H2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

Dispenser Reliability
2017 DOE Annual Merit Review

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National Renewable Energy Laboratory
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Project ID # PD140

Overview

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T I M E L I N E

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

* Project continuation and direction determined annually by DOE

B A R R I E R S

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*

B U D G E T

- Project funding FY17: **$1,300K**

P A R T N E R S

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

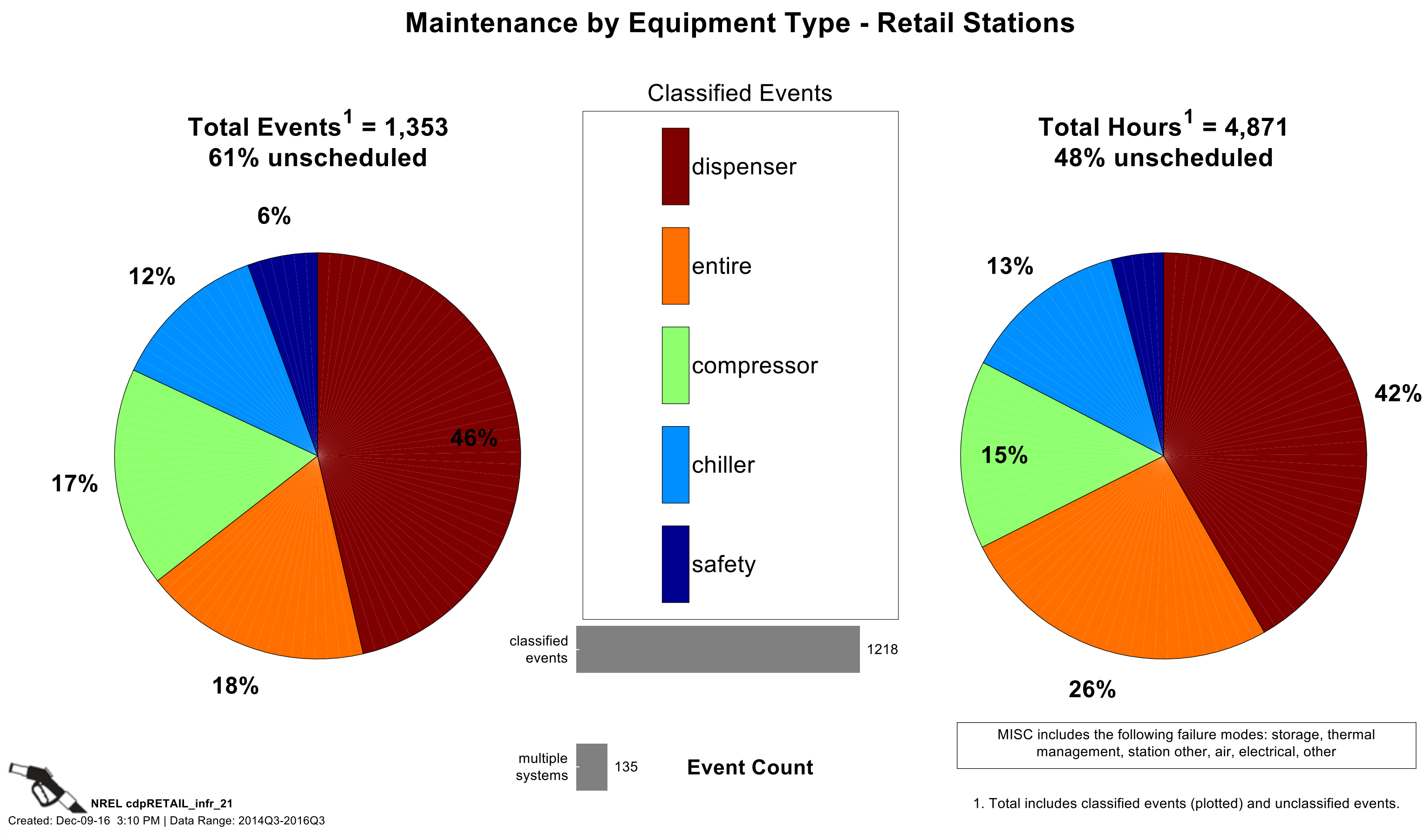
Tony Lindsay, Ted Barnes, Brian Weeks

CSA Group

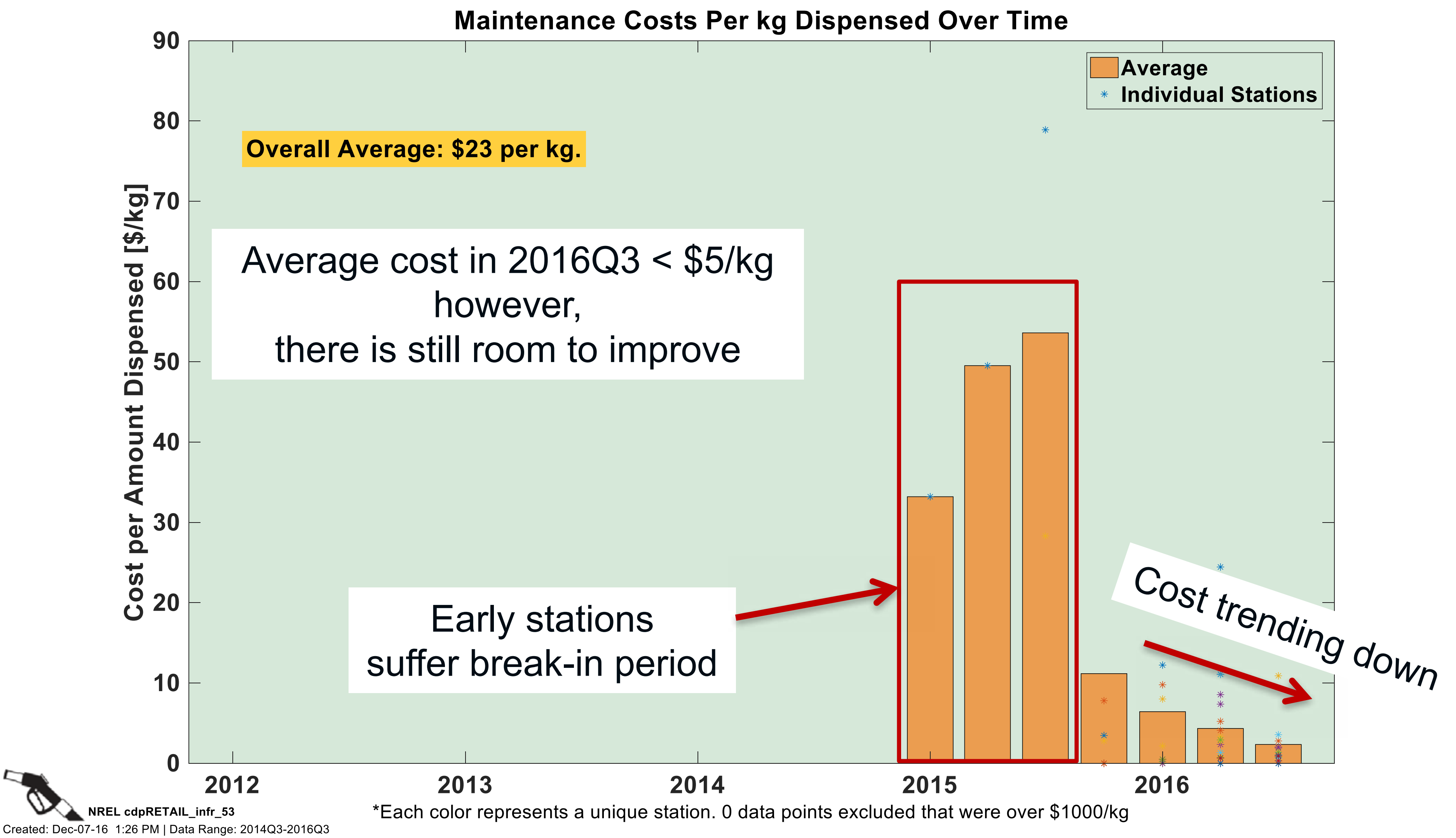
Livio Gambone

Relevance: #1 in Downtime

Dispensers are the top cause of maintenance events and downtime at retail hydrogen stations



Relevance: Station O&M Cost



Relevance: Striking the Right Balance

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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

3 Year Project Timeline*

*Not to scale

Big Picture

How does fueling protocol affect the FCEV customer?

