STARK STATE COLLEGE

LOCKHEED MARTIN

Fuel Cell Balance of Plant Reliability Testbed

PI: Susan Shearer

Presenters:

Rob Shutler - Lockheed Martin MS2

&

Educational Project Coordinator:

Vern Sproat, PE - Stark State College

10 May 2011

Project ID #: **FC075**

Overview

Timeline

- Start – Aug 2008
- Finish – July 2011
- 75% Complete

Budget

- Total project funding
  - DOE $787,200
  - Contractor 196,800

Barriers

- Technology Validation: Project will generate a reliability database for candidate PEM fuel cell BOP components
- Education: Project will enhance the education of technical workforce trained in PEM fuel cell system technology

Partners

- Stark State College: Project Lead and location of 2 testbeds built by students
- Lockheed Martin: Location of 1 of 3 testbeds and design

Relevance

Balance of Plant (BOP) – Evaluation of components for use in hydrogen fuel cell systems and workforce development

- Reliability
- Durability as defined by Mean Time Between Failure (MTBF)
- Hands on workforce / technician training for maintaining fuel cell systems and documentation of component capability

Approach

- Develop testbeds to address the challenge to the fuel cell industry for the durability and reliability of components that comprise the complete system - Balance of Plant (BOP).
- Develop test plan to address the candidate BOP components and basic testbed design for long-term operation.
- Collaborate with component manufacturers to develop and enhance final product performance.
- Develop statistical models for extremely small sample sizes while incorporating manufacturer validation data for future evaluation of candidate components.
- Conduct real-time, in-situ analysis of critical components' key parameters to monitor system reliability.
- Utilize testbeds to enhance the education of the technical workforce trained in PEM fuel cell system technology.

Approach / Progress

Task #	Project Milestones	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	**Test Bed Design**	3/31/09		3/31/09	**100%**	
2	**Renovation of College Facility**	3/31/09	9/30/09	9/31/09	**100%**	
3	**College Testbed Fabrication & Test**	6/30/09	3/30/11		80%	The first test stand is built and leak test is underway. The second test stand frame is built. BOP components and temperature control components must still be specified and purchased.
4	**Parallel Testbed Fabrication & Test**	6/30/09	3/30/11		95%	Components are identified and undergoing testing. System testing is underway.
5	**Reliability Analysis**	6/30/11			20%	Tested components are under analysis
6	**Failure Analysis**	6/30/11				
7	**Consulting**	6/30/11				
8	**Project Management & Reporting**	4/30/11	6/1/09		99%	The Hydrogen Safety Plan was returned to Stark State and is under review for update.

Technical Accomplishments & Progress

- ✓ Reliability data generated for pressure sensors, tubing and hydrogen circulating pump
- ✓ Students have been trained in construction, programming, operation, data acquisition and automated control of testbeds
- ✓ Testing of Pressure Hydrogen Safety Plan implemented to ensure safe operation of the testbeds with hydrogen
- Continue to test components and document reliability
- Commission third testbed
- Continue to evaluate failure modes of tested components

