Fuel Cell Electric Vehicle Evaluation

Jennifer Kurtz (PI), Chris Ainscough, Genevieve Saur, Sam Sprik, & Shaun Onorato
National Renewable Energy Laboratory
June 13, 2018

DOE Hydrogen and Fuel Cells Program
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID # TV001

This presentation does not contain any proprietary, confidential, or otherwise restricted information.
Overview

Timeline and Budget

• Project start date: 10/2012*
• FY17 DOE funding: $200K
• FY18 planned DOE funding: $120K
• Total DOE funds received to date: $1,885k

Barriers

• Lack of current controlled and on-road hydrogen fuel cell vehicle data

Partners

• Daimler
• Hyundai
• Honda

• GM
• Nissan
• Toyota
• Electricore

*Project continuation determined annually by DOE
Relevance

• Objectives
  – Analyze and report data on hydrogen fuel cell electric vehicles (FCEVs) operating in a real-world setting.
  – Identify current status and evolution of the technology.
  – Publish performance status and progress from multiple FCEV models.

• Relevance
  – Objectively assess progress toward targets and market needs.
  – Provide feedback to hydrogen research and development.
  – Publish results for key stakeholder use and investment decisions.

**FY18 Objectives**
Analyze and report on FCEV fuel economy, range, and fueling behavior.
Approach: NFCTEC Analysis and Reporting

**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

Bundled data (operation and maintenance/safety) delivered to NREL quarterly

Data collection, analysis, aggregation, and reporting consistent with FY17 approach

Results

National Fuel Cell Technology Evaluation Center

www.nrel.gov/hydrogen/technology-validation.html
Approach: Schedule and Milestones

Regular project activities include:
- Quarterly analysis
- Annual technical CDPs
- Detailed data and analysis reviews with project partners
- Publishing and presenting results
- Collaborating with infrastructure evaluation

<table>
<thead>
<tr>
<th>Task</th>
<th>Start</th>
<th>End</th>
<th>Days</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CY16Q4 Data Delivery and Analysis</td>
<td>1/31/2017</td>
<td>3/10/2017</td>
<td>38</td>
<td>Complete</td>
</tr>
<tr>
<td>Spring 2017 CDP Review Cycle</td>
<td>3/10/2017</td>
<td>4/28/2017</td>
<td>49</td>
<td>Complete</td>
</tr>
<tr>
<td>Publish Spring 2017 CDP Results</td>
<td>5/31/2017</td>
<td>5/31/2017</td>
<td>1</td>
<td>Complete</td>
</tr>
<tr>
<td>CY17Q1 Data Delivery and Analysis</td>
<td>4/28/2017</td>
<td>6/30/2017</td>
<td>63</td>
<td>Complete</td>
</tr>
<tr>
<td>CY17Q2 Data Delivery and Analysis</td>
<td>7/31/2017</td>
<td>9/29/2017</td>
<td>60</td>
<td>Complete</td>
</tr>
<tr>
<td>CY17Q3 Data Delivery and Analysis</td>
<td>10/31/2017</td>
<td>12/29/2017</td>
<td>59</td>
<td>Complete</td>
</tr>
<tr>
<td>CY17Q4 Data Delivery and Analysis</td>
<td>1/31/2018</td>
<td>3/10/2018</td>
<td>38</td>
<td>Complete</td>
</tr>
<tr>
<td>Publish Spring 2018 CDP Results</td>
<td>5/31/2018</td>
<td>5/31/2018</td>
<td>1</td>
<td>In Progress</td>
</tr>
<tr>
<td>Publish FCEV Reports</td>
<td>6/12/2018</td>
<td>6/12/2018</td>
<td>1</td>
<td>In Progress</td>
</tr>
</tbody>
</table>
Accomplishments and Progress: Historical FCEV Evaluation Phases, Partners, and Publications

Current evaluation includes three OEMs delivering data from FCEVs currently on-road. The data are varied between OEMs and the analysis is focused on FCEV operation to provide technology status and support hydrogen station operation and improvement. Not all analysis topics are published due to data limitations.

“LD” - Indicates Learning Demonstration Phase
Approach: On-Road FCEVs and Partners Supplying Data

OEMs supplying data for both pre-commercial and commercial vehicles on the road. Reduction in number of partners from FY16 is due to award completion and on-road vehicles.
Accomplishments and Progress: Analysis Categories

- Deploy
- Driving
- FC Performance
- Reliability
- Range
- Durability
- Fuel Economy
- H2 Performance
- Fueling
- Specs
- Other
- Other

Analyzed data through 12/2017. Not all results are included here or published. All published results are available online: www.nrel.gov/hydrogen/technology-validation.html.
Accomplishments and Progress: FCEV Deployment and Operation Through CY2017Q4

- **54** FCEVs total
- **51** FCEVs retired
- **>2,675,280** Average on-road fuel economy miles/kg
- **>296,830** Max FCEV odometer miles
- **9** FCEVs retired
- **>2,675,280** miles traveled
- **>83,466** Fuel cell operation hours
- **>5,648** Max fuel cell operation hours

Current performance benchmarked since 2006 includes 230 vehicles and more than 7.39 million miles traveled.