Task 1 – Techno-economic Analysis

Short term – Station

How can we improve reliability?

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

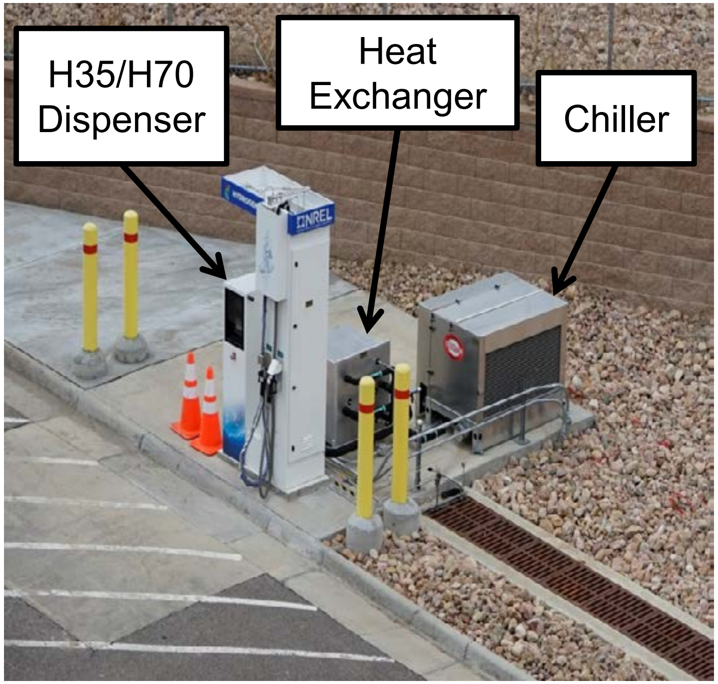
Long term - Station

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

	2017 Honda Clarity	2017 Hyundai Tucson Fuel Cell	2017 Toyota Mirai
			
Fuel Economy and Related Estimates			
Fuel Economy (mi/kg)	**67** comb **68** city **66** hwy	**49** comb **48** city **50** hwy	**66** comb **66** city **66** hwy
Range (miles)	366	265	312
Annual Fuel Cost *	$1,250	$1,700	$1,250
Vehicle Characteristics			
Vehicle Class	Midsize Car	Small SUV	Subcompact Car
Motor	AC Permanent Magnet Synchronous (130 kW)	AC Induction (100 kW)	AC Induction (56 kW)
Battery	346 V Lithium Ion	180 V Lithium Ion	245 V NiMH
Availability	Select dealers in California	Select dealers in California (lease only)	Select dealers in California & Hawaii (sale or lease)

* Annual fuel cost calculated assuming a hydrogen cost of $5.55/kg, 15,000 annual miles of travel, and 55% city and 45% highway driving.

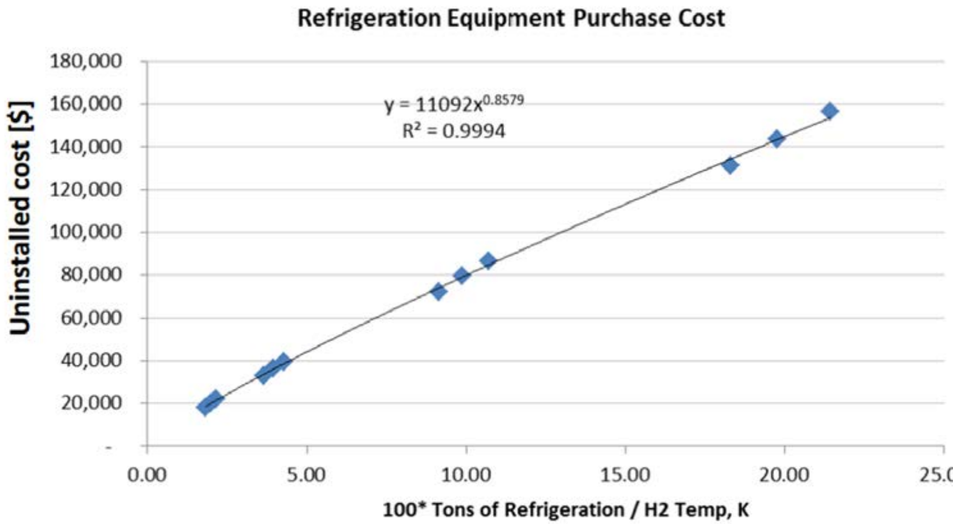
Approach: Task 1 - TEA

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



Source: A. Elgowainy, K. Reddi, and D. Brown. “Analysis of Incremental Fueling Pressure Cost.” DOE Annual Merit Review. Washington, D.C., June 17, 2014

