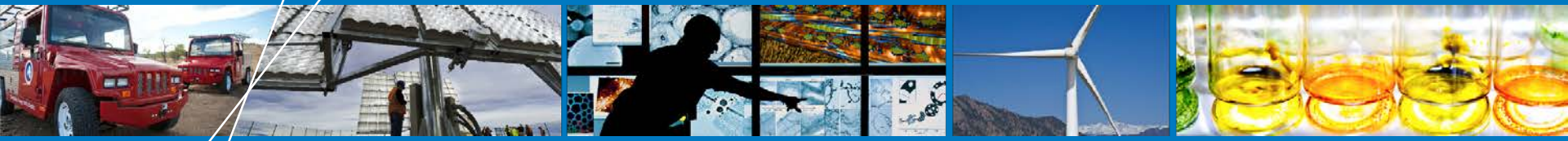
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen Component Validation



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National Renewable Energy Laboratory
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Project ID #TV019

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

Overview

Timeline and Budget

- **Project start date: 10/2012**
- **FY16 DOE funding: $0 (carryover)**
- **FY17 planned DOE funding: TDB**
- **Total DOE funds received to date: $758k**

Barriers

- **Barriers addressed**

D - Lack of Performance Data (detailed compressor reliability data and analysis)

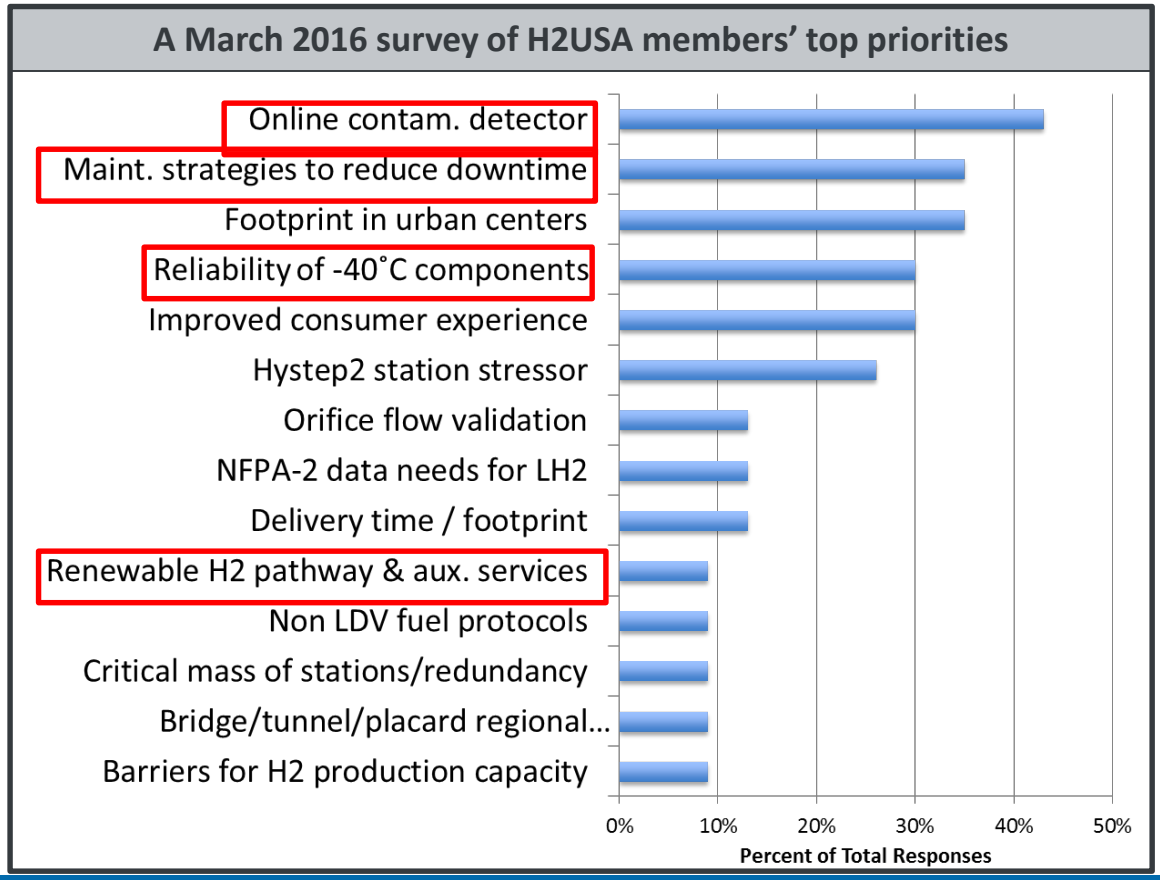
Partners

- **HydroPac**
- **PDC**
- **PPI/Sundyne**
- **Shell Hydrogen**
- **CSULA**
- **SCAQMD**
- **Sunline**
- **H2Frontiers**
- **ANL**

Relevance

- **Objectives**
  - Reduce fuel contamination introduced by forecourt station components
  - Improve station reliability and uptime
  - Increase the publicly available energy and performance data of major station components

- **Areas of Focus**
  - Contaminant Library
  - Station Reliability and Maintenance
  - Station Power and Energy Demand



Approach – Leveraging Existing Projects

- **Leverage current DOE projects at the Hydrogen Infrastructure Testing and Research Facility (HITRF) at NREL**
  - 700 bar station configured similar to a retail station
  - No retail customer base allows for research space
  - Unfettered access to components
  - Current projects generate data useful to this project

- **Leverage NREL hydrogen program**
  - Material Data Screening tools and fuel cell research
  - FCEV filling using SAE J2601 T40 protocol
  - NFCTEC Composite Data Products (CDPs)
  - Safety Codes and Standards group

