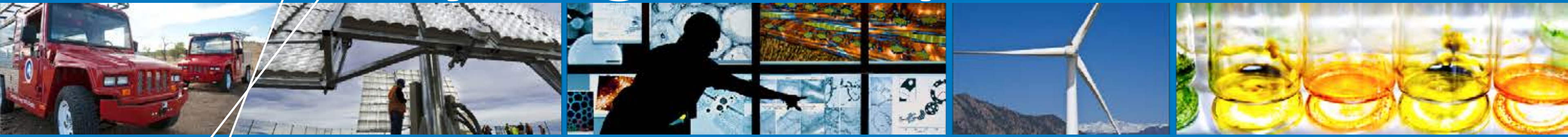
Hydrogen Component Validation



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National Renewable Energy Lab
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***presenter**

TV-019

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Overview

Timeline

Project start date: 10/2012

Project end date: 10/2015[1]

Barriers

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

Budget

Total DOE funds received to date: $758k
FY14 DOE funding: $265k
FY15 planned DOE funding: $300k

Partners

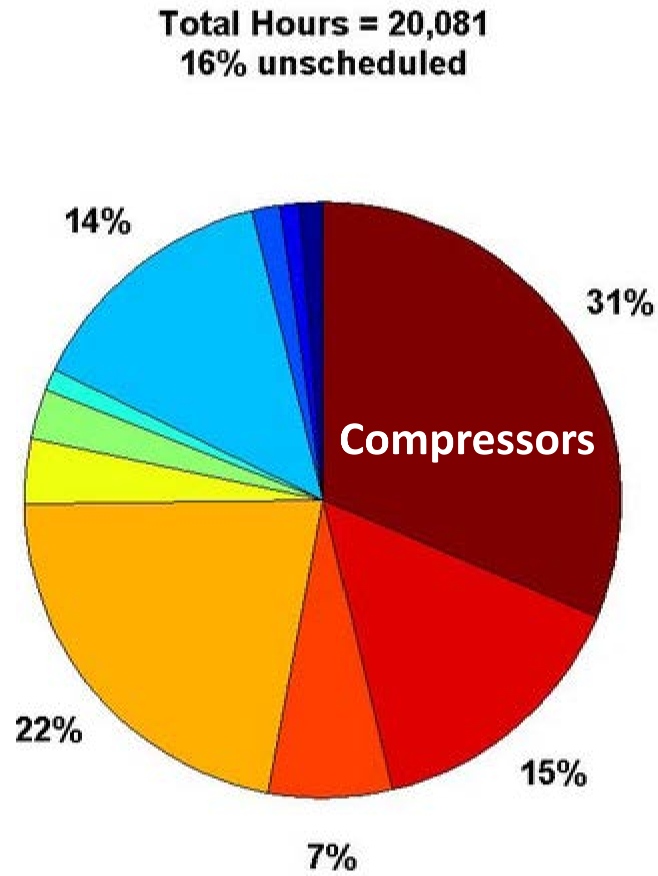
- PDC Machines (CRADA)
- XCEL Energy (CRADA)

1 project continuation and direction determined annually by DOE

Objective and Relevance

Compressors are #1 in downtime and maintenance event count accounting for 1/3 of maintenance hours at stations

- **Goal –** Generate data and study compressor operation to determine common failure modes and performance in variable conditions
- **Impact**
  - Improve compressor operation and reliability
  - Generating performance data on compressor operation
  - Highlighting compressor failures and consequences
  - Work with manufacturer to improve design and increase reliability



NREL CDP INFR 21 – Created Oct 14

Approach

- **Collect data on 4 compressors and ambient conditions while operating within manufacturer's recommendations**
  - Integrate compressors with hydrogen production and fueling station
- **Current Scope**
  - Extensive data collection on temperature, pressure, etc. for DUT1 only
  - Failure data collected for DUT2 and 3

