Fuel Cell Electric Vehicle Evaluation

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NREL/PR-5400-66760
• Why FCEVs
• Overview of FCEV evaluation
• Results
NREL RD&D accelerates the process of bringing sustainable transportation technologies to the market with the ultimate goals of:

- Reduction of GHG emissions in the transportation sector to meet a 2050 goal of 80% below 2005 levels
- Diversification of transportation energy sources to reduce petroleum consumption and promote U.S. energy security
Why Hydrogen Fuel Cell Electric Vehicles

Hydrogen FCEVs are clean, efficient, refuel quickly, and provide long driving range.

Challenges include hydrogen infrastructure cost & reliability, fuel cell durability & reliability.
Ensure that FCEV customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are introduced (2015-2017), and transition to advanced refueling technology beyond 2017.

1. Reduce the installation cost of a hydrogen fueling station to be competitive with conventional liquid fuel.
2. Improve the availability, reliability, and cost while ensuring the safety of high-pressure components.
3. Focus a flexible and responsive set of technical experts and facilities to help solve today’s urgent challenges and the future unpredicted needs.
4. Enable distributed generation of renewable hydrogen in a broader energy ecosystem.
Renewable Hydrogen Options

- Biomass Pyrolysis
- CO₂ Storage
- Bioreactor
- Natural Gas Storage
- CNG Fueling
- Hydrogen Fueling
- Hydrogen-Fueled Vehicles
- CNG-Fueled Vehicles
- Home Heating and Hot Water
- Wind
- Short-Term Energy Storage
- Fuel Cells and Engines
- Fueling Station Electrolyzer
- Electric Line
- Hydrogen Piping
- CO₂ Piping
- Natural Gas Piping

Other Renewables: Solar, Geothermal, Hydro
NFCTEC Analysis and Reporting of Real-World Operation Data

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Results
- Bundled data (operation and maintenance/safety) delivered to NREL quarterly
- Internal analysis completed quarterly in NFCTEC

www.nrel.gov/hydrogen/proj_tech_validation.html
Objectives

- Data analysis and reporting of hydrogen fuel cell electric vehicles (FCEV) operating in real-world setting
- Identify current status and evolution of the technology
- Publish performance status and progress from multiple FCEV models

1DOE project overview:
- $5.5 million DOE funding
- Data to be collected from up to ~90 vehicles

2Project managed by Electricore Award completed
<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCEVs total</td>
<td>55</td>
</tr>
<tr>
<td>Average on-road fuel economy miles/kg</td>
<td>51</td>
</tr>
<tr>
<td>FCEVs retired</td>
<td>24</td>
</tr>
<tr>
<td>miles traveled</td>
<td>&gt; 3,052,000</td>
</tr>
<tr>
<td>Max fleet voltage durability</td>
<td>4,100</td>
</tr>
<tr>
<td>(Hours to 10% degradation metric)</td>
<td></td>
</tr>
<tr>
<td>Max FCEV odometer miles</td>
<td>&gt; 190,300</td>
</tr>
<tr>
<td>Fuel cell operation hours</td>
<td>&gt; 101,400</td>
</tr>
<tr>
<td>Max fuel cell operation hours</td>
<td>5,600</td>
</tr>
</tbody>
</table>
Vehicle Count & Miles Since 2006

Diverse and statistically significant data set

Pause in evaluation project

Total Vehicle Count = 222

Total Miles = 6,335,866
Participants and Trips Since 2006

NREL analyzed trips decreasing due to planned vehicle decommissioning of older generation vehicles.
FCEV Analysis Categories

Analyzed data through 12/2015
All results not included here. All results available online at www.nrel.gov/hydrogen/proj_tech_validation.html
Average fleet voltage durability projection increased > 160% from initial projections in 2006 (CDP-FCEV-31)
Comparison of FC Stacks Operated Beyond 10% Voltage Degradation

More than 60% of analyzed stacks have not operated beyond 10% voltage degradation.
The median on-road vehicle fuel economy is 51 miles per kg, nearly twice the 2013 EPA adjusted fuel economy for gasoline.
The on-road fuel economy has consistently increased over the last 10 years.
Overall median fuel economy = 51 m/kg, more than two times the average 2008 (comparable model year of FCEVs analyzed) EPA car fuel economy.
Scenario B: Median FCEV GHG 30% lower than passenger car and 35% lower than light duty truck baselines. Majority of current stations are delivered gas and FCEVs analyzed include sedan and SUV.
Majority of FCEVs are older generation without commercial grade maintenance expectations. Simple unscheduled maintenance (72%) filters and coolant fills. Only 3.5% of failures occurred on-road (CDP-FCEV-73). Average maintenance per vehicle decreasing since 2012 (CDP-FCEV-68).
Comparison of Fills to SAE J2601 Temperature and Pressure Limits

Fills (35 and 70 MPa) following pressure and temperature SAE J2601 limits
Updated values since 6/2015 report and continued progress demonstrated over the four evaluation periods with FCEV technology improvements especially in key technical areas like fuel cell durability, range, and fuel economy.