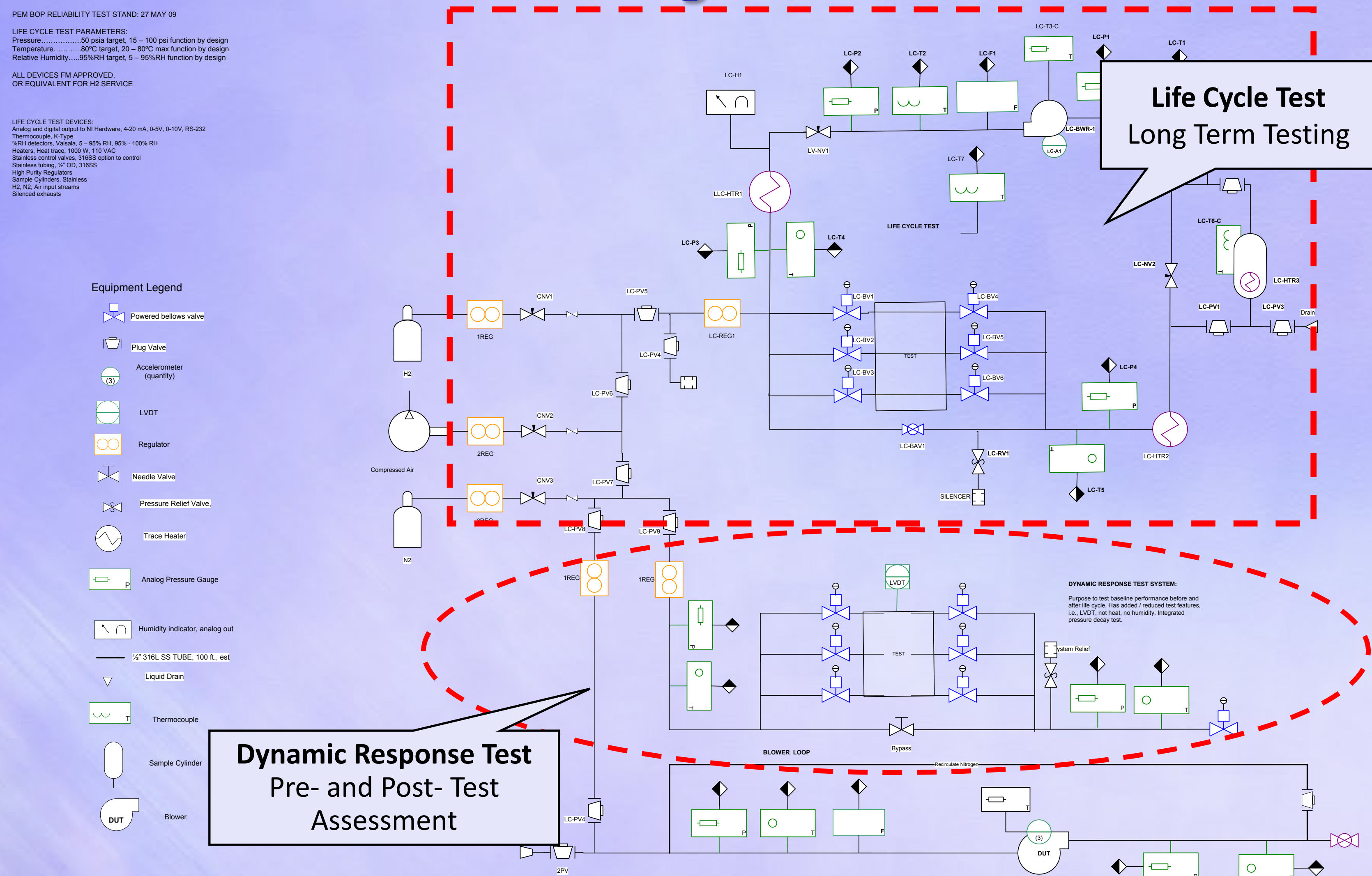
Technical Accomplishments and Progress

Fuel Cell Testbeds

Fuel Cell BoP Reliability Testbeds

Technical Accomplishments and Progress

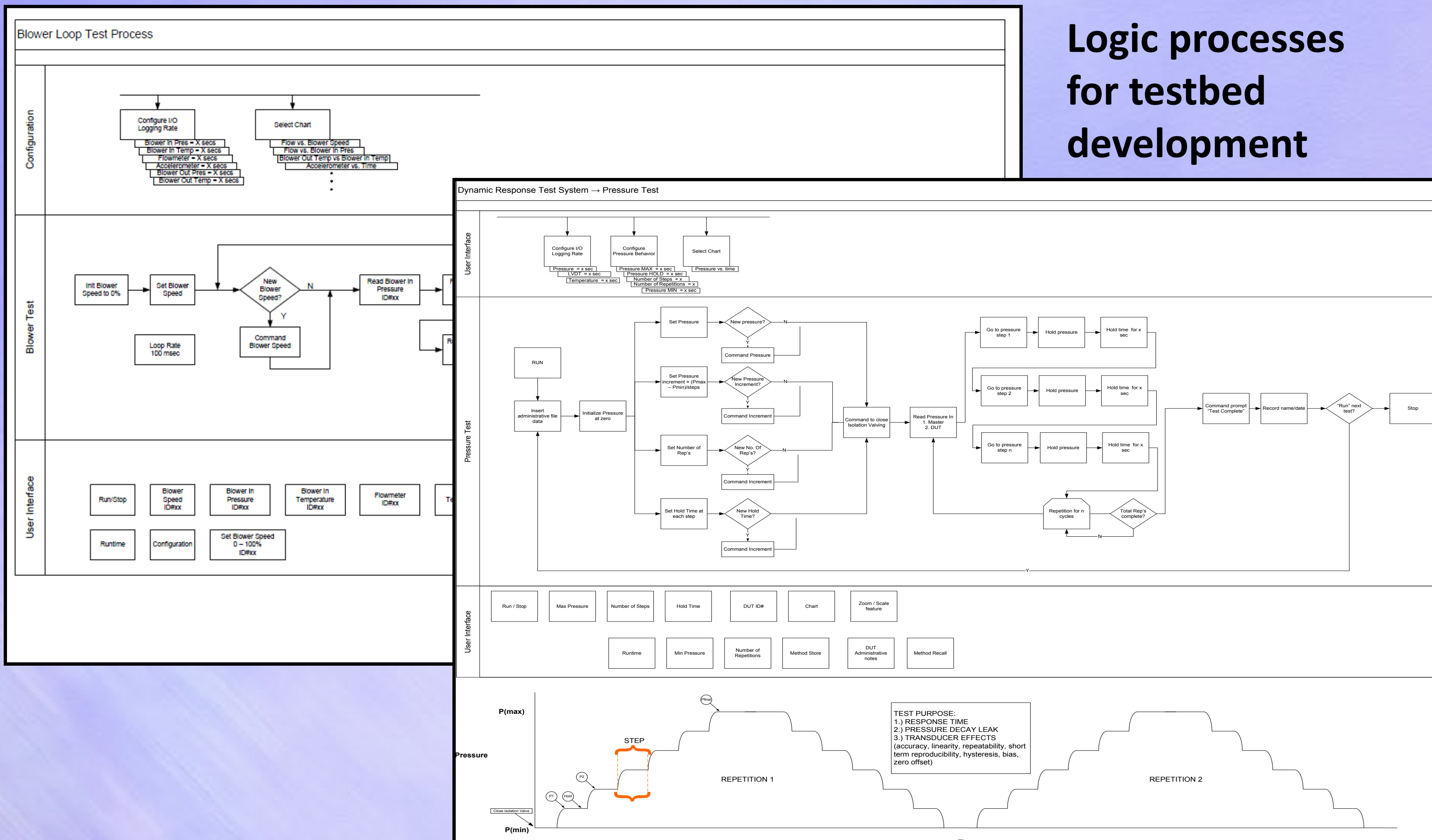
Testbed Design - Hydrogen Recycle