Approach: Task 1 - TEA

Filling case

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

Idle case

- Input: differential temperature between ambient and cooling block (^oC)
- 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

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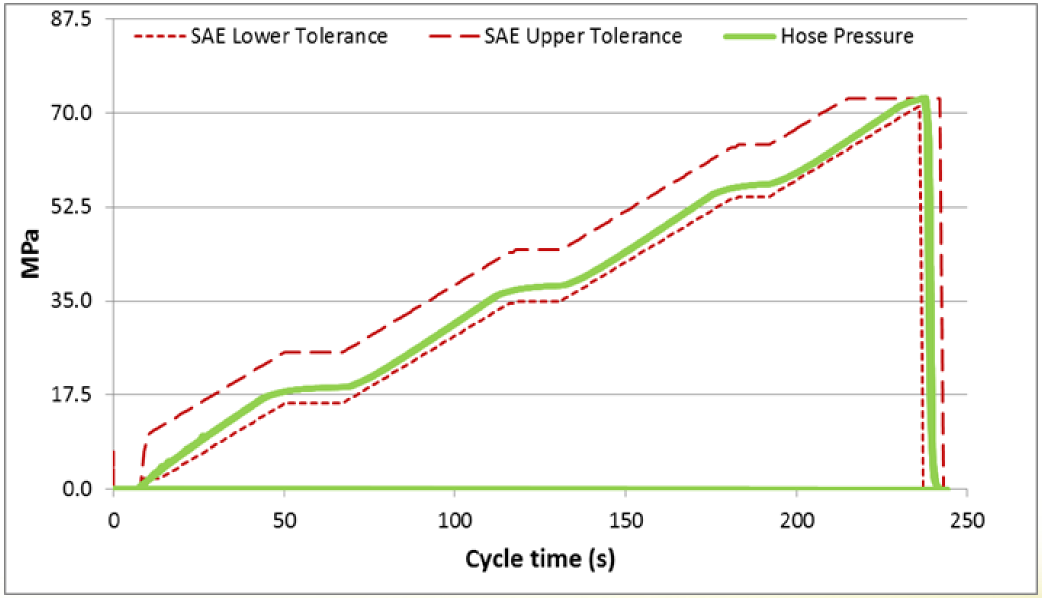
Design of Experiment