Parameter	DUT1	DUT2	DUT3	DUT4
Duty Cycle	20 hrs/day	As Needed	As Needed	As Needed
Max Discharge Pressure (psig)	6,000	6,000	20,000	14,000
Flow Rate (SCFM[1])	25	18.8	5	140
Start of Operation	April 2014	December 2014	January 2015	Exp Sept 2015

1) 60ºF, 1 atm

Approach

- **Deep dive analysis into failures**
  - Leverage NREL's chemical analysis capabilities for contaminants
  - Corroborate failures with similar compressors operating at NREL
  - Compare reliability and performance data with data collected through NFCTEC on compressors in the field
  - Present analysis to manufacturer on failure causes for DUT1 only

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Accomplishments and Progress

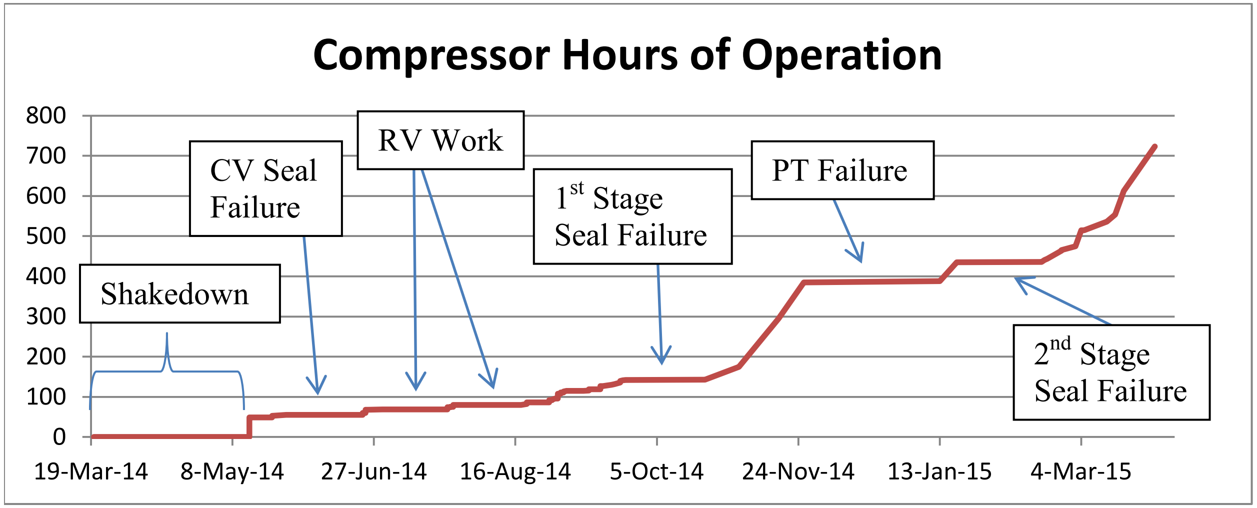
- **Key Findings**
  - Compressor Performance and Reliability Data
  - Seal Weakness is the Main Failure Mechanism
  - Preemptive Detection of Catastrophic Seal Failure
  - Repairs of Most Common Failures are Expensive and Time Consuming

On frame hoist

Seal Failure

Accomplishments and Progress: Data Collection

- **One year of operational data collected for DUT1**



RV – Readiness Verification
PT – pressure transducer
CV – check valve

Parameter	DUT1
Operating Time	753 hours
Start/Stops	81
Amount of H2 Compressed	1808 kg
Number of Major Failures	4
Mean Time Between Failures	49 days
Calculated Flow Rate	3.7 kg/hr
Average Efficiency[1]	3.54 kWh/kg

[1] Constant suction pressure, pf=0.8, includes coolant pump and radiator power consumption (1.86 kW)