Approach - Contaminant Research

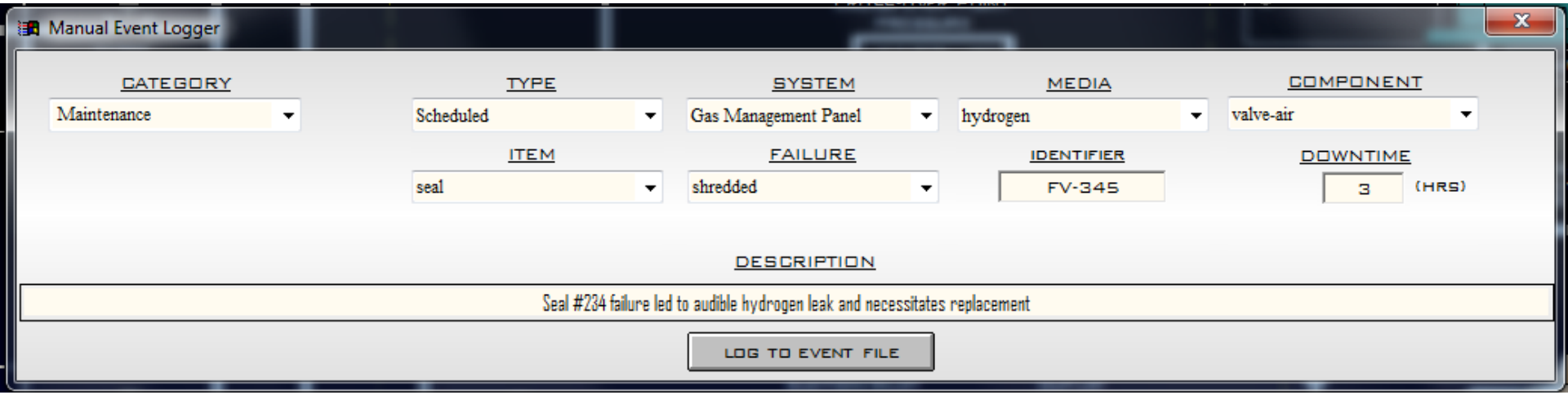
- **Collection of contaminants**
  - Work with forecourt station operators to send samples to NREL
  - Identify location of collection and operating conditions
- **Deep dive analysis into failures**
  - Microscopic and other optical techniques
  - Corroborate failures with similar components/operating conditions

***Milestone*: Status report on participation in contaminant collection – 31 March 2016**

Sample Location	Compressor discharge isolation valve
Reason for taking sample	Known component failure
Equipment upstream	Diaphragm compressor
Equipment downstream	Type 2 storage tank
Estimated sample source	Failed o-ring in air-operated valve
Date of sample	20 November 2015
Vial Number	Vial 1

Approach – Maintenance and Reliability

- Logging of all HITRF station events, downtime and resolution – aligned format with NFCTEC standard January 2016
- Monthly station reports
- Sharing data on H2Tools, SOSS and NREL CDPs

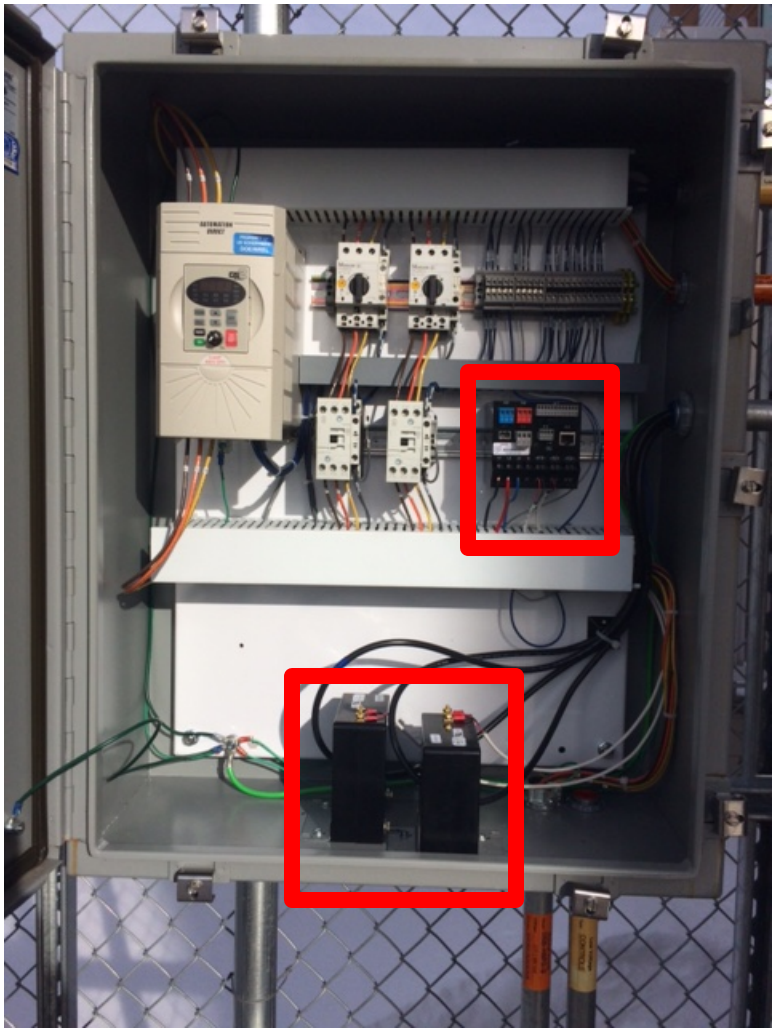


Approach – Station Power and Energy Demand

- **Power Meter Installation**
  - Hydrogen Pre-cooling Chiller
  - 400b Compressor
  - 875b Compressor
- **Data comparison with NREL CDPs**
- **Data sharing with station analysis groups**