- 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

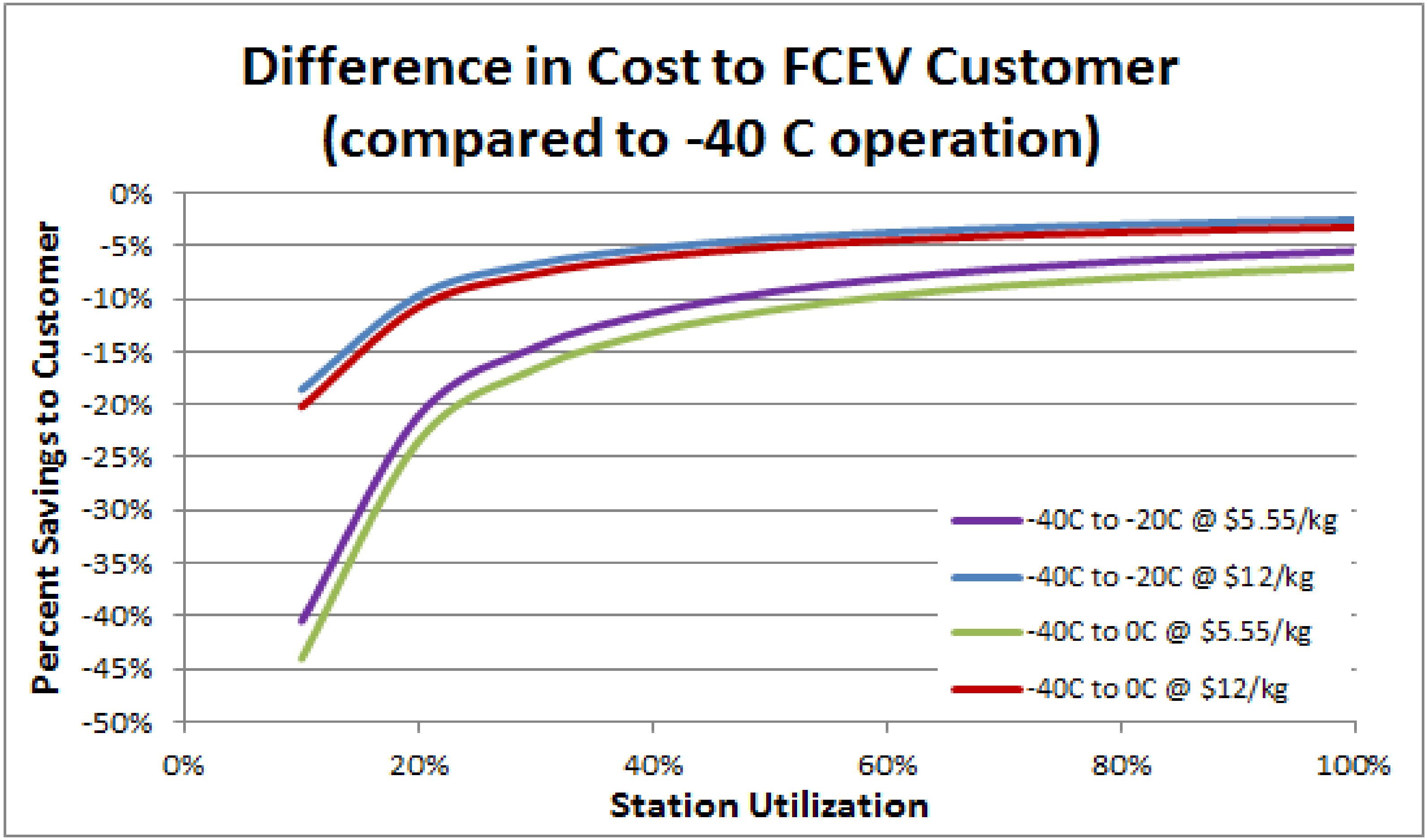


Approach: Task 3 – Fueling Model

- 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

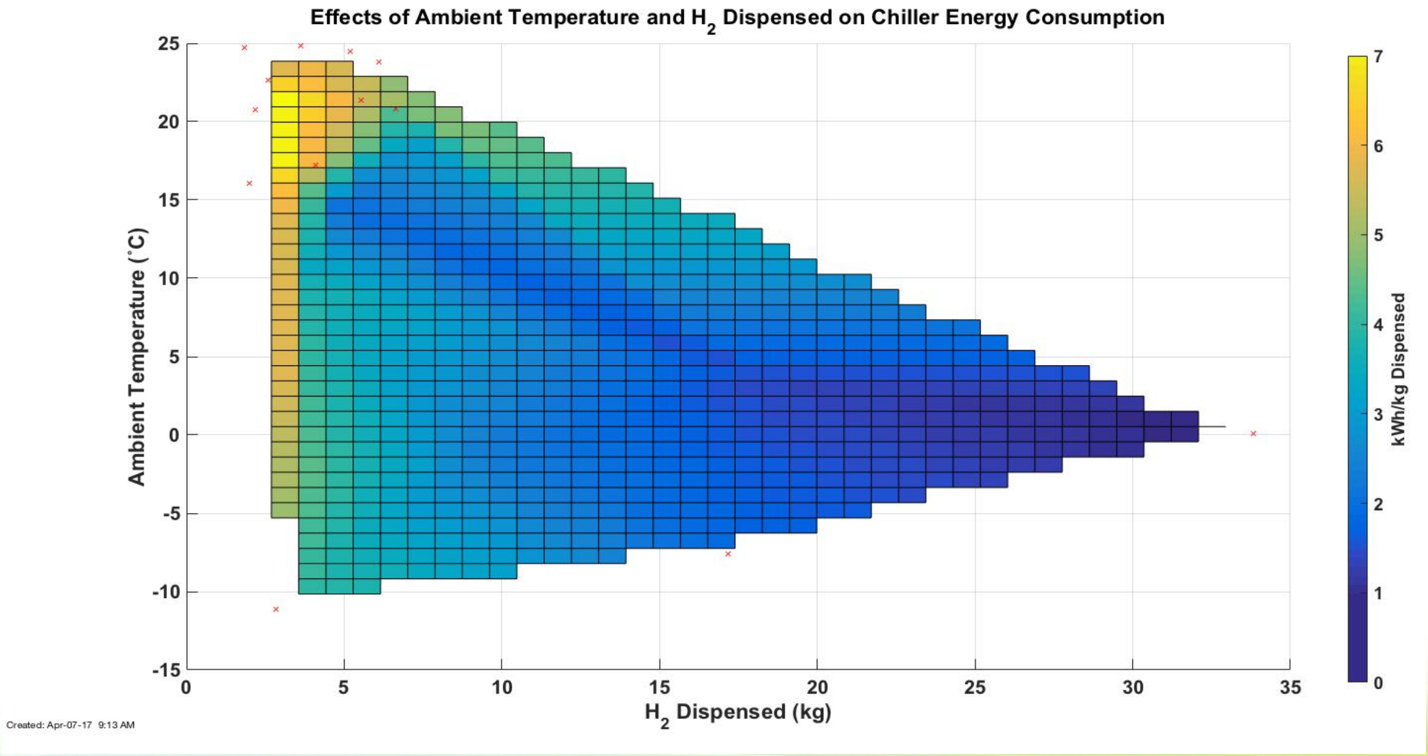
