EVS28
KINTEX, Korea, May 3-6, 2015

Impact of Fast Charging on Life of EV Batteries

Jeremy Neubauer[2], Eric Wood[2], Evan Burton[2], Kandler Smith[2], Ahmad A. Pesaran[1]
[1](corresponding author) National Renewable Energy Laboratory, Golden, Colorado, ahmad.pesaran@nrel.gov
[2]National Renewable Energy Laboratory

NREL/PR-5400-63700
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Introduction and Overview

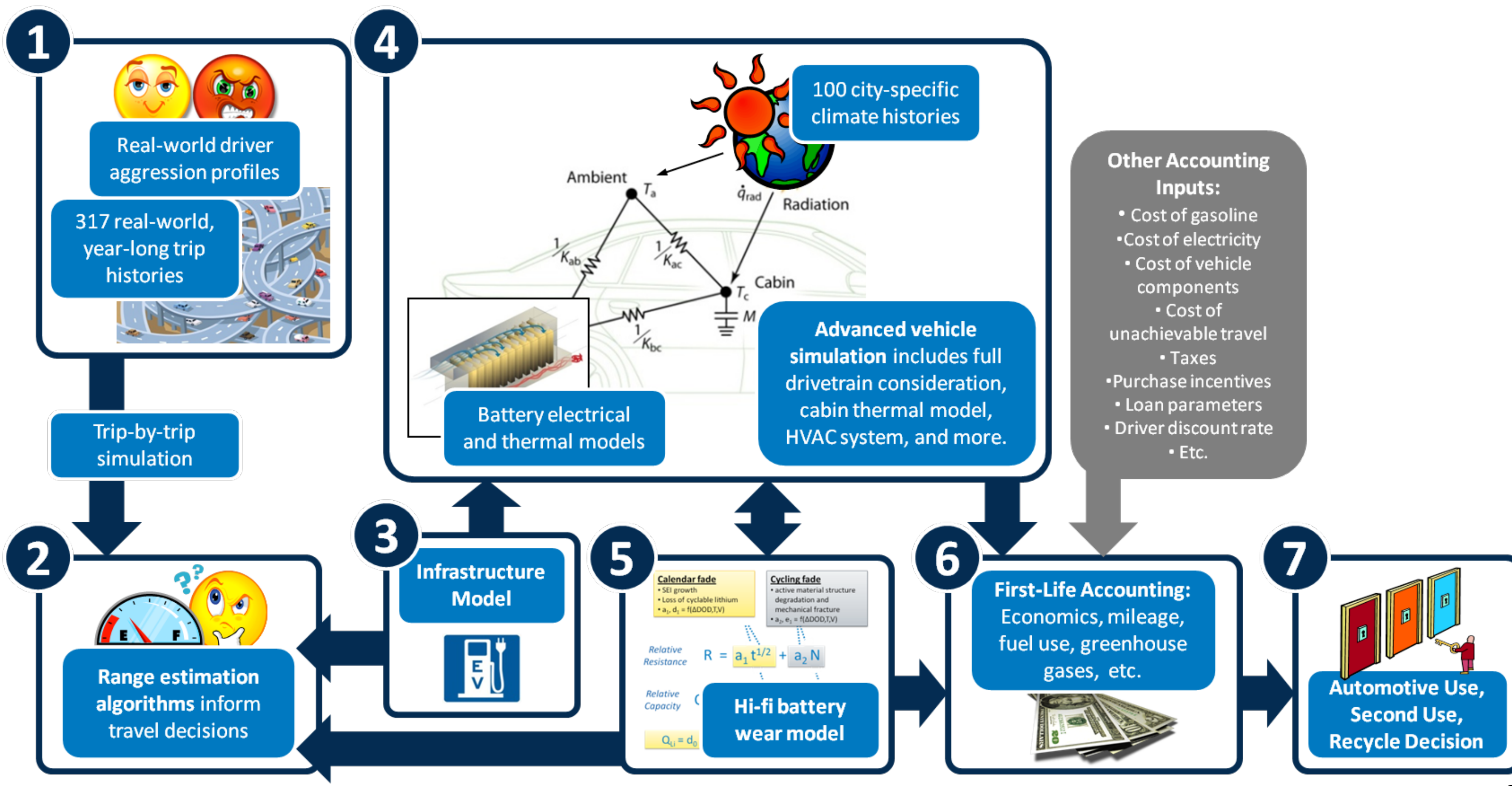
I. Objectives:
   1. Modify travel data collected from conventional gasoline vehicles to include stops at fast charge stations as necessary during simulation of battery electric vehicles
   2. Study impact of fast charging on vehicle utility, battery thermal management, and simulated battery degradation rate

II. BLAST tour planning
   1. Nominal method
   2. Rerouting for stops at fast charge stations

III. Fast charge impact analysis
   1. Public EVSE availability
   2. Example simulation of fast charge event
   3. Sensitivities to fast charge availability, climate, BTMS, and driving profile

Techno-Economic Analysis Tool: BLAST-V

- Battery Lifetime Analysis and Simulation Tool for Vehicles
- Objective: Perform accurate techno-economic assessments of HEV, PHEV, and BEV technologies and operational strategies to optimize consumer cost-benefit ratios, petroleum use reductions, and emissions savings



Assumptions

I. 180 12-month driving histories from the Seattle area
   1. Collected in conventional vehicles w/o FC stops
   2. Source: NREL Transportation Secure Data Center *www.nrel.gov/tsdc*

II. 75 mile BEV (22kWh pack)

III. DC Fast charge stations provide 50kW

IV. Level 2 home charging (6.5kW), no Work Charging
   1. Work charging was investigated using BLAST in recent journal article *"The impact of range anxiety and home, workplace, and public charging infrastructure on simulated battery electric vehicle lifetime utility" Journal of Power Sources, July 2014.*

V. NCA/graphite life model

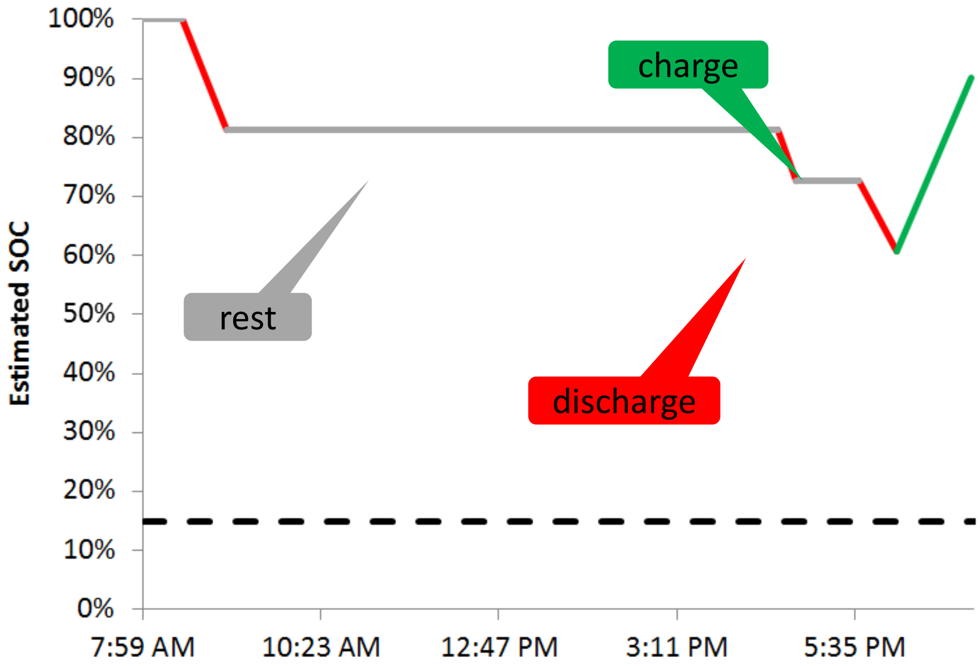
VI. Pack thermal model considers connections to ambient and cabin

