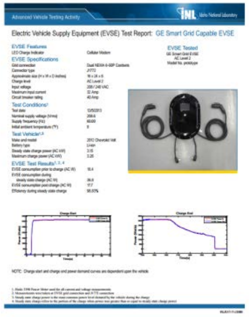
- Baseline Track Vehicle Performance & Lab Battery Testing
- 50,000 Miles of on-road mileage accumulation and data collection
  - Consistency in operation among vehicles confirmed via data
  - Battery utilization for all vehicles very similar for driving segments
- 50k Track testing in-progress at time of submission

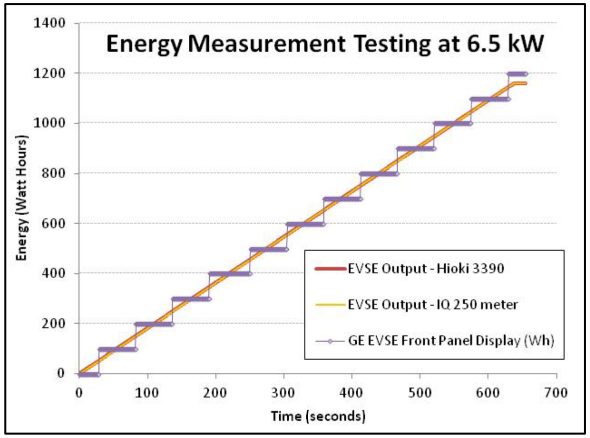




Technical Accomplishments, Smart Grid EVSE Testing

- Testing designed with calibrated instrumentation
  - Hioki Power meter (0.13% accuracy)
  - Eaton Energy meter (0.2% accuracy)
- J1772 functionality testing completed
  - Grid Test EVE-100L
  - 2012 Chevrolet Volt
- Testing completed, fact sheet published
  - Power Consumption while not charging
  - Average efficiency while charging
  - Evaluation of EVSE internal energy meter





J1712 State	Left Plug (Plug #1)	Right Plug (Plug #2)
State B	17.7 Watts	17.8 Watts
State C	19.8 Watts	19.9 Watts
State D	NA	NA

Test Condition	Average EVSE Efficiency (Output Power/Input Power)
50 watts	71.9%
1.1 kW	97.8%
3.3 kW	98.7%
6.5 kW	98.5%

Technical Accomplishments – Smart Grid EVSE continued

- Cyber Security testing was completed for the one EVSE delivered
  - Identified severity and cause of vulnerabilities
    - Hardwired connections
    - Wireless communication
    - Invasive investigation internal to EVSE
    - Firmware and back-office vulnerability testing
  - Report to EVSE manufacturer

Responses to previous year reviewer comments

- The reviewer asked whether running four vehicles for 30,000 miles of a single chemistry with a single Battery Management System is going to conclude much about the fundamental effects of fast charging. Also, the reviewer asked would the research be better served to have more varieties of packs under more controlled conditions with key parameters identified by battery chemists. The reviewer added that the road approach is expensive, less controlled and thus sample limited. Another reviewer observed that battery technology is changing and improving. The reviewer added that this project may be measuring something that is always changing.
  - *The on-road testing, while providing useful data on specific current technology, also gives researchers data that, when combined with the complementary laboratory testing, enable further development of test methods. Such methods in lab testing would allow larger sample sizes, diverse chemistries, and lower costs simultaneously with a linkage, through this project's data, to real-world benchmark testing. This project has also been extended to 70k miles, to add two more lab tests.*

Responses to previous year reviewer comments, cont'd

- Reviewer stated: "…future work was identified for most of the projects as time dependent on others for the evaluations. INL appeared to be ready for evaluations and not the cause for any delays. ."
  - *Response: The one EVSE that was delivered to INL was tested and evaluated in a timely manner. The other three EVSE had not yet been delivered at the time this presentation was prepared.*
- This reviewer said that questions on the methodology (and what can be concluded) may require more core scientific interactions with battery expert groups; this is not clear.
  - *On-road and laboratory data are being analyzed by electrochemical battery experts at INL to examine changes to the battery over time, and explore linkages between usage and degradation. Expansion of this effort would influence testing methods being developed to allow smaller scale, laboratory testing to address different battery chemistries and configurations*

Collaboration

- Smart-grid capable EVSE testing – INL, ANL Complementary testing
  - Idaho is testing efficiency, functionality, and cyber security while Argonne is testing other aspects of functionality and smart-grid communication protocols
- DC Fast Charge Study – INL, Intertek Testing Services
  - Intertek is the sole subcontractor providing on-road testing, lab battery testing, and track testing for the four on-road vehicles
  - INL is the project lead for analysis and for lab pack cycling
- DC Fast Charge Study – INL, VSST Labs
  - Driving and charging thermal data, power profiles available
  - Discussions with NREL, Argonne
- DC Fast Charge Study – INL, USABC (OEMs, National Labs, DOE)
  - Project presented to USABC TAC meeting, anticipate another meeting
  - Incorporates pre-release procedures (EVPC)

Remaining Challenges and Barriers

- Effects of fast charging on other types of batteries
- Lab cycling results remain to be seen
  - Isolate temperature variation
  - Further isolate cycling variation
- Data points to-date include less than two years
  - Expansion will allow about two calendar years
  - Better certainty on seasonal (temperature) effects

Future Work

- Testing and reporting pending delivery of the other three EVSE from the FOA-554 awardees (Eaton, Delta, and Siemens)
- Expanded DC fast charge effects study to 70k to include two more intervals and battery tests
- Continued Lab cycling
- Report on full results of on-road and lab testing at completion
- Propose deep-dive of on-road data to examine more subtle changes beyond capacity, power capability, i.e. resistance growth
- Propose work to link cell or module testing to full-pack testing
  - Ideally enable lower cost testing of other technologies
- Planned peer-reviewed paper on key findings of study

