WASHINGTON STATE UNIVERSITY

CLEAN ENERGY SYSTEMS INTEGRATION LAB

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PERFORMANCE OF PRESSURIZED ANODE SUPPORTED SOLID OXIDE FUEL CELL

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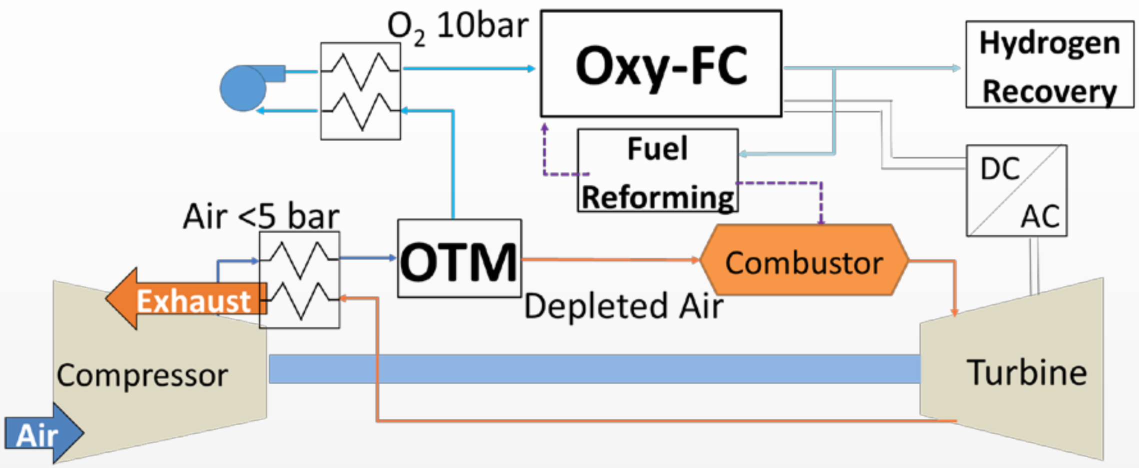
Outline

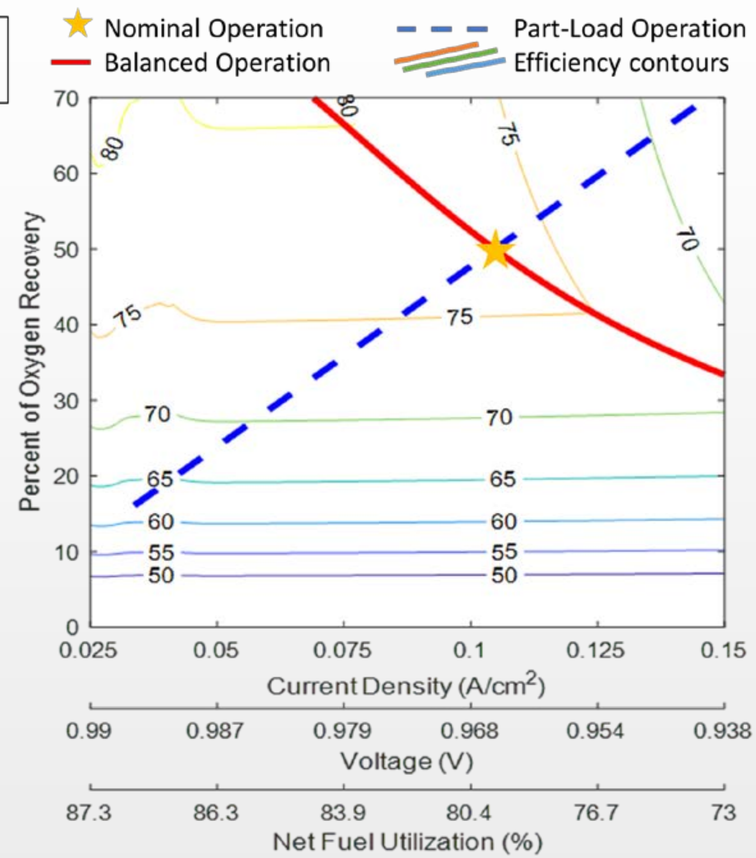
- Motivation for Pressurization
- The De-coupled Hybrid Cycle
- WSU's Test Stand
- Initial Test Results
- Upgraded Stack Results

Why Pressurization?