VII. Cabin HVAC loads dynamically calculated and impact vehicle range

Tour Planning in BLAST - 1

Example Tour 1

Depart / Arrive	Miles	Minutes	Estimated SOC
8:31am / 9:07am	21.2	36.3	100% → 81%
4:33pm / 4:48pm	9.9	15.6	81% → 73%
5:39pm / 6:10pm	13.7	30.9	73% → 61%



BLAST estimates SOC through tour using reduced order battery model

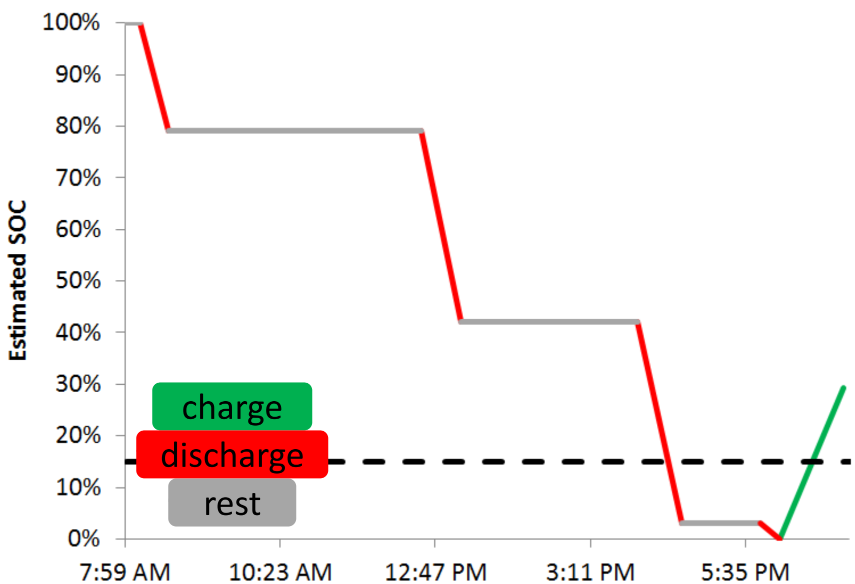
If minimum estimated SOC is above driver's range tolerance, BLAST proceeds with simulating the tour, otherwise tour is evaluated as single parked event

Tour Planning in BLAST - 2

Example Tour 2

Depart / Arrive	Miles	Minutes	Estimated SOC
8:14am / 8:40am	20.0	26.3	100% → 79%
12:34pm / 1:11pm	35.0	37.0	79% → 42%
3:55pm / 4:36pm	37.3	41.2	42% → 3%
5:49pm / 6:07pm	13.6	19.0	3% → 0%

If minimum estimated SOC drops below range tolerance, BLAST attempts to reroute select trips to include stops at fast charge stations



Tour Planning in BLAST - 3

BLAST considers two data sources when rerouting tours

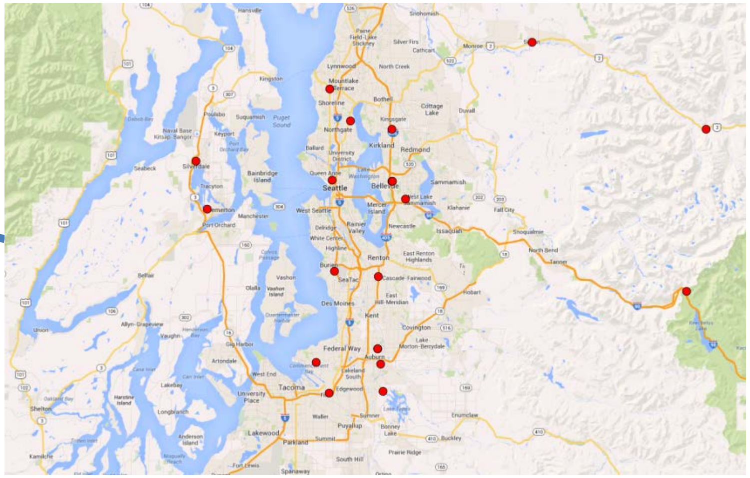
1. Alternate path of travel combinations using O/D pairs from original travel data and Google Maps Directions API
2. User-defined EVSE networks

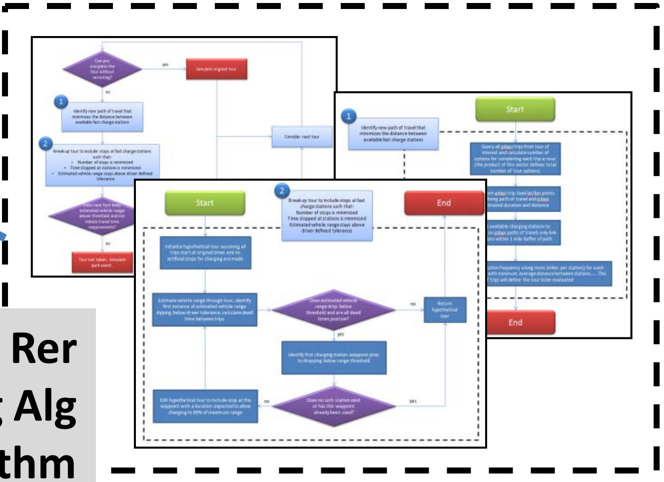
Using said input data, BLAST reschedules the original tour while attempting to:

- Keep minimum estimated SOC above driver tolerance
- Minimize number of stops and time spent at FC stations

*Constraint is applied that all trip start times be preserved from original travel data

