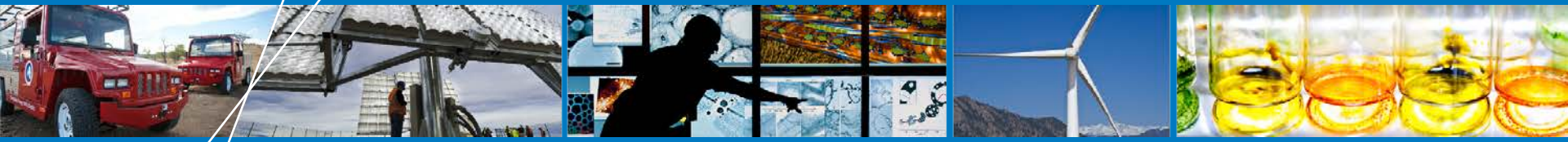
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# 2014 DOE Hydrogen and Fuel Cells Program Review



# Hydrogen Component Validation

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**June 19, 2014**

**Project ID: TV019**

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

# Overview

## Timeline

Project start date: October 2012
Project end date: August 2015*

## Barriers (2012 MYRDD)

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

## Budget

- FY13 DOE Funding: $265k
- Planned Funding for FY14: $265k
- PDC Machines Contribution:
  - $193k labor and equipment
- Total DOE Project Value: $458k

## Partners

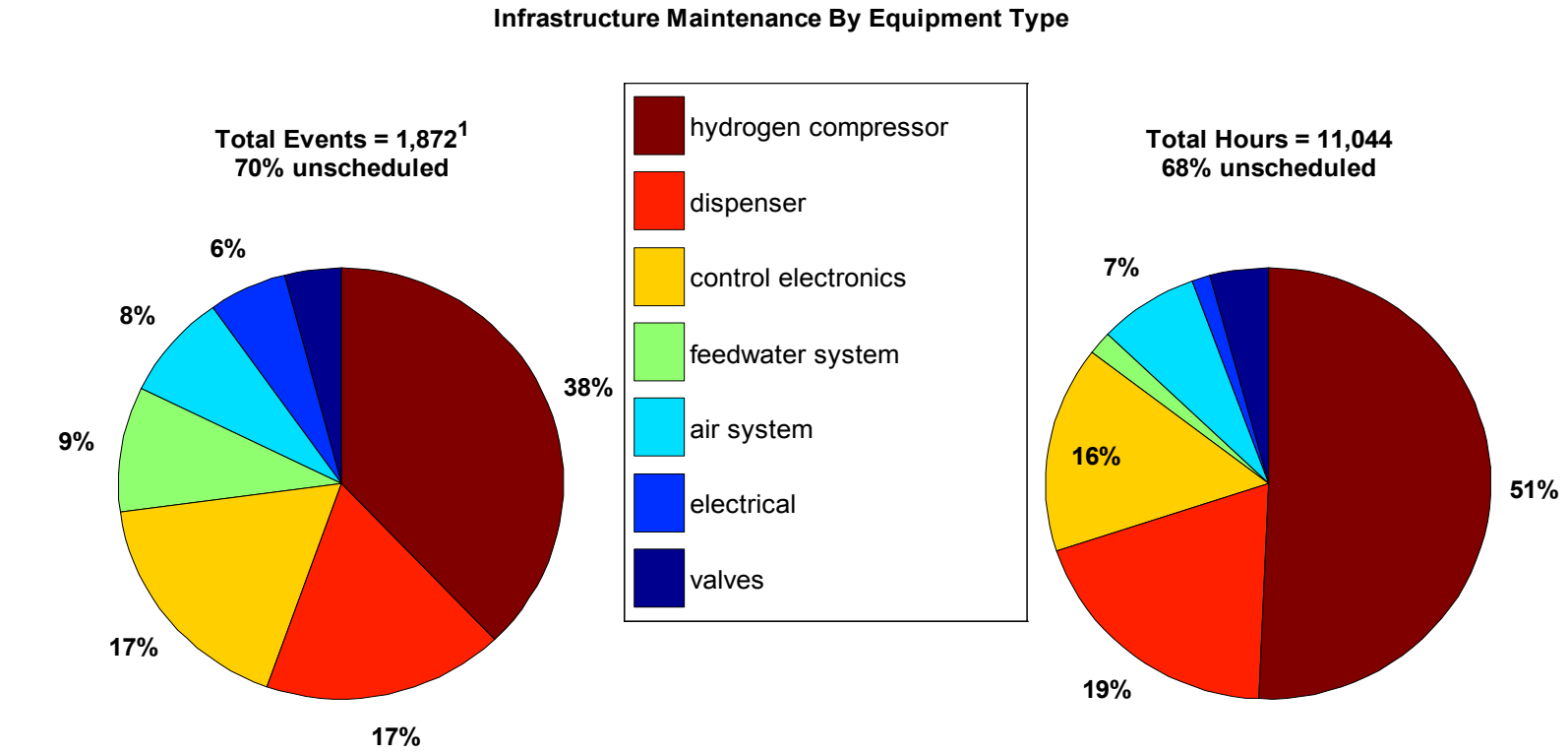
- PDC Machines (CRADA)
- Xcel Energy (CRADA)
- Project Lead: Kevin Harrison

