Impacts of Mileage Accumulation and Fast Charging on EV Range and Energy Usage

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Introduction and Objectives

- **Previous Studies**
  - A 2012 study found reduced driving range for a BEV after mileage accumulation of 12,000km in Ottawa
  - A 2015 INL/Intertek study quantified BEV battery capacity loss at between 25% and 35 % with 80,000km accumulated in a hot climate (Arizona)
    - Accelerated capacity loss with DCFC and hot ambient temperatures

- **Objectives of this Study**
  - Evaluate the impact of mileage accumulation on the usable battery energy (UBE), full-recharge energy (FRE), FRE_{DC}, range and energy consumption (ECdc) of a 2015 BEV
  - Investigate how fast charging (DCFC) affects these performance metrics
  - Investigate the impact of cold temperature mileage accumulation

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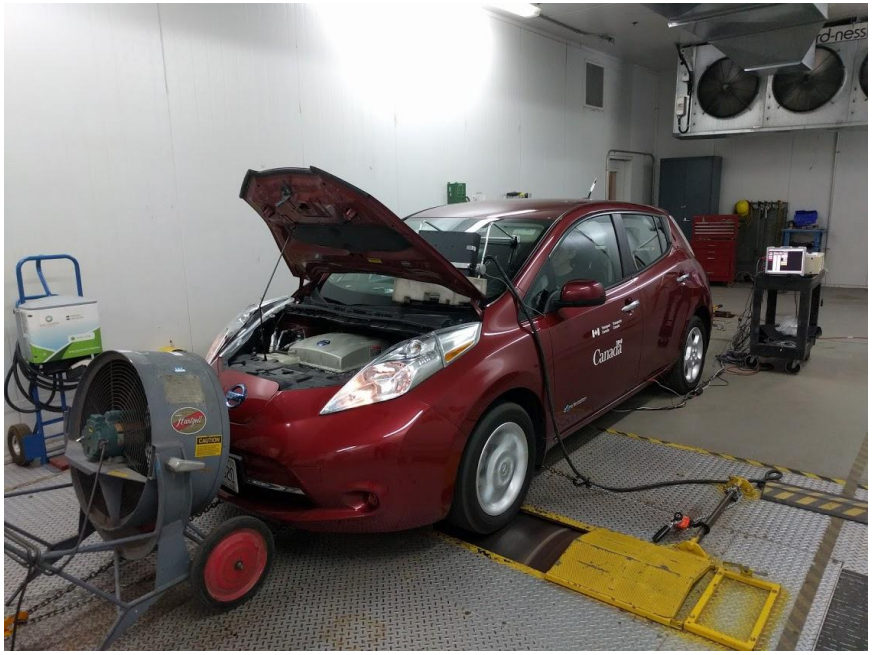
Test Design

- 2 identical 2015 model year BEVs
  - BEV1 charged exclusively on DCFC
  - BEV2 charged exclusively on SAE AC Level 2 (ACL2)
- Simultaneous mileage accumulation (within two week margin) on-road in Ottawa
- Dynamometer testing at ~15,000km intervals until study concludes at 105,000km mileage
  - Baseline testing at 1,600km
  - Round 2 at 15,000km
  - Round 3 at 35,000km



