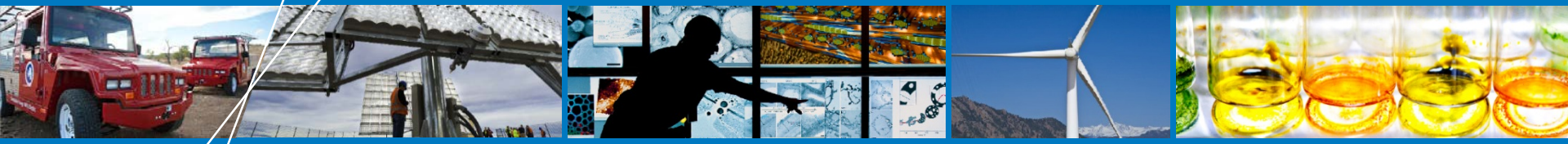
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Overview of an Integrated Research Facility for Advancing Hydrogen Infrastructure



Kevin Harrison (PI), Josh Martin, Mike Peters (Presenter), Owen Smith, Danny Terlip, Kevin Hartmann

National Renewable Energy Laboratory

DOE 2017 Annual Merit Review
June 7, 2017

Project ID: TV038

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

Overview

Timeline

Project start date: February, 2015
Project end date: TBD

Partners

- Proton OnSite
- Giner Inc.
- PDC Machines Inc.
- H2FIRST

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***

Safety Codes and Standards Barriers

- ***F.*** **Enabling national and international markets requires consistent RCS**
- ***G.*** **Insufficient technical data to revise standards**
- ***J.*** **Limited participation of business in the code development process**

Budget

Total Budget: N/A

Project Objective & Relevance

Design, build, commission, and operate a hydrogen station to understand industry challenges, provide hydrogen to DOE and industry-funded research projects, fill hydrogen fuel cell vehicles, and provide a test platform for hydrogen infrastructure components.

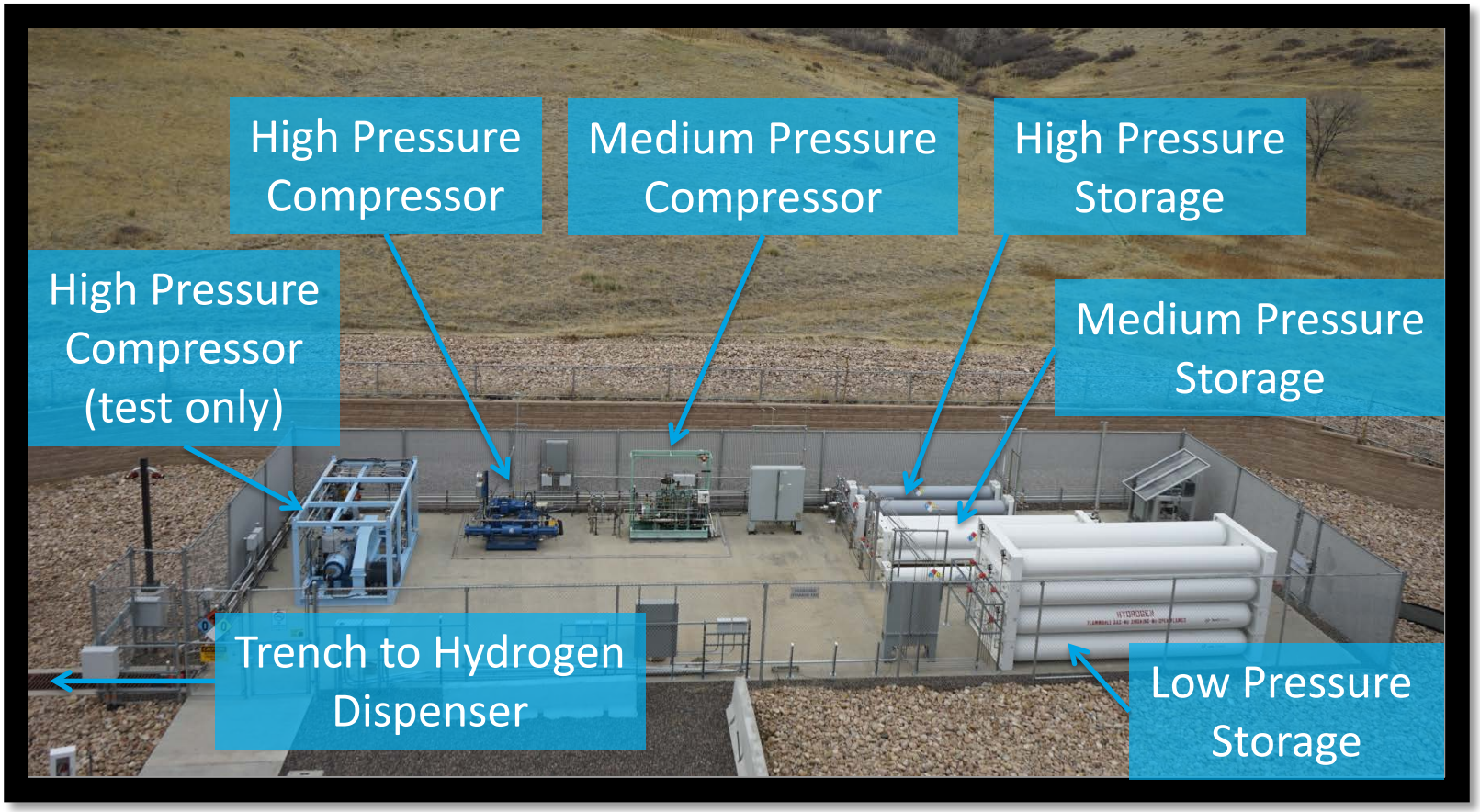
- The Hydrogen Infrastructure Testing and Research Facility, HITRF, encompasses all elements of a commercial gaseous hydrogen fueling station with on-site forecourt production
- The integrated system leverages NREL's research in production, compression, storage, and dispensing into a unified system capable of fueling fuel cell electric vehicles and fuel cell forklifts
- Station is utilized to help achieve H2FIRST objective to ensure that the fuel cell electric vehicle customers have a positive fueling experience similar to conventional gasoline/diesel stations.