* Project continuation and direction determined annually by DOE

# Relevance to Addressing Barriers

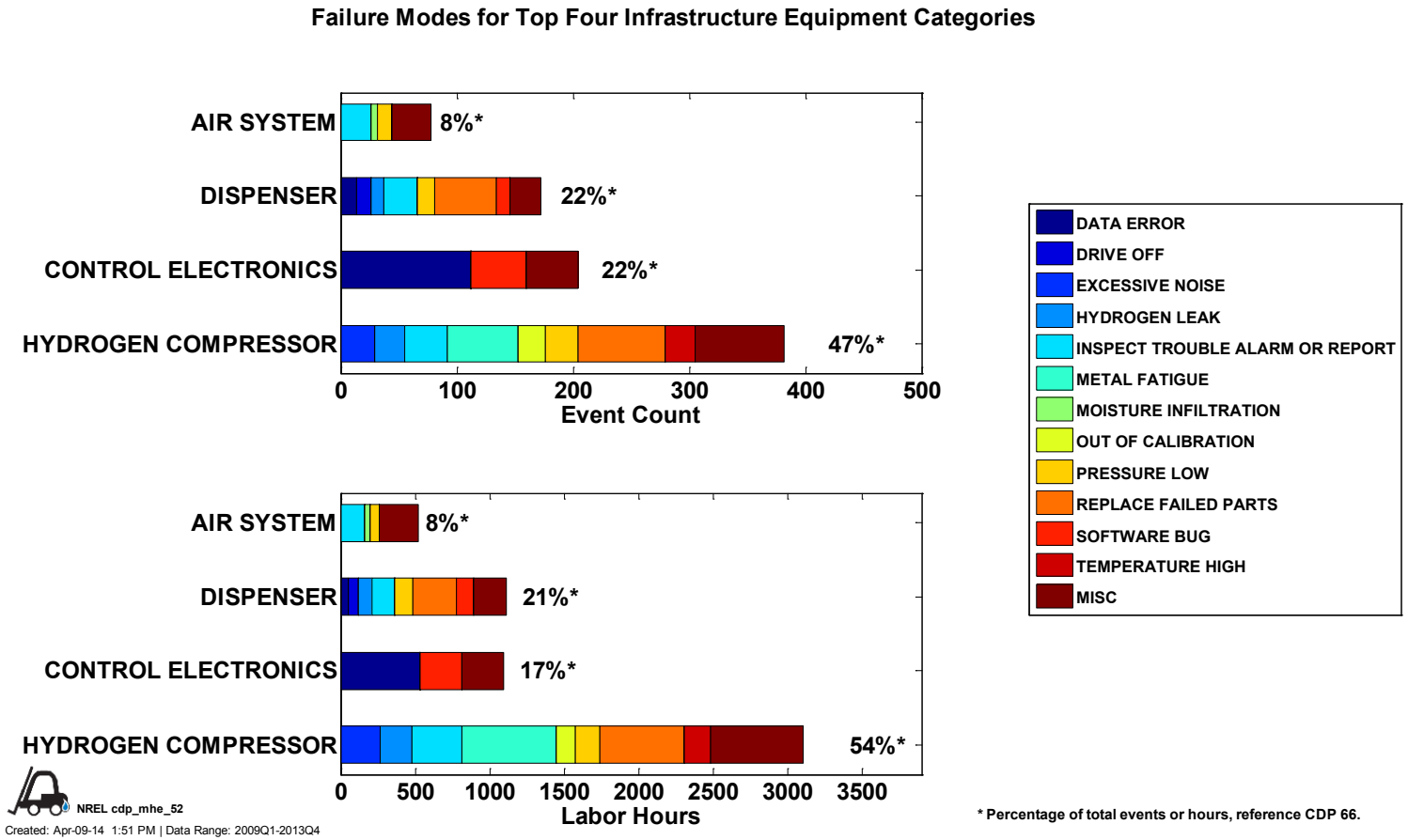
Technology Validation data from real-world hydrogen stations:

- Compressors are #1 in downtime and maintenance event count accounting for ½ of unscheduled maintenance hours
- High level snapshot of compressor performance