Accomplishment: Task 1 - TEA

Reducing pre-cooling temperature results in significant reductions in H_2 cost.



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



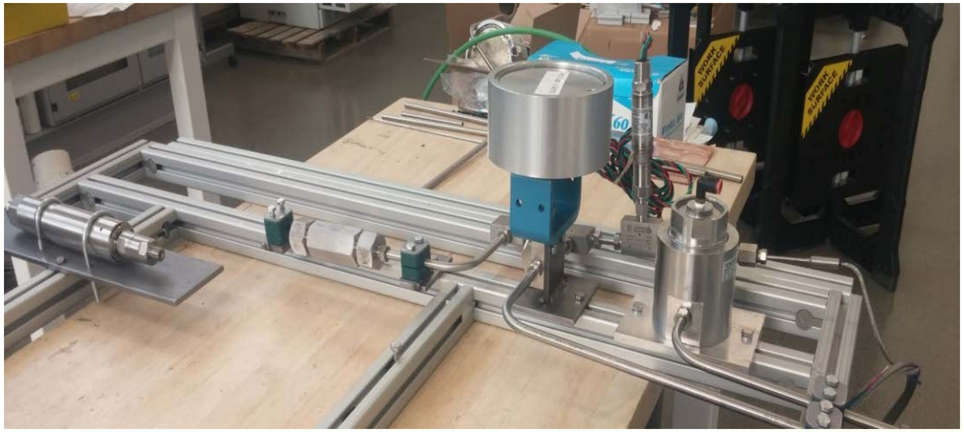
Accomplishment: Task 2 - Component Testing