Google Maps Directions API





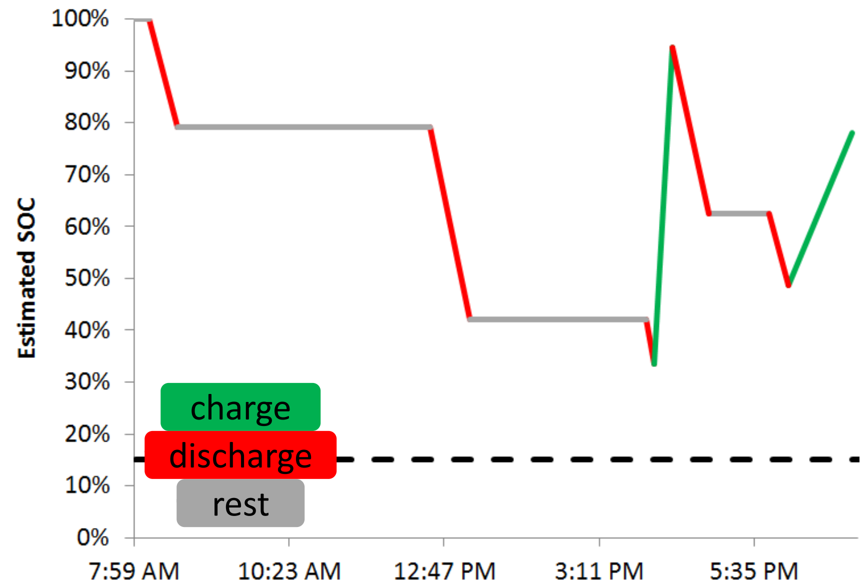
BLAST Rerouting Algorithm

Tour Planning in BLAST - 4

Example Tour 2: Rerouted Tour w/ stop at FC station

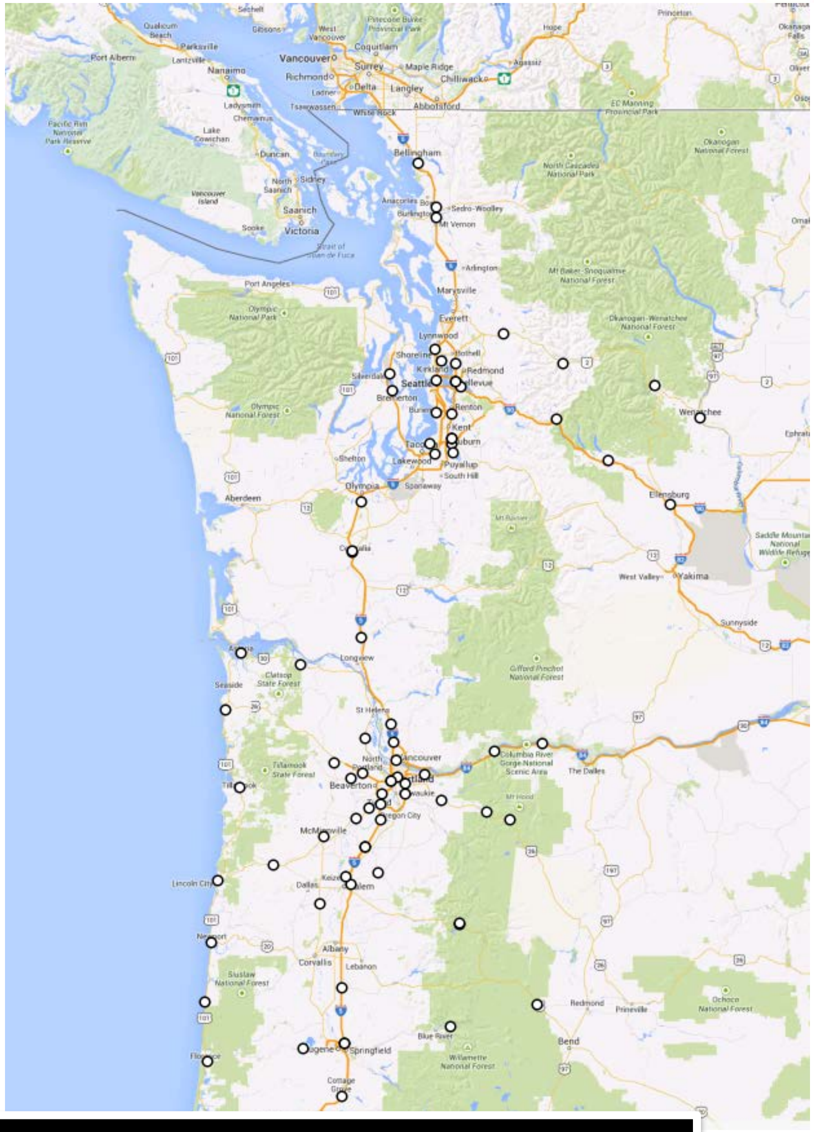
- All rerouted trips start on time (per original data)
- BLAST records statistics on incremental driving time and distance resulting from rerouting and FC stops
- Algorithm can enable very long tours that require several stops at fast charge stations. While such tours are deemed feasible during tour planning, BLAST will additionally evaluate the thermal and life impacts of such an aggressive cycling profile

Depart / Arrive	Miles	Minutes	Estimated SOC
8:14am / 8:40am	20.0	26.3	100% → 79%
12:34pm / 1:11pm	35.0	37.0	79% → 42%
3:55pm / 4:03pm	7.8	8.3	42% → 34%
17 minute FC			
4:20pm / 4:53pm	30.0	32.9	95% → 62%
5:49pm / 6:07pm	13.6	19.0	62% → 49%



Baseline EVSE Scenario

- For analysis of fast charging (FC) impact on batteries, it was necessary to select a baseline public infrastructure scenario
- The Pacific Northwest has fairly good geographic coverage of existing FC stations already in the ground
  - 34 existing FC stations in Washington State



Existing DCFC Stations (source: NREL Alternative Fuels Data Center, Jan 2014)

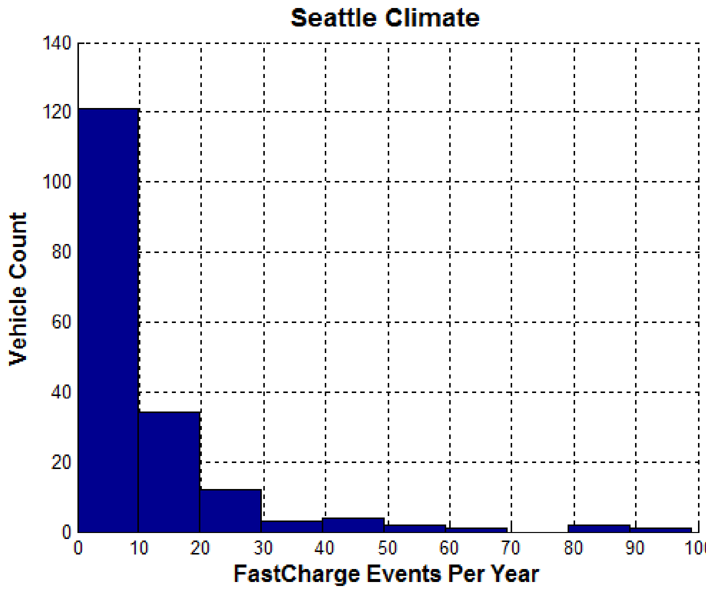
Simulation Sweep

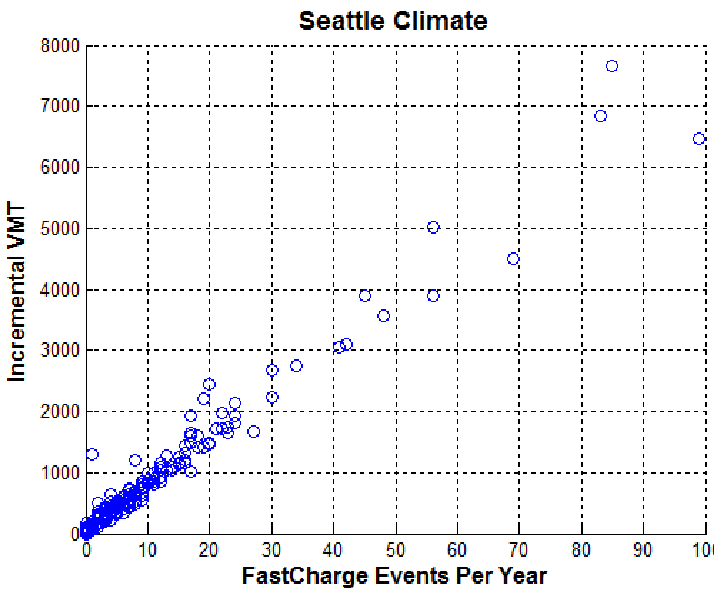
I. Perform 10 years of battery simulations for 180 driving profiles given…

