

SPORIAN
MICROSYSTEMS, INC

Advanced Ceramic Materials and Packaging Technologies for Realizing Sensors for Concentrating Solar Power Systems.

DOE SBIR program

Grant #: DE-SC0009232

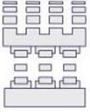
April 20, 2016

Sporian Microsystems, Inc.

www.sporian.com

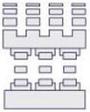
TPOC: Dr. Kevin Harsh

BPOC: Dr. Michael Usrey



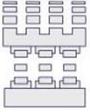
Acknowledgement

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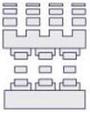
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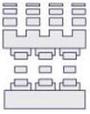
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Overview

- Sporian Introduction
- Cross-Cutting Power Generation Sensors
- CSP Project Motivation
- Current Effort Progress Update



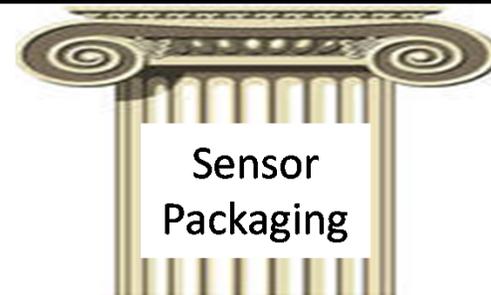
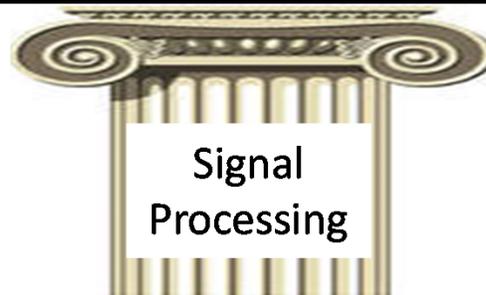
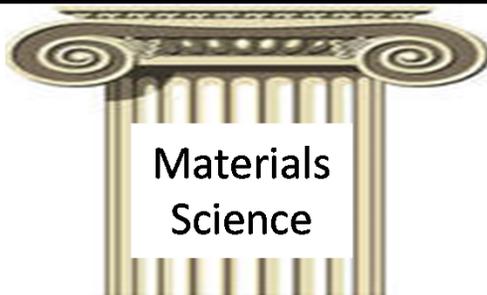


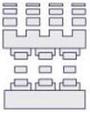
Sporian Microsystems Introduction



Energy & Aerospace Sensors

Bio Chem Sensors





Sporian Microsystems Introduction

- Sporian develops advanced sensors and sensor systems for a range of applications.

Core Technical Competencies

Novel Materials Science

Leading edge signal Conditioning & Smart Electronics

Advanced Electronics & Hardware Packaging

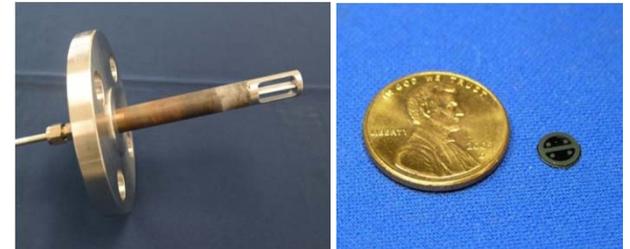
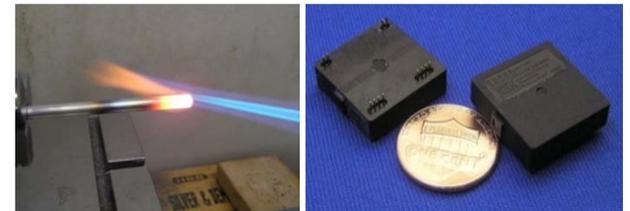
Advanced Sensor Technologies