Test Bed Designed for Multiple Test Modes

Technical Accomplishments and Progress

Testbed Design - Hydrogen Recycle

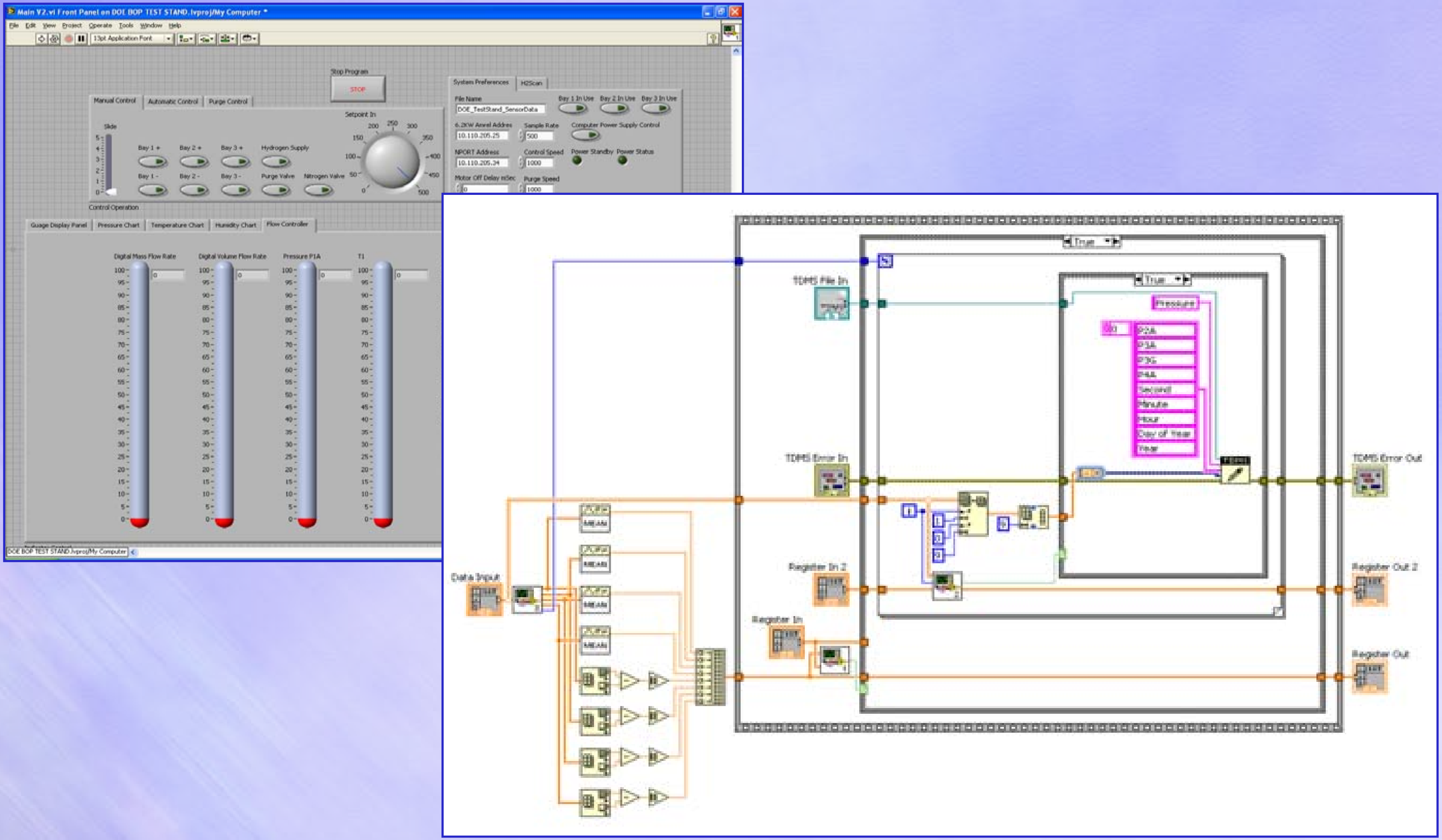


Logic processes for testbed development

Testbed Logic Process Diagrams

Technical Accomplishments and Progress