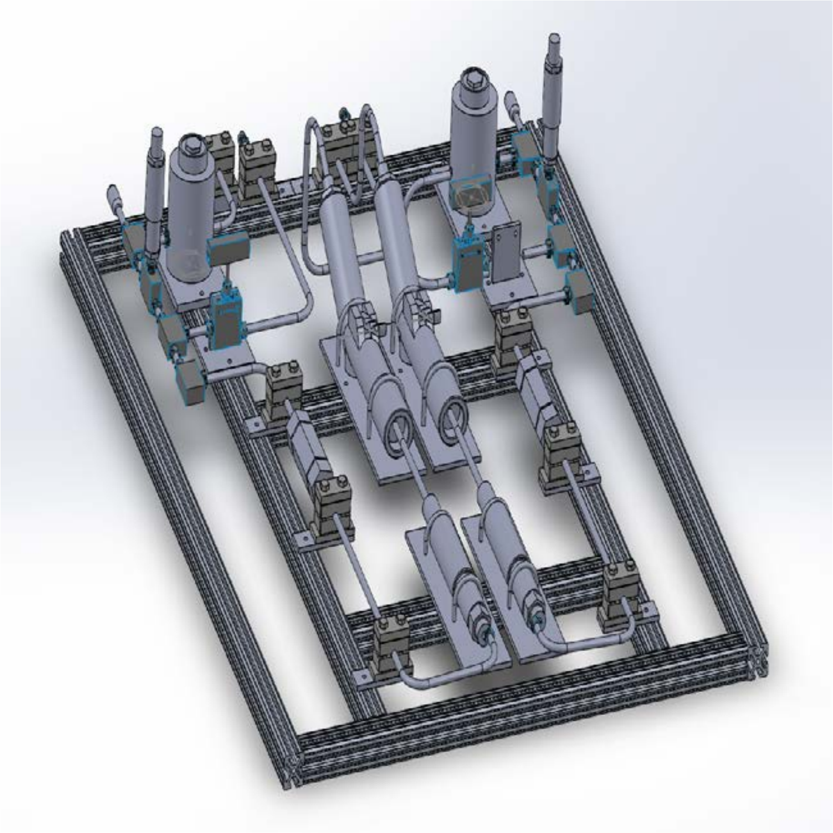
Literature search

- 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

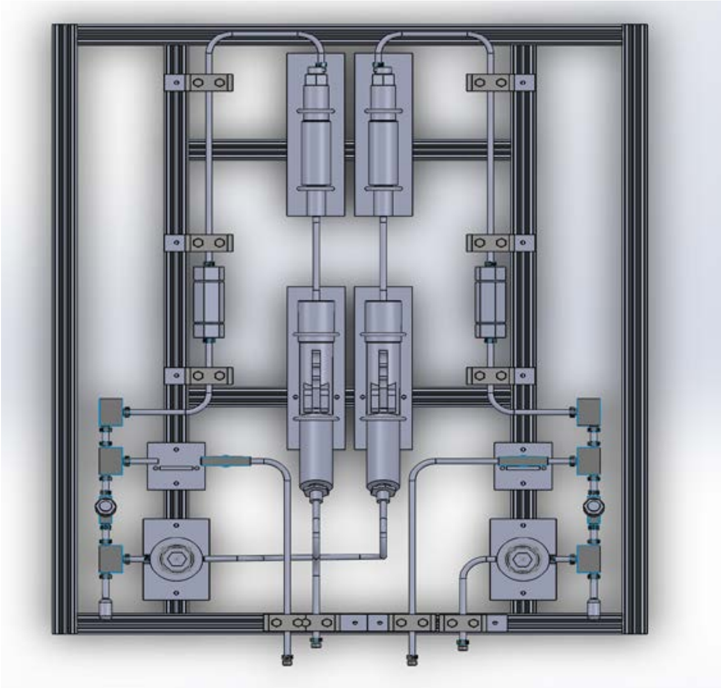
Future Work:

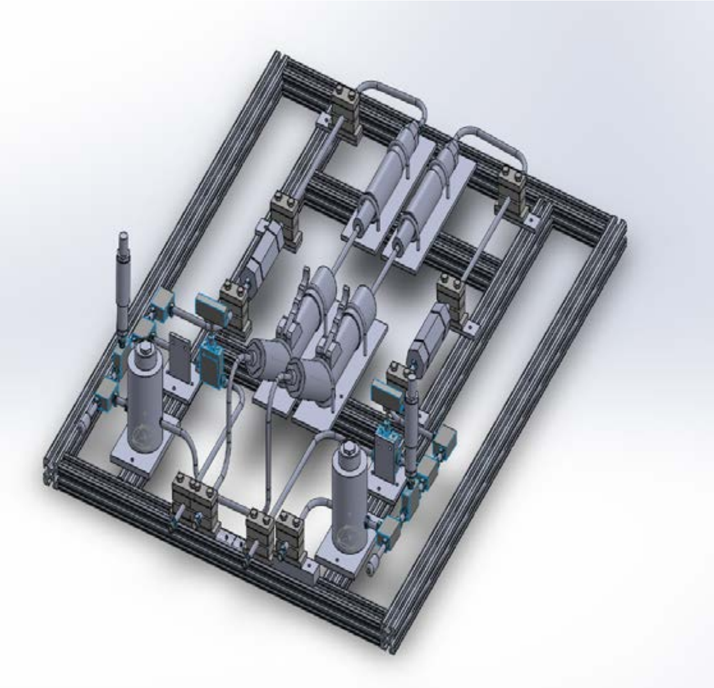
- **Task 1 – TEA**
  - Complete 3/31/17
- **Task 2 – Component Testing**
  - Finalize selection of component manufacturers 5/31/17
  - Begin flow testing 9/1/17
  - Begin material testing on components 9/1/17
- **Task 3 – Fueling Model**
  - Document detailing the modeling inputs/outputs 3/31/18
  - 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 manufactures 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