Approach: Operation and Data Collection

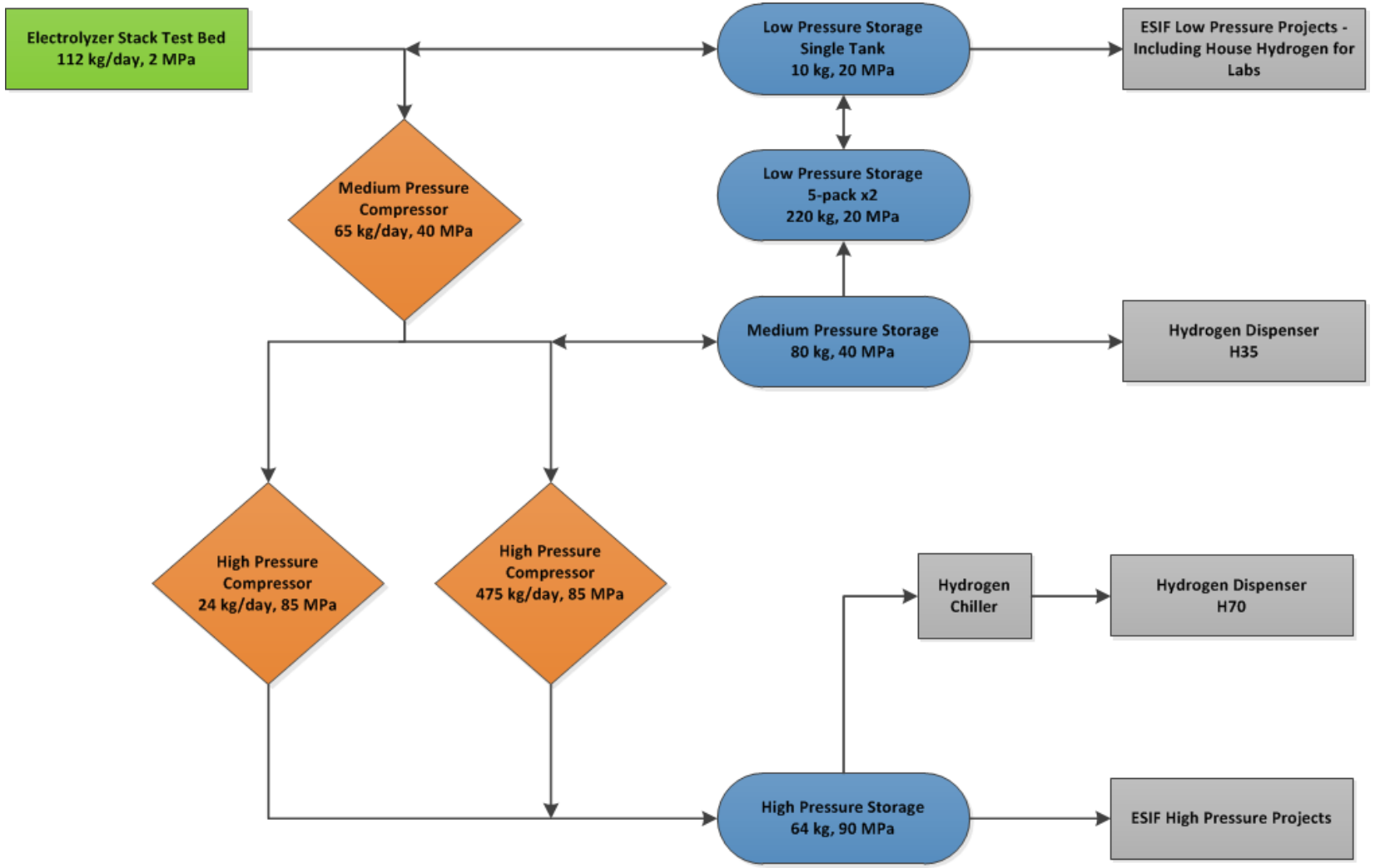
- **Mimic current and future hydrogen stations by fueling FCEVs and simulated vehicles to report on hydrogen station performance.**
- **Collect and report on every facet of a hydrogen station:**
  - System efficiency, downtime, maintenance cost/time, capital cost, lead times based on components, system integration, safety, controls
- **Engage industry on findings and work together on solutions**