Summary of FCEV operation from the current three OEM fleets. Summary statistics are from more detailed aggregated results that show distribution of available data. Durability analysis was completed but not published because of data aggregation limits.

**Summary operation statistics support the status reporting project objective.**
Accomplishments and Progress: Predictive Fueling Demand Model

NREL utilized fueling data to develop a model for predictive fueling demand that can be integrated with hydrogen stations for operation and control improvements as well as optimization.

Refueling by Time of Day

Total Fill Events\(^1\) = 18,568

1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
Accomplishments and Progress: Predictive Fueling Demand Model

Data from more than 18,568 fills were used to develop the first model iteration based on fill days, time, amount, and driving.

Refueling by Day of Week

- FCEV Fills
- Sample Gasoline Station Profile

18,568 Fills

Accomplishments and Progress: Predictive Fueling Demand Model

FCEV driving data are shown in comparison with standard gasoline vehicle driving trends (over 177,428 trips). The similarity in driving times and trends help support the predictive hydrogen refueling demand.

\[
\text{Total Drive Events}^1 = 177,428
\]

1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
3. 2009 NHTS Data Includes Car, Truck, Van, & SUV day trips
   ASCII cov Source: http://nhts.ornl.gov/download.shtml#2009
Accomplishments and Progress: Predictive Fueling Demand Model

On-board tank refueling data support understanding of station fueling performance from the perspective of the vehicle.
Temperature data are used to understand the actual range of tank temperatures with the expected extreme temperature conditions at a fill.
Accomplishments and Progress: Responses to Previous Year Reviewers’ Comments

• “The collaboration does not include the one OEM that sells FCEVs, and one of the OEMs included has reported plans for new models (but does not sell or lease the new models).”
  – NREL maintains open dialogue with FCEV OEMs. Availability of FCEV data is determined by OEM participation interest and diversity of vehicles operating on the road.

• “A potential downside is the age of this project and whether the industry needs it as much now as in the past 10 years (even though not all DOE targets are met). The fact that there are fewer participants may be a testament to this fact.”
  – Lack of operating FCEV fleets have dictated the decline of OEM participants and availability of data. This particular project is completing the high fidelity analysis work and shifting into tracking commercial vehicle deployment and specifications.

• “The project could have been a much better project if there had been more analysis. The slide 11 spider chart demonstrated that the NREL team can analyze, and its “Remaining Challenges & Barriers” and “Proposed Future Work” sections advise that NREL wants to analyze. It would have been nice to see more analysis in this presentation.”
  – NREL performs analysis on a variety of FCEV refueling events. Due to lack of diversity in the data, not all analysis can be publicly disseminated in order to preserve anonymity. More CDPs are published than what is in this presentation. A full list of CDPs and analysis is available at <https://www.nrel.gov/hydrogen/fuel-cell-vehicle-evaluation.html>.
Collaboration and Coordination

- Three participating OEMs—Daimler, Honda, & Hyundai
- These OEMs:
  - Supply data
  - Review detailed data analysis and approve published results
  - Review current and future analysis topics.

Industry working groups (California Fuel Cell Partnership, H2USA, and Fuel Cell and Hydrogen Energy Association)
  - Participation and briefings

Example Data Results (if needed) → Draft CDPs → OEM Initial Review (~4 weeks) → Final Draft CDPs (<1 week) → OEM Final Review (2 weeks) → Finalized CDPs (<1 week)

 (~8 weeks excluding data processing and analysis)

Detailed view of a typical data cycle with OEMs before every publication of analysis results
Remaining Challenges/Barriers and Proposed Future Work

• Remaining Challenges/Barriers
  – Lack of current controlled and on-road hydrogen fuel cell vehicle data.

• Future Work
  – Complete quarterly analysis of received CY18 data.
  – Publish analysis results of on-road vehicle evaluations (Spring 2018).
  – Disseminate data analysis through reports, white papers, and online content.
  – Utilize available fueling data for a predictive fueling models to inform decisions regarding station operation optimization, availability, and locations.
  – Shift focus of controlled demonstration from reporting on pre-competitive technologies to reporting on the current market status of commercially available FCEVs, production figures, market analysis, and geographic distribution.
    • Interact directly with OEMs, leveraging existing relationships and agreements.
    • Work closely with state, federal, and local government agencies (California Air Resources Board, California Energy Commission, U.S. Environmental Protection Agency, DOE, U.S. Department of Transportation, etc.).