Voltage, current:	± (0.08% MV + 0.02% MR) [1) 2)]
Power:	± (0.16% MV + 0.04% MR) [3) 2)]
Power factor:	± 0.1° [4)]
Frequency:	± 0.01 Hz
Imbalance U, I:	± 0.5%
Harmonics:	± 0.5%
THD Voltage:	± 0.5%
TDD Current:	± 0.5%
Active energy:	Class 0.5S, EN 62053-22
Reactive energy:	Class 2, EN 62053-23
Measurement with fixed system frequency:	
General	± Basic uncertainty x (F_{konfig}–F_{ist}) [Hz] x 10
Imbalance U	± 1.5% up to ± 0.5 Hz
Harmonics	± 1.5% up to ± 0.5 Hz
THD, TDD	± 2.0% up to ± 0.5 Hz

1) MV: Measured value, MR: measurement range (maximum)
2) Additional uncertainty of 0.1% MV if neutral wire not connected (3-wire connections)
3) MR: maximum voltage x maximum current
4) Additional uncertainty of 0.1° if neutral wire not connected (3-wire connections)

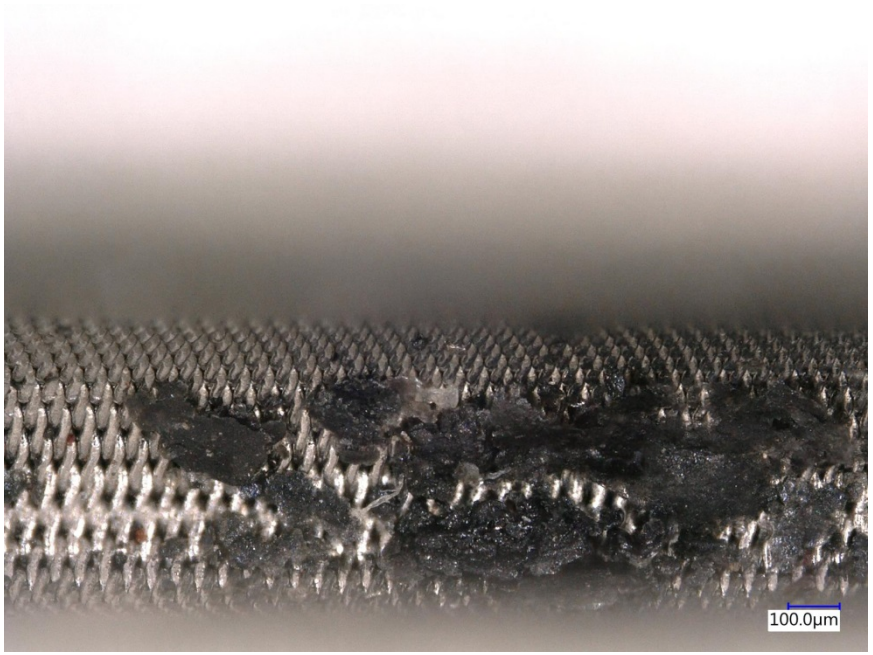


Accomplishments - Contaminant Library

New since June 2015

- Seven forecourt stations participating
- One external result, multiple NREL results
- Identified H2Tool.org as location for publication of contaminant findings

Seat material from a valve exposed to pre-cooled hydrogen. Metal flakes visible near fracture.



Contents of a filter downstream of the hydrogen pre-cooling system. The material appears to be elastomers and grease.

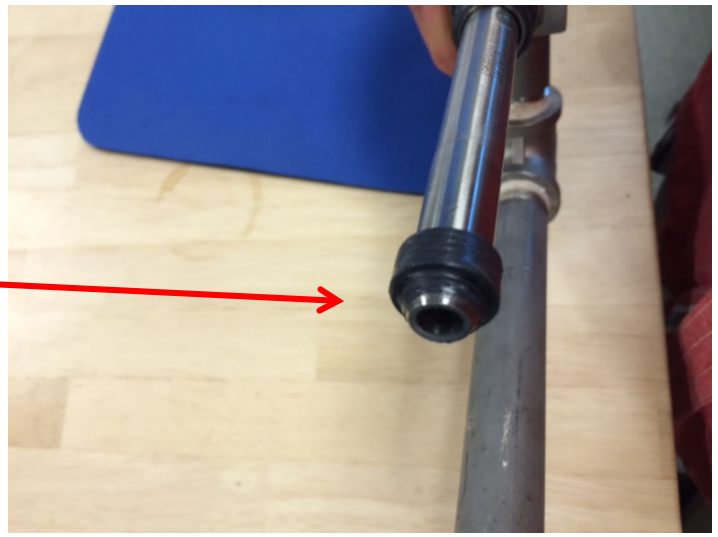
Accomplishments – Contaminant Outreach

New since June 2015

- **Outreach to three major compressor manufacturers regarding grease materials in use known to degrade fuel cells**
  - Refining of best practices
  - Material selection guidance

