Dispenser Reliability
2017 DOE Annual Merit Review

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Overview

• Start date: 10/1/2016
• End date: 09/30/2017*

* Project continuation and direction determined annually by DOE

• Project funding FY17: $1,300K

Multiyear RD&D Barriers

Technology Validation Barriers

• D. Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

• E. Codes and Standards - Validation projects will be closely coordinated with Safety, Codes and Standards

NREL
Chris Ainscough, Mike Peters, Ahmad Mayyas, Sam Sprik, Josh Martin, Petr Sindler, Kevin Hartmann, Erin Winkler, Danny Terlip, Rob Burgess, Owen Smith, Kevin Harrison

SNL (Sandia National Laboratory)
Joe Pratt, Nalini Menon, Ethan Hecht

GTI
Tony Lindsay, Ted Barnes, Brian Weeks

CSA Group
Livio Gambone
Dispensers are the top cause of maintenance events and downtime at retail hydrogen stations.
Relevance: Station O&M Cost

Early stations suffer break-in period however, there is still room to improve.

Average cost in 2016Q3 < $5/kg

Overall Average: $23 per kg.

Cost trending down
Relevance: Striking the Right Balance

Cost
- Capital
- Operation and maintenance

Performance
- 3 – 5 minute fills
- High State of Charge (> 95%)
- Cost of fuel to customer
- 99% station reliability
Approach: Project Tasks

Big Picture
How does fueling protocol affect the FCEV customer?

3 Year Project Timeline*
*Not to scale

Task 1 – Technoeconomic Analysis

Task 2 – Reliability Testing of Components
Quantify reliability
Work with manufacturers to improve reliability and cost

Short term – Station
How can we improve reliability?

Long term - Station
Are improvements in fueling methods possible?

Task 3 – Fueling Model
Open source, free to use
Industry accepted
Approach: Task 1 – Techno-economic Analysis

- **Explore cost**, to the fuel cell vehicle customer, of changing the pre-chilled hydrogen temperature

- **Use fill data** from NREL’s station to make a regression model to predict cost savings

- Main driver of pre-cooled cost is the chiller/heat exchanger capital cost and O&M

- Expected component reliability differences between operating temperatures are **not** added into this analysis
Approach: Task 1 - TEA

- Uses **NREL’s station data as base for regression analysis** around chiller/heat exchanger capital and O&M cost
  - A variety of ambient conditions in Golden, CO gives the data a wide range of differential temperatures between cooling block and ambient

- Cooling requirements were split into two categories: filling and idle

- Cost was normalized to $/year to FCEV customer
Approach: Task 1 - TEA

Capital Cost
- Take maximum of peak power between idle and filling case and add design factor of 1.5
- Use previous analysis from ANL to predict capital cost of equipment

O&M Cost
- Look at station utilization from 0 - 100% and weigh idle versus filling energy consumed
- 180 kg/day station example
- Cost of electricity: $0.175/kWh
- Bookend cost of H2: $5.55/kg and $12/kg

Approach: Task 1 - TEA

Filling case
- Input: dispensed amount (kg), differential temperature between ambient and cooling block (°C), restoration time (min)
- Output: Peak power (kW) for capital cost, Energy per fill (kWh)

Idle case
- Input: differential temperature between ambient and cooling block (°C)
- Output: Peak power (kW) for capital cost, Energy per fill (kWh)

Energy (kWh)
- Kilograms dispensed is dominant factor in the energy equation for filling case

Sizing (kW)
- Filling case dictates maximum power output needed to get to chiller/heat exchanger capital cost
Approach: Task 2 – Component Testing

- Literature review on material testing of hydrogen components looking at temperature effects of hydrogen components
- Highly **accelerated life testing** of hydrogen components downstream of heat exchanger
- Work with component manufacturers to improve hydrogen component reliability
- **Measure reliability differences** of hydrogen components when exposed to different temperatures (-40°C, -20°C, 0°C, Ambient)
- Perform **material analysis pre and post exposure** to hydrogen
Approach: Task 2 - Component Testing

Design of Experiment

- 4 different levels of temperature: -40°C, -20°C, 0°C, ambient
- Testing 11 components per level -> 44 + 1 for material testing
- Pressure ramp rates and flow rates similar to J2601
- Pressure ramp rates 15 – 25 MPa/min
- Flow rates 2 – 3 kg/min
- Expose components to thermal shock – i.e., reach -33°C within 30 seconds
Approach: Task 3 – Fueling Model

- Open source, free to use hydrogen fueling model that will be accepted by the codes and standards community and other key stakeholders
- Model spans from station to vehicle tanks
- Leverage existing fueling models to make one open source, free to use model to spur innovation
- Allows entity with idea for new protocol to test the protocol and provide data before approaching appropriate C&S committee
Reducing pre-cooling temperature results in significant reductions in H₂ cost.