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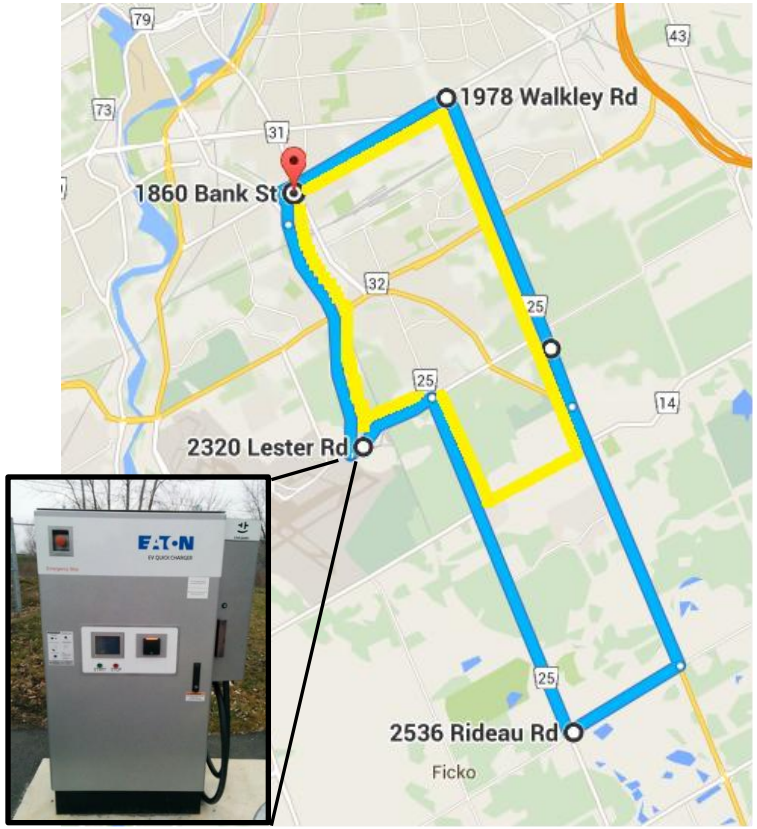
On-Road: Accumulation Routes

- Summer Route (May - Sept)
  - Distance: 33.6 km
  - Duration: 39 min
- Winter Route (Oct – March)
  - Distance: 22.8 km
  - Duration: 28 min
- Daily Distance: 100 km
- Daily Charging: mid-day and overnight
- CANbus data collection



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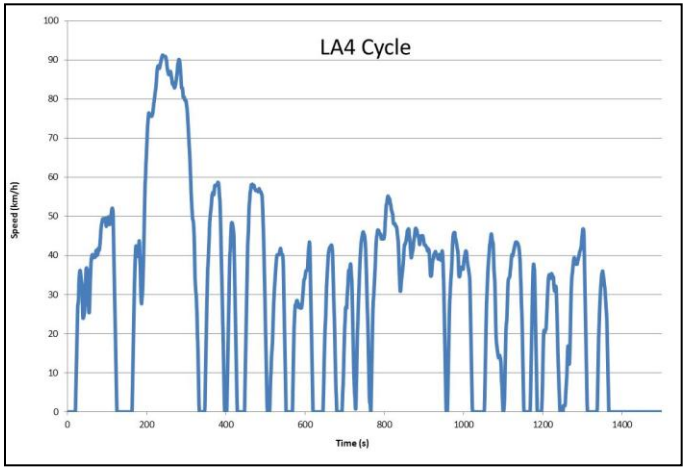
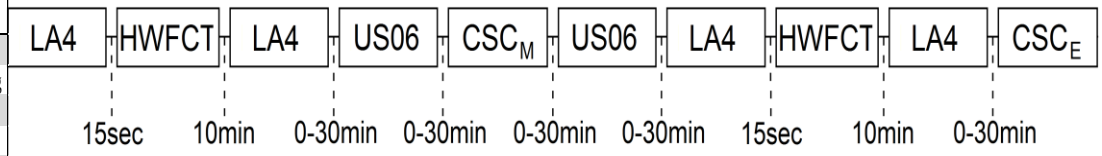
Chassis Dynamometer Test Cycles