Biological & Chemical

- Specific
- Selective
- Gas Composition
- Biomedical
- Hyperspectral Imaging

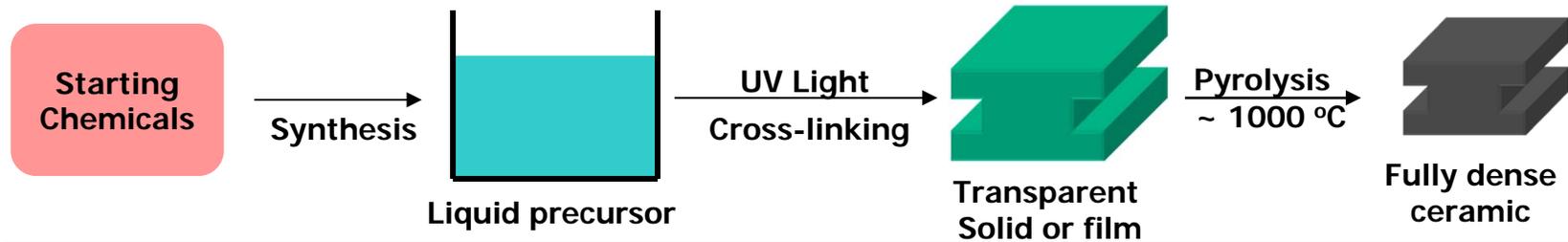
Energy & Aerospace

- Very High Temperature
- Harsh Environments
- Asset monitoring
- Condition-Based Maintenance



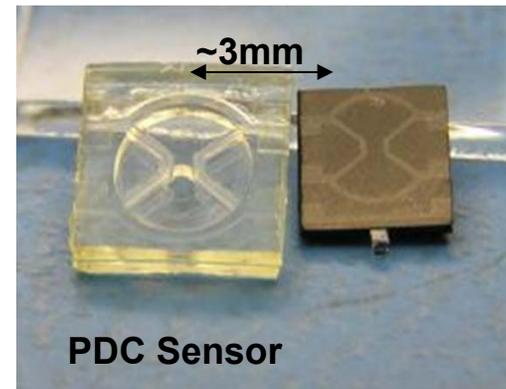
Sporian Cross-Cutting Power Generation Sensor Technology

PDC Synthesized by Thermal Decomposition of Polymeric Precursors



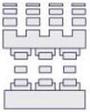
Demonstrated HT Sensor Technology:

- Thermo-resistive temperature sensor
- Piezo-resistive pressure sensor
- Capacitive based pressure sensor
- Anemometric flow sensors



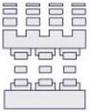
Features, Advantages & Benefits

Features	Advantages	Benefits
Polymer derived ceramic materials	<ul style="list-style-type: none"> • Operating temperature >1000°C w/o liquid cooling or fiber routing • Highly oxidation/corrosion resistant • Thermal shock resistant • Low creep rate & diffusion rate 	<ul style="list-style-type: none"> • Lower weight, smaller size • Lower cost, low-maintenance • Higher durability • Higher operational availability
Temperature / pressure sensor suite	<ul style="list-style-type: none"> • Improved T-compensation of pressure measurements • Opportunity for redundancy and/or sensor fusion 	<ul style="list-style-type: none"> • Lower weight, smaller size • Higher accuracy
Immersion sensing at source	<ul style="list-style-type: none"> • Eliminate capillary tubes 	<ul style="list-style-type: none"> • Lower cost, higher accuracy • Lower weight • Avoid failure mechanism • Improved dynamic response
Smart signal conditioning electronics	<ul style="list-style-type: none"> • Compatible with existing systems • Temperature compensation • Signature analysis 	<ul style="list-style-type: none"> • Lower cost • Higher operational availability



Cross-Cutting Sensor Applications

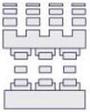
- Concentrated Solar Power
- Nuclear
- Gas Turbine
- Supercritical Steam
- Liquid Natural Gas



CSP Project Motivation

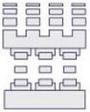
- **Concentrated Solar Power HTF/TES:**
 - Robust sensing systems for monitoring and control
 - Temperature, Pressure, Flow and Level
- **Primary Technical Challenges:**
 - Extremely harsh working conditions
 - High Operating Temperature
 - Highly Corrosive Molten Salt
 - Solar Heating Loads on Signal Conditioning Electronics
 - Installation Costs
- **Long-Term Goal:**
 - Leverage Sporian sensor/packaging technology to support applications in CSP systems:





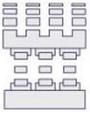
Overview of the SBIR Effort

- **Phase II:** December 23, 2013 to June 22, 2016
- **Primary PII Efforts/Tasks**
 - Work with Stakeholders to guide the development and facilitate transition.
 - Materials compatibility
 - Develop designs for CSP HTF/TES fluid capable pressure/temperature (P/T) sensor and flow/temperature (F/T) sensor.
 - Developed common hardware useful in range of HTF/TES fluid
 - Rigorous testing of prototypes in lab scale environments.
 - Material HTF/TES fluid corrosion testing (sensor and packaging materials)
 - Performance testing
 - Revise designs and construct next generation prototypes.
 - **Demonstration of next generation prototypes including demonstration in OEM application relevant environment test systems.**
 - **Focus of this presentation**



Stakeholder HTF Sensor Requirements

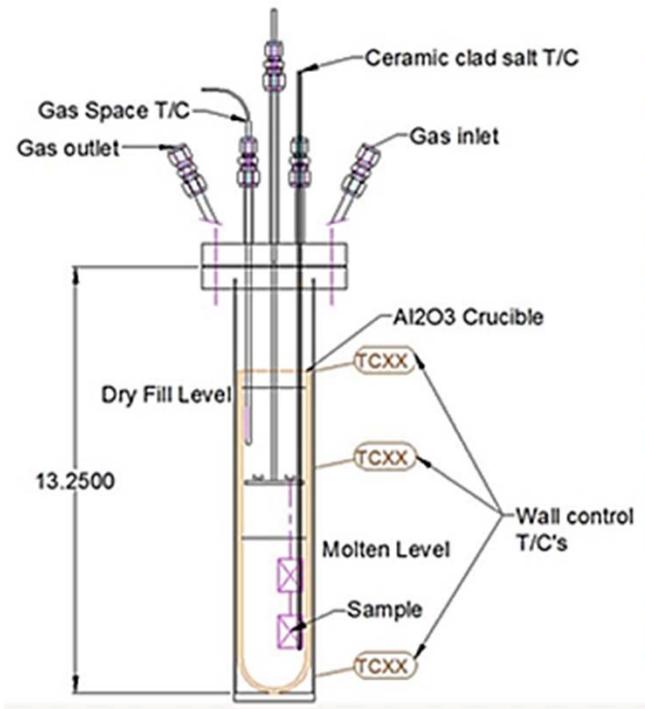
CSP Type	<ul style="list-style-type: none">• Tower (T): 550 to 600°C.• Trough (Tr): 500°C.• Dish (D): 700°C.• DOE EERE MURI (M): 1300°C.
Sensor Types / Location(s)	<ul style="list-style-type: none">• Receiver inlet and outlet: flow rate, temperature and pressure. (T, Tr, D)• Steam generator inlet: flow rate and pressure. (T, Tr)• Thermal energy storage tank: level. (T, Tr)
Sensor Packaging Materials	<ul style="list-style-type: none">• Nickel-based superalloys (T, Tr)• Stabilized austenitic stainless steel and carbon steel (T, Tr).• SiC, alumina and graphite (T, Tr).
Pressure	<ul style="list-style-type: none">• Range 0-870 psi (T, Tr).• Range 290-2200 psi (D)
Mass Flow Rate	<ul style="list-style-type: none">• 700 kg/sec (T).• 30 kg/sec (Tr).• <1 kg/sec (D)
I/O Signals	<ul style="list-style-type: none">• Current: Analog signal: 0-10VDC/4-20mA. (T, Tr, D)• Future: Digital output. (T, Tr, D)
System Integration	<ul style="list-style-type: none">• Sensors/conditioning system can be located 300-500 feet from control systems. (T, Tr, D)• Sensor system should be weather proof with heavy solar load. (T, Tr, D)