1. EVSE:
    1) L2 home charging
    2) L2 home charging + present day FC station availability
2. Climate:
    1) Seattle (coincident with travel data)
    2) Phoenix (worst case thermal management)
3. Battery Thermal Management System:
    1) Passive cooling
    2) High-power liquid cooling (active driving)
    3) High-power liquid cooling (active driving + charging)

FC Utilization & Validation

I. Average driver utilized FC 10 times in first year of life
   1. Extreme case driver utilized FC at an average rate of 8 times a month
II. FC utilization correlates well with incremental VMT
III. Some drivers complete 100 % of travel w/o need for FC



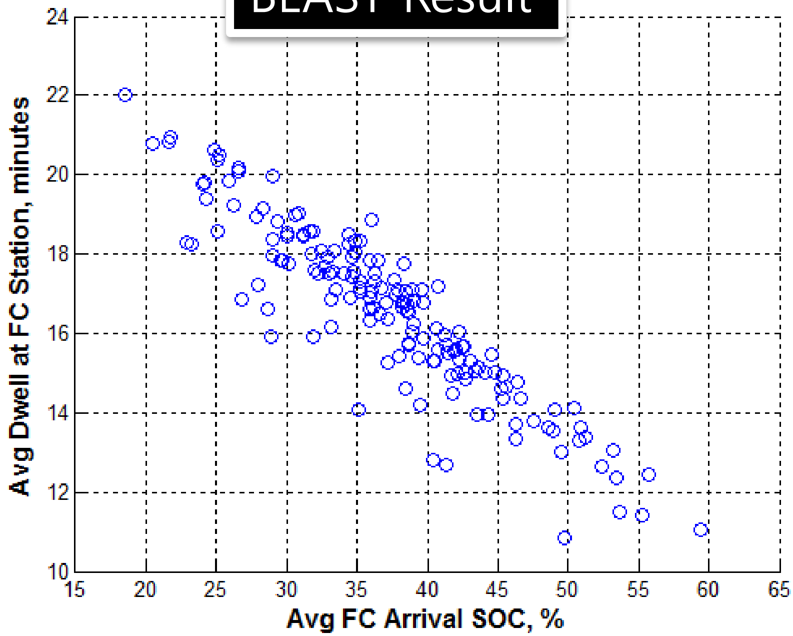


FC Utilization & Validation

I. BLAST runs reveal average FC connection times of 10-22 minutes
   1. Dependent on arrival SOC

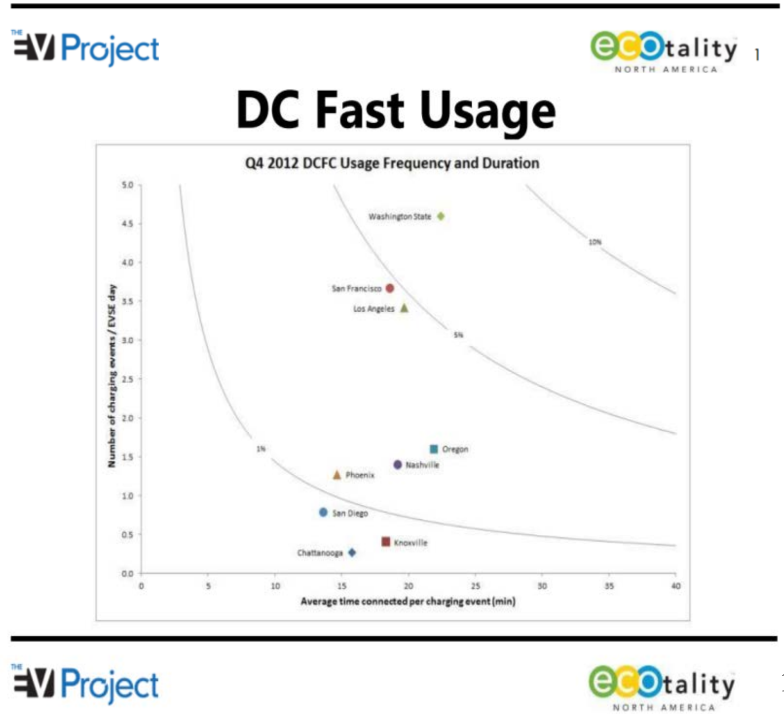
II. EV Project data indicated average FC connection times of 14-24 minutes

BLAST Result



EV Project Data

- This presentation was given for the Navigant Research Webinar on *Fast DC Charging for Electric Vehicles*
  - http://www.navigantresearch.com/webinar/fast-dc-charging-for-electric-vehicles
- April 9, 2013

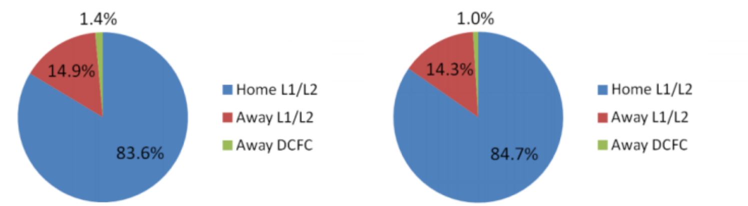


Supporting Data for Validation

From EV Project Data

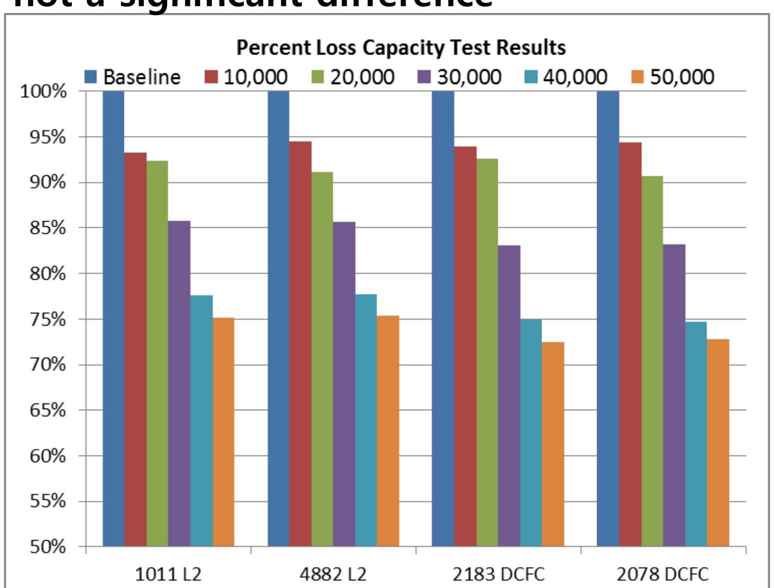
Infrastructure Usage by EV Project Leafs

- 4719 vehicles contributing data in vehicle months where home location is known



INL DC Fast Charging Impact Study on 2012 Leafs

- **Level 2 Leafs averaged 75.2% SOC @ 50k miles**
- **DCFC Leafs averaged 72.6% SOC @ 50k miles**
- **2.6% capacity difference @ 50k miles, probably not a significant difference**