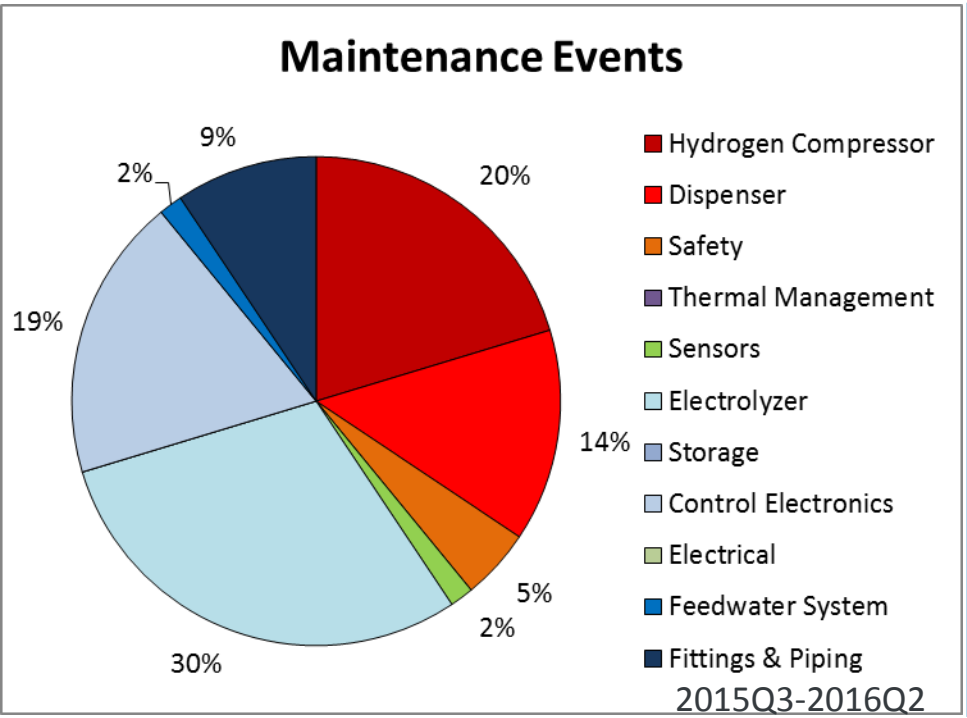
Hydrogen Service Valve downstream of compressor

- **Function group contaminant studies performed at NREL highlight**
  - Amides
  - Sulfur compounds
  - Aromatics (paraffinic)



Accomplishment - Maintenance Data

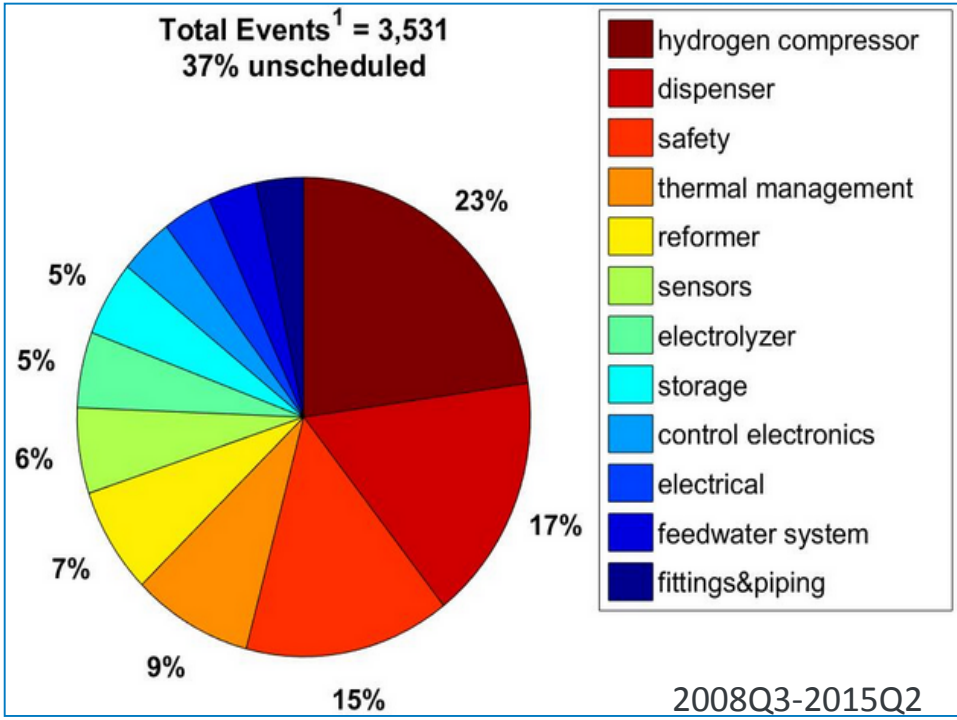
Research Facility - NREL HITRF



2015Q3-2016Q2

Industry – CDP INFR 21

New since June 2015



2008Q3-2015Q2

*The HITRF is a research station that focuses on component research rather than servicing FCEV customers, yet **compressors** and **dispensers** remain major maintenance burdens*

Progress – Maintenance Reduction (NREL)

NREL has the ability to test components in various configurations under retail station conditions and analyze failures more deeply than retail station operators

- **Component performance at -40C**
  - Needle and Air-Operated Valve failures identified
  - Failure corroborated with other station operators
  - Seal material with a wider temperature range installed, yet failures remain
  - Investigating possibility of installing multiple manufacturer components
- **Communicating with equipment manufacturers**

Accomplishment – Added Capability

New since June 2015

- **Linear Piston 900 Bar Compressor Installation**

Specification	Value
Inlet Range	12.1-41.3 MPa
Max Discharge	96.5 MPa
Capacity (35 MPa)	140 SCFM
Stages	1
Motor Power	40 hp
Compressor Weight	4,500 lbs