- Increased performance
  - Higher Nernst potential
  - Reduced activation losses and gas diffusion
- Efficient hybridization
- Reduced steam methanation kinetics distributes reforming across cell
- Compact gas manifolding
- Possibility of pressure sealing
  - Vessel pressure applies external force evenly to seal area
- Hydrogen production at storage/use pressure

De-coupled Hybrid





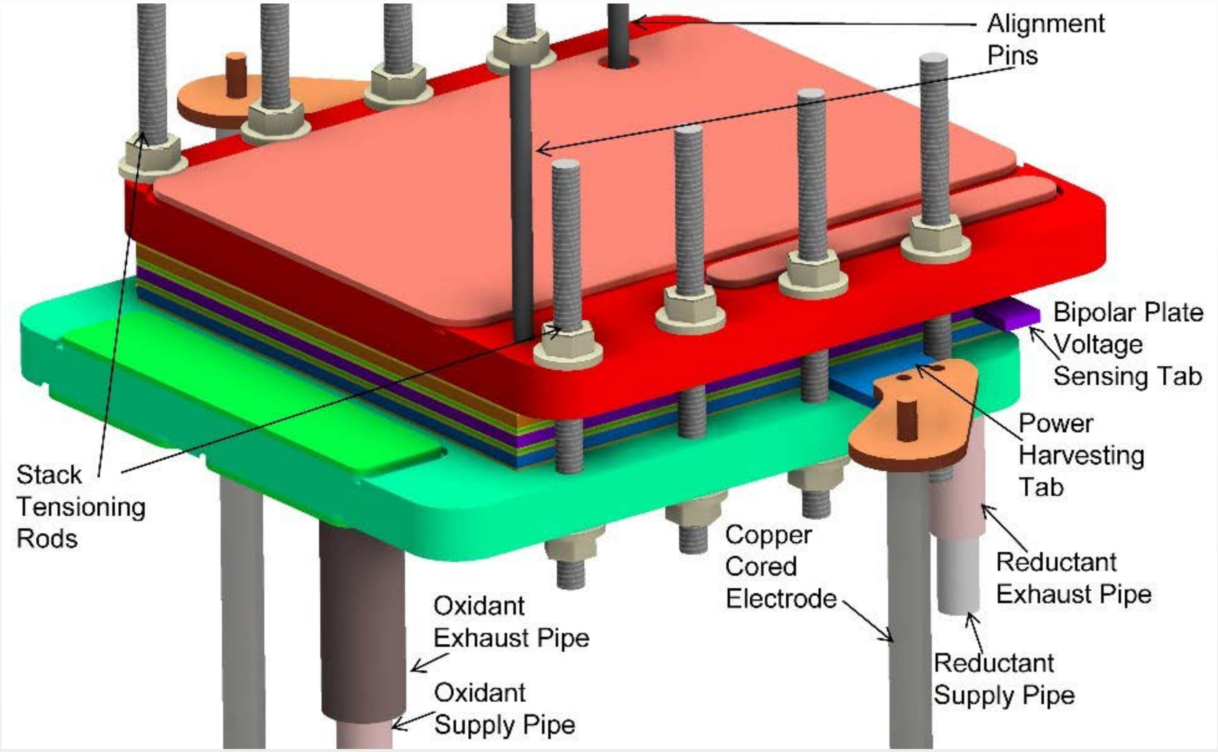
- 65 kW gas turbine + 400kW SOFC @ 70% LHV
- Oxygen membrane isolates SOFC from gas turbine
  - Separate startup
  - Increased operating range
- Pure oxygen cathode should improve performance

Test Station Design

- Furnace rating: 10 bar, 1000 ˚C
- Bronkhorst mas flow meters with 50:1 turndown ratio:
    - Anode: 5slpm N_2, 5slpm H_2, 0.2 slpm CO_2, 2 slpm CO, and 5slpm CH_4
    - Cathode: 10slpm N_2 and 10slpm O_2
- Independent/coupled back pressure control to 145 psi for cathode/anode/furnace
- A hydraulic ram assembly to provide stack compression for sealing.

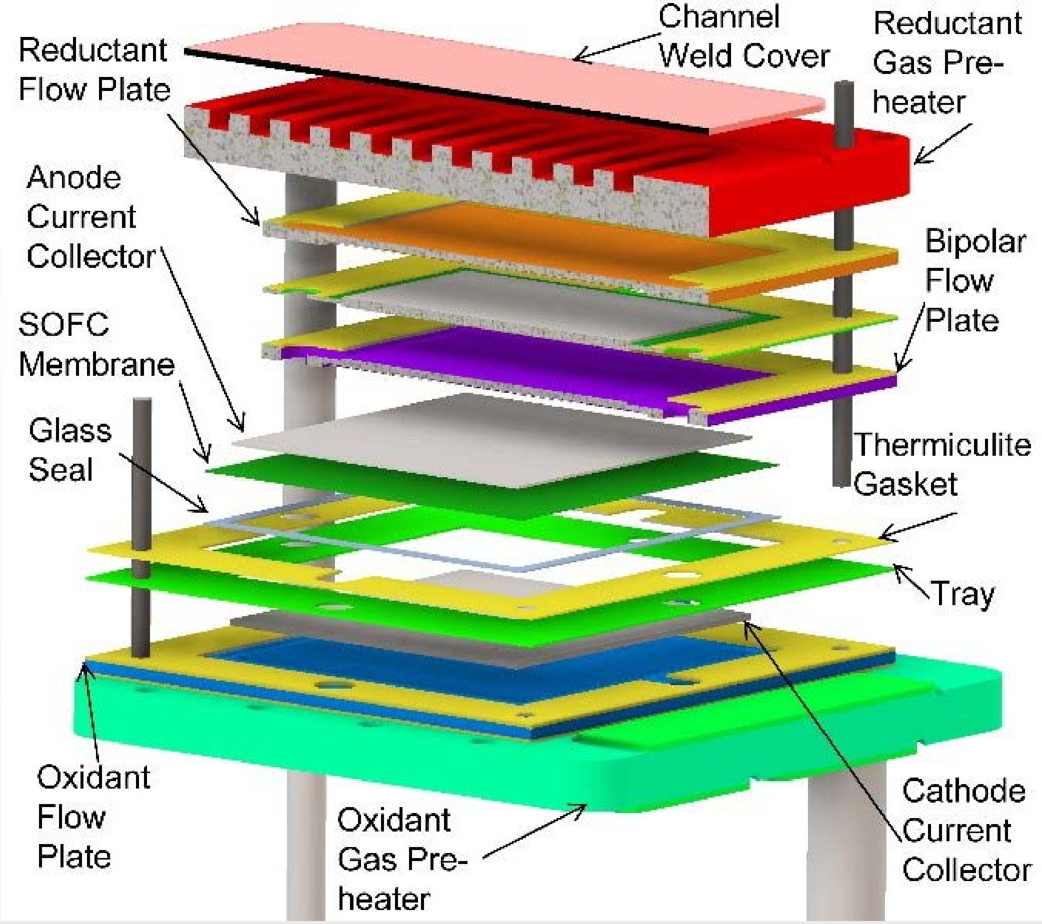
Stack Design

- Copper cored electrodes for high current, >50 amps
- Separate alumina spinel coated Inconel preheaters for anode and cathode gases.
- Concentric piping, inlet inside exhaust, reduces furnace penetrations and improves pre-heating



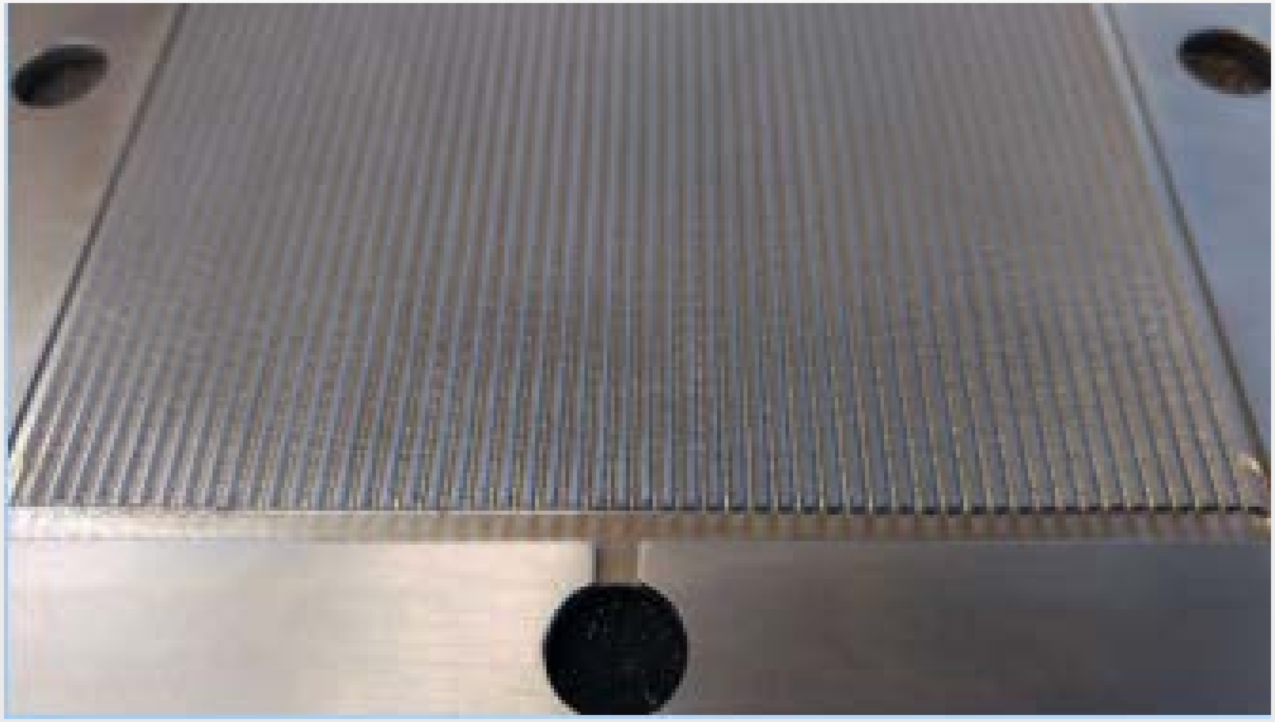
Stack Sealing

- Kerafol glass seal cell to tray
- Flexitallic's Thermiculite 866 seals tray to interconnect and interconnect to manifold.
  - Compressed to 10 MPa with external press



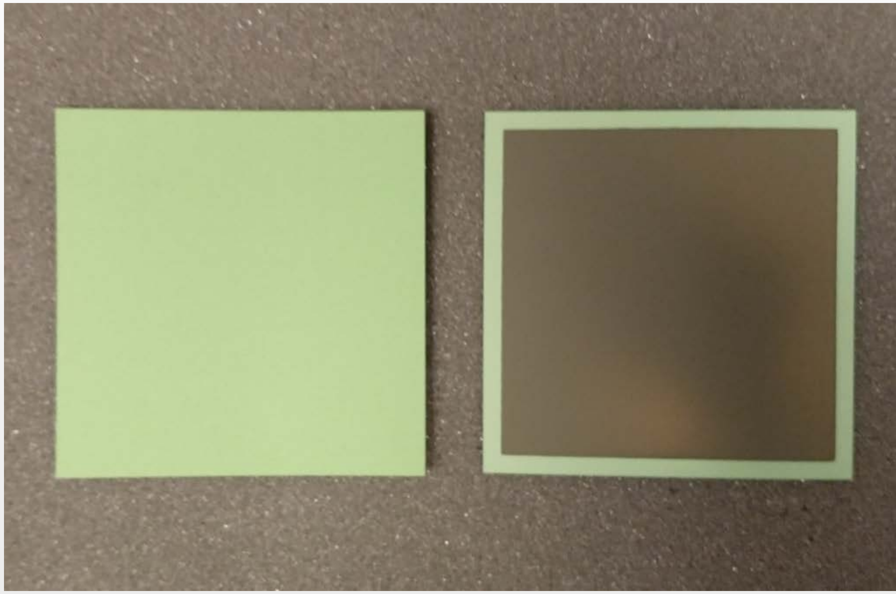
Flow Plate Design

- Cross flow interconnect plates:
  - Channels:1 mm wide, 1mm deep at 1mm spacing
  - Thermally sprayed with manganese cobalt spinel



Cell Specs and Procedures

- Elcogen anode supported cell with an active area of 9 cm X 9 cm.
  - NiO/YSZ anode, 8YSZ electrolyte, and an LSC cathode with a GDC diffusion barrier layer.
- Silver and nickel mesh were used as current collectors at the cathode and anode respectively.



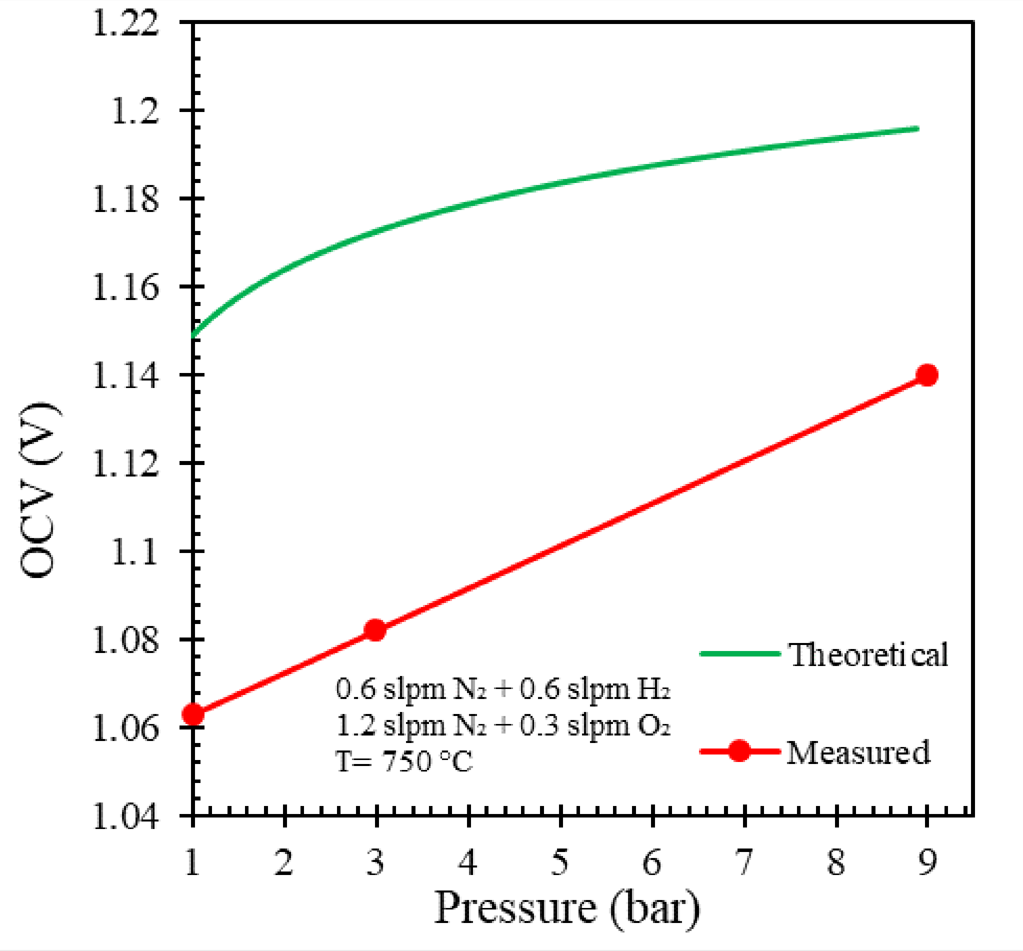
Start Up Procedures

- Warm up at at 2 ˚C per min to 750 ˚ C
  - Dwell at 500 ˚C for glass binder burnout
  - Cathode flow: 0.2 SLPM of O_2 and 0.8 SLPM N_2
  - Anode flow: 1 SLPM N_2 was initiated
- Cell reduction at 750 ˚C: procedure below
  - Conditioning: constant current density of 0.25 A cm^2

Step	Time (min)	Anode (slpm)		Cathode (slpm)	
		H_2	N_2	O_2	N_2
Reduction 1	60	0.1	2.5	0.2	0.8
Reduction 2	30	0.1	1.5	0.2	0.8
Reduction 3	30	0.2	1	0.2	0.8
Conditioning	30	0.5	0.5	0.2	0.8

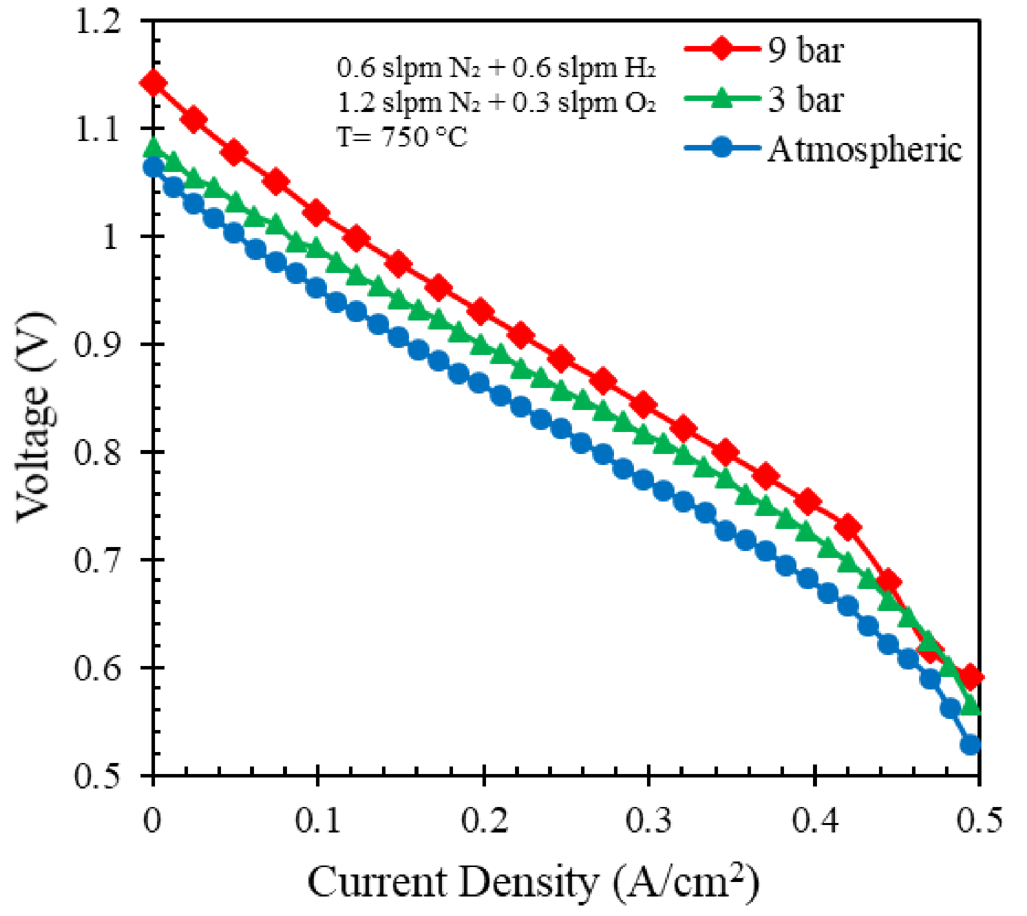
Leak Characterization

- Measured OCV at atmospheric flow was lower than the theoretical voltage by 87 mV, indicating an internal gas leak.
- Leakage is likely due to a cracked cell or glass seal.
- Predicted OCV and the measured OCV began to converge with increasing applied pressure.
- Higher pressure decreases average gas velocity, minimizing leakage.

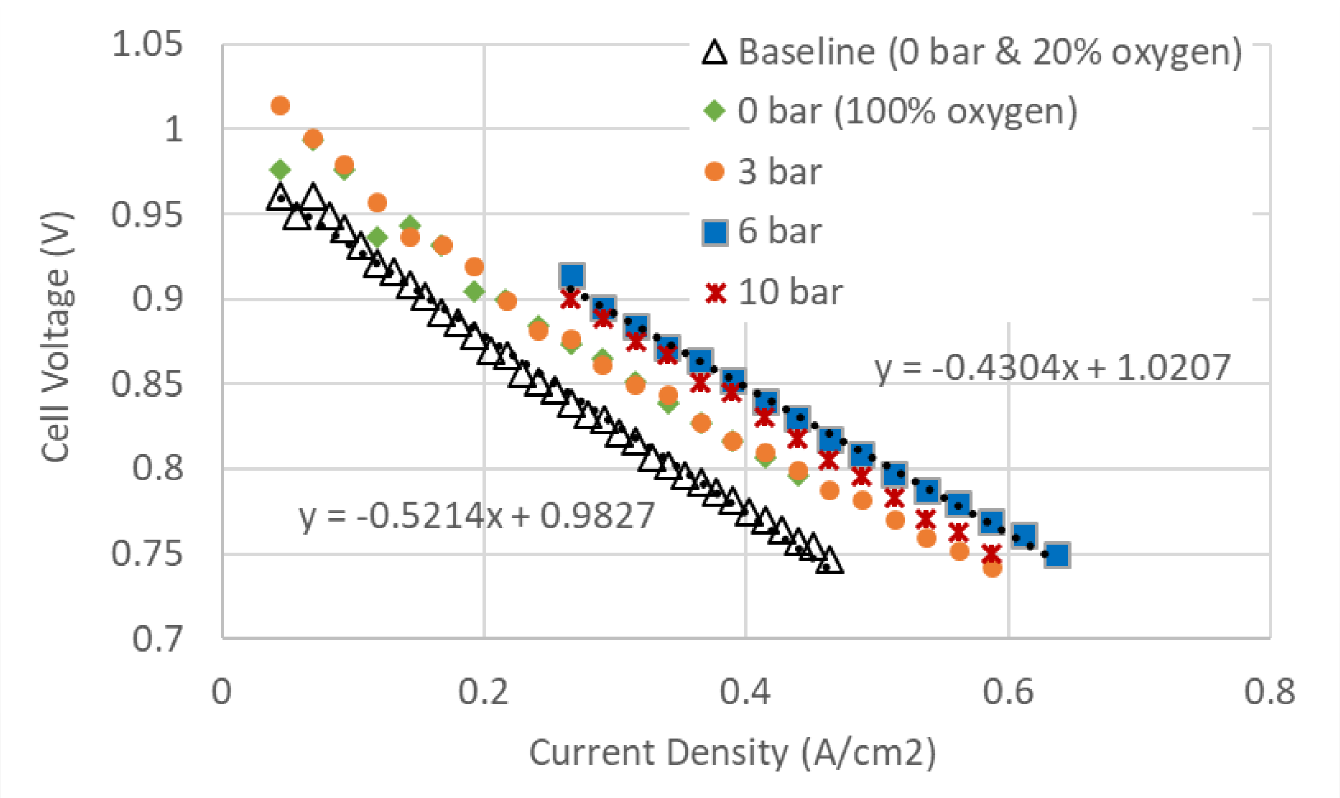


I-V cell characterization

- Despite the leakage, the cell was functioning, and I-V curves were collected.
- By increasing pressure from atmospheric to 9 bar, the power density at 0.85 V saw a 37.3% increase.
- ASR was not constant, varying from 1.01 Ω cm² at atmospheric pressure then dropping to 0.76 Ω cm² at 3 bar, and again increasing to 0.82 Ω cm² at 9 bar.



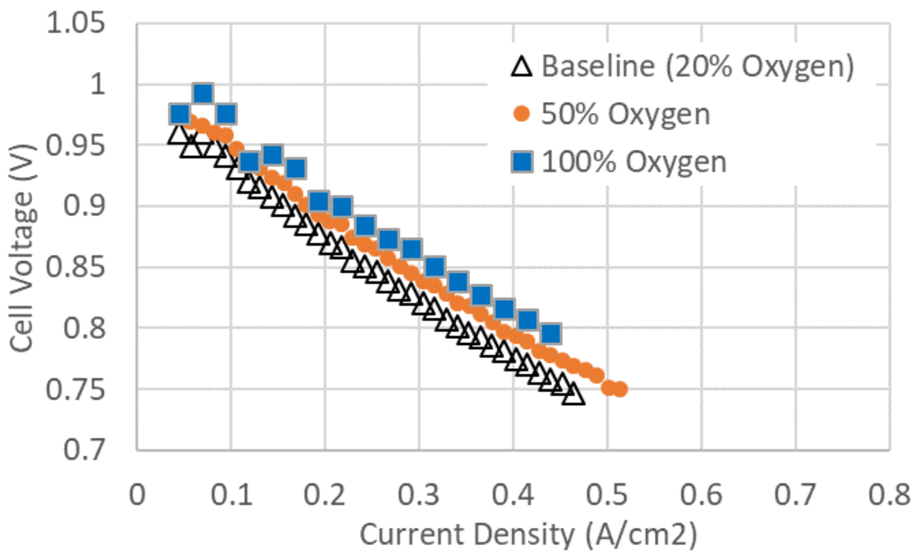
Impact of Pressurization on Performance



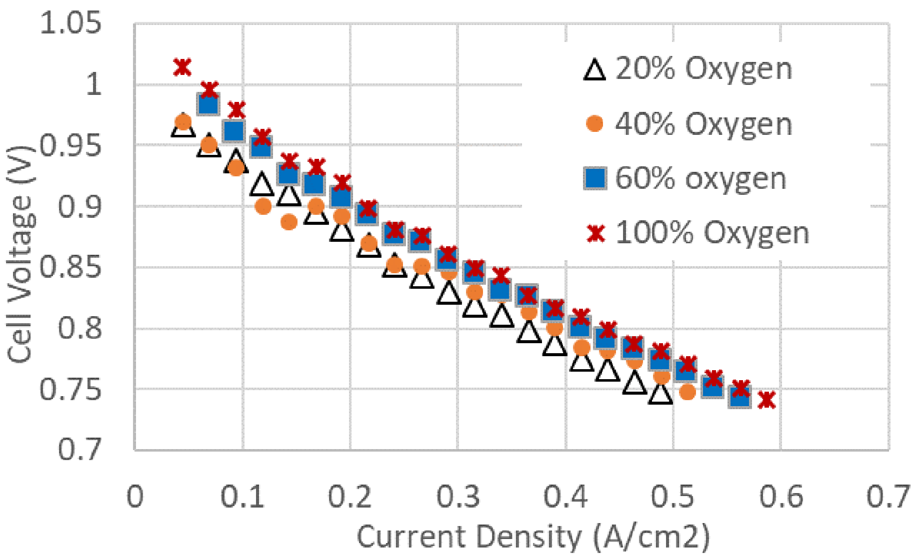
- Changing from baseline conditions to pressurized operation (6 bar), with a 100% oxygen cathode resulted in a 61% improvement in operating power at a voltage of 0.85V
- There is a decrease in performance between 6 bar and 10 bar.

Oxygen Concentration Sweep

Atmospheric Pressure



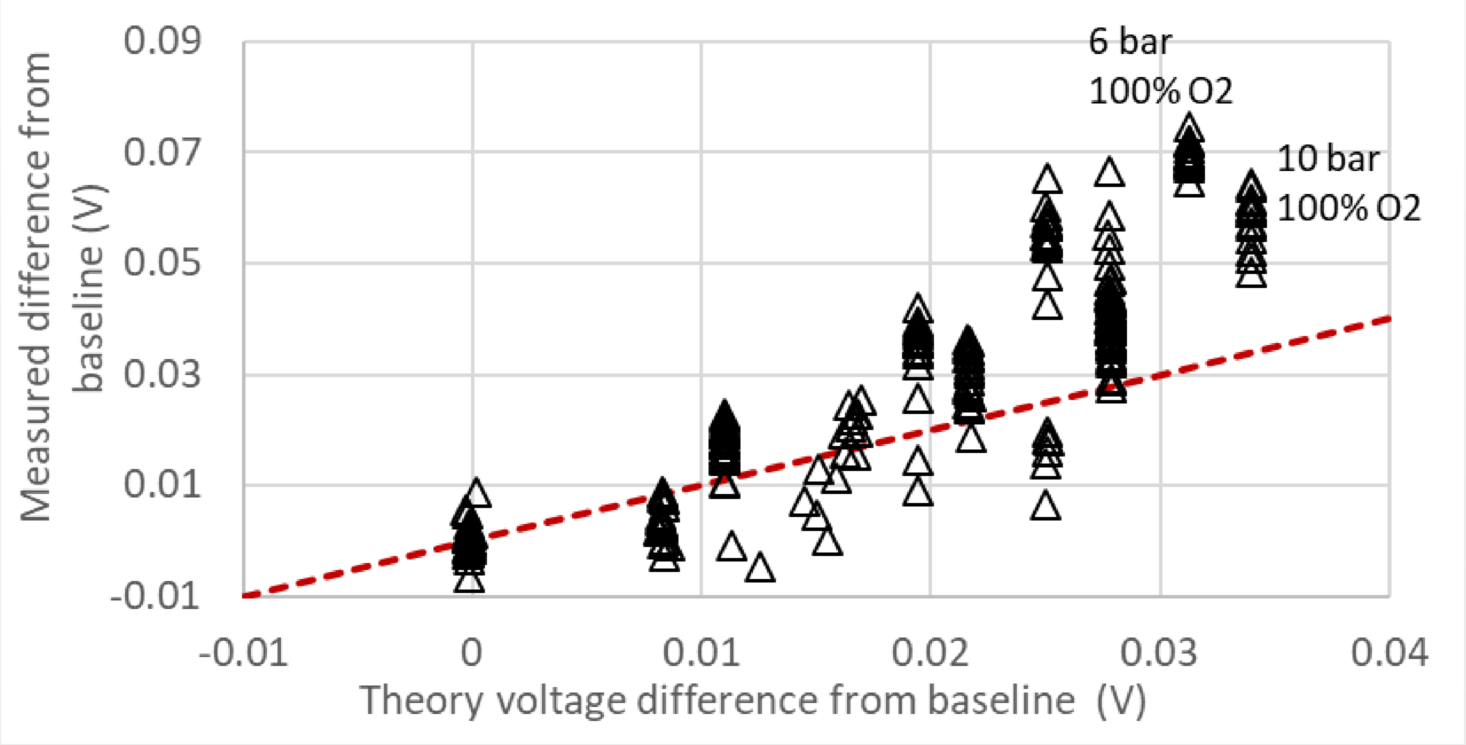
3 bar Gauge



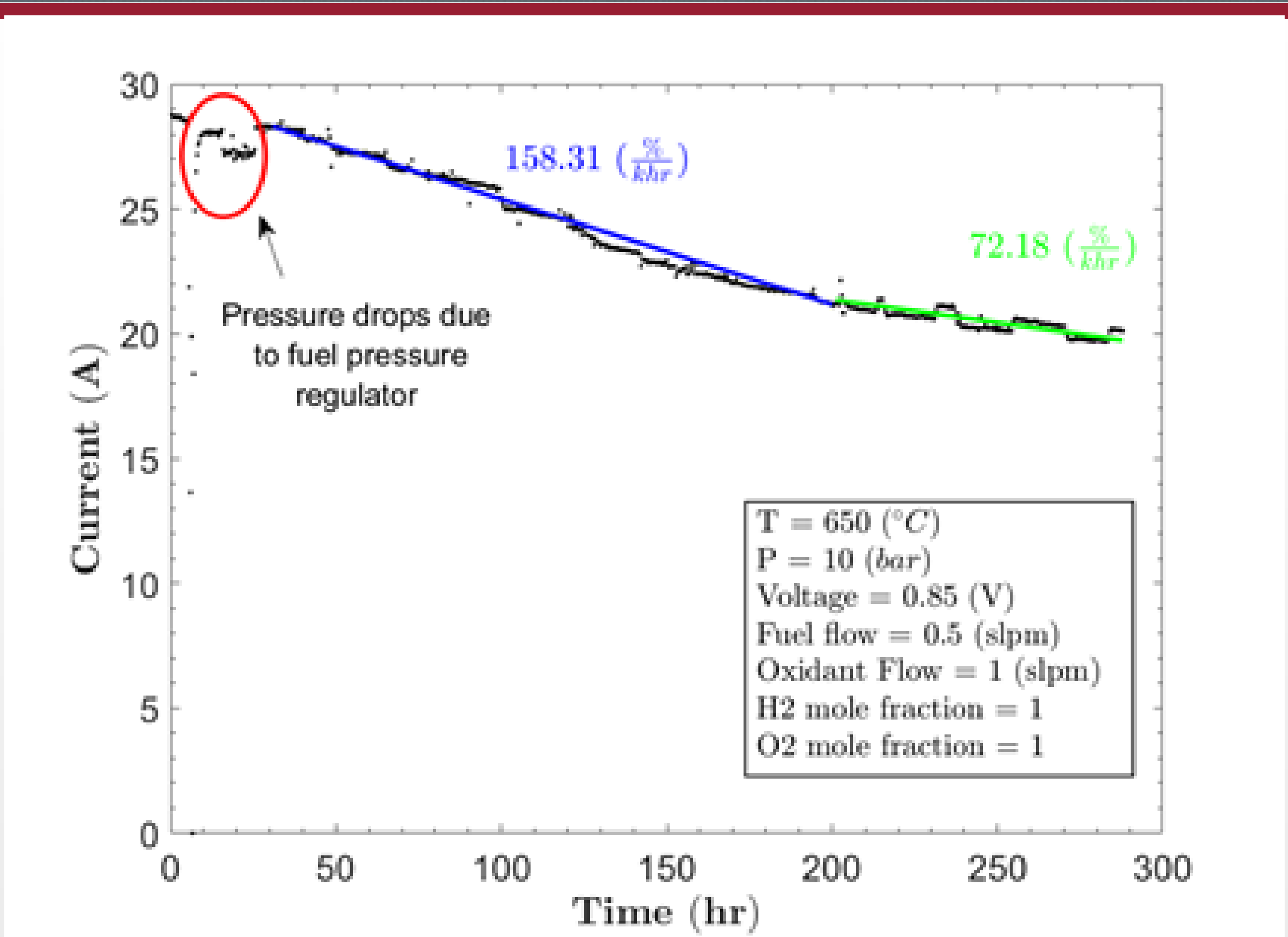
- Testing was performed at a constant 50% H_2 utilization, and 12.5 % O_2 utilization.

Impact of Pressurization on Performance

- Improvement exceeds that expected from enhanced Nernst Potential
- Pressurization is significantly reducing loss mechanisms above 3bar