Before and After DCFC Fees: Leafs Which Most Often Fast Charged

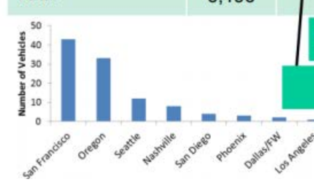
106 Leafs with >= 10% of charging events at DCFC in Q2 2013	Before DCFC Cost 4/1/2013-7/1/2013				After DCFC Cost 9/1/2013-12/1/2013			
	Number of charging events	Percent of charging events	Energy consumed during charging (SOC%)	Percent of energy	Number of charging events	Percent of charging events	Energy consumed during charging (SOC%)	Percent of energy
DCFC Usage	1,304	21%	49,595	21%	436	8%	16,913	8%
Away L1/L2 Usage	1,051	17%	33,979	14%	850	16%	31,078	15%
Home L1/L2 Usage	3,841	62%	154,741	65%	3,958	76%	156,187	77%
Total	6,196		238,315		5,244		204,178	

Big drop in DCFC usage

Not much change in away L1/L2 usage

Increase in home charging

Decrease in overall charging

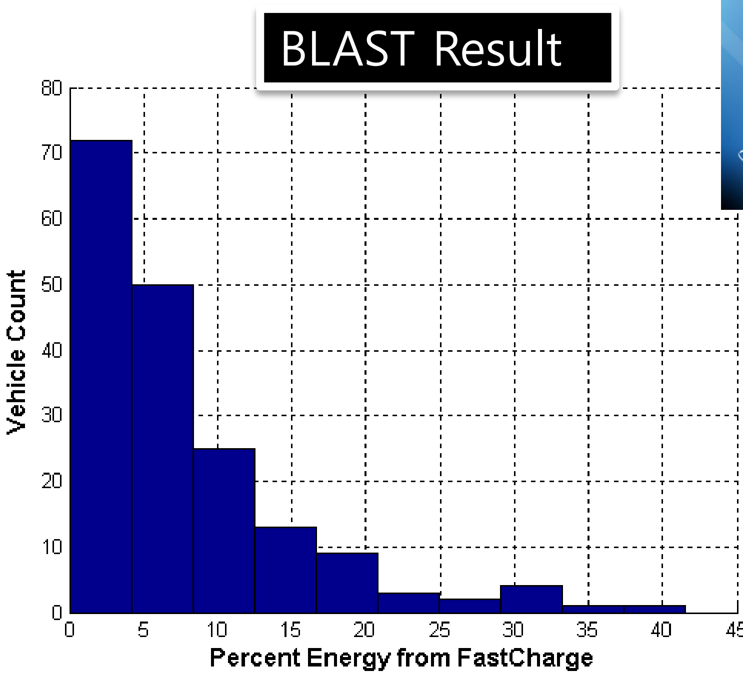


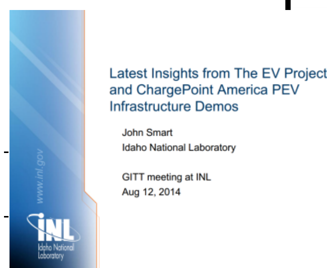
FC Utilization & Validation

I. BLAST aggregates charge energy by location

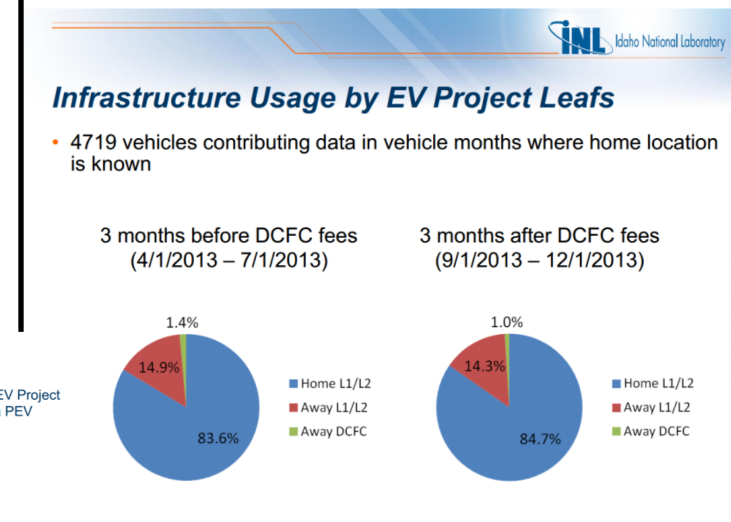
II. Group all FC locations together and average driver receives 7.6% of energy from fast charging
  1. Max: 41.5%
  2. Min 0.0%

III. EV Project reports fast charges accounting for 1-21 % of all charge events for Nissan Leaf's under study that frequently used fast chargers
  1. Where a cost for fast charging was present, **8%** of charging energy came from fast charging for Nissan Leaf's under study





EV Project Data



Before and After DCFC Fees: Leafs Which Most Often Fast Charged

106 Leafs with >= 10% of charging events at DCFC in Q2 2013	Before DCFC Cost 4/1/2013-7/1/2013				After DCFC Cost 9/1/2013-12/1/2013			
	Number of charging events	Percent of charging events	Energy consumed during charging (SOC%)	Percent of energy	Number of charging events	Percent of charging events	Energy consumed during charging (SOC%)	Percent of energy
DCFC Usage	1,304	21%	49,595	21%	436	8%	16,913	8%
Away L1/L2 Usage	1,051	17%	33,979	14%	850	16%	31,078	15%
Home L1/L2 Usage	3,841	62%	154,741	65%	3,958	76%	156,187	77%
Total	6,196		238,315		5,244		204,178	