Approach: Layout

- Station pad is more spaced out than typical hydrogen stations to allow for infrastructure components, both research and commercial, to be moved in and out easily

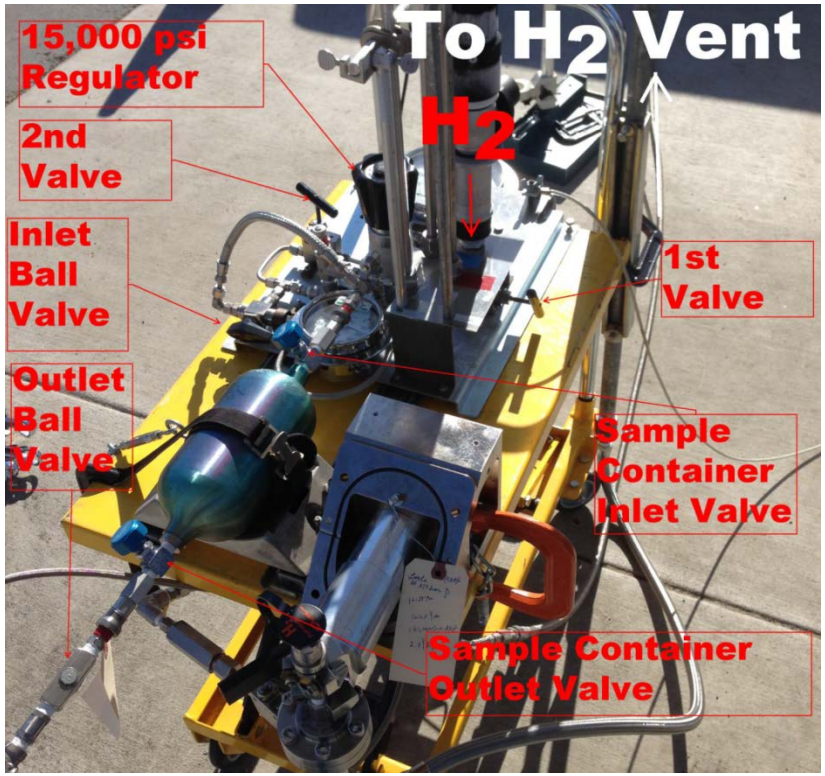


Approach: Station Flow Diagram



Accomplishment: Hydrogen Quality

Station passed SAE J2719: Hydrogen Fuel Quality for Fuel Cell Vehicles

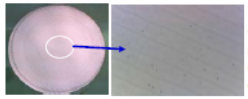


SAE J2719	SAE J2719 Limits (µmol/mol)	Smart Chemistry Detection Limits (µmol/mol)	H70 H2 @Nozzle sampled on 06/30/2016 Concentration (µmol/mol)	Analytical Method
Water	5	1	< 1	
Total Hydrocarbons (C_1 Basis)	2		**0.043**	ASTM D7892
Methane			0.013	
Acetone			0.024	
Isopropyl Alcohol			0.0063	
Oxygen	5	1	< 1	ASTM D7649
Helium	300	10	< 10	ASTM D1946
Nitrogen, Argon	100			
Nitrogen		5	**5.1**	ASTM D7649
Argon		0.4	< 0.4	ASTM D7649
Carbon Dioxide	2	0.1	< 0.1	ASTM D7649
Carbon Monoxide	0.2	0.0005	**0.0015**	ASTM D5466
Total Sulfur	0.004	0.000001	**0.000074**	ASTM D7652
Hydrogen Sulfide		0.000001	0.000023	ASTM D7652
Carbonyl Sulfide		0.000001	0.000047	ASTM D7652
Methyl Mercaptan (MTM)		0.00001	< 0.00001	ASTM D7652
Ethyl Mercaptan (ETM)		0.00001	< 0.00001	ASTM D7652
Dimethyl Sulfide (DMS)		0.00001	< 0.00001	ASTM D7652
Carbon Disulfide		0.000002	0.0000037	ASTM D7652
Isopropyl Mercaptan (IPM)		0.00001	< 0.00001	ASTM D7652
Tert-Butyl Mercaptan (TBM)		0.00001	< 0.00001	ASTM D7652
n-Propyl Mercaptan		0.00001	< 0.00001	ASTM D7652