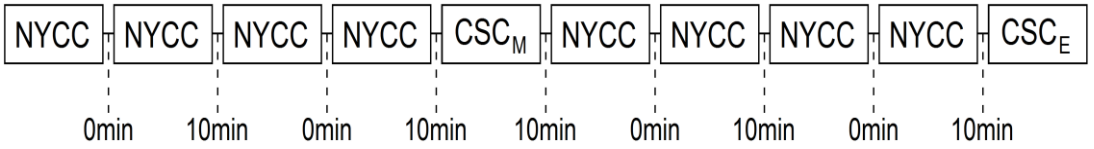
Drive Schedule	Description
LA4	moderate speed city cycle: part of the Canadian and U.S. 5-cycle fuel economy test
HWFCT	Highway fuel consumption test: part of the Canadian and U.S. 5-cycle fuel economy test. Simulates free-flow high driving
CSC	Constant speed driving at 55mph. Used to deplete the battery between transient cycles
US06	Aggressive high-speed driving cycle: part of the Canadian and U.S. 5-cycle fuel economy test
NYCC	New York City Cycle: Simulates congested urban driving
SC03	low speed city cycle with high ambient temperature: part of the Canadian and U.S. 5-cycle fuel economy test. Used to simulate cabin air cooling driving conditions



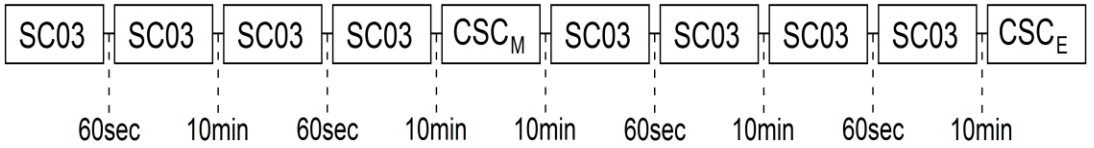
SAE J1634 US06 MCT



NYCC FDT



SC03 FDT



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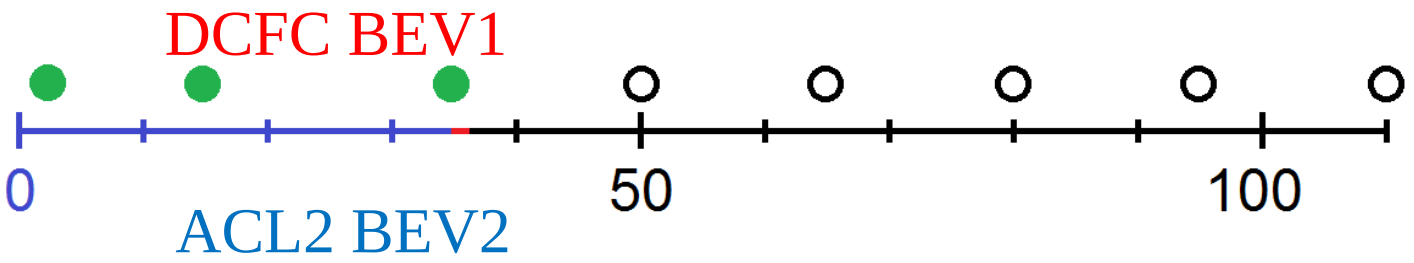
Test Matrix

Baseline (Round 1) and Final (Round 8)

Test Sequence	Ambient Temperature [°C]		
	35	25	-7 w cabin heat
SAE J1634 US06 MCT		3	3
NYCC FDT		2	2
SC03 FDT	2		

Rounds 2 to 7

Test Sequence	Ambient Temperature [°C]		
	35	25	-7 w cabin heat
SAE J1634 US06 MCT		3	
NYCC FDT		2	
SC03 FDT	2		



Odometer [km x 1000]

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Instrumentation

- HIOKI 3930-10 high-precision power analyzer
- HIOKI clamp-on and solid-core AC/DC amp probes
- Thermocouples
- CANbus signals