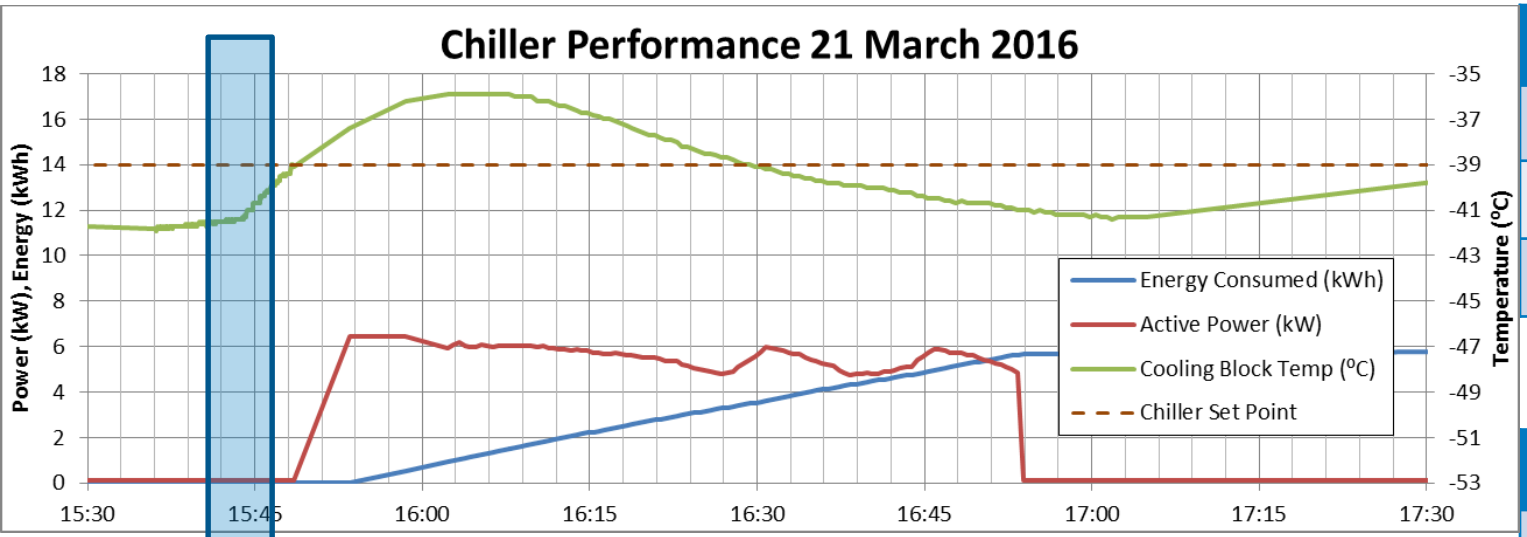
Research Topics Refill Storage

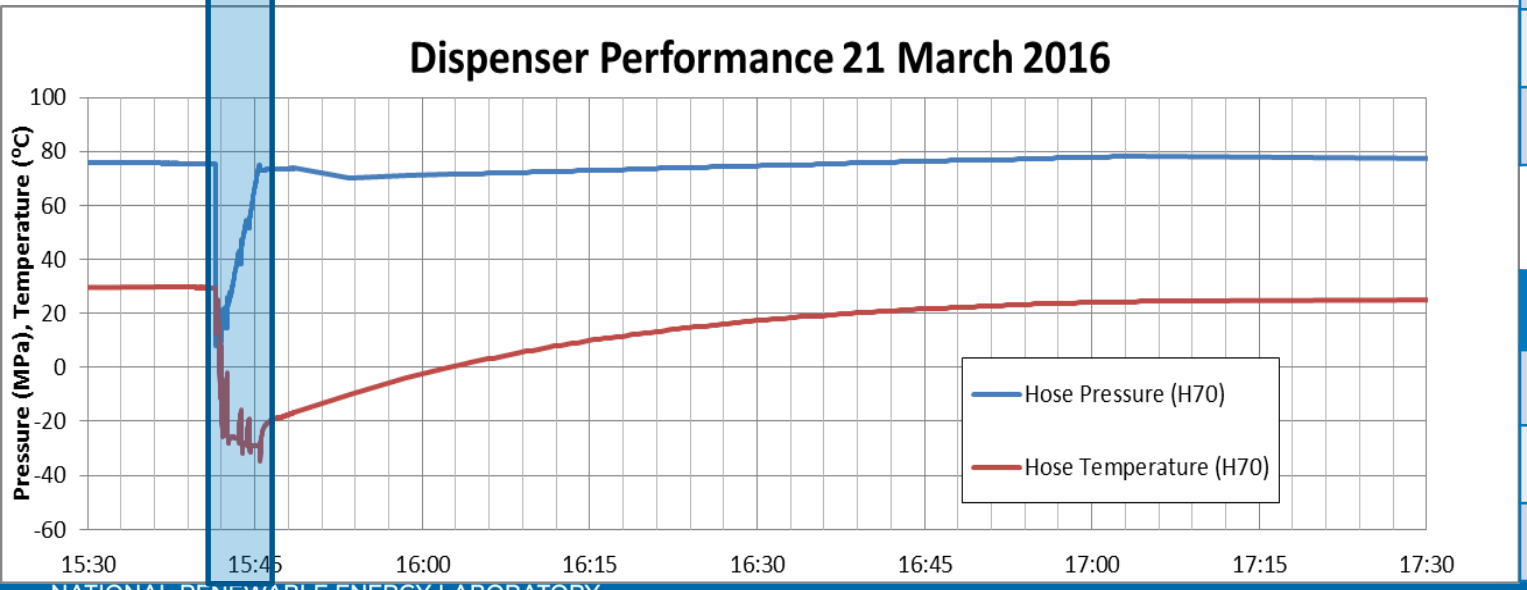
- Energy Demand
- Filling Protocol
- Contamination

Accomplishments - Chiller Performance Data

New since June 2015

Data critical to improve modeling accuracy and benchmarking (see PD104 - Elgowainy)