Testbeds
LabVIEW Programming



Student Constructed Operator Interface

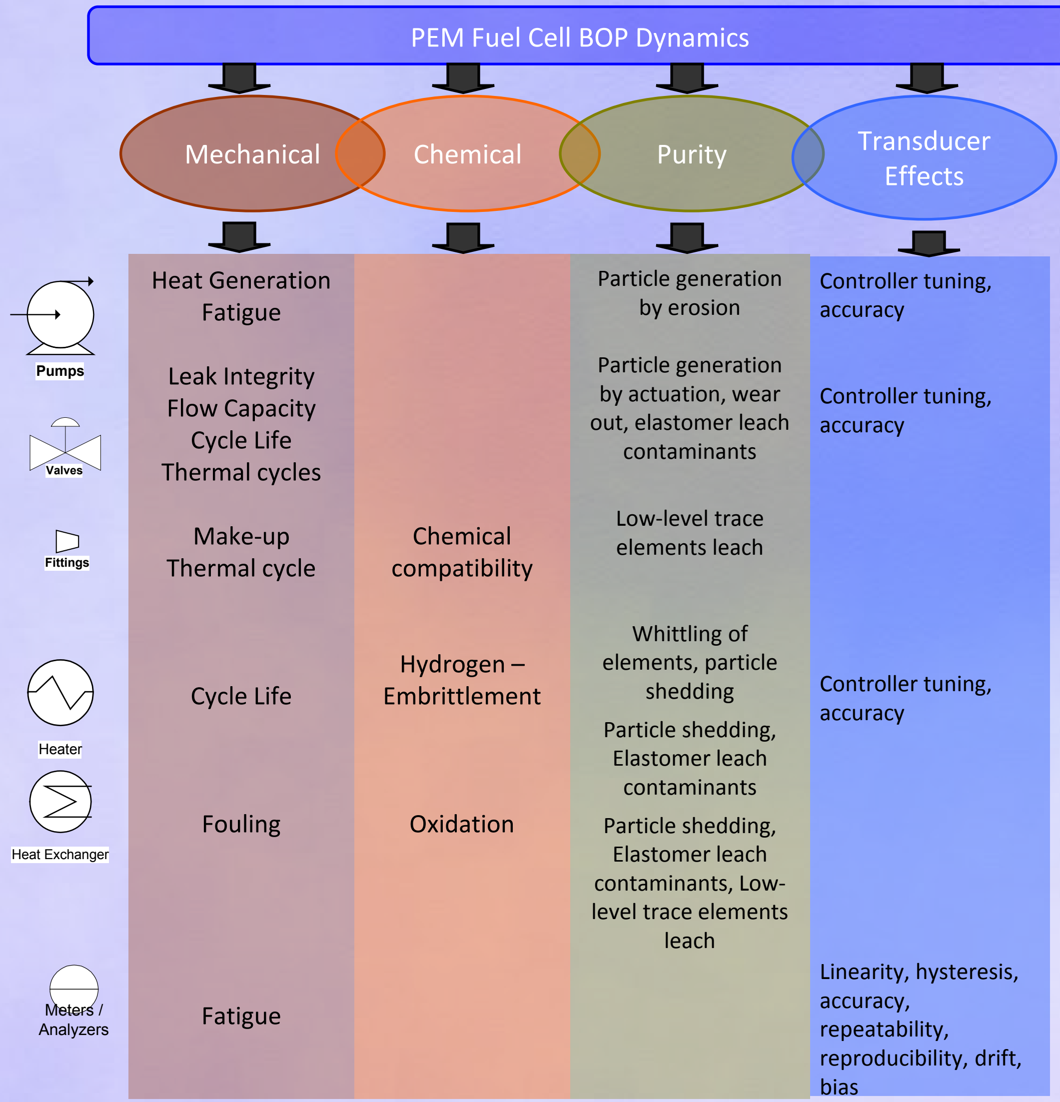
Reliability Testbed

Reliability is the ability of an item to perform the required function, under stated conditions, for a period of time.