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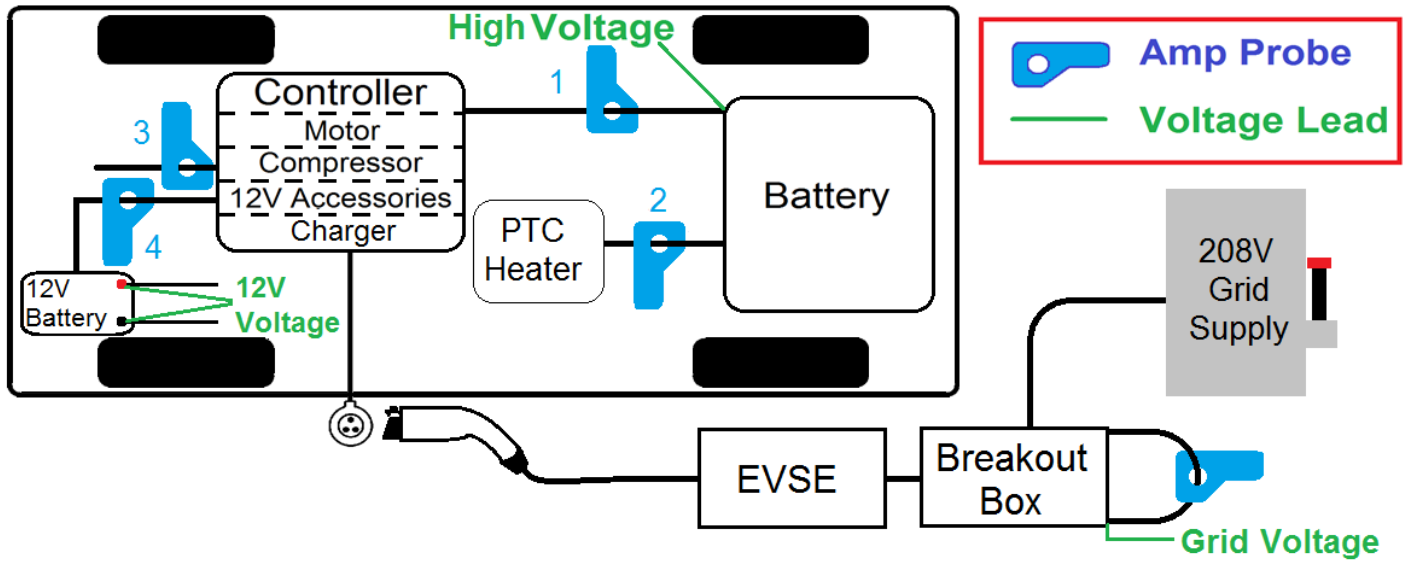
Instrumentation…cont'd



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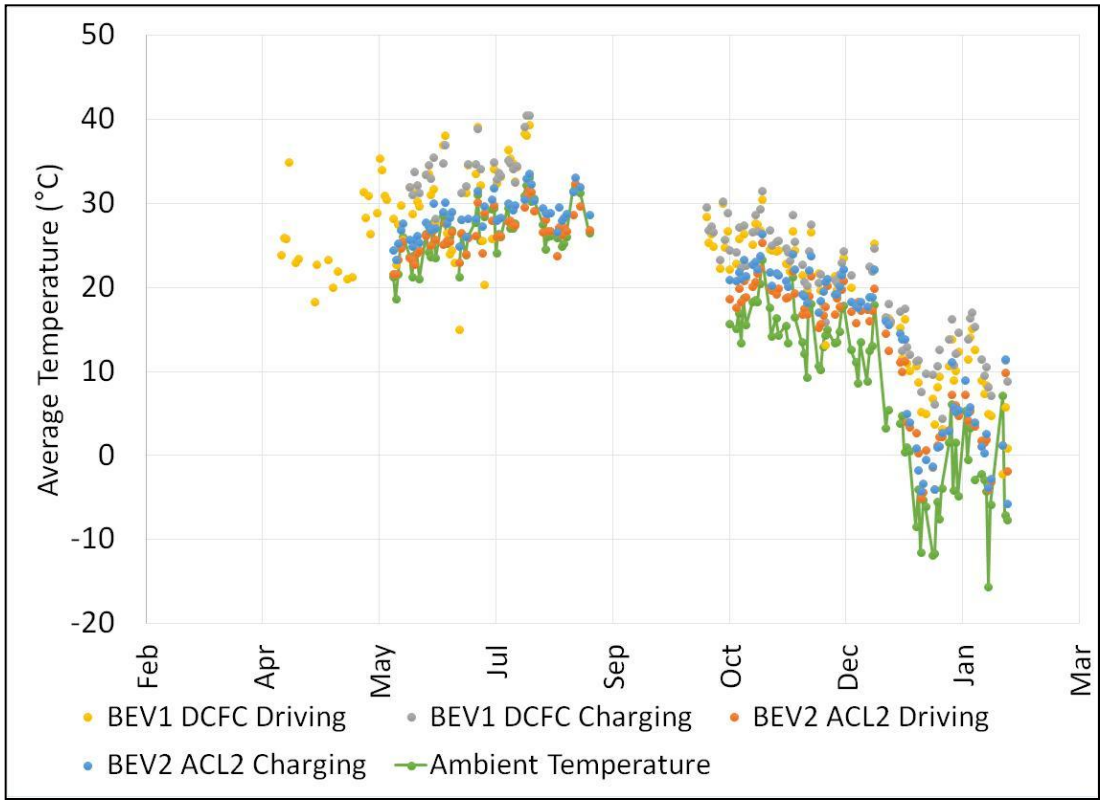
On-Road: Temperatures