n-Butyl Mercaptan		0.00001	< 0.00001	ASTM D7652
Tetrahydrothiophene (THT)		0.00001	< 0.00001	ASTM D7652
Formaldehyde	0.01	0.001	< 0.001	ASTM D7892
Formic Acid	0.2	0.001	< 0.001	ASTM D5466
Ammonia	0.1	0.01	< 0.01	ASTM D5466
Total halogenates	0.05			
Chlorine		0.001	< 0.001	ASTM D5466
Hydrogen Chloride		0.003	< 0.003	ASTM D5466
Hydrogen Bromide		0.001	< 0.001	ASTM D5466
Organic Halides (32 compounds in red and bold listed in "Other Hydrocarbons"). Both Smart Chemistry and method limits is for each individual organic halide.		0.001	< 0.001	ASTM D7892

Particulate Concentration - ASTM D7651

0.51 mg/kg

Particulates Found & Size - ASTM D7634



There are total 39 particulates found with the sizes in micrometer: 106, 97, 93, 84, 78, 70, 70, 70, 67, 66, 64, 63, 62, 59, 57, 55, 55, 53, 51, 51, 49, 49, 49, 49, 47, 46, 46, 45, 43, 43, 39, 39, 33, 29, 29, 28, 25, 20, 16.

Hydrogen Fuel Index The hydrogen fuel index is the value obtained when the amount of aggregate impurities, as, expressed as percent (µmole/µmole), is subtracted from 100%. (Section 3.5 of SAE J2719)

99.99949%

Accomplishment: Fuel Cell Vehicles

- NREL has 2 Fuel Cell Electric Vehicles onsite
  - Toyota Mirai
  - Hyundai Tucson
- NREL uses the vehicles for education, outreach, and VIP tours

Accomplishment: Supporting Research

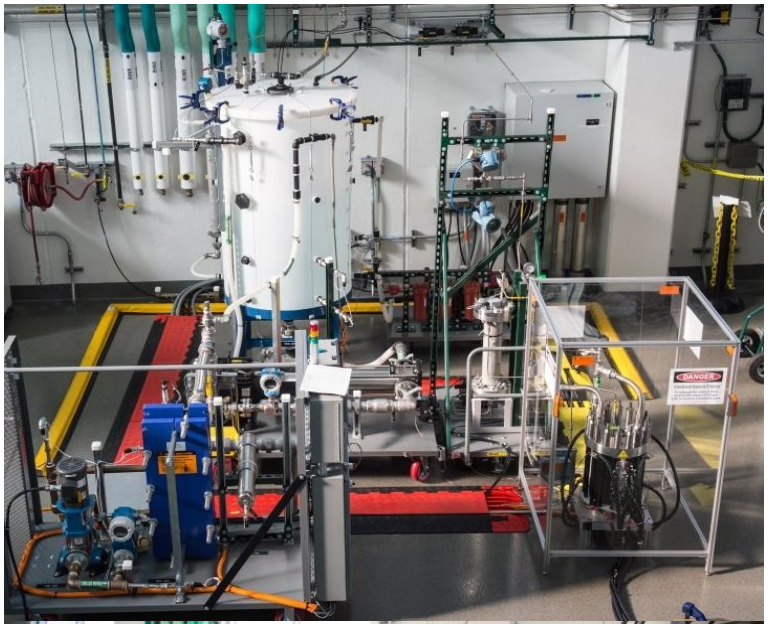
HITRF supports numerous high pressure research projects