Big drop in DCFC usage

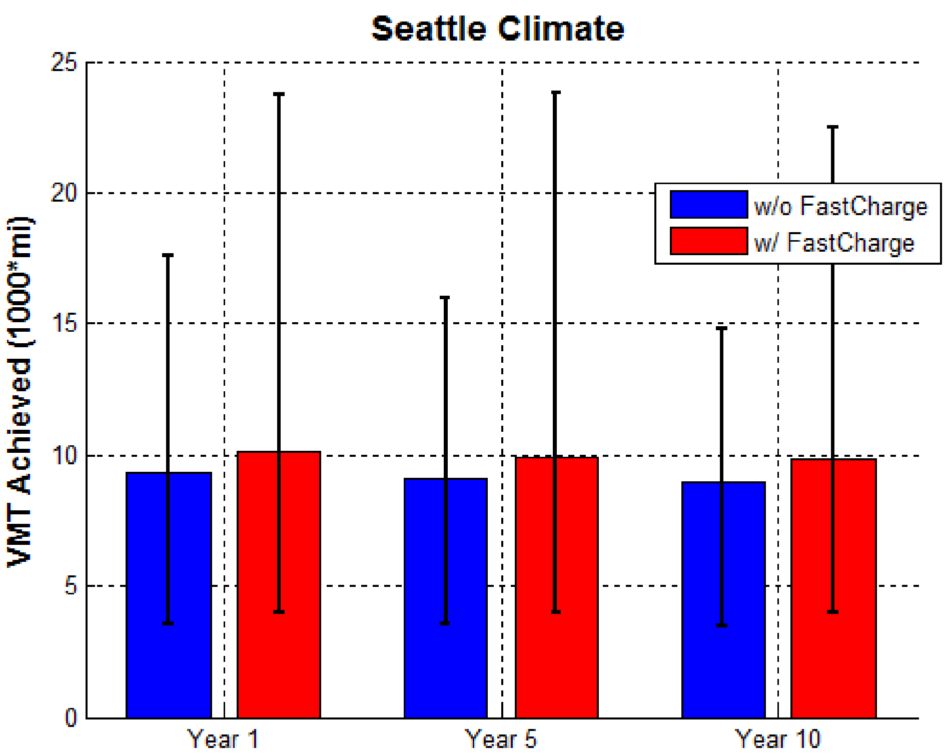
Not much change in away L1/L2 usage

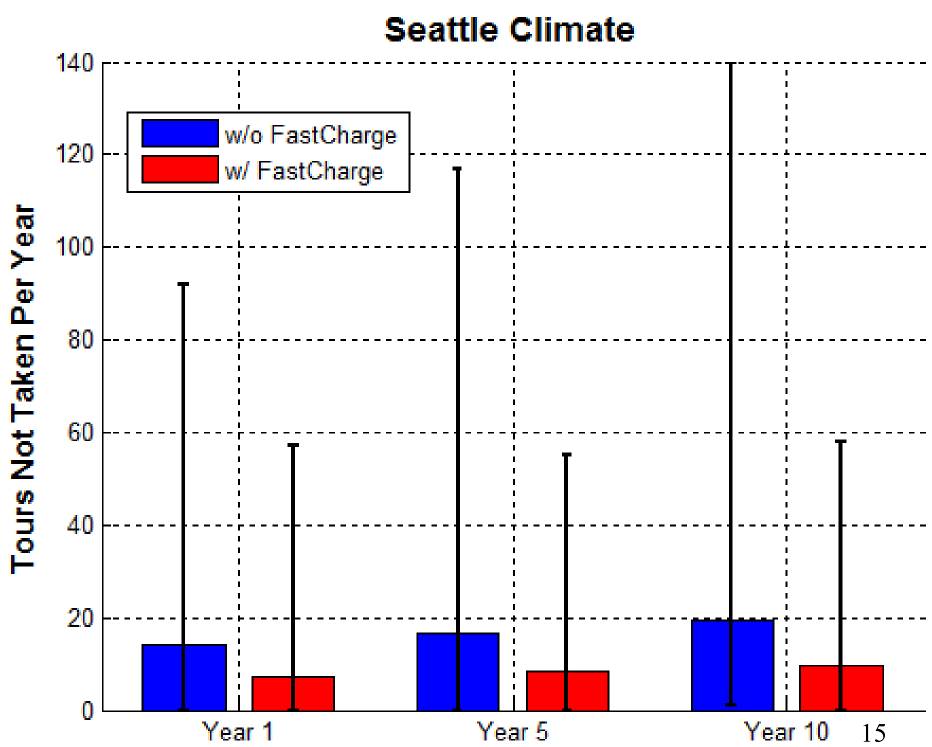
Increase in home charging

Decrease in overall charging

Seattle Results: Incremental Utility

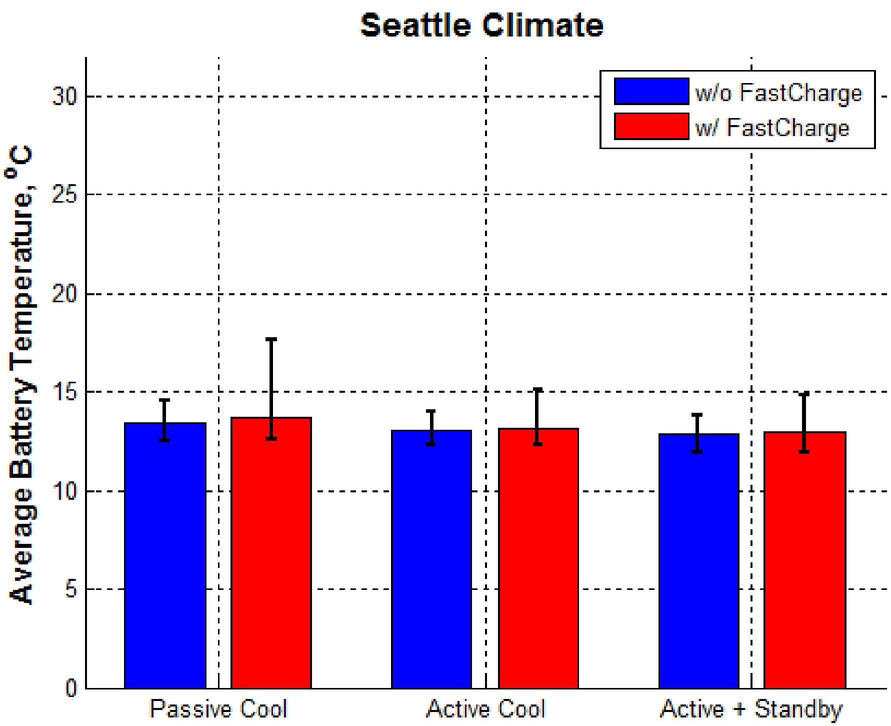
I. FC availability improves utility for most drivers
   1. Annual VMT increases by 800 miles on average
   2. Annual tours not taken decreases by 8 on average

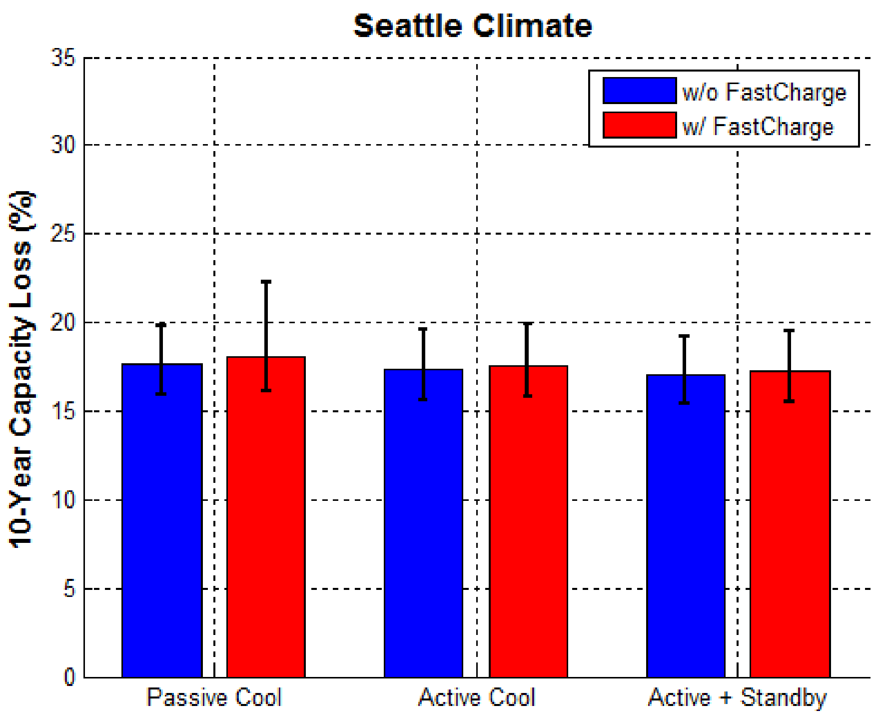




Other Effects

Due to the low frequency of fast charger usage, average battery temperature and capacity loss are negligibly affected