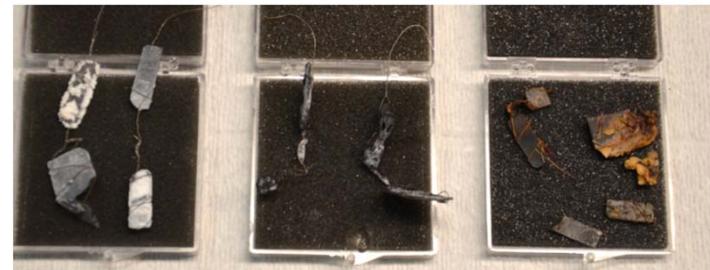
500hr Solar Salt Exposure Testing

3 Different CSP Relevant Inorganic Salts and Test Facility in UW

HOT Fluid Mixture	M.P. [°C]	T.S.B.P. [°C]	Test T [°C]	Duration [hour]	Cp [J/g-K]	V.P. @800°C	Corrosion with SS	Cost [\$/kg]
DOE's Target	250	800			1.5	<1atm	Excellent	<1
NaNO ₃ KNO ₃	228	600	550°C	500 hr	1.5	<1atm	Good	~1
K ₂ LiNa ₂ CO ₃	397	>830	650°C	500 hr	1.8	<1atm	Fair	~2
KCl MgCl ₂	426	>1418	750°C	500 hr	na	<0.1atm	Fair	~0.2