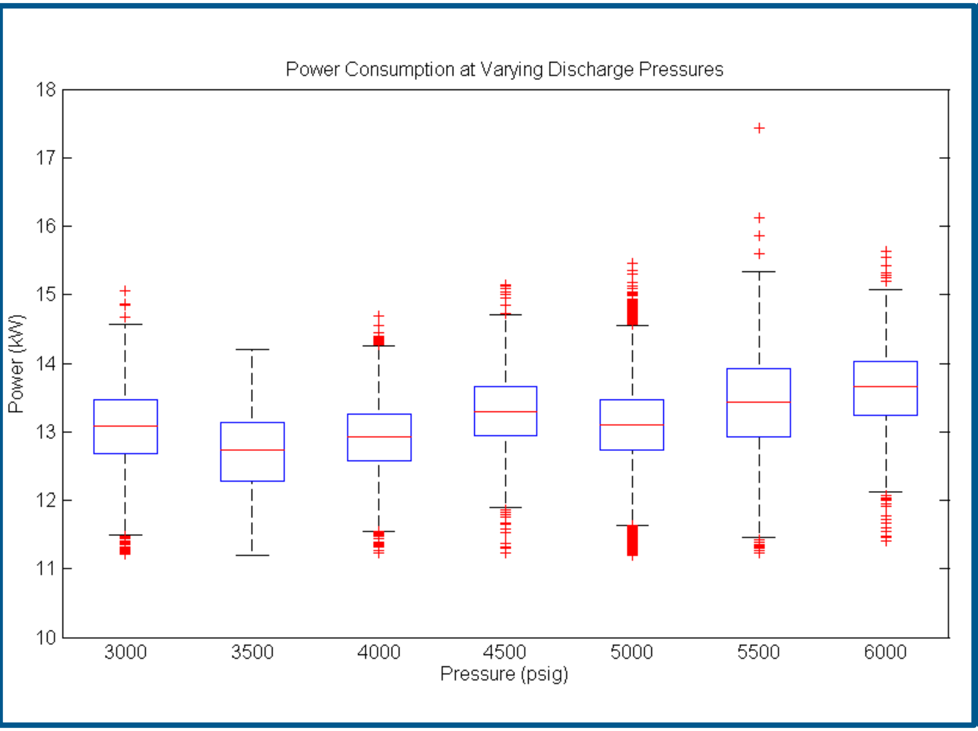
Accomplishments and Progress: Data Collection

- **Power consumption found to be consistent for DUT1**

Varying discharge pressure

Full Year

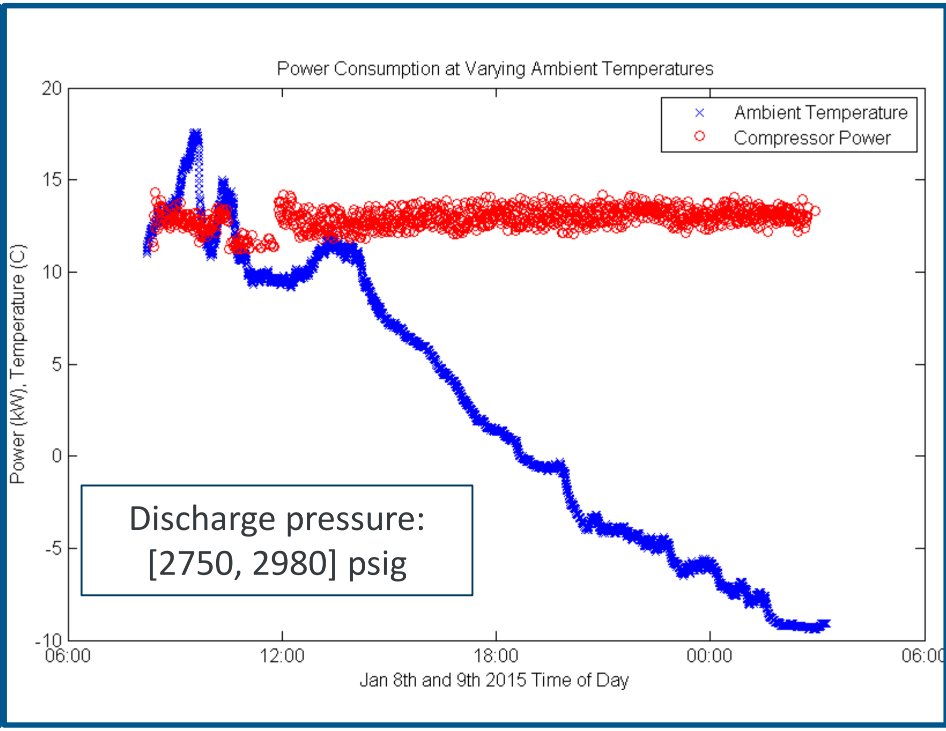
P_{avg} = 13.1 kW; SD = 0.6 kW; m = 200 W/ksi