Full Recovery
6.0 kWh
58.9 min
6.46 kW_{max}

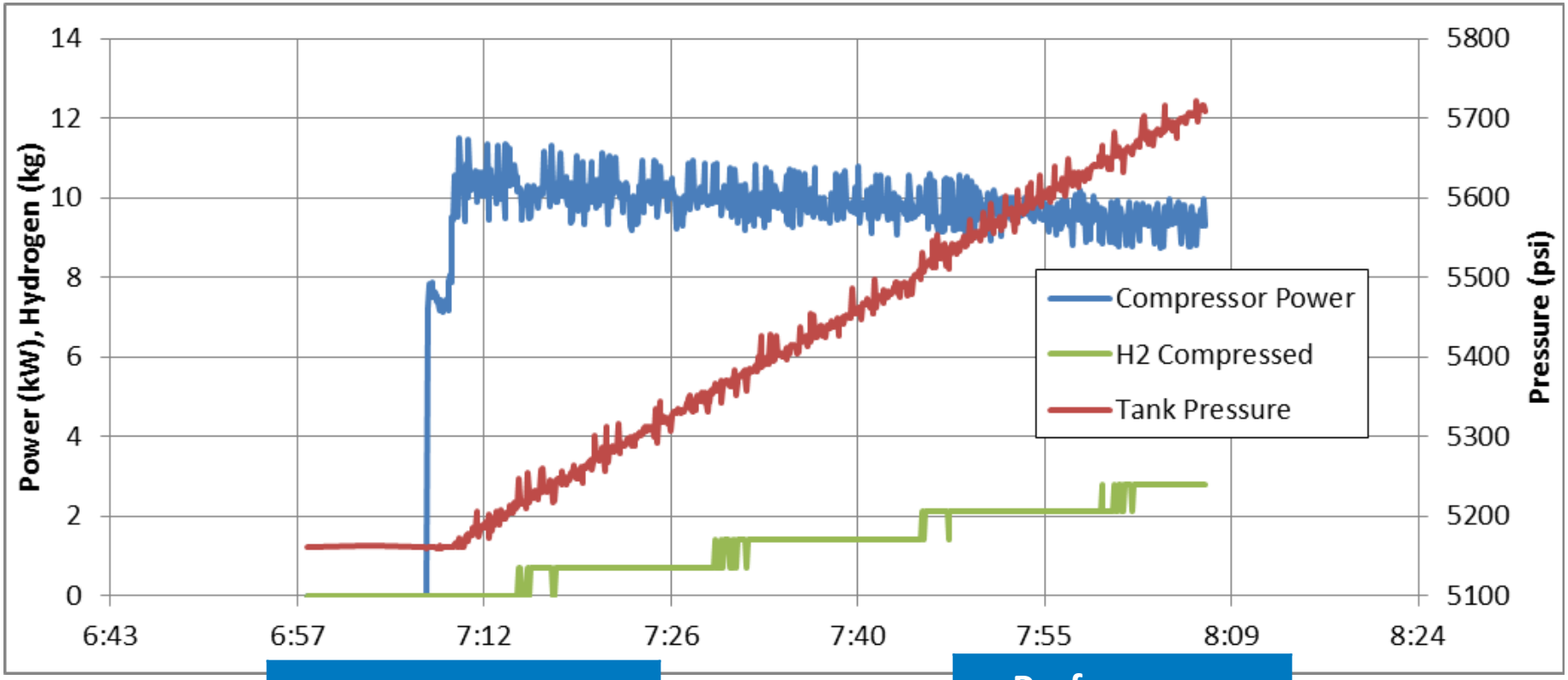
B2B Recovery
3.7 kWh
35.4 min
6.46 kW_{max}