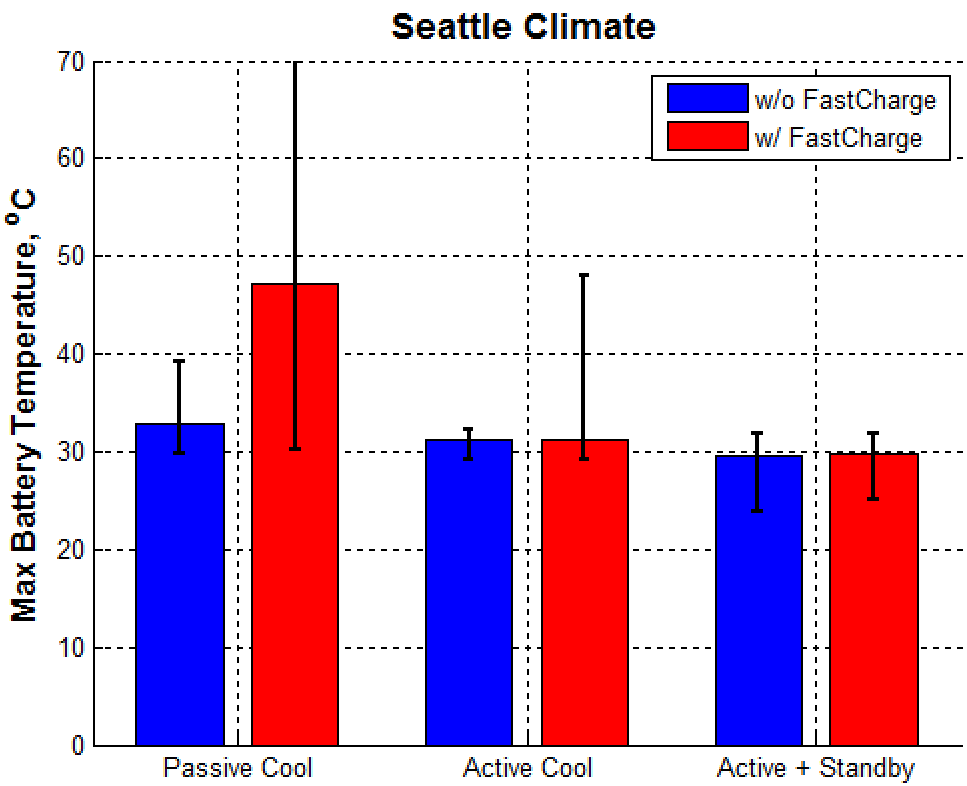




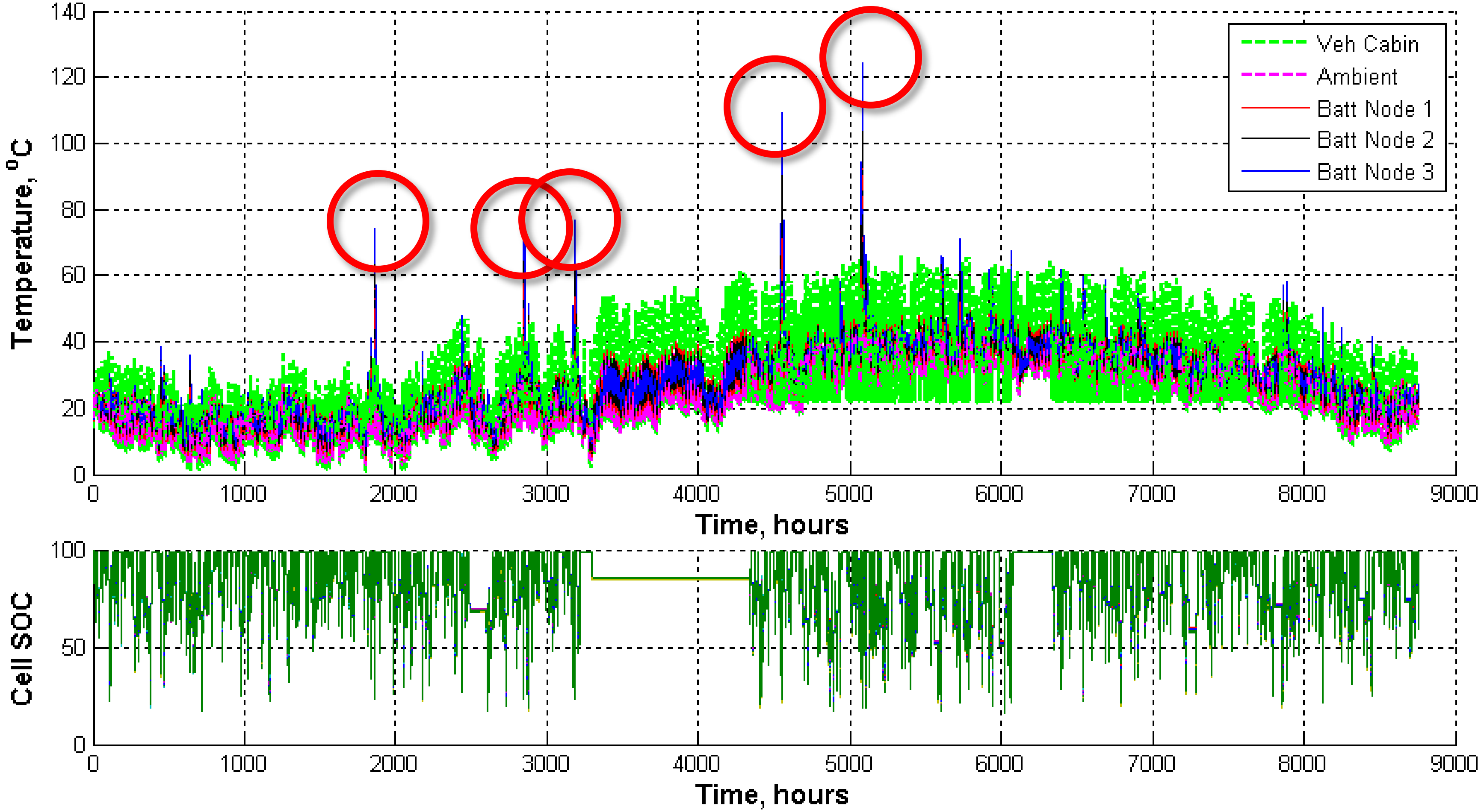
Seattle Results: Battery Max Temp

I. Impact of FC was most observable in maximum pack temperatures from passively cooled packs
   1. Back-to-back sequencing of drive-FC-drive produces significant heat generation resulting in dangerous thermal conditions