Varying ambient temperature

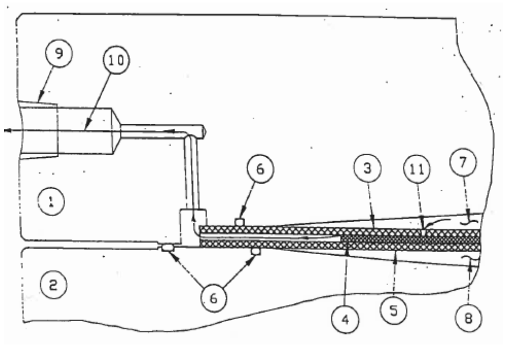
Single Day

P_{avg} = 12.9 kW; SD = 0.5 kW

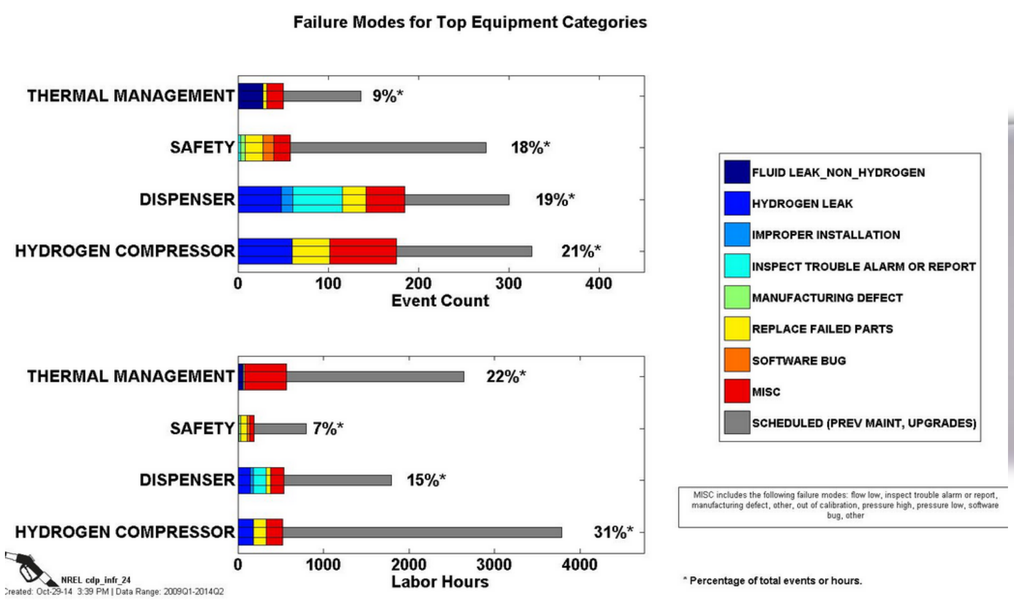


Accomplishments and Progress: Failure Mode Analysis

- **Five seal failures have occurred**
  - Four in compressor heads
  - One on a check valve seal
- **Consistent with NFCTEC CDP24**