Fill Data
4.36 kg
3.8 min
20 g/s_{avg}

Accomplishments and Progress

New since June 2015

- **Compressor Performance Data**



Stats
20 HP
2 stage diaphragm
100 psi suction

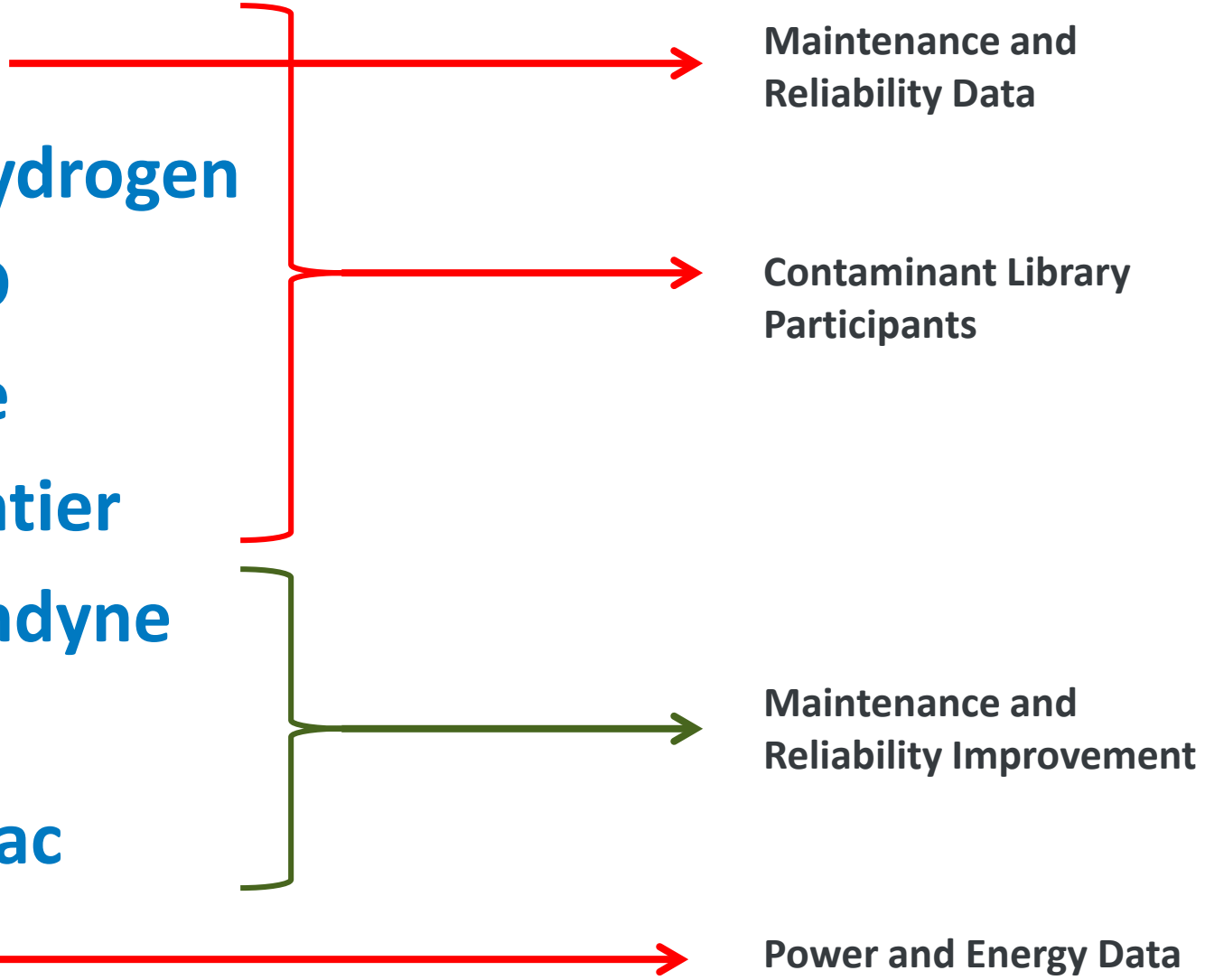
Performance
3.53 kWh/kg
2.78 kg/hr
11.5 kW_{max}

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **"The project should consider testing ionic compressors and Hydro-Pac piston compressors"**
  - A Hydro-Pac piston compressor has been installed at HITRF
- **"The limited operational data and run time is an area of weakness."**
  - NREL now has three compressors in operation and is routinely collecting data on each, as well as numerous other components in the HITRF

Collaborations

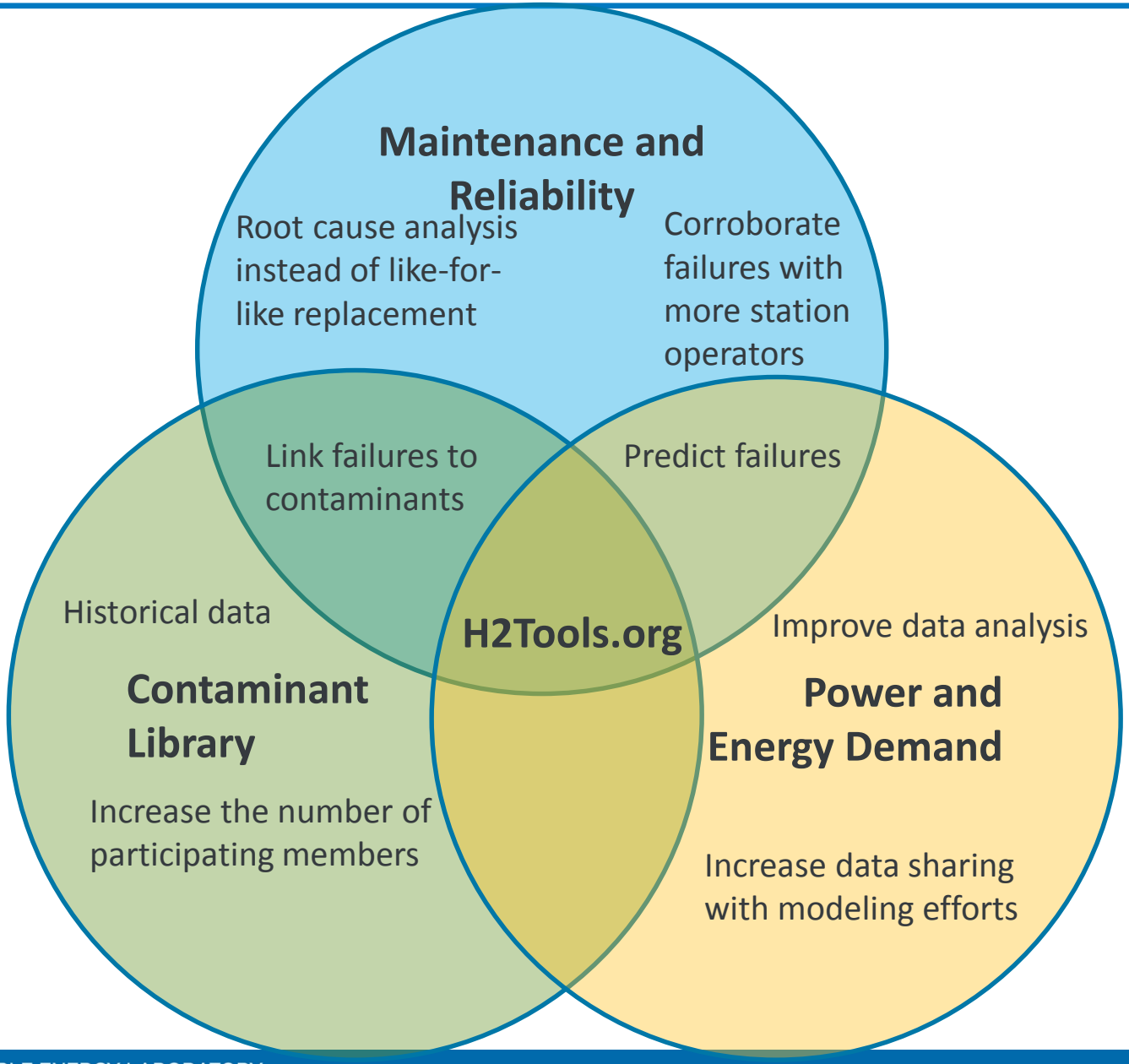
- CSULA
- Shell Hydrogen
- SQAMD
- SunLine
- H2 Frontier
- PPI/Sundyne
- PDC
- HydroPac
- ANL