Candidate BOP Components

COTS - Commercial off-the-shelf components

- High-production products such as piping, fittings, etc. where past history is available.
  - Use Weibull and Weibayes Analysis for those components with previous history. This procedure incorporates test and field data (vendor reliability and quality analysis) to demonstrate the component product meets the reliability target at the desired confidence level.
- Low production units with no manufacturer reliability data.
  - End-of-life component data and Forensic Failure Analysis will be the most important test data.



Analysis Method for Test Components

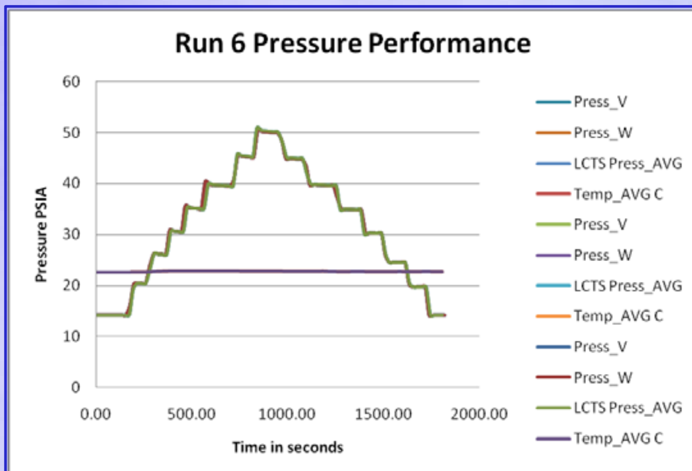
Technical Accomplishments and Progress

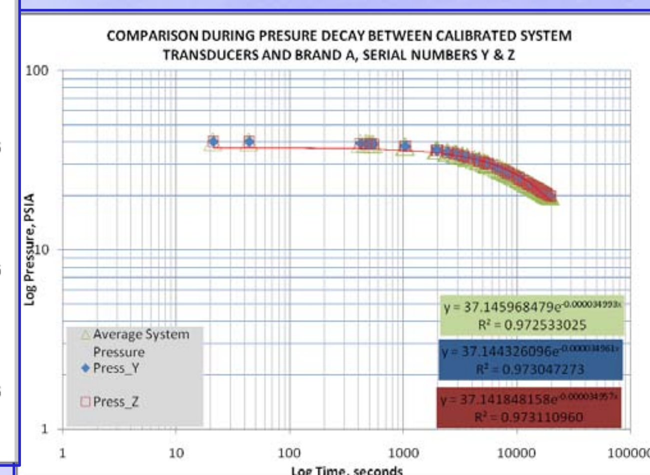
Pressure Sensors

Component	Absolute	PSI	Error	Price $	Dimensions	Ranking
Brand A	Yes	0-50	0.25%	87	1.12	1
Brand B	NO	0-50	0.25%	87	1.12	2
Brand C	Available	0-50	1%	69	2.6	3
Brand D	NO	0-50	0.25%	134	1.12	4
Brand E	Yes	0-60	0.25%	435	4.3	5
Brand F	NO	0-50	0.50%	150	2.91	6
Brand G	Yes	0-50	0.25%	360	3.27	7
Brand H	NO	0-50	1%	79	3.3	8
Brand I	Yes	0-50	±0.15% FS	525	3.825	9
Brand J	Yes	0-60 (0-4 bar)	0.175% > 0.4 bar		3.68+connector	10
Brand K	Yes	0-50	0.5%FS	495	3.1+ connector	11
Brand L	Yes	0-50	0.5%FS	301	4.17 inches	12
Brand M	Yes	0-50	0.25% FS	600	4.13+connector	13
Brand N	Yes	0-50	0.4% of RO	580	4.8 inches	14

Trade Study for low cost, high reliability, compact sensors

Evaluation Test Data for Devices Under Test





Several Hard and Soft Sensor Failures Have Been Documented

Hydrogen Recirculation Pump

- Hydrogen recycle pump chosen for COTS Capability
- Recycle pump search identified the following issues:
  - Reliability of limited production components
  - Materials compatibility, special order necessary for 316 SS with sealed operation
  - Development costs required for specialized hydrogen blower
- Pump chosen: Parker Univane™
  - Rated off-the-shelf for hydrogen operation and operation conditions - $8K
- Issue: Product line has been discontinued
- Substituting COTS blower with lesser capability