Response to Reviewers Comments:

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**
  - Document detailing the modeling inputs/outputs 3/31/18
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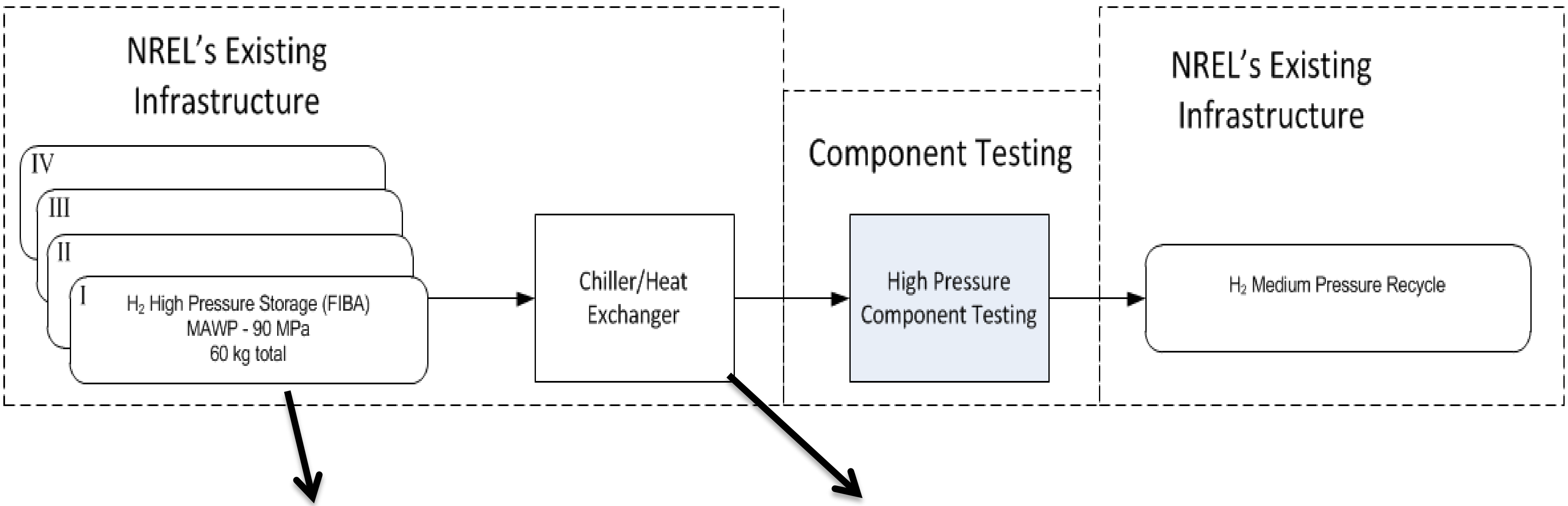
TECHNICAL BACKUP SLIDES

Approach: Task 2 - Component Testing



Accomplishment: Task 1 – TEA Regression Equations

$$Cooling\ Energy\ ,Filling\ (kWh) =$$
$$0.0911 * \Delta T +$$
$$0.052 * t_{restoration} +$$
$$0.6475 * kg\ dispensed - 6.266$$
$$R^2 = 0.87$$
$$Adjusted\ R^2 = 0.85$$

$$Cooling\ Energy, Idle\ (kWh) = 0.68649 * \ \Delta T - 7.1742$$
$$R^2 = 0.76$$
$$Adjusted\ R^2 = 0.76$$

Task 2 – Component Testing Material Testing

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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