PDC Samples before/after Cleaning

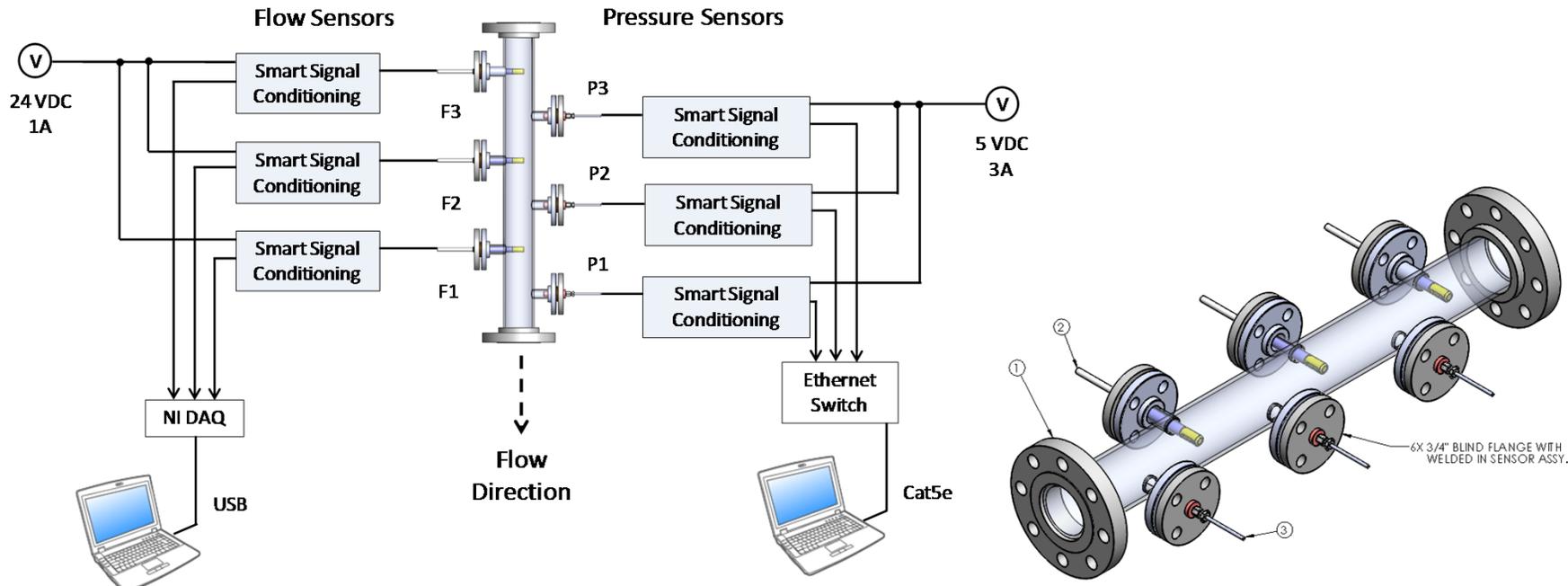


Nitrate Salt
550 °C

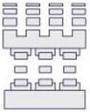
Carbonate
650 °C

Chloride Salt
750 °C

SkyTrough® Test Schematic

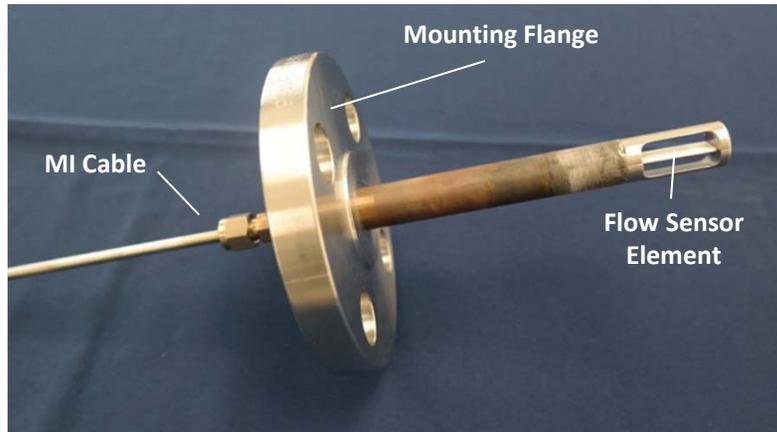


- First test of Sporian Hardware in a flowing molten salt environment

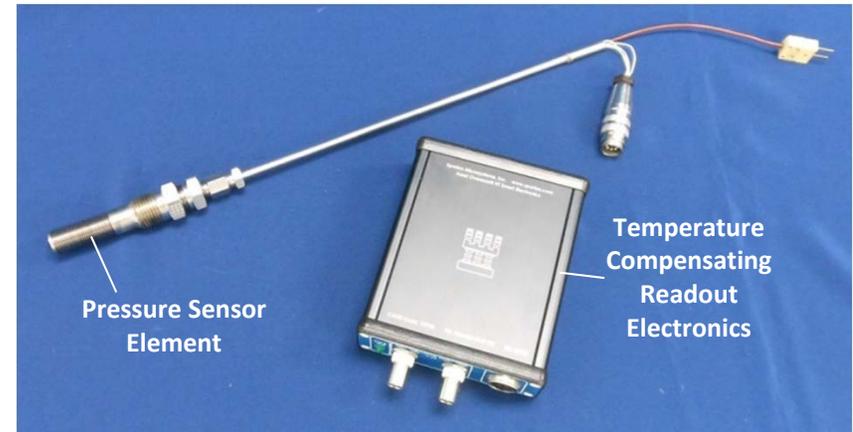


Sporian Test Hardware

Prototype Flow Sensor

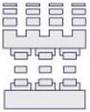


Prototype Pressure Sensor

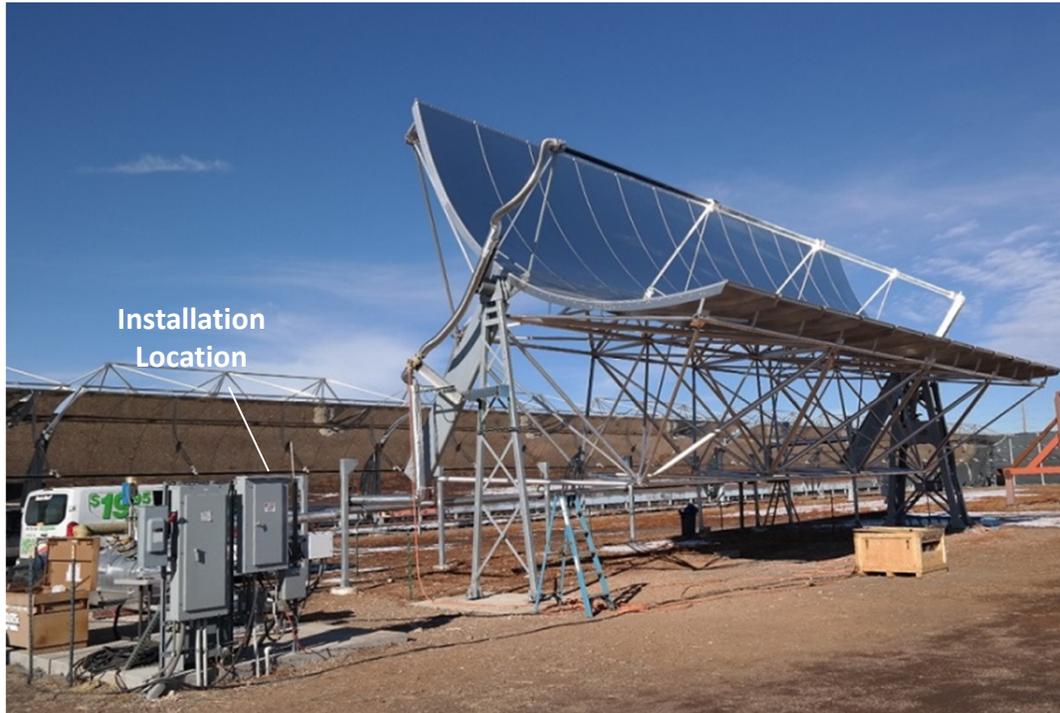


Instrumented Pipe Section





Test Site



Installation
Location



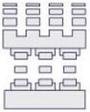
Installed Instrumented Pipe Section



Cabling To DAQ/Electronics (Van)

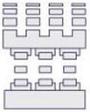


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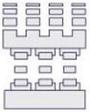
Test Duration

- Sensors installed duration - ~720 hours (~30 days)
 - Exposed to molten/flowing salt ~ 80 hours,
 - Solidified salt for ~630,
- 10 total cycles ambient to $> 200^{\circ}\text{C}$
- Ambient temps ranged from 2°F - 60°F