- BEV1 experienced higher battery temperatures during driving and charging throughout all seasons
- During winter months, ambient temperatures reached -15°C during mileage accumulation

Season	Battery Temperatures [°C]			
	Charging		Driving	
	BEV1	BEV2	BEV1	BEV2
Spring (Apr-Jun)	32.94	26.88	27.61	24.79
Summer (Jul-Sep)	35.35	29.68	33.25	27.76
Fall (Oct-Dec)	23.65	20.52	22.44	18.63
Winter (Jan-Mar)	13.15	5.21	10.26	4.57



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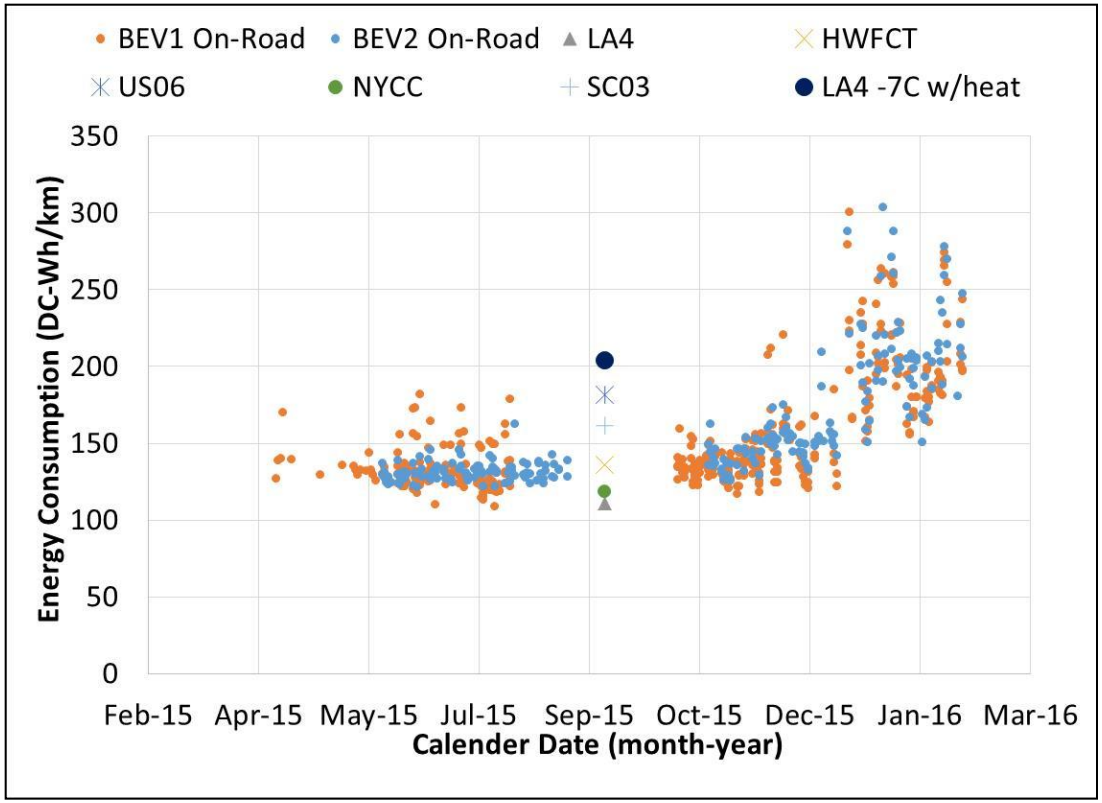
On-Road: Energy Consumption Rates