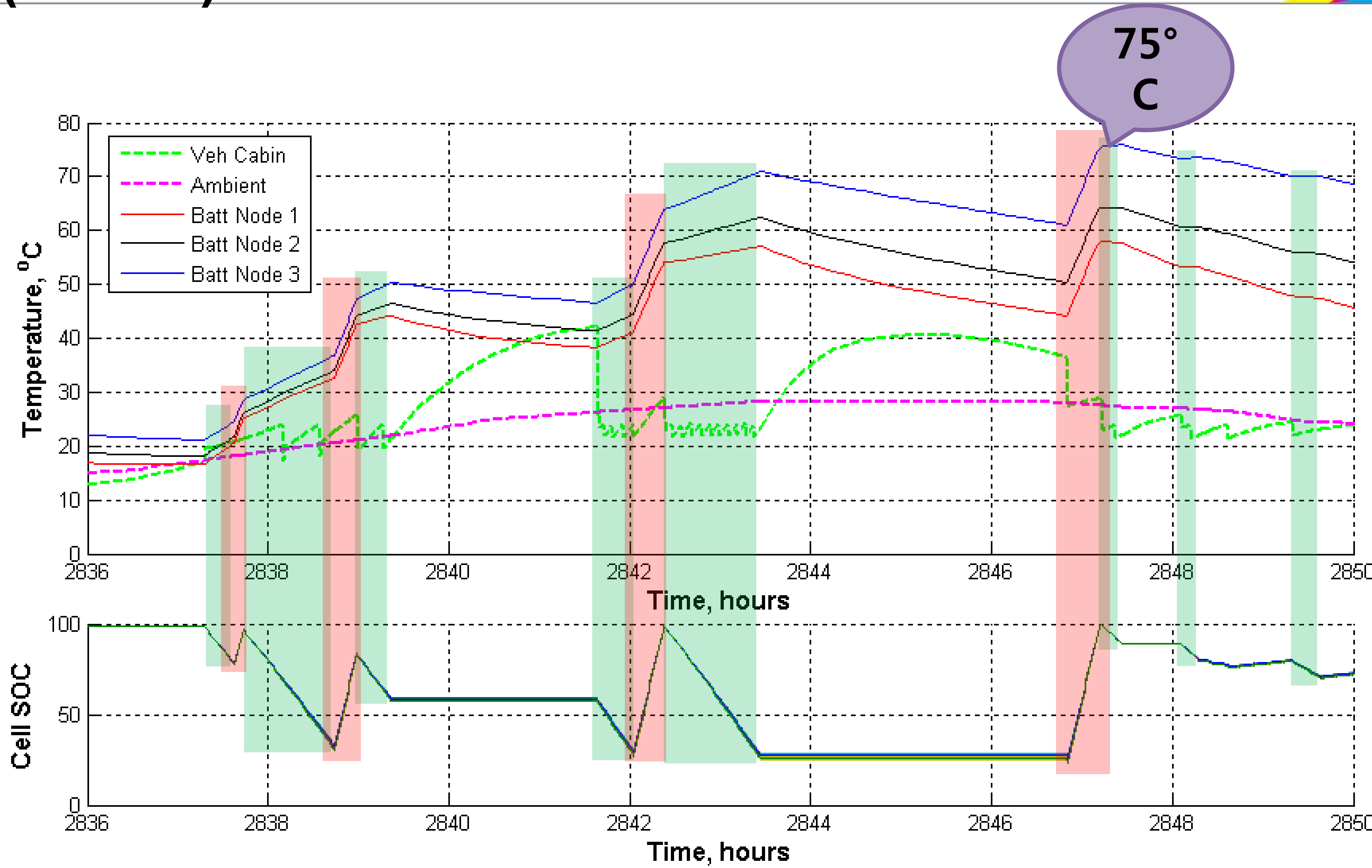
II. Simulated packs with high capacity cooling systems were able to mitigate heat generation on FC tours and maintain safe thermal conditions



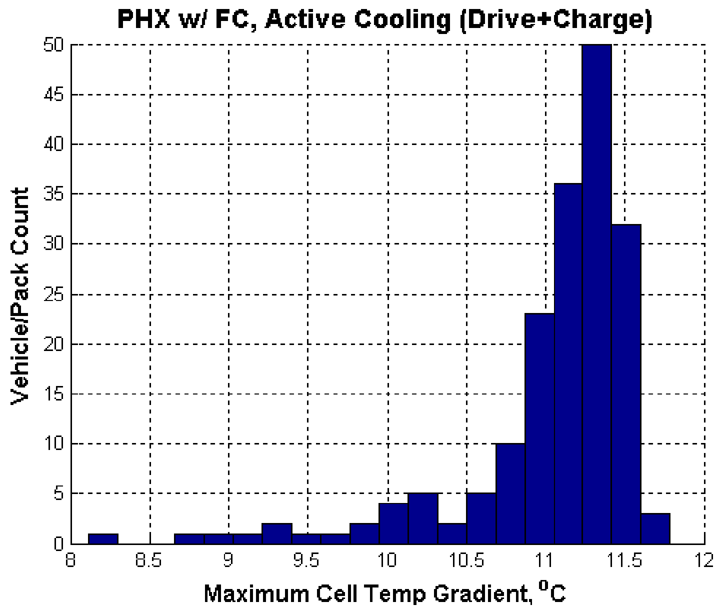
Example Fast Charging + Passive Cooling (1 yr)



Example Fast Charging + Passive Cooling (14 hrs)

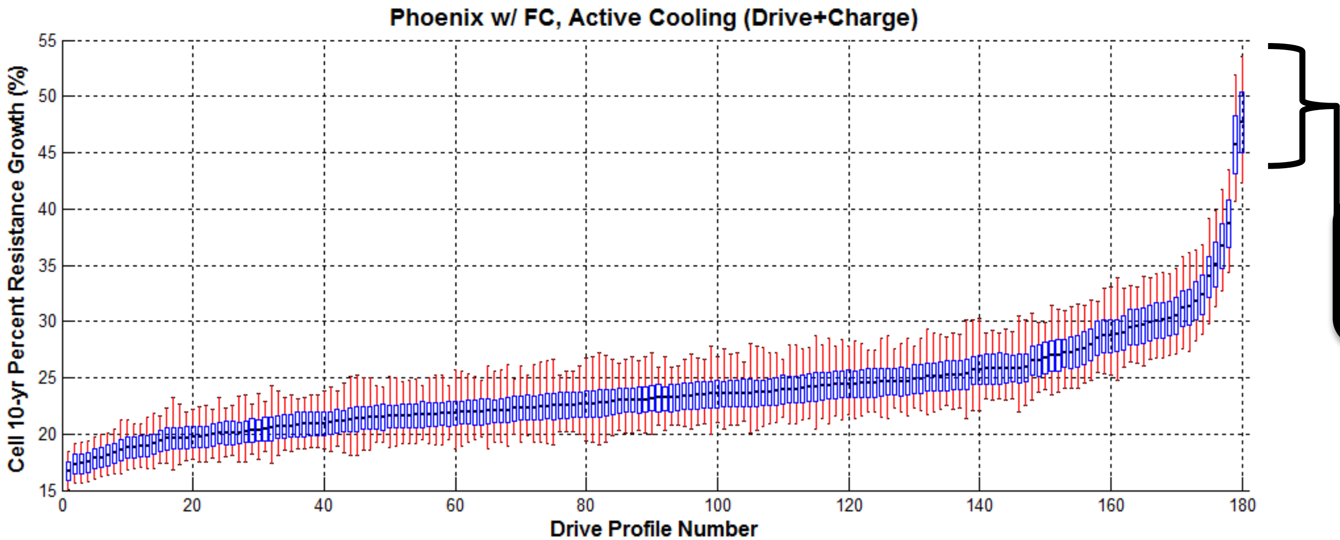


Variation Within the Pack



I. Instantaneous thermal gradients are affected by fast charging

II. Variation of degradation within a pack is affected less so, due to i nfrequency of fast charge events



Distribution across c ells in one pack

Conclusions

I. Utilization of public charging infrastructure is heavily dependent on user-specific travel behavior

II. Fast charger availability can positively affect the utility of BEVs, even given infrequent use

III. Estimated utilization rates do not appear frequent enough to significantly impact battery life

IV. Battery thermal management systems are critical in mitigating dangerous thermal conditions on long distance tours with multiple fast charge events

Acknowledgments

I. This work was funded by US Department of Energy, Vehicle Technologies Office
   - Brian Cunningham
   - David Howell

I. Appreciate the input provided by other colleagues
   - Shriram Santhanagopalan (NREL)
   - Matthew Keyser (NREL)
   - John Smart (INL)
   - Ignacio Martin (Circe)