- H2FIRST
  - Consolidation (**FY16 AMR PD133)**
  - HySTEP
  - Meter Benchmarking **(FY16 AMR TV037)**
  - Hose Reliability **(FY16 AMR PD100)**
- Component Validation **(FY16 AMR TV019)**
- Renewable Electrolysis **(FY16 AMR PD031)**
- INTEGRATE – Electrolyzers for use in grid applications (**FY16 AMR TV031)**
- Hydrogen Contaminant Detection (HCD)

Top: Vehicle Simulator (5 vehicles) Bottom: H2FIRST Testing

Accomplishment: Electrolysis Production

- Onsite H_2 production – 112 kg/day
- Flexible platform for large active area stack balance-of-plant testing
- AC-DC power supplies capable of 4,000 A DC, 250 V DC
- Real time monitoring of stack and cell efficiency through stack and individual cell voltage measurements
- Electrolyzer and power supply hardware-in-the-loop testing capabilities with millisecond time step and remote grid simulation



Accomplishment: Compression

Hydro Pac – Upgraded high pressure compression capabilities to 18 kg/hr

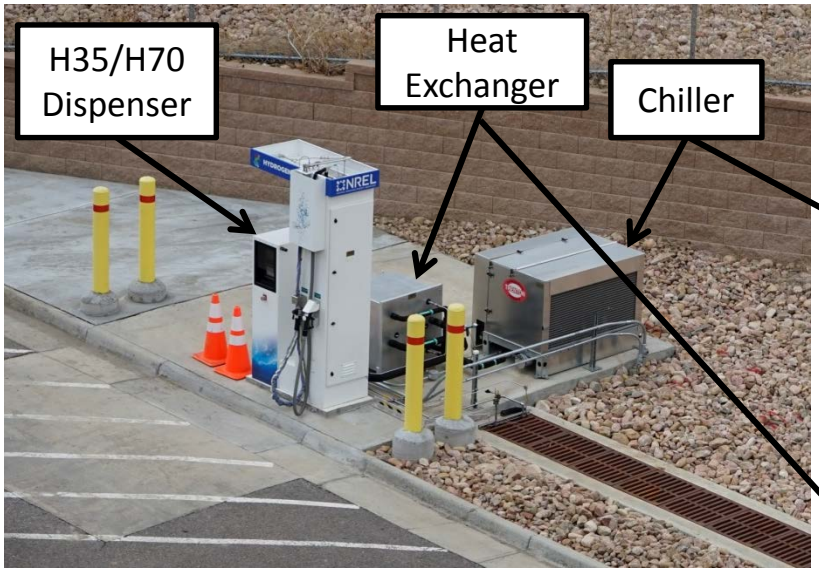
*PDC – New compression capabilities to support Consolidation **PD133***

Parameter	HYDRO PAC	PDC
Max Discharge Pressure (MPa)	96.5	90
Flow Rate (kg/hr)	18	45.4
Start of Operation	Sept 2016	April 2017

Accomplishment: Storage

- Low Pressure Storage
  - 200 kilograms total at 20 MPa
    - 100 kilograms added in 2017
  - Provides house hydrogen to fuel cell lab experiments
  - Feeds medium pressure compressor
  - Supports consolidation testing
- Medium Pressure Storage
  - 80 kilograms at 40 MPa
  - Used for 35 MPa forklift fills and 70 MPa vehicle cascade fills
  - Feeds high pressure compressors
- High Pressure Storage
  - 64 kilograms at 90 MPa
  - Used for 70 MPa vehicle fills, hose validation, dispenser component testing, and high pressure test bay experiments