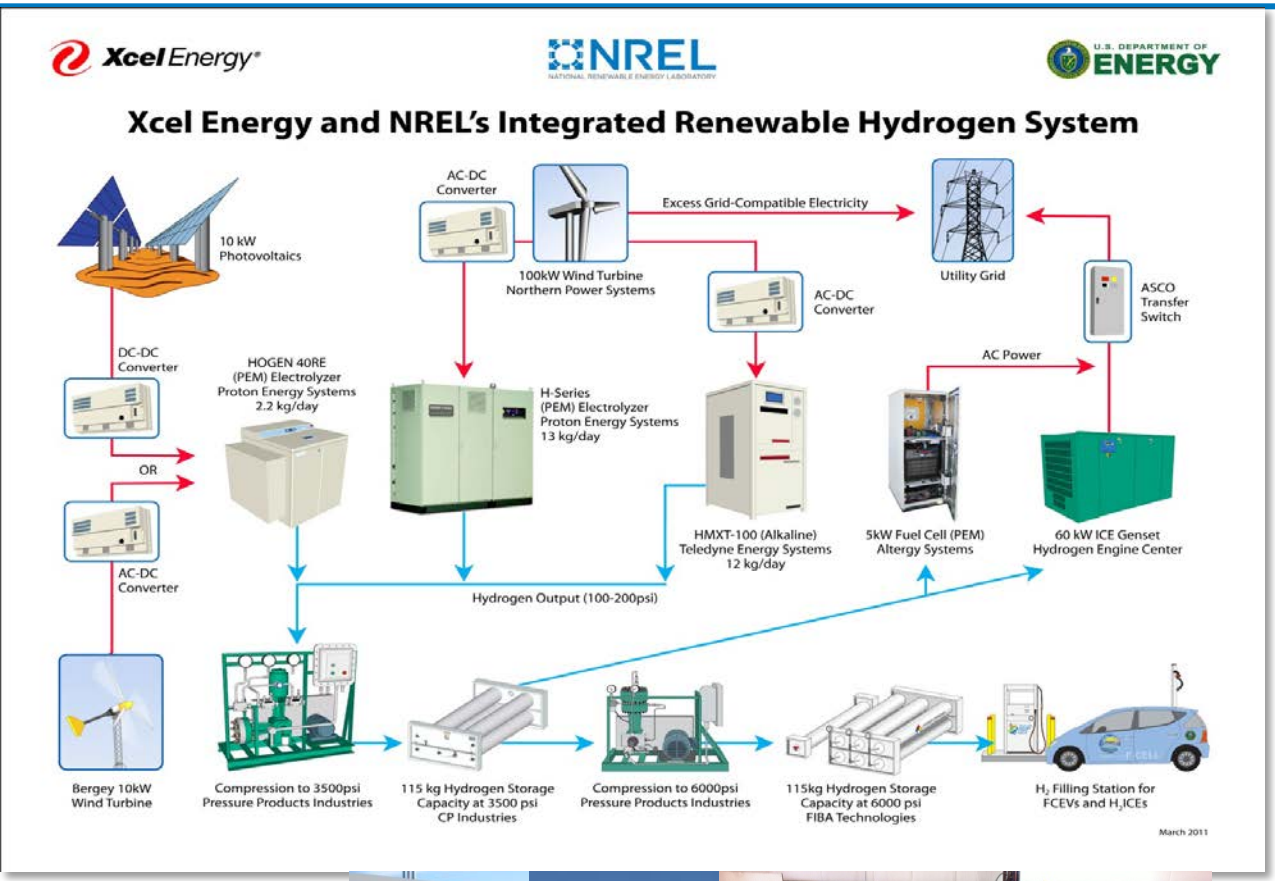


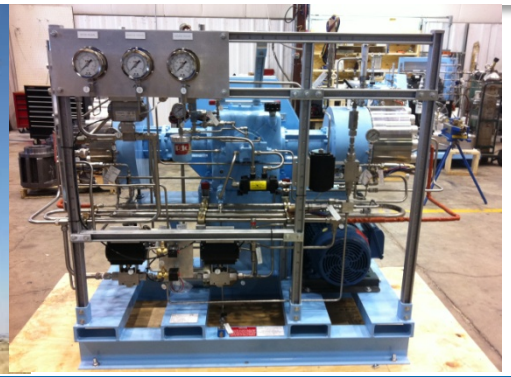
# Objectives

- Highly Accelerated Life Testing (HALT) to reproduce failures on a shorter time scale
- Correlate to real-world usage with statistical methods
- Work with manufacturer to improve designs and reduce downtime



# Approach: Component Testing in a Fully Integrated System



## Equipment Involved

**Electrolyzers (Quantity: 4)**
- 3 PEM, 1 Alkaline
- 250kW stack test bed

**Compressors (7)**
- 3 diaphragm, 4 piston

**Compressor (1)**
- PDC Machines – CRADA

**Hydrogen Storage (19)**
- 350 kg, 3500 to 10k psig

**Fuel cells (5, PEM)**

**Dispenser (350 bar)**

**Dispenser (700 bar July 14)**

**1 MW AC/DC Buss Network**

**100 kW Wind Turbine**

**Configurable PV array**

# Approach: Installed and Initiated Accelerated Compressor Test

## Industry Collaboration

### PDC Machines (CRADA)

- PDC-4 Series diaphragm compressor
  - Commercially available unit
  - 85 kg/day max flow
  - 6,000 PSI discharge
  - 30 HP TEFC motor
- System Instrumentation
  - High resolution hydraulic oil pressure (25kS/s)
  - Temperatures
  - Pressures
  - Alarms
  - AC power transducer
- As of April 15, less than 100 hours of operation

# Approach for Accelerated Compressor Testing

## Operational Reliability & Performance Testing

- Partnered with compressor manufacturers (CRADA) and PNNL to instrument, monitor and analyze performance in a relevant accelerated-testing environment (actual fueling station serving vehicles)

## Exercise Existing Test Platform

- Interfaced with existing electrical and gas infrastructure
- Control system for unattended operation and recycle mode
- Hydrogen used to fuel vehicles, support facility hydrogen needs and fuel cell testing
- Installed high-speed data acquisition platform

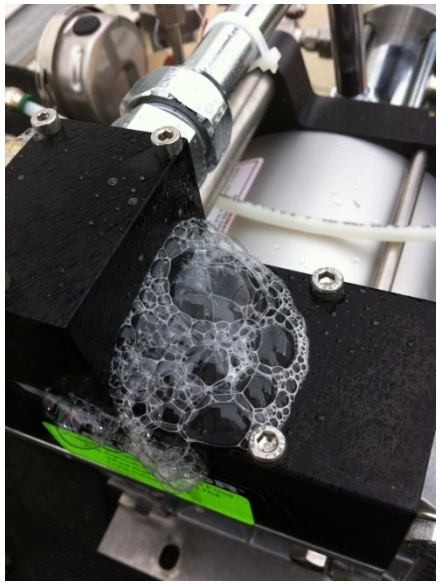
# Approach: Lessons Learned from FY13 Compressor Performance