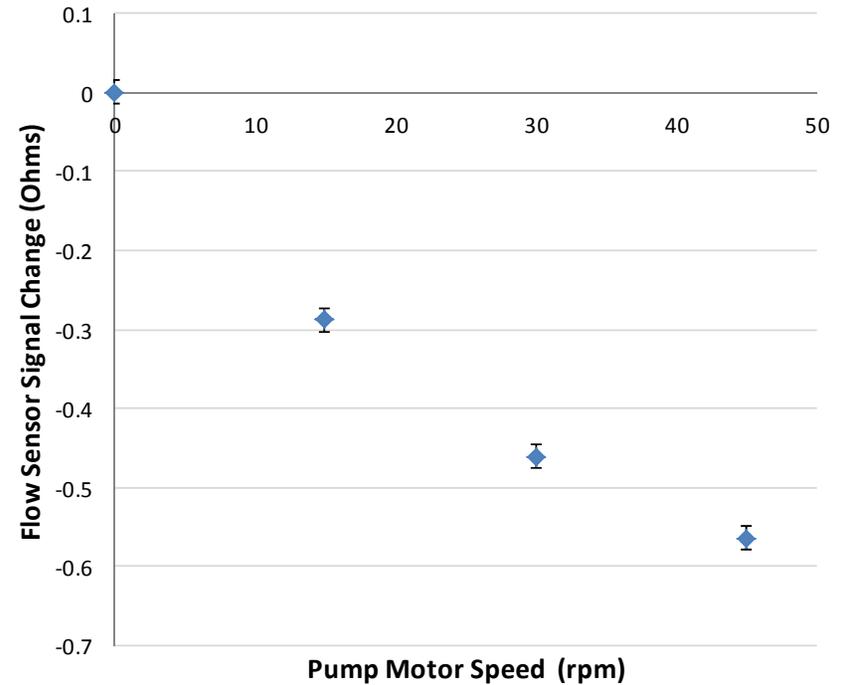
Sensor Performance

- Pressure Sensors
 - 2/3 survived complete.
 - Durability/stability demonstrated
 - 1 Failed at exterior cable connector – likely due to cold/water ingress
 - Replaced with backup sensor mid test
 - Sensors re-tested at Sporian after loop test - no noticeable difference in performance.
- Flow sensors
 - 4 flow sensors tested – performed to expectations.
 - 1 intentionally driven to failure - dialing in drive power settings.
 - 2 failed during system down times (test days 4 and 5)
 - functional at shutdown, not functional upon arrival for next day testing.
 - ceramic sensor cracked, believed due to solidification

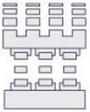


Sensor Performance - Continued

- **Typical flow sensor data set.**
- Varied Pump motor drive freq.(0-45 Hz)
- No reference flow sensor available
- Error bars = sensor noise & flow instability
 - High frequency noise (+/- 0.1% of full scale) – electrical
 - Low frequency noise (+/- 3% full scale) - flow instability?