Compressor assembly (6) are seals



Seal Failure 1

Seal Failure 2

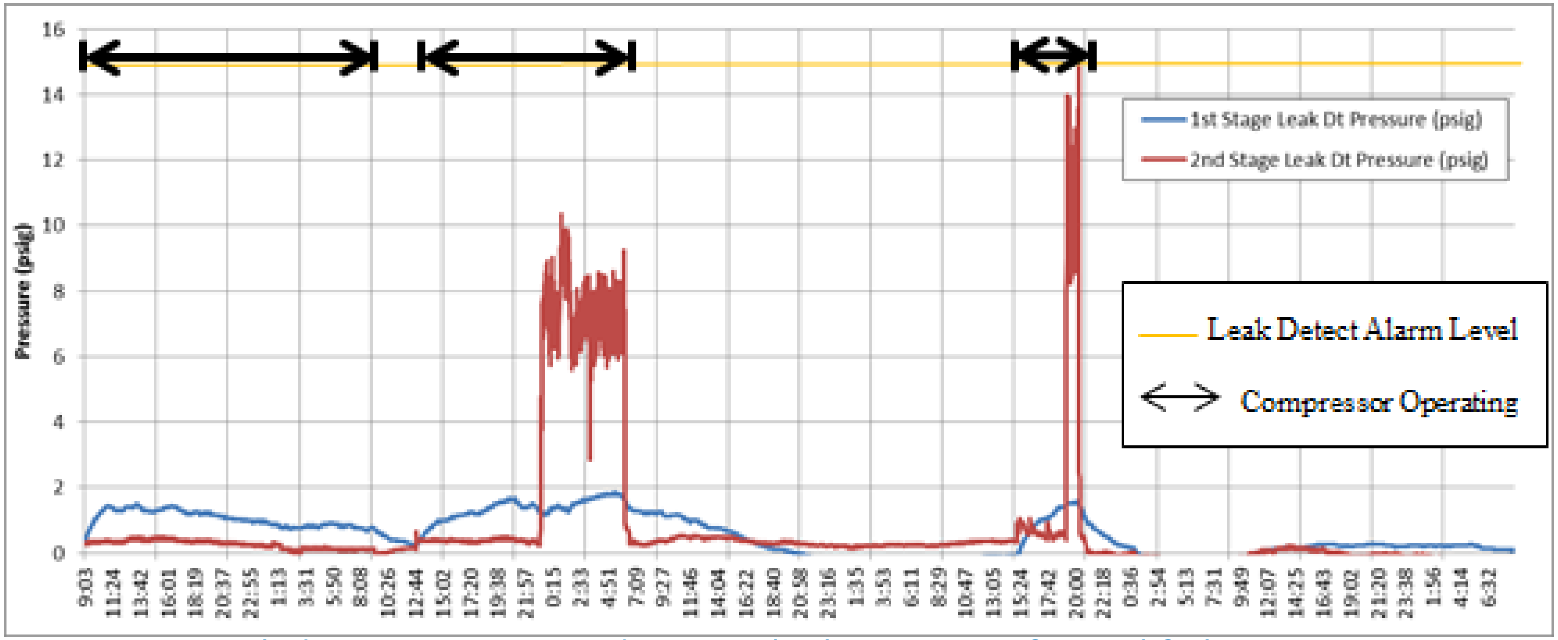
Accomplishments and Progress: Repair Cost

Failure	Repair Time	People Required	Parts Cost	Parts Lead time	Uncommon Tools Required
CV Seal	<1 hour	1	$20	3 weeks	Torque wrench, long pick
1st Stage Seal	3 hours	2	$1000	6 weeks	Torque wrench, breaker bar, hoist, lint free wipes
2nd Stage Seal	4 hours	2	$1,200	6 weeks	Large torque wrench, large breaker bar, hoist, lint free wipes
Minor Leaks	<1 hour	1	N/A	N/A	Torque wrench, leak detector

Downtime can be minimized if spare kits offered by compressor manufacturers are on hand