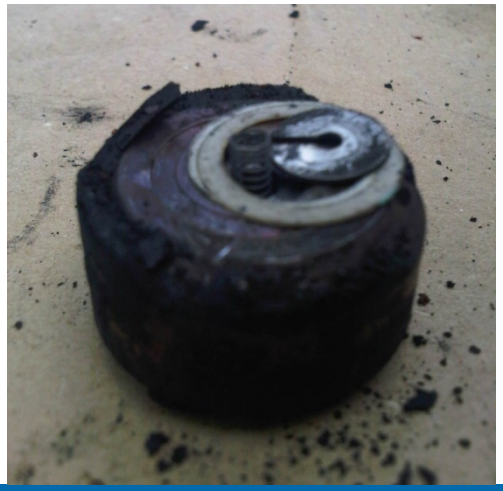
## Failure of Material with diaphragm compressors

- Compressor rebuild due to failures
  - Check valves
  - Diaphragms

## Air leaks with piston compressors

- Frequent replacement of high pressure seals
- Issues surrounding sealing

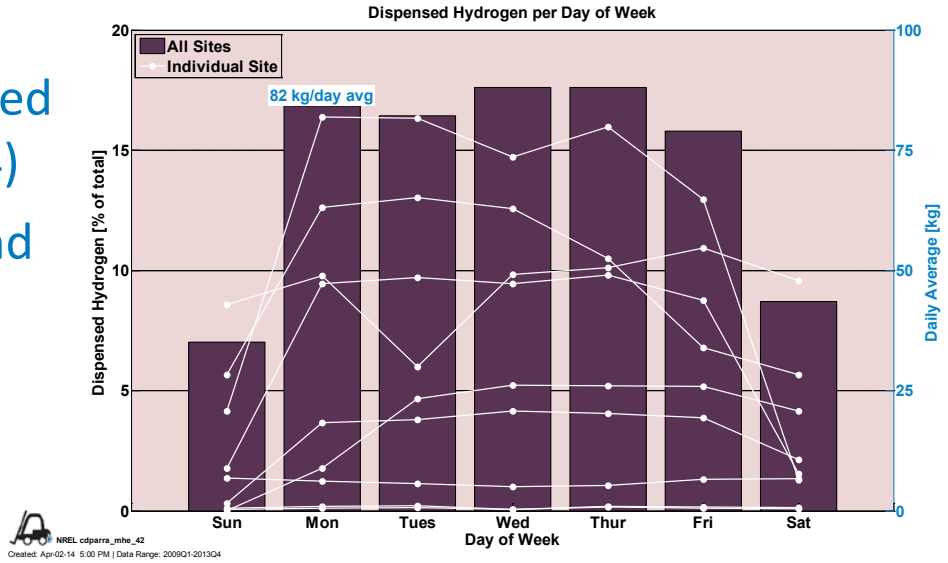




# Approach: Operation Targets

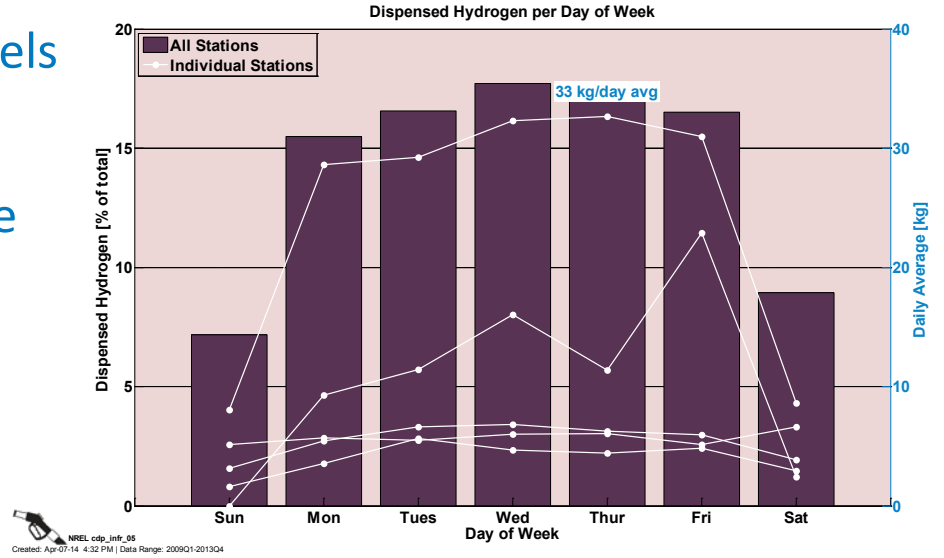
## Lifetime and Duty Cycle

- Operation of one compressor expected for 12 months (begin data April 2014)
- Target 4,500 hours (~50% uptime) and 17,000 kg compressed (unless significant failure results in extended downtime)
- Operation based on high use MHE stations
- Transfer data to PNNL to inform models




## Milestones

- Study and quantify power vs pressure requirements (‘14 Q3)
- 1,000 hours of operation (‘14 Q4)
- Compare HALT results with field demonstration results (‘14 Q4)



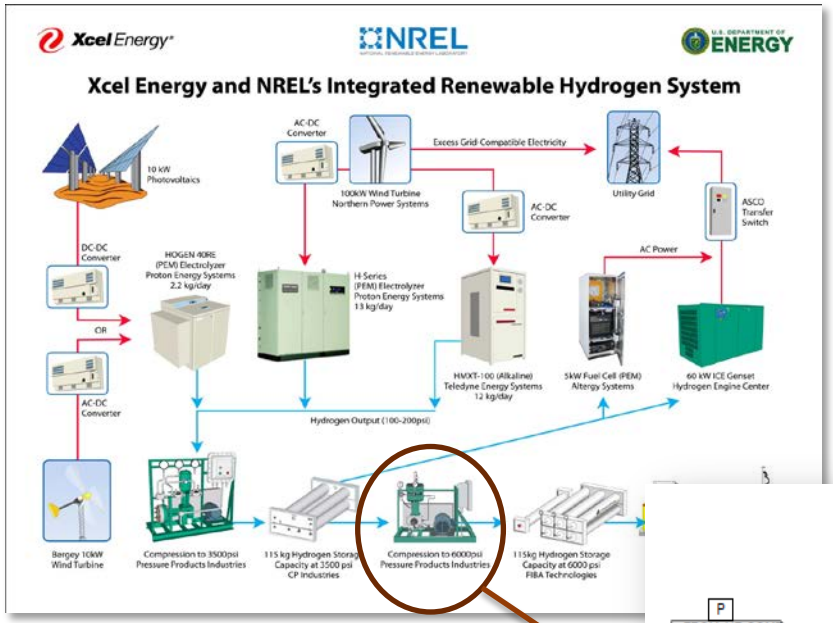
# Approach: Accelerated Compressor Reliability Test Plan