Accomplishment: Chilling and Dispensing



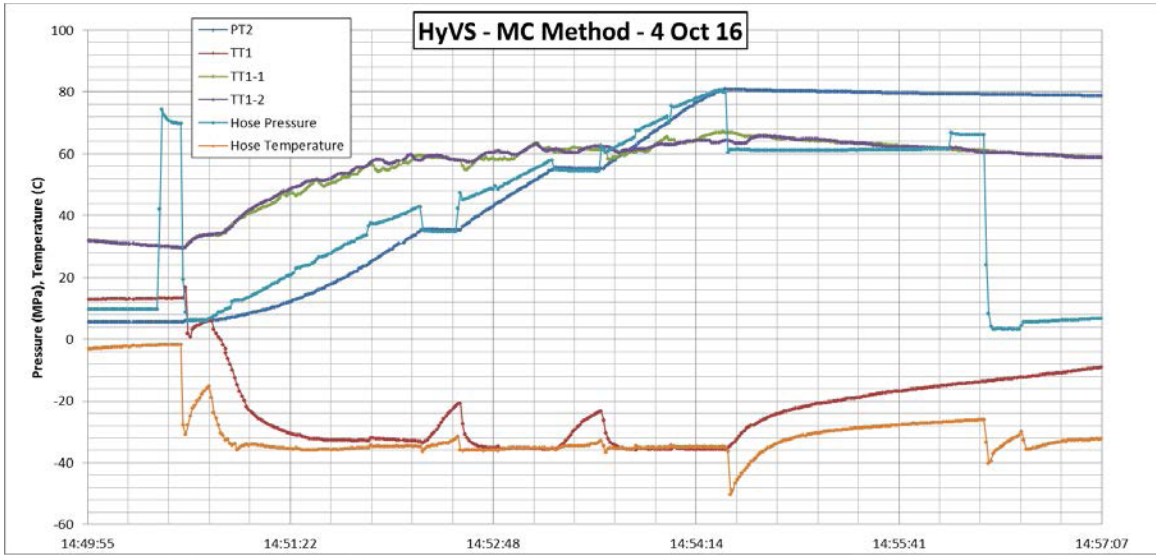
2016 - Dispenser, chiller, and heat exchanger

Upgraded to 12 kW chiller and triple block heat exchanger provided by Air Products

2017 - Dispenser with new chiller and triple block heat exchanger

Accomplishment: Chilling and Dispensing

- Dispenser is programmed to SAE J2601-2014 table based fueling protocol
- MC Formula capable
- Completed Metering Testing
- Initiated particulate contamination study
- Vehicle Simulator (HyVS) completed
- Key parameters tracked
  - H70 Hose Pressure
  - H70 Hose Temperature
  - Cooling Block Temperature
  - Vehicle Tank Pressure
  - Vehicle Tank Temperature
  - Vehicle Tank Volume



Responses to Reviewer Comments

This project was not reviewed last year.

Collaborations:

- Proton OnSite
- Giner Inc.
- PDC Machines Inc.
- H2FIRST

Challenges and Barriers

- Station downtime is an issue with hydrogen stations and NREL has seen these issues firsthand at their station
- NREL is actively working on how to engage research and industry more with the NREL hydrogen fueling station.
- Findings from NREL's station need to be public knowledge and reported in places where people can easily find them
  - NREL is working with H2Tools to begin reporting station findings and issues that arise

Proposed Future Work

New projects already scheduled for the station

- Power to Gas (Collaboration with Southern California Gas)
- H_2 Liquefaction – Vortex Tube
- MC Formula Testing
- Tube trailer consolidation model verification

Plans for future projects

- Test new hydrogen chiller technologies

Any proposed future work is subject to change based on funding levels.

Summary

Relevance:

- Experiencing hydrogen infrastructure performance, NREL will inform DOE, federal and state governments, academia, and industry of issues and solutions to commonly observed problems at hydrogen stations.

Approach:

- Mimic current and future hydrogen stations by fueling FCEVs and simulated vehicles to report on hydrogen station performance
- Collect and report on every facet of a hydrogen station

Technical Accomplishments:

- Station Upgrades
- Fueling Hydrogen Fuel Cell Vehicles

Collaborations:

- Proton OnSite, Giner Inc., PDC Machines Inc., H2FIRST

Proposed Future Research:

- Power to Gas (Collaboration with Southern California Gas)
- H_2 Liquefaction – Vortex tube
- MC Formula Testing

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Technical Back-Up Slides

HITRF Layout