<table>
<thead>
<tr>
<th>Vehicle Performance Metrics</th>
<th>DOE Target (Year 2020)(^a)</th>
<th>LD3(^b)</th>
<th>LD2(^c)</th>
<th>LD2(^c)</th>
<th>LD1(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Fuel Cell Durability Projection (hours)</td>
<td>5,000</td>
<td>4,130</td>
<td>--</td>
<td>2,521</td>
<td>1,807</td>
</tr>
<tr>
<td>Average Fuel Cell Durability Projection (hours)</td>
<td>2,149</td>
<td></td>
<td>1,748</td>
<td>1,062</td>
<td>821</td>
</tr>
<tr>
<td>Max Fuel Cell Operation (hours)</td>
<td>5,605</td>
<td></td>
<td>1,582</td>
<td>1,261</td>
<td>2,375</td>
</tr>
<tr>
<td>Adjusted Dyno (Window Sticker) Range</td>
<td>200 - 320 miles</td>
<td>--</td>
<td>196-254 miles</td>
<td>103-190 miles</td>
<td>98 miles</td>
</tr>
<tr>
<td>Median On-Road Distance Between Fuelings</td>
<td>123</td>
<td></td>
<td>43 – 58 mi/kg</td>
<td>42 – 57 mi/kg</td>
<td>43 miles</td>
</tr>
<tr>
<td>Fuel Economy (Window Sticker)</td>
<td>51 mi/kg (median)</td>
<td>--</td>
<td>53% – 59%</td>
<td>51% – 58%</td>
<td>51% – 58%</td>
</tr>
<tr>
<td>Fuel Cell Efficiency at ¼ Power</td>
<td>60%</td>
<td>57% (average)</td>
<td>--</td>
<td>53% – 59%</td>
<td>51% – 58%</td>
</tr>
<tr>
<td>Fuel Cell Efficiency at Full Power</td>
<td>43% (average)</td>
<td></td>
<td>42% – 53%</td>
<td>30% – 54%</td>
<td>30% – 54%</td>
</tr>
<tr>
<td>Specific Power (W/kg)</td>
<td>650</td>
<td>240 - 563</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Density (W/L)</td>
<td>850</td>
<td>278 - 619</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Gravimetric Capacity (kg H2/kg system)</td>
<td>5.5%</td>
<td>2.5% - 3.7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Volumetric Capacity (kg H2/L system)</td>
<td>0.04</td>
<td>0.018 - 0.054</td>
<td></td>
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</tr>
</tbody>
</table>


Learn more at
www.nrel.gov/transportation
and
www.nrel.gov/hydrogen/proj-tech-validation
Technical Back-Up Slides
On-road stack efficiency compared with dyno system efficiency and DOE MYRDD 2020 Stack Target (65%). Average system efficiency at 25% power is 57%.
Voltage Degradation Analysis Approach

Analysis – EXAMPLE DATA

1. Voltage and current data
2. Apply polarization fit
3. Corresponding operation hour
4. Voltages from polarization fit at set currents
5. Fit voltage and operation data
6. Degradation linear fit
7. Y-intercept beginning of life voltage
8. Record operation hour when fit crosses 10% nominal voltage drop
9. Investigate fit quality

Fuel Cell Stack VI Animation for Vehicle19-Stack1

- 2500 data points per curve fit
- Time (vehicle oper hrs) = 1164

Stack Weight Factors

- Overall
- DatQty
- DatGap
- DR1ci
- DR2ci

Created: Oct-09-08  3:01 PM

- warm-up time = 10 min
- pwr rate filt = 1000 kW/s
- amp rate filt = 1000 A/s
- pts per fit = 2500
- 1 data pt every 1 seconds

Voltage vs. Operation Hours at 300A: Vehicle19-Stack1

- 300
- 290
- 280
- 270
- 260
- 250
- 240
- 230
- 220

Op Hours
### Key Analysis Topics

**Critical**
- Fuel cell durability
- Vehicle operation (hours, miles)
- Specs (power density, specific power)
- Range, fuel economy, and efficiency
- Fill performance
- Reliability

**Important**
- Drive behaviors
- Fill behaviors
- Power management
- Energy
- Transients
- Comparisons to conventional vehicles

These key topics were selected based on review of past CDPs, targets, most commonly referenced topics, and DOE feedback.
Templates enable collection of similar data from all the projects.
Thank you!