*Any proposed future work is subject to change based on funding levels.*
Technology Transfer Activities

• None to date. However, this project helps inform industry on the status of FCEV technology and support research, development, and hydrogen station operation and improvement.
Summary

"For more than 10 years, NREL has been a trusted analysis partner. NREL turns our raw data into business intelligence. This gives us insight into how our vehicles are progressing toward targets, and how we compare against our peers. NREL has robust security procedures to keep our data safe and provide us useful results on a regular basis.” – FCEV OEM Partner

• **Relevance**
  – Independent validation of FCEV on-road performance against DOE and industry targets.

• **Approach**
  – Collaborate with industry partners to receive new vehicle data.
  – Continue to develop core NFCTEC and analysis capability and tools.
  – Leverage 8+ years of analysis and experience from the Learning Demonstration.

• **Technical Accomplishments and Progress**
  – Analyzed data from three OEMs.
  – Performed detailed reviews of individual OEM data results.
  – Published results via 20 CDPs that cover topics such as deployment, fuel cell performance, fuel economy, range, driving, fueling, and specifications.

• **Collaborations**
  – Working closely with industry partners and other strategic sources of data to validate methodology and with other key stakeholders to ensure relevance and accuracy of results.

• **Future Work**
  – Shift focus from reporting on pre-competitive technologies to reporting on current market status of commercially available FCEVs.
# Summary of Key FCEV Metrics

<table>
<thead>
<tr>
<th>Vehicle Performance Metrics</th>
<th>DOE Target (Year 2020)</th>
<th>LD3</th>
<th>LD2+</th>
<th>LD2</th>
<th>LD1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Fuel Cell Durability Projections (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>2,442</td>
<td>1,748</td>
<td>1,062</td>
<td>821</td>
<td></td>
</tr>
<tr>
<td>Max Fuel Cell Operation (hours)</td>
<td>5,648</td>
<td>1,582</td>
<td>1,261</td>
<td>2,375</td>
<td></td>
</tr>
<tr>
<td>Adjusted Dyno (Window Sticker) Range (miles)</td>
<td>200 - 320</td>
<td>--</td>
<td>196 - 254</td>
<td>103 - 190</td>
<td></td>
</tr>
<tr>
<td>Median On-Road Distance Between Fuelings (miles)</td>
<td>124</td>
<td>98</td>
<td>81</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Fuel Economy (Window Sticker) (mi/kg)</td>
<td>53 (median)</td>
<td>--</td>
<td>43 - 58</td>
<td>42 - 57</td>
<td></td>
</tr>
<tr>
<td>Fuel Cell System Efficiency at 1/4 Power</td>
<td>65</td>
<td>57% (average)</td>
<td>--</td>
<td>53% - 59%</td>
<td>51% - 58%</td>
</tr>
<tr>
<td>Fuel Cell System Efficiency at Full Power</td>
<td>43% (average)</td>
<td>--</td>
<td>42% - 53%</td>
<td>30% - 54%</td>
<td></td>
</tr>
<tr>
<td>Specific Power (W/kg)</td>
<td>650</td>
<td>240 - 563</td>
<td>306 - 406</td>
<td>183 - 323</td>
<td></td>
</tr>
<tr>
<td>Power Density (W/L)</td>
<td>650</td>
<td>278 - 619</td>
<td>300 - 400</td>
<td>300 - 400</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>2.5%</td>
<td>2.5% - 4.4%</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>0.018 - 0.025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thank You

www.nrel.gov

Publication Number: NREL/PR-5400-xxxxx
Technical Back-Up Slides
Hydrogen Fill Amount

Average fill amount varies from the station data evaluation project due to different data sets. Station and FCEV data comparisons for fueling demand profiles will be investigated.

Average Fill Amount = 1.5 kg
Total Number of Fills = 18,568

1. Data comes from fcev onboard sensors, includes fills from 2012 to 2018
2. Tanks range from 3.8 to 6.3 kg
Only 3.6% of fills happen more than 14 days apart; 100 miles are traveled ~70% of the time with 1–2 days between fills, which indicates high daily miles traveled.
The impact of average trip speed on fuel economy follows an expected trend, where the peak on-road fuel economy is when average trip speed is 20–25 mph.
FCEVs have made good progress toward DOE targets **without losing efficiency**, but work remains to achieve targets.