## Test Plan – NREL/PDC Machines

- Accelerated operation designed to quickly reach failure
- Deep dive failure investigation with manufacturer includes disassembly, visual inspection, material property testing, and rebuild
- Target multiple failures on one compressor through rebuild/repair for continued operation
- Results corroborated with the manufacturer for reliability improvements, reducing unplanned station maintenance, maintenance cost, and down-time.

| Step | Test Action | Description |
|---|---|---|
| 1 | Start-Up Characterization | *Power draw dictates electrical system requirements* |
| 2 | Pressure Sweep | *Record compressor flow rate for variable discharge pressures* |
| 3 | Extended Operation | *Monitor system variables to predict failures* |
| 4 | Cold Start | *Characterize performance in difficult ambient conditions* |
| 5 | Feed Pressure Sensitivity | *Determine performance impacts of varying feed pressure* |
| 6 | Start/Stop Cycling | *Analyze performance impacts of rapid start/stop operation* |

# Accomplishment: Installed and Initiated Accelerated Compressor Test

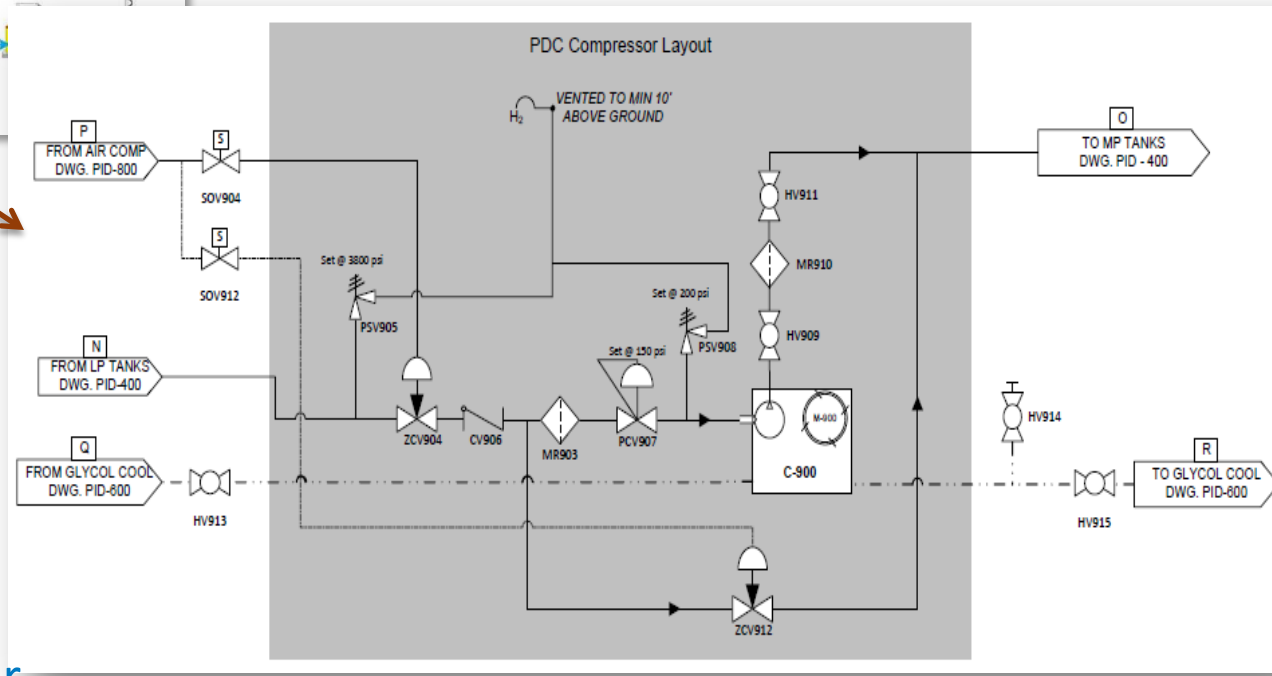



## System Integration

- Compress gas from Renewable Electrolysis project (M Peters, PD031)
- Use compressed gas to fill FCEV (Toyota, Mercedes, CSU-EcoCar2)
- Power from Renewable Hydrogen System (Xcel/NREL Wind-to-Hydrogen)

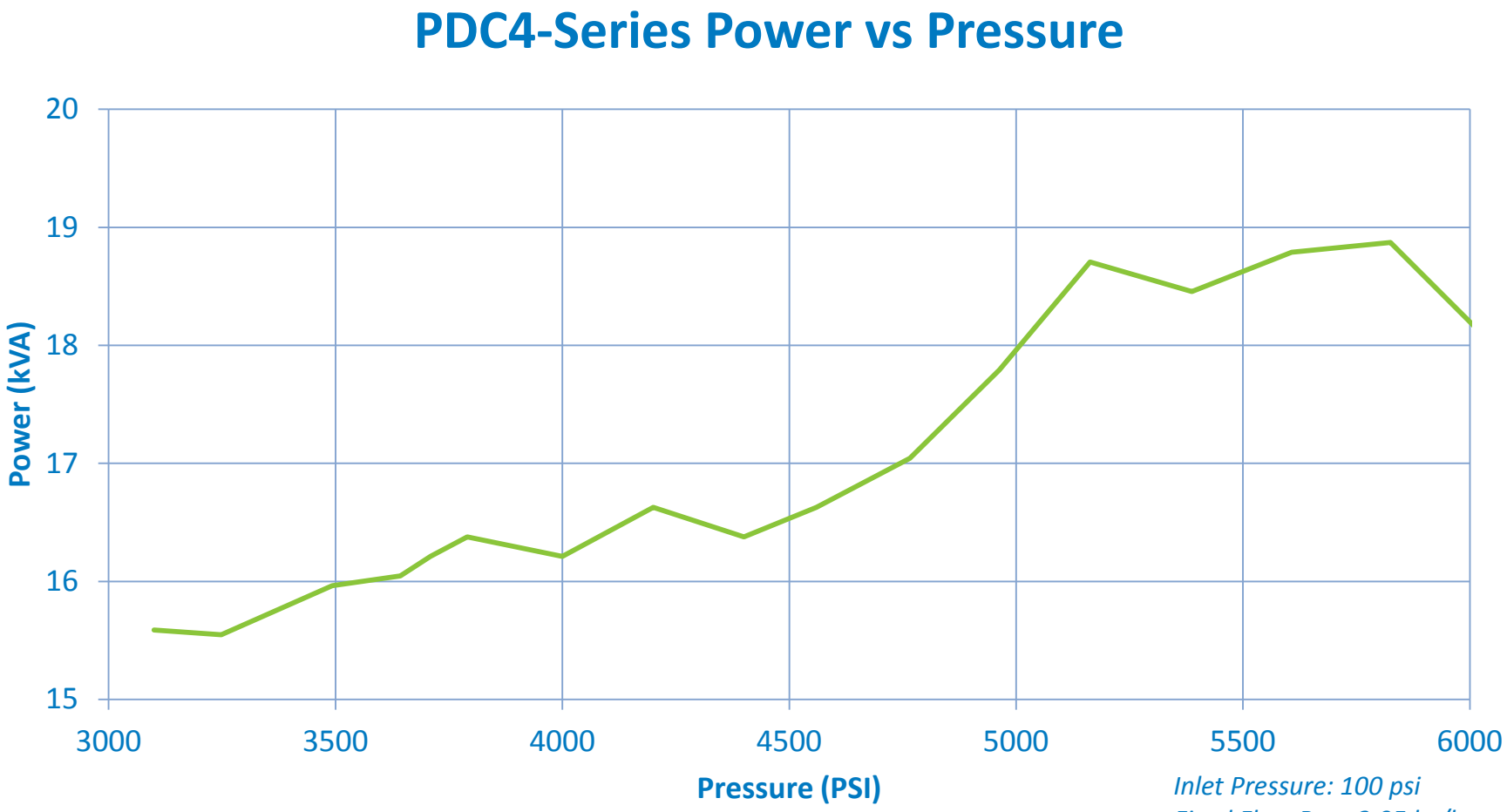
## Recirculation process added

- No H2 generation necessary
- Constant discharge pressure
- Isolation/concentration of impurities from compressor



# Accomplishment: Compressor Performance

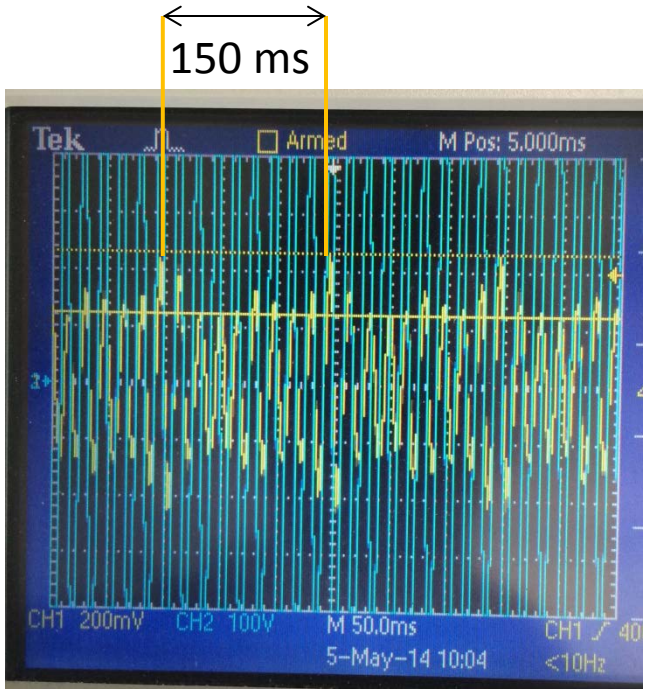
## Power vs Pressure Profile

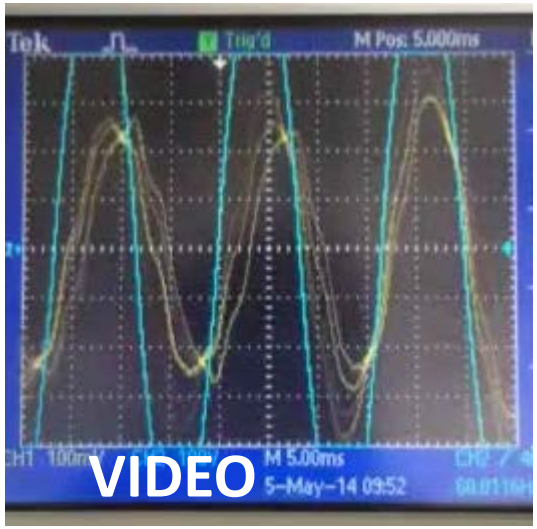



*Inlet Pressure: 100 psi*
*Fixed Flow Rate 3.05 kg/hour*
*Ambient Temp: 65°F*

# Accomplishment: Compressor Performance

- 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



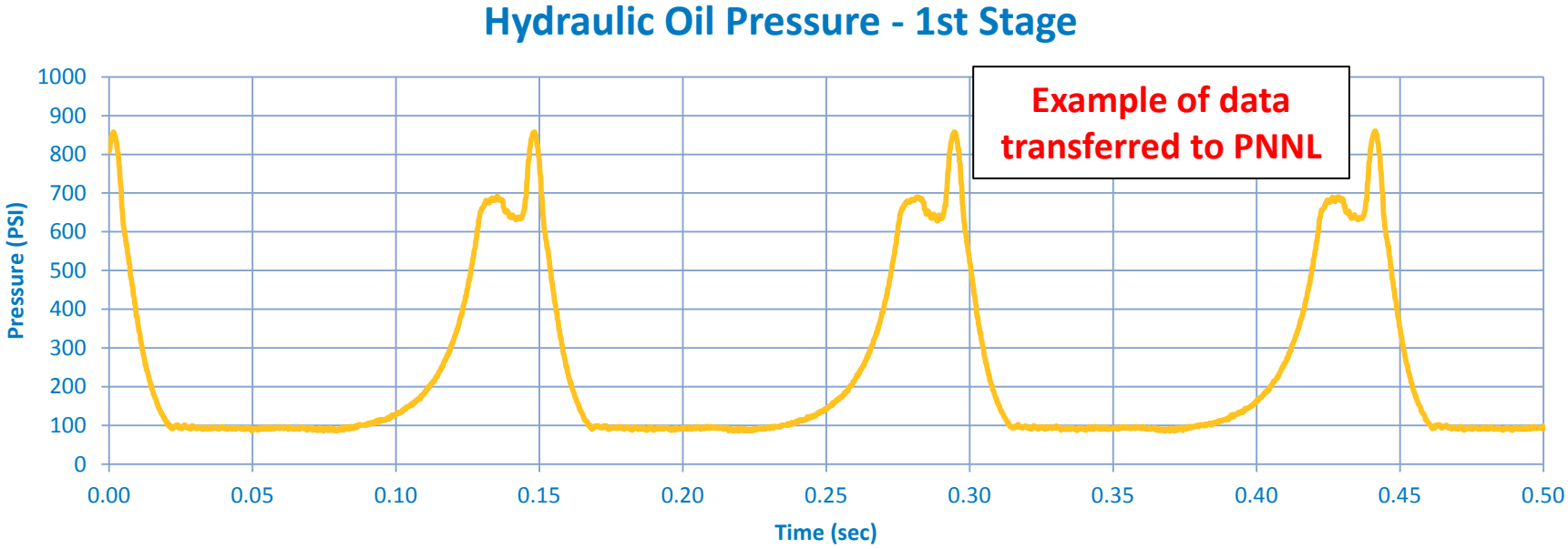



# Accomplishment: Compressor Reliability & Performance

## National Lab Collaboration

### PNNL – Using PDC Results

- Data transfer to PNNL from NREL testing
- Oil pressure on diaphragm
- High-speed data collection (< 25,000 samples/sec)
- Support dynamic compressor modeling at PNNL



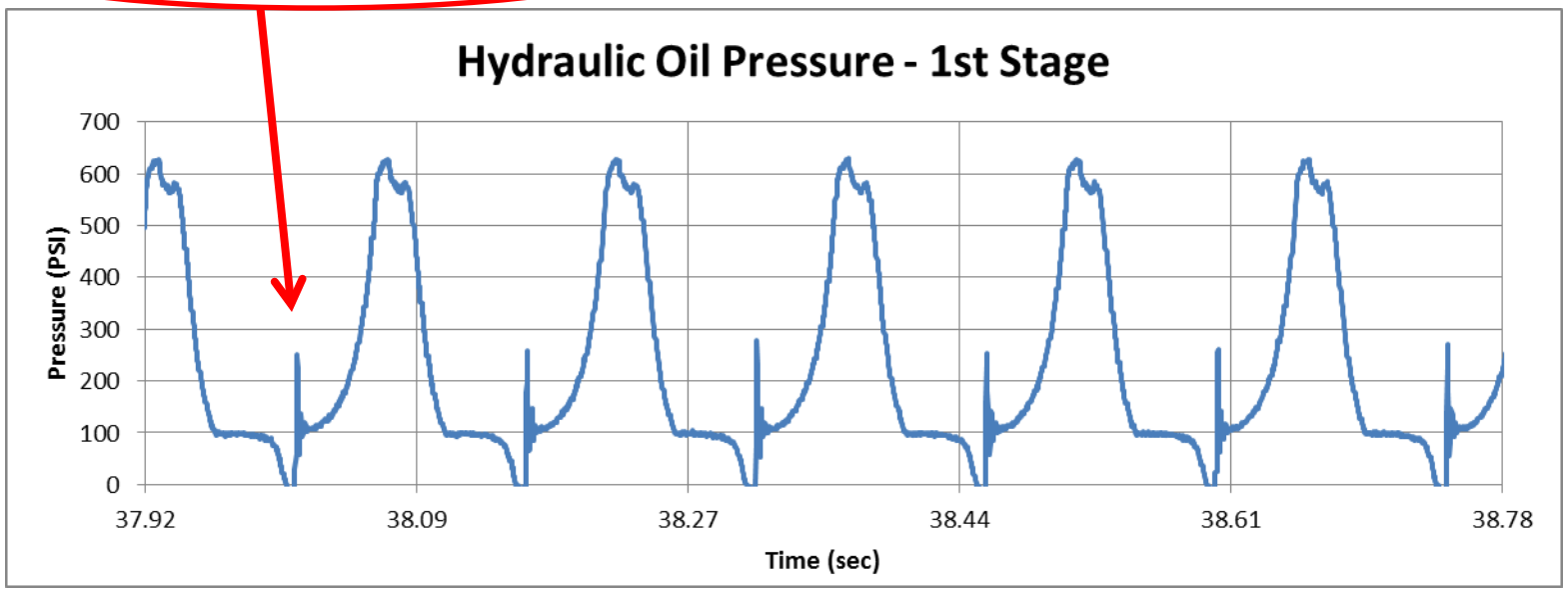
# Accomplishment: Compressor Reliability & Performance (cont'd)

## Industry Collaboration – Predicting Failures

PDC Machines – Troubleshooting compressor problems

- Informed from data collection
- List of maintenance activities

*Actual abnormal pressure data*



# Collaborations

## Formal

- PDC Machines (CRADA) – Compressor reliability testing
- Xcel Energy (CRADA) – Wind-to-Hydrogen demonstration project since 2005

## Informal

- Proton Onsite – Electrolyzer stack durability testing

## Information Sharing

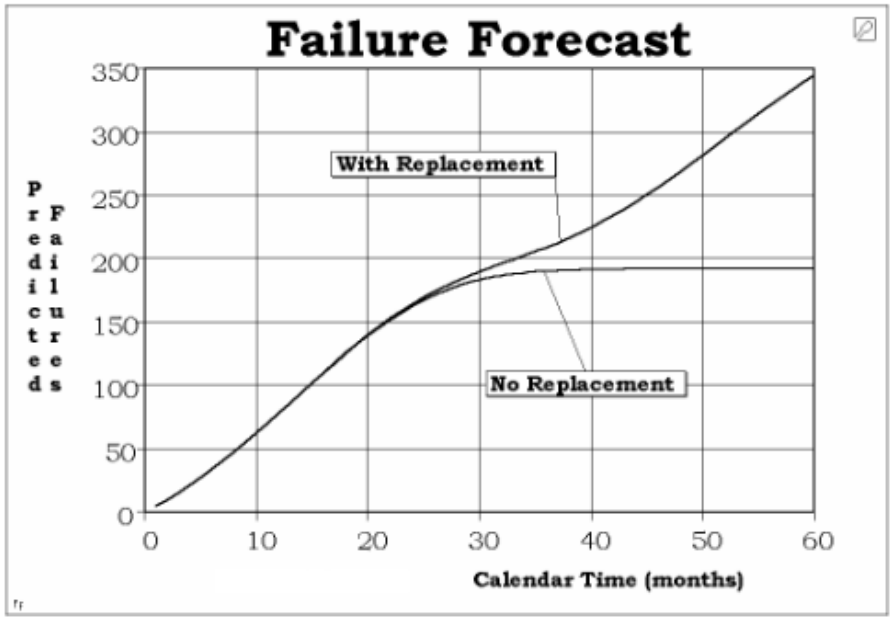
- PNNL – Advanced diaphragm compressor modeling
- H2FIRST - Hydrogen Fueling Infrastructure Research and Station Technology (TV026)

## Internal

- Hose Reliability Improvement (PD100)
- INTEGRATE - Integrated Network Testbed for Energy Grid Research and Technology Experimentation
- Renewable Electrolysis: Integrated System Development and Testing (PD031)

# Future Work: Reliability Analysis Framework

- Complete Weibull component reliability analysis
- Analyze details of unscheduled maintenance and failure investigation
- Specific metrics include:  Mean time between failure, frequency, reliability growth (lambda and beta), cumulative hydrogen compressed, cumulative operation hours, maintenance categories, failure modes, and root cause
- Collect operation data
- Example analysis results:



# Future Work: RD&D Challenges

## Operational Reliability & Performance Testing

- PDC Machines Compressor CRADA
  - Test plan includes long-duration compressor operation (>1000 hours), periodic rebuild and maintenance
  - Identify failures, MTBF, down-time and failure indicators
  - Work with manufacturer to improve reliability of future designs
- Develop another CRADA with different compressor technology manufacturer in 2015
- Work with PNNL to improve advanced diaphragm compressor modeling
- Test additional hydrogen fueling station components 'in-situ' at new NREL 700 bar fueling station

# Summary

**Relevance:** Address barriers that include; lack of performance data, instrumentation, sensor accuracy, technology transfer and integration with renewable sources like wind and solar.

**Approach:** Work closely with industry to understand and improve compressor reliability and exercise NREL's existing test platform.

**Technical Accomplishments:**

- Installed, commissioned and began operation of PDC-4 Series compressor in Integrated Renewable Electrolysis System at NREL-NWTC
- Analysis of compressor power and pressure data
- Logging of hydraulic oil pressures and other system variables

**Technology Transfer & Collaborations:** Two new CRADA's in 2013. Validate system performance and disseminate results to industry. Formal and informal partnerships with industry, academia and domestic/international researchers.

**Proposed Future Research:**

- Long-duration testing of piston and diaphragm compressors
- Reach out to different compressor technology manufacturers
- Transition compressor testing to ESIF