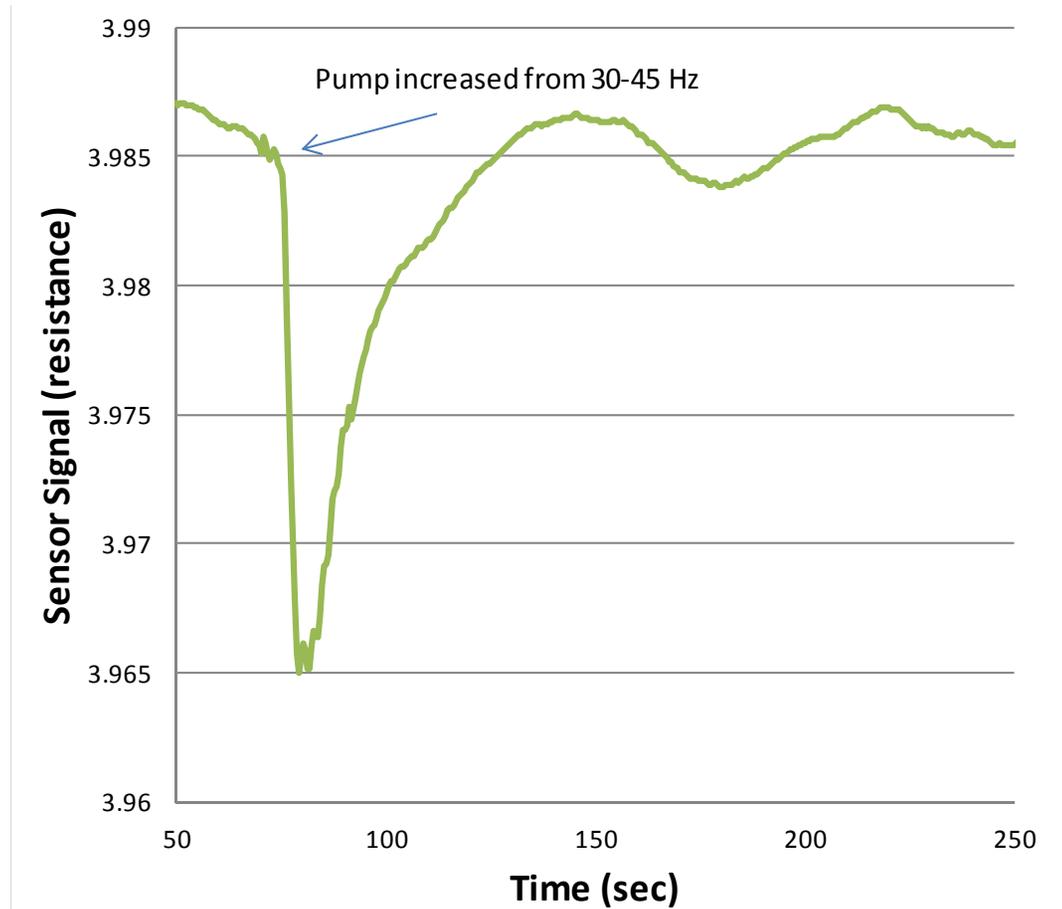


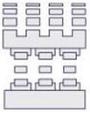
Pump Drive Frequency (Hz)	Sporian Estimated Flow (gpm)
15	6.7 +/- 0.35
30	12.9 +/- 0.35
45	19.4 +/- 0.35



SkyTrough® Transient Conditions

- Example flow sensor data set when system was partially obstructed





Next Steps

- SBIR Period of Performance ends June 22, 2016
 - Remaining effort focused on
 - Hardware optimization
 - Lab-scale reliability testing, particularly salt solidification
 - Additional molten salt loop testing at $>500^{\circ}\text{C}$
 - Identifying additional trough/tower demonstration opportunities