Summary

- Four smart-grid EVSE evaluated for efficiency, functionality, and cyber security.
- On-Road operation of 4 identical EVs, dedicated to DC-Fast or AC Level-2 Charged
- Laboratory cycling and testing of 2 identical EV packs: DC-Fast or AC Level-2 Charged
- Comparison of battery performance between types of charging at 10, 20, 30, 40, and 50 thousand miles. Continuation to 70k.
- Lab testing at constant, moderate temps to remove temperature variability – compare trends back to on-road tested packs as secondary study
- Complete data logging on-board to understand ambient conditions and usage, to then link to lab results.
- Additional EV driving and charging data available to AVTA partners

Acknowledgement

This work is supported by the U.S. Department of Energy's EERE Vehicle Technologies Program

More Information

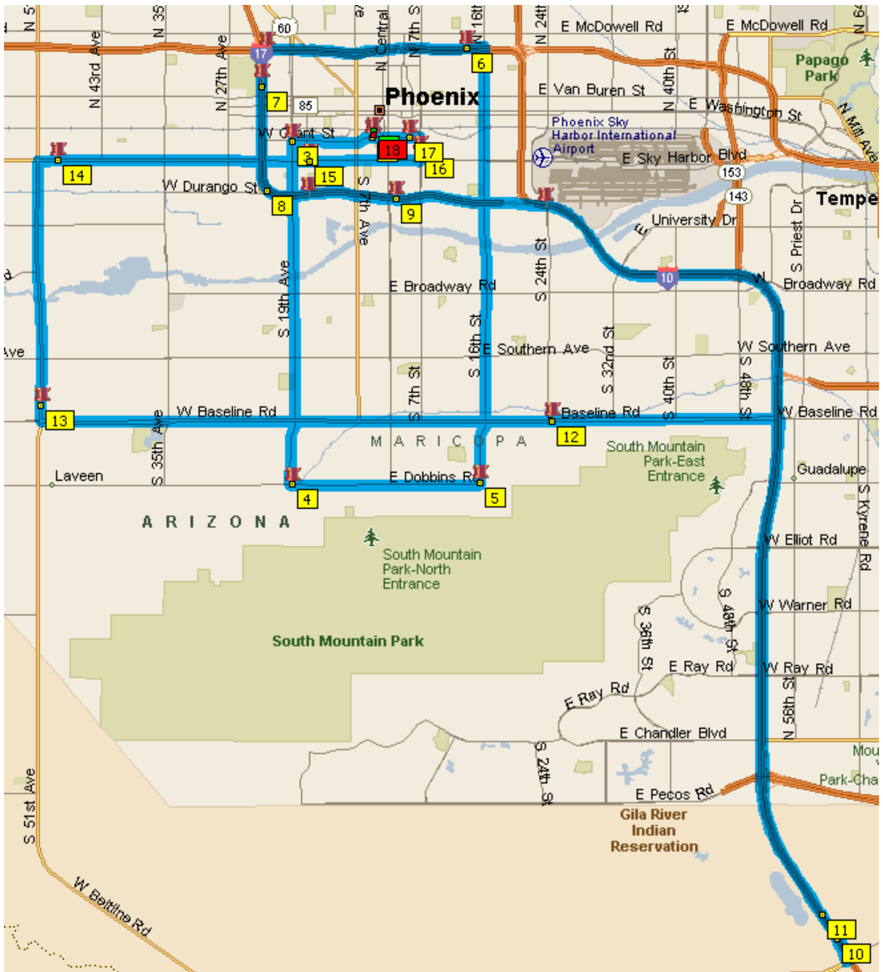
http://avt.inl.gov

Technical Back Up Slides

Backup Slide 1

- *"……A goal of the OE Smart Grid Research and Development (R&D) Program is to develop and implement smart grid technologies to support transportation electrification. A near-term objective of the program is to reduce electric charging infrastructure costs in support of the President's initiative of putting one million electric vehicles on the road by 2015…."*

Backup Slide 2



Advanced Vehicle Testing Activity — Idaho National Laboratory

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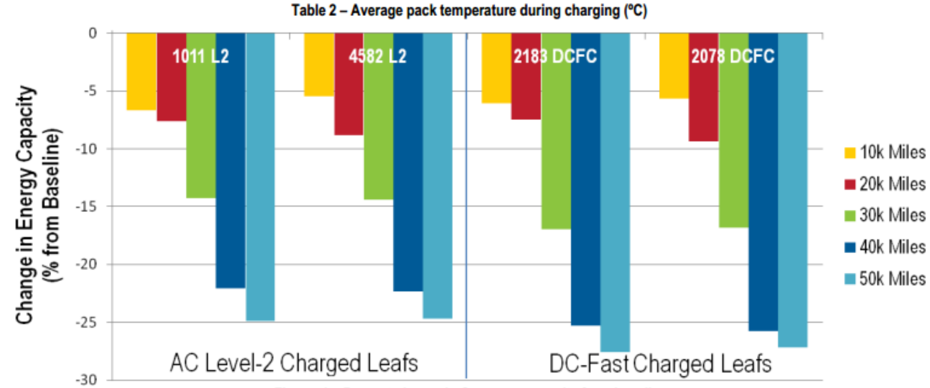

Figure 1 – Percent change in C_3 energy capacity from baseline

1. Capacity and Peak Power tests based on tests from USABC Electric Vehicle Battery Test Procedures Manual Revision 2. Electric Vehicle Power Characterization test adapted from the *Hybrid Pulse Power Characterization Test* from the FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles.
2. C_3 capacity reported is the mean value of 3 tests performed sequentially.