Accomplishments and Progress: Preemptive Detection

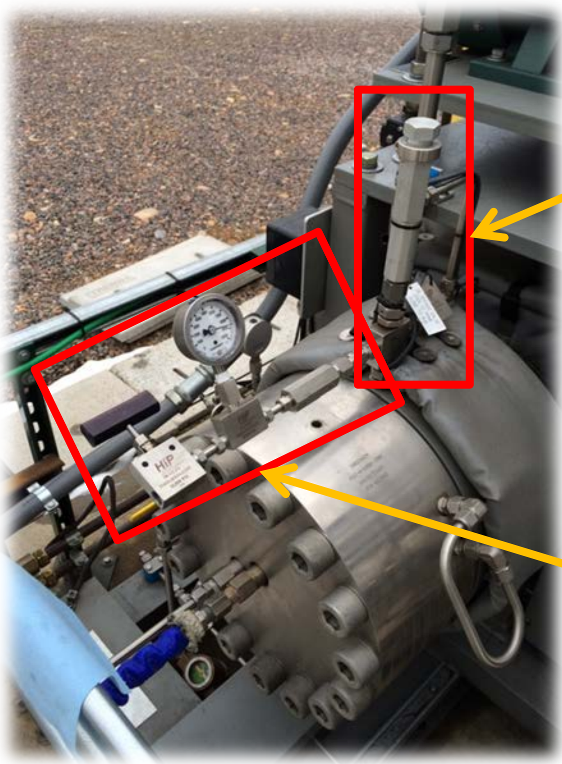
- **Monitor leak detection circuit**
  - Alarms are set at levels above what may indicate the beginning of a failure
  - Early action may prevent contamination and downtime

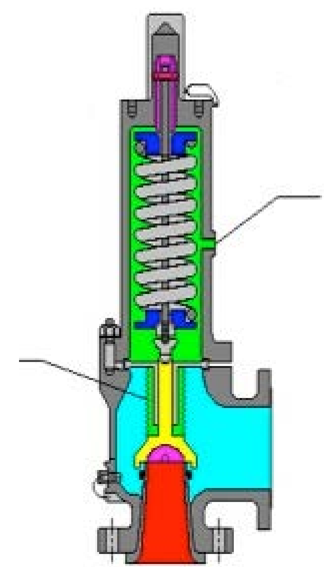


Leak detection circuit indicating the beginning of a seal failure

Accomplishments and Progress

- **Suggested Improvements**
  - Generate More Performance and Reliability Data
  - Overpump Valve Setting Monitor



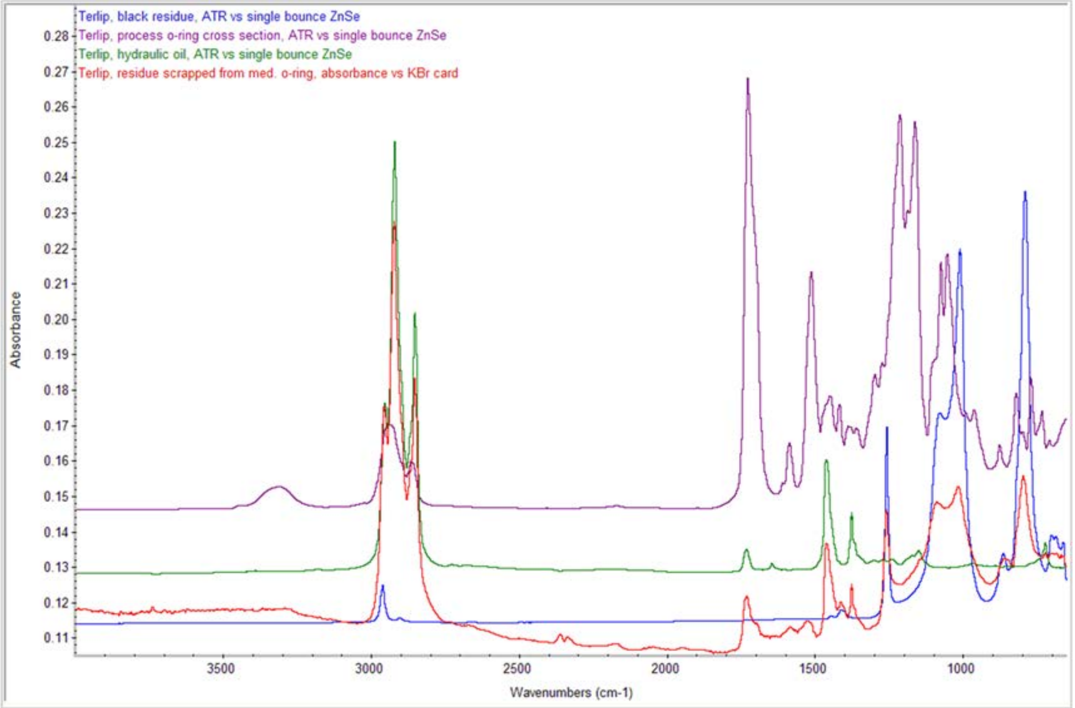


Overpump valve schematic

Accomplishments and Progress

- **Suggested improvements**
  - Alternate Testing Schemes
  - Contaminant Analysis