![Graph showing the difference in cost to FCEV customer compared to -40 C operation.](image)

-40C to -20C @ $5.55/kg
-40C to -20C @ $12/kg
-40C to 0C @ $5.55/kg
-40C to 0C @ $12/kg
Accomplishment: Task 1 - TEA

- Cost savings higher at low utilization stations due to idle energy requirements from chillers
- TEA showed significant cost savings in capital and O&M from chiller/heat exchanger alone
Accomplishment: Task 2 - Component Testing

Literature search

- No available data that can be leveraged to reduce the planned testing scope of this project
- Some test campaigns on performance of piping components at the pressures and temperature in a fueling dispenser
  - Available information is qualitative only or,
  - Result of specific qualification tests do not assess effects other than pass/fail
- Planned component testing work will have a high impact on component selection and design, fueling method evaluation, and dispenser reliability
Accomplishment: Task 2 - Component Testing

- Building prototype device to ensure temperature, pressure, and flow rates can be achieved on multiple “dispenser” systems
- Components in scope:
  - Normally open valves (control valves), normally closed valve (control valve), Filters, Nozzles, Receptacles, Breakaways, Fittings
Collaboration:

Component Manufacturers

• 45 components total is very expensive, i.e., 45 nozzles, 45 breakaways (all per manufacturer)
• Have talked with multiple component manufacturers about testing

Industry Expert Panel

• Tracks progress and provides feedback
  – Current participants: Air Liquide, Air Products, CaFCP, FastTech Inc., Ford, Honda, Linde, Shell, ZCES
Future Work:

• Task 1 – TEA
  – Complete 3/31/17

• Task 2 – Component Testing
  – Finalize selection of component manufacturers 5/31/17
  – Begin flow testing 9/1/17
  – Begin material testing on components 9/1/17

• Task 3 – Fueling Model
  – Document detailing the modeling inputs/outputs 3/31/18
  – Preliminary station-side model 6/30/18
  – Vehicle complete vehicle-side model to NREL 3/31/19
Challenges and Barriers:

Cost Share

- Need to get in-kind, discounts, or cost share of components to be able to test multiple manufacturers
Technology Transfer Activities:

**Component Testing**
- Working with component manufacturers should lead to new products or different designs

**Fueling Model**
- Gain acceptance from C&S committees and industry for future use
  - SAE J2601 committee needs to be engaged early
This project was not reviewed last year.
Summary:

Relevance:
• Dispensers are top cause of maintenance events and labor time
• O&M cost at stations has room for improvement
• Balance between station cost and performance needs to be found

Approach:
• Task 1 – Techno-economic analysis
• Task 2 – Component Testing
• Task 3 – Fueling Model

Technical Accomplishments:
• Task 1 – TEA
  • Showed significant cost savings to FCEV customer with capital and O&M improvements to chiller/heat exchanger
  • Cost savings are higher at less utilized stations due to idle operation of chiller
• Task 2 – Component testing
  • Building prototype device

Collaborations:
• Project partners: SNL, GTI, CSA
• Industry expert panel: Air Liquide, Air Products, CaFCP, Fasttech Inc., Ford, Honda, Linde, Shell, ZCES

Proposed Future Research:
• Task 2 – Component Testing
  – Finalize selection of component manufacturers 5/31/17
  – Begin flow testing 9/1/17
  – Begin material testing on components 9/1/17
• Task 3 – Fueling Model
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TECHNICAL BACKUP SLIDES
Approach: Task 2 - Component Testing

NREL's Existing Infrastructure

IV
III
II
I

H₂ High Pressure Storage (FIBA)
MAWP - 90 MPa
60 kg total

Chiller/Heat Exchanger

Component Testing

High Pressure Component Testing

H₂ Medium Pressure Recycle

NREL's Existing Infrastructure
Accomplishment: Task 1 – TEA Regression Equations

Cooling Energy, Filling (kWh) = 0.0911 * ΔT + 0.052 * t_{restoration} + 0.6475 * kg dispensed − 6.266

\[ R^2 = 0.87 \]

\[ Adjusted \ R^2 = 0.85 \]

Cooling Energy, Idle (kWh) = 0.68649 * ΔT − 7.1742

\[ R^2 = 0.76 \]

\[ Adjusted \ R^2 = 0.76 \]
Polymeric Components:

- Evaluation of changes in glass transition temperature and moduli (DMTA - Dynamic Mechanical and Thermal Analysis)
- Mass loss effect (TGA - Thermogravimetric Analysis)
- Density changes for exposed and non-exposed components (ASTM D792-13)
- Changes in degree of crystallinity for semi-crystalline polymers (DSC - Differential Scanning Calorimetry and XRD - X-Ray Diffraction)
- Optical imaging (Micro CT - Computerized Tomography) and microscopy (TEM – Transmission Electron Microscopy) for bulk and surface defects
- Changes in molecular weight of polymers (GPC – Gel Permeation Chromatography) before and after testing

Elastomeric Components:

- Changes in compression set properties (ASTM D 395 Method B)
- Microscopic techniques (TEM) will be used to characterize possible damage such as shredding or tearing due to rapid gas decompression effects