Remaining Challenges and Barriers

- **Data collection and analysis improvements**
  - A wealth of data is available through the HITRF and NREL's connection with hydrogen industry
  - The local maintenance system at NREL should be improved to collect data in a format more friendly to analysis. This data can then be shared publicly and in near real time.
  - Publication of data to stakeholders
- **Key participation**
  - More participants are desired for the contaminant library
  - Participation is needed from hydrogen component manufacturers

Proposed Future Work



Summary

- **HITRF unique opportunity for data collection/analysis**
  - Contaminant Library – field sample collection, analysis and publication
  - Power and Energy Demand – analyzing energy costs for major station components
  - Maintenance and Reliability - collecting data
- **Significant industry interest**
- **Publish data through H2Tools.org**

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Technical Back-Up Slides

Technical Backup Slides

- **HITRF Reliability Data[1]**

Component	Hours of Operation	Major Failures
MP Compressor	274	Small leaks
HP Compressor	117	Seals
Misc[2]	N/A	Wrong settings and small leaks
Valves	TBD	Seats and seals
Dispenser	8740	Valves and filters
Electrolyzer	~1000	Dew point sensors
Pre-cooling	8752	Clogged

1) April 2015 through March 2016
2) Miscellaneous items include PSV, PSH, PSL, SV

Technical Back Up

- **Monthly station maintenance logs**

HITRF Monthly Report – March 2016

Highlights

Hydrogen Dispensed	12.7 kg
Hydrogen Produced	175 kg
Station Downtime[1]	11%
Active Projects	INL Stack Testing, Renewable Electrolysis Drying, Component Validation Contaminant Collection, Hose Reliability

Equipment Log

Equipment Tested	Type of Data	Data Total	Date
Puck Sensor	Functioning?	Yes	3/4/16
PPI MP Compressor CNM-351	Runtime Hours	262:30	3/16/16
HP Compressor CNM-601	Runtime Hours	63:13	3/16/16
Flow Meter	Total H_2O Consumption	3320 Dial read ~ 8.85	3/29/16
Spare Stacks	Bladder Hydration	Full	3/29/16

Hydrogen Car Fills

Car	Pre-Fill	Post-Fill	Comments	Date
Tuscon	10.0 MPa	70.0 MPa	Interrupted by GMP LFL% alarm, then finished	3/10/16
Highlander	11.9 MPa	66.8 MPa	PT disagree before fill. No problems during	3/15/16
Mirai	15.4%	92%	Fill ended due to low station pressure	3/21/16

Planned Maintenance

What	Planned/Unplanned	Task	Result	Date
Heated N_2 Purge	Planned	Purge Dryer Bed B	Purged for 63 hours	3/3/16
Desiccant Beds A & C	Planned	Pulled & Replaced	Replaced	3/4/16
Heated N_2 Purge	Planned	Purge Dryer Bed C	Purged for 15 hours	3/9/16
Heated N_2 Purge	Planned	Purge Dryer Bed B	Purged for 14 hours	3/10/16
Heated N_2 Purge	Planned	Purge Dryer Bed A	Purged for 16 hours	3/11/16
Heated N_2 Purge	Planned	Purge Dryer Bed A/C	Purged for 64 hours	3/14/16

[1] Station downtime is calculated by adding up downtime documented in Misc. Events and dividing by the number of hours in the month

Other Misc. Events

Event	Duration	Result	Downtime	Date
PSH-362 Failed	N/A	Set Point Adjusted Up	1 hour	3/7/16
HV 632 Leak thru	Months	Replaced	1 hour	3/7/16
Equalized HPTank 3	6 hours	Equalized w/ MP Banks A,C	6 hours	3/11/16
PPI Failed to Start	2 days	Replaced motor contactor	3 days	3/24/16
New Hydrogen Storage Tanks	1PM-4PM	New tanks placed on top of low pressure ones	3 hours	3/29/16

Current Station Snapshot

Component	Current Status	Comments
Dryer Skid	B and D	On 3/4, D calibrated & installed, Desiccant being heated and weighed
Stack Test Bed	Active	
LP Storage	Active (Minot 5-pack placed but not plumbed)	Consolidation 5-pack to arrive late March 2016
MP Compressor	Not Starting	New motor contactors ordered
MP Storage	Active	
HP Compressor HydroPac	Placed	Still need to: secondary containment, process connection, ESP, operation manual NOTE: Cannot be used for fills. Fill only into FIBA ¾
HP Compressor HI	Active	
HP Storage	Active	FIBA ¾ placed, but not plumbed
Chiller/HX	Active	
Dispenser	Active (Manual H70 vent line plugged)	NV needs to be replaced, already ordered. Breakaway replacement arrive 2/2/16
Hose Test Stand	Attended Cycling	