Contaminant in hydrogen line



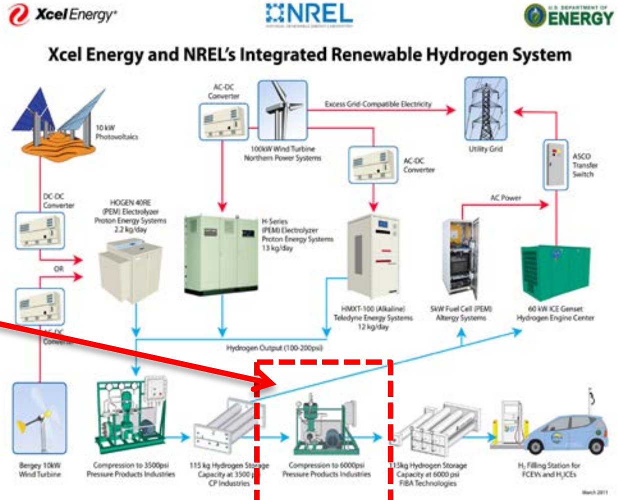
FTIR contaminant analysis

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **Technoeconomic analysis of failures lacking**
  - Documented for each failure
    - Time for repairs, assuming parts are on hand
    - Parts
    - Uncommon tools
    - Man-power
  - Impacts on station availability are variable
    - Commercial station utilization is low
    - Station configuration can allow for operation without compressor
- **"Very few operating hours for how much time project has been ongoing"**
  - Installation problems were solved
  - Operating time significantly increased, but still more limited than commercial
- **"It is not clear if it will be possible to reduce the maintenance time and associated costs."**
  - Leak detection circuit can pre-emptively indicate a failure and drastically reduce maintenance time
  - A monitor on the overpump valves can warn of drift and corrections can be made before failures occur

Collaborations

- **External**
  - PDC Machines Inc. (CRADA) – Equipment, technical support, project direction
  - XCEL Energy (CRADA) - Equipment to build hydrogen production and fueling station
  - Proton OnSite (informal) – Electrolyzer for hydrogen production
  - PNNL (info sharing) – advanced diaphragm compressor modeling
  - Vehicle OEM (informal) – testing FCEV technology
- **Internal**
  - Renewable Electrolysis (PD031) – Integrated system development and testing



Proposed Future Work

- **DUT1**
  - CRADA ends 15 October 2015
  - NREL discussing next steps with CRADA partner
- **DUT2, DUT3 and DUT4**
  - More operating hours
  - Collect more data and publish results for multiple hydrogen compressor technologies
  - Power meters for DUT2 and 4 needed
  - Comparison of MTBF and failure modes
- **Correlate contaminant analysis results**
  - Effects on fuel cells
  - Source of contaminant

Summary

- **Four compressors are currently in operation at NREL**
  - DUT1: Extensive data collection and purposeful testing
  - DUT2-4: Failure data and operating hours
  - All are integrated into hydrogen stations that fill FCEVs
- **Performance and reliability data is compared to NFCTEC CDP**
- **Key findings and recommendations determined from deep dive failure analyses are given**

Technical Back-Up Slides

Power Measurement

- Variable power consumption
  - Constant discharge pressure 4500 psig
  - Current (yellow) fluctuation [17, 33] A
  - Voltage (cyan) fluctuation highly stable
  - Power fluctuation [14, 27] kVA
  - Average power factor [0.28, 0.99]
- Averaging required for long term data collection