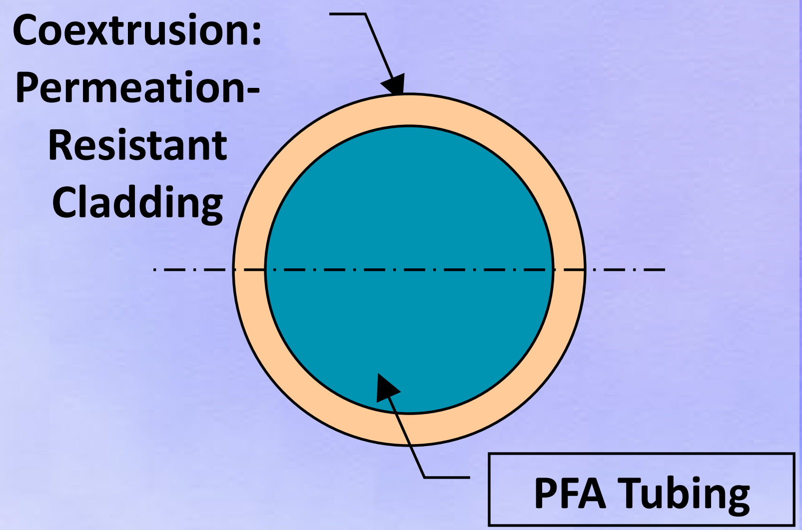
Search for Low Cost, Low Power, Low Weight Component

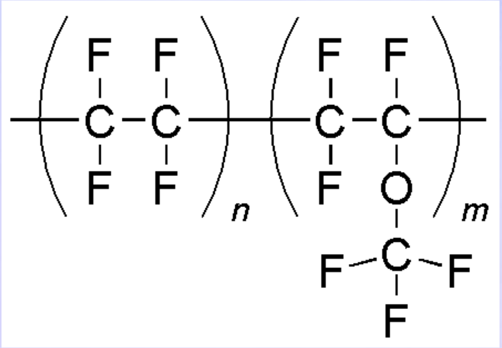
Fuel Cell Tubing

Component	Comments
316 Stainless Steel Tubing	DI water compatible
Coextrusion PFA Tubing	DI water and chemical resistant, corrosion resistant, lightweight

- <u>Alternate Tubing Choice</u>
  - Performance tubing with greater resistance to permeation Zeus® Perme-Shield™ high-purity PFA. Perme-Shield demonstrates exceptional barrier properties and significantly defends against gas permeation and chemical leaching through the tubing walls used in wet chemical processing.

