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

Aaron Loiselle¹, Ian Whittal², Martha Christenson²

¹Emissions Research and Measurement Section, Environment and Climate Change Canada
²ecoTECHNOLOGY for Vehicles Program, Transport Canada

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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), \( \text{FRE}_{DC} \), 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
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
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**
# Chassis Dynamometer Test Cycles

## SAE J1634 US06

<table>
<thead>
<tr>
<th>LA4</th>
<th>HWFC</th>
<th>LA4</th>
<th>US06</th>
<th>CSC₉</th>
<th>US06</th>
<th>LA4</th>
<th>HWFC</th>
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<td>0-30min</td>
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<td>0-30min</td>
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## SC03 FDT

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<th>CSC₉</th>
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<th>SC03</th>
<th>CSC₉</th>
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<tbody>
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<td>60sec</td>
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### 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
**Test Matrix**

Baseline (Round 1) and Final (Round 8)

Rounds 2 to 7

<table>
<thead>
<tr>
<th>Test Sequence</th>
<th>Ambient Temperature [°C]</th>
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<tbody>
<tr>
<td>SAE J1634 US06 MCT</td>
<td>35  25  -7 w cabin heat</td>
</tr>
<tr>
<td>NYCC FDT</td>
<td>3  3   -7 w cabin heat</td>
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<tr>
<td>SC03 FDT</td>
<td>2  2   -7 w cabin heat</td>
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</tbody>
</table>

Odometer [km x 1000]
Instrumentation

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

<table>
<thead>
<tr>
<th>Season</th>
<th>Battery Temperatures [°C]</th>
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<tr>
<td></td>
<td>Charging</td>
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<tr>
<td></td>
<td>BEV1</td>
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<tr>
<td>Spring (Apr-Jun)</td>
<td>32.94</td>
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<tr>
<td>Summer (Jul-Sep)</td>
<td>35.35</td>
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<tr>
<td>Fall (Oct-Dec)</td>
<td>23.65</td>
</tr>
<tr>
<td>Winter (Jan-Mar)</td>
<td>13.15</td>
</tr>
</tbody>
</table>
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.
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
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)
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
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
Acknowledgements

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Thank You!

Contact:

Aaron Loiselle-Lapointe  
aaron.loiselle@canada.ca

Ian Whittal  
ian.whittal@tc.gc.ca

Martha Christenson  
martha.christenson@tc.gc.ca

Photos: Michel Jouvenier