- Energy consumption (ECdc) increased by up to 2 times during the winter months
- Energy consumption rates over various cycles in-lab were comparable to on-road consumption rates between April and December.



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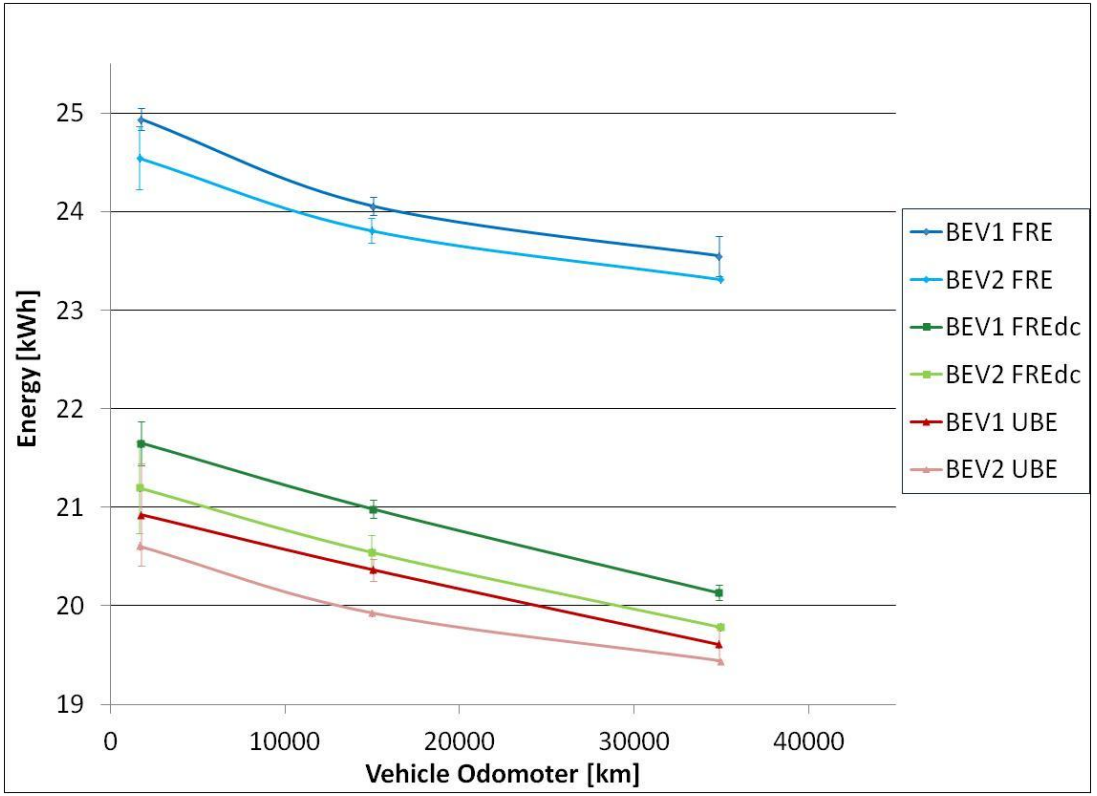
Charging and Usable Energy at 25°C

- Some initial differences between BEV1 and BEV2
- Full recharge energy (FRE) decreased by:
  - 3% after 15,000km, and 5% after 35,000km for BEV2 (ACL2)
  - 4% after 15,000km, and 6% after 35,000km for BEV1 (DCFC)
- Usable battery energy (UBE) decreased by 3% after 15,000km and 6% after 35,000km for both BEV1 and BEV2
- Trends were similar for DCFC and ACL2



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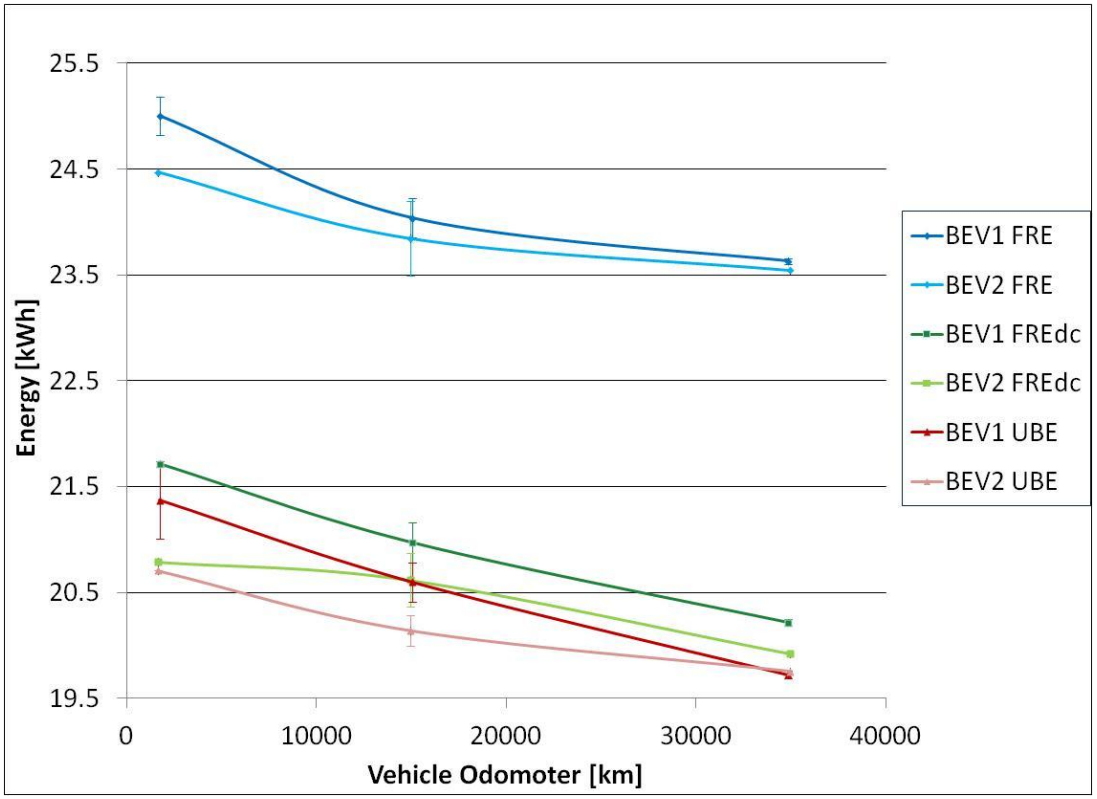
Charging and Usable Energy at 35°C

- Some initial differences between BEV1 and BEV2
- Full recharge energy (FRE) decreased by:
  - 3% after 15,000km, and 4% after 35,000km for BEV2 (ACL2)
  - 4% after 15,000km, and 5% after 35,000km for BEV1 (DCFC)
- Usable battery energy (UBE) decreased by:
  - 3% after 15,000km and 5% after 35,000km for BEV2 (ACL2)
  - 4% after 15,000km and 8% after 35,000km for BEV1 (DCFC)



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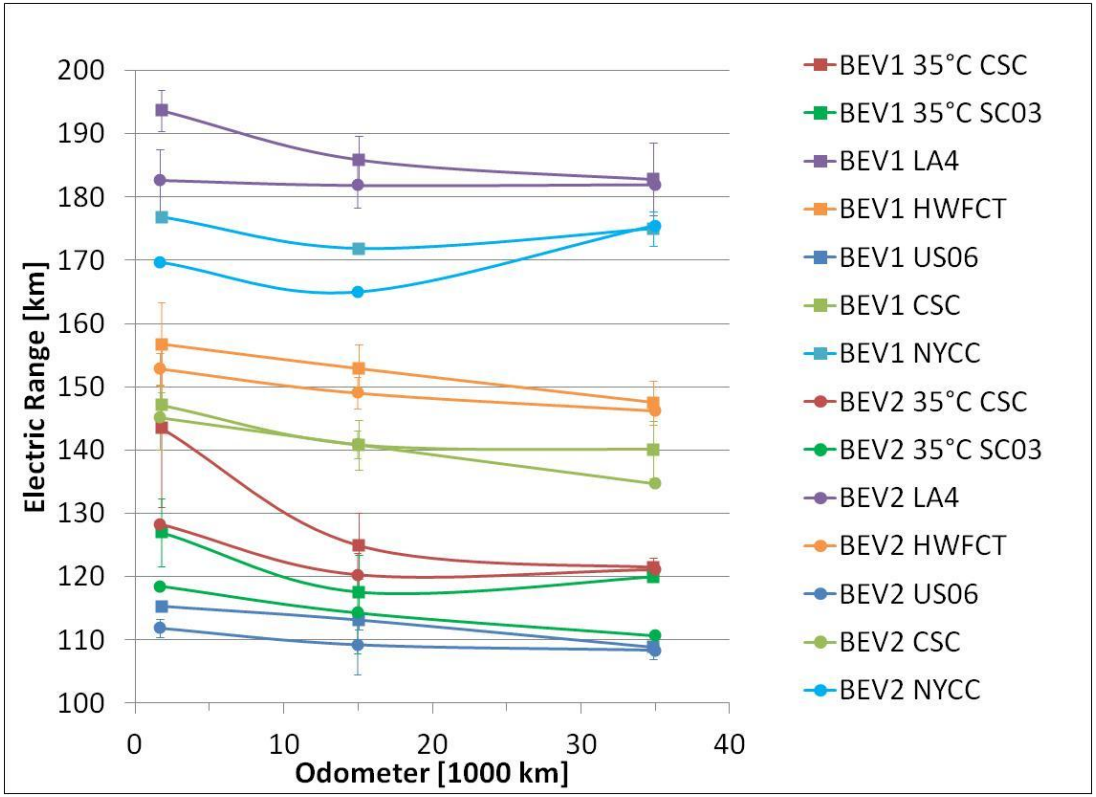
Driving Range

- Range is based on UBE, and cycle energy consumption rate (ECdc)
- Some initial differences between BEV1 and BEV2
- On HWFCT, US06, and CSC range decreased by:
  - 2-3% after 15,000 km and 3-7% after 35,000km for BEV2 (ACL2)
  - 2-4% after 15,000 km and 5-6% after 35,000km for BEV1 (DCFC)
- Results varied for other cycles



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Summary

- Charging energy and usable battery energy decreased at 35,000 km compared to baseline
  - FRE decreased by 5% (BEV2) and 6% (BEV1) at 25°C, and 4%(BEV2) and 5% (BEV1) at 35°C
  - UBE decreased by 6% for both vehicles at 25°C, and 5% (BEV2) and 8% (BEV1) at 35°C
- Driving range varied with mileage accumulation
  - Decreased driving range on HWFCT, US06, CSC after 35,000 km (3-7%)
  - Varied results on urban routes
  - Some leveling off after 15,000 km testing
- Mileage accumulation will continue to 100,000km

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