Zeus® PFA Tubing

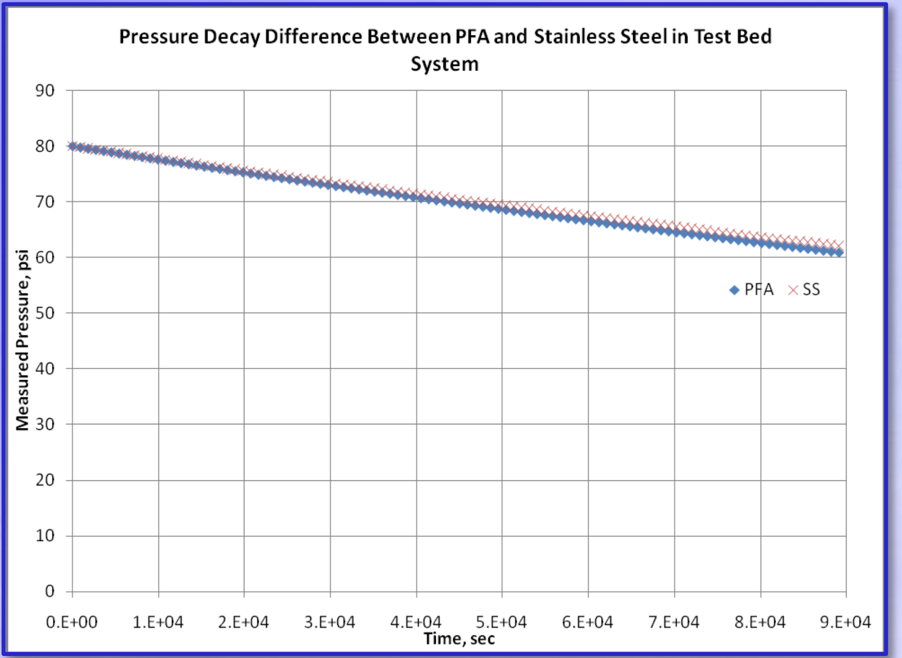


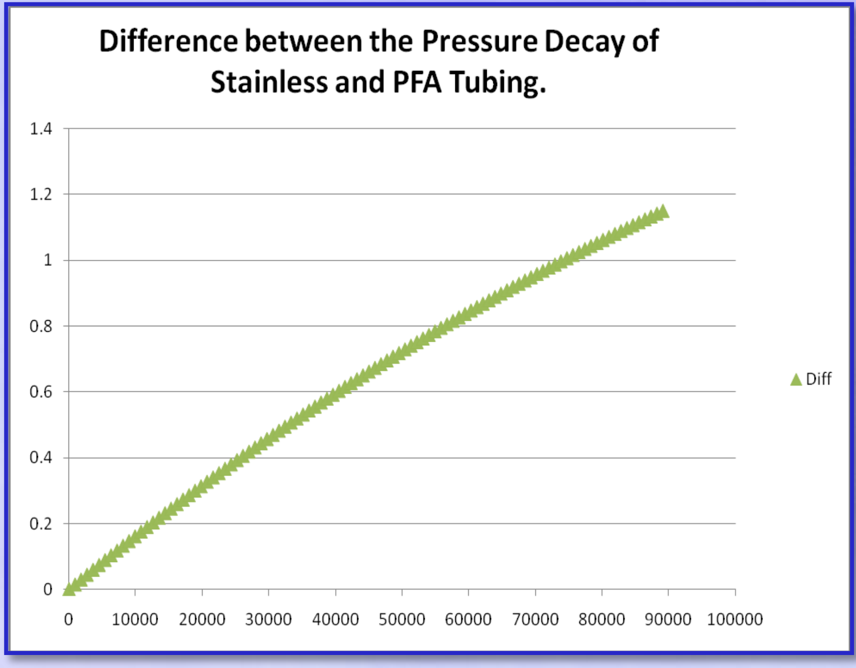


PFA- Perfluoroalkoxy

Lightweight, Chemical Resistant Tubing

PFA vs. Stainless Steel





- **Pressure decay method used to test feasibility of PFA tubing**
- **In the process of higher temperature and long-term exposure to PEM environment testing**

PFA Test Data

Collaborations

Lockheed Martin

- Subcontract
- Initial Testbed Design
- Parallel Testbed Construction
- Failure Analysis
- Reliability Analysis

- Parker
- Swagelok
- National Instruments
- Omega Dyne
- Rockwell Automation
- Microchip
- National Semiconductor
- Zeus
- Thomas
- Buzmatics
- Newport
- BELLOFRAM
- Proportional-air
- SI Pressure
- Summit Instruments
- Blaze Technical Services

- SMC
- AMREL
- BALLARD
- Brisk Heat
- Fluke
- H2Scan
- Keithley
- Keyence
- Kikusui
- Roxtec
- Vaisala
- Clippard
- Omega
- Ameritrol
- ATEX
- BelGAS

- Intek
- Asmeblon
- Sandia Labs
- McMaster-Carr
- Auto Zone
- Fluidtrol
- Alicat
- Ametek
- Fox Valve
- EBZ
- EXAIR
- Pfizer
- Airgas Great Lakes
- NoShock
- Chevron Phillips Chemical Company

- Mound Technical Solutions
- Agilent
- Neteon
- Praxair
- Item America
- 8020
- Rexel
- Texas Instruments
- Prosoft
- Tektronix
- Comsol
- Piedmont Plastics
- OFCC
- HYGROSENS
- AMETEK
- National Semiconductor

Educational Institution Dialogue

- **NSF Great Lakes Fuel Cell Education Partnership State Coordinators**
  - Indiana
    Vincennes University
    Rose Hulman Institute of Technology
  - Michigan
    Kettering University
    Lansing Community College
    Michigan Technical College
  - New York
    Rensselaer Polytechnic Institute
    Hudson Valley Community College
  - Ohio
    University of Akron
    Stark State College
    Kent State University
    Hocking Technical College
  - Pennsylvania
    Penn State University
  - *Tennessee*
    University of Tennessee

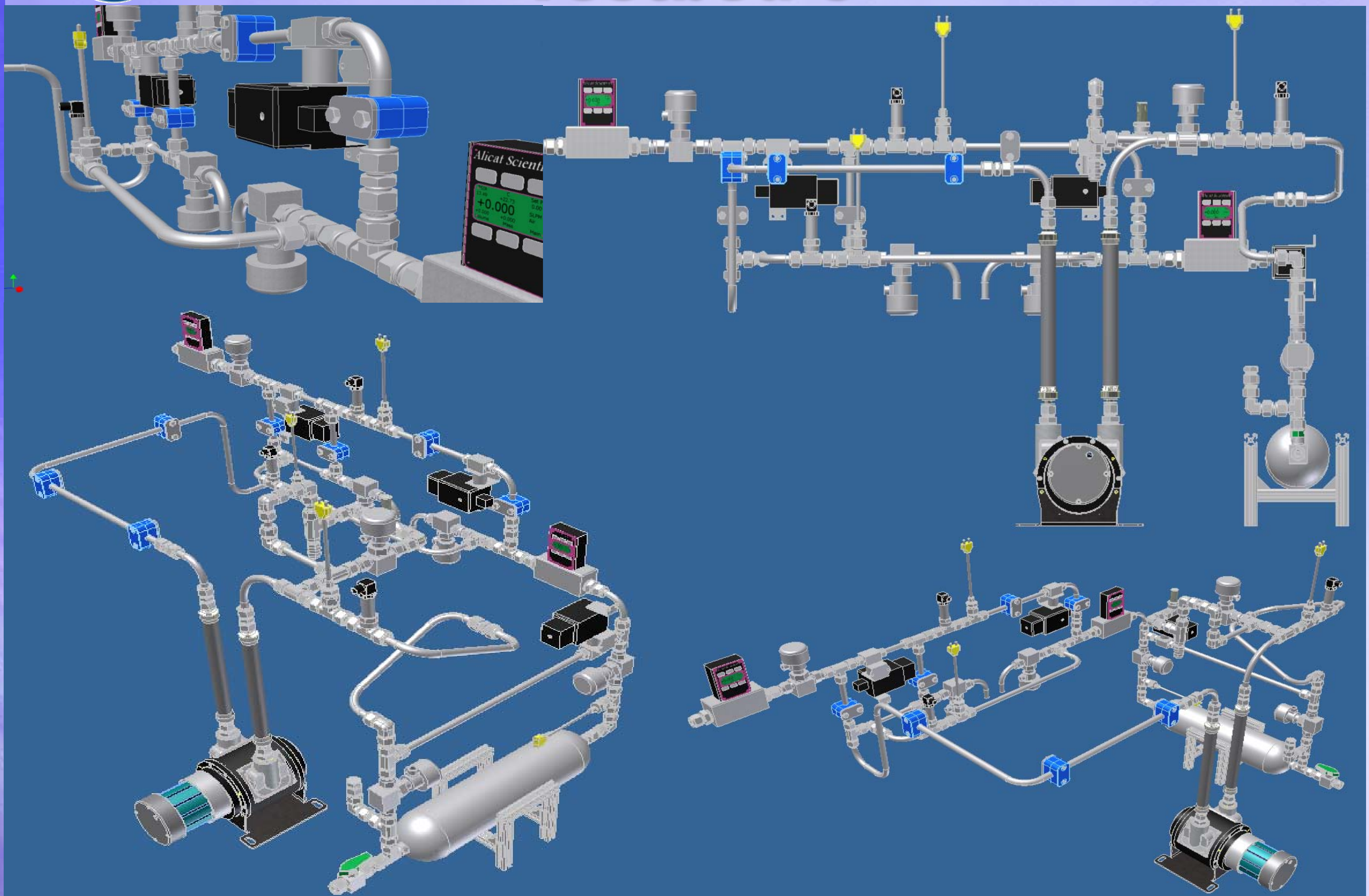
- **Educational Institution Dialogue** (cont.)
  - Early College course
    Alternative Energy and Fuel Cells
  - Engineering & Science Career Field
    Technical Fuel Cell Energy
  - Project Lead the Way, Ohio Fuel Cell Option
  - Upward Bound Fuel Cell Course
  - Support for First Fuel Cell Contest teams
  - High School Student Science Projects
  - Ohio Energy Project

Proposed Future Work

- Identify additional parts to test
- Acquire real-time, in-situ data from the operation of the testbeds
- Address failure analysis and reliability analysis as failures occur

Proposed Future Work

Testbed 3



Acknowledgements

- **Project Director: Susan Shearer, Stark State College**
  SShearer@starkstate.edu
- **Educational Project Coordinator: Vern Sproat, P.E. Stark State College;** vsproat@starkstate.edu
- **Steven Sinsabaugh, Lockheed Martin Fellow**
- **Debbie LaHurd, PhD, Lockheed Martin MS2**
- **Rob Shutler, Lockheed Martin MS2**
- **Marc Griffin, Lockheed Martin MS2**
- **DOE Managers:**
  Greg Kleen, Project Officer
  Kathi Epping, HQ Technology Manager

Project Summary

- **Relevance**: Balance of Plant (BOP): To use hydrogen in fuel cells, a balance must be engineered for reliability and technician training for fuel cell system.
- **Approach**: Develop BOP testbeds, collaborate with component manufacturers to enhance product performance, and train technical workforce in PEM fuel cell systems.
- **Technical Accomplishments & Progress**: Generation of Test Plan

  Students are being trained on the construction and operation of the test bed, and the Hydrogen Safety Plan has been implemented to ensure safe operation of the testbeds with hydrogen.
- **Technology Transfer/Collaboration**: Active partnership with Lockheed Martin and industry dialogue with Parker, Swagelok, National Instruments, Omega Dyne, and others.
- **Proposed Future Work**: Execute Test Plan; construct third reliability testbed with students; begin acquiring real-time, in-situ data; address failure analysis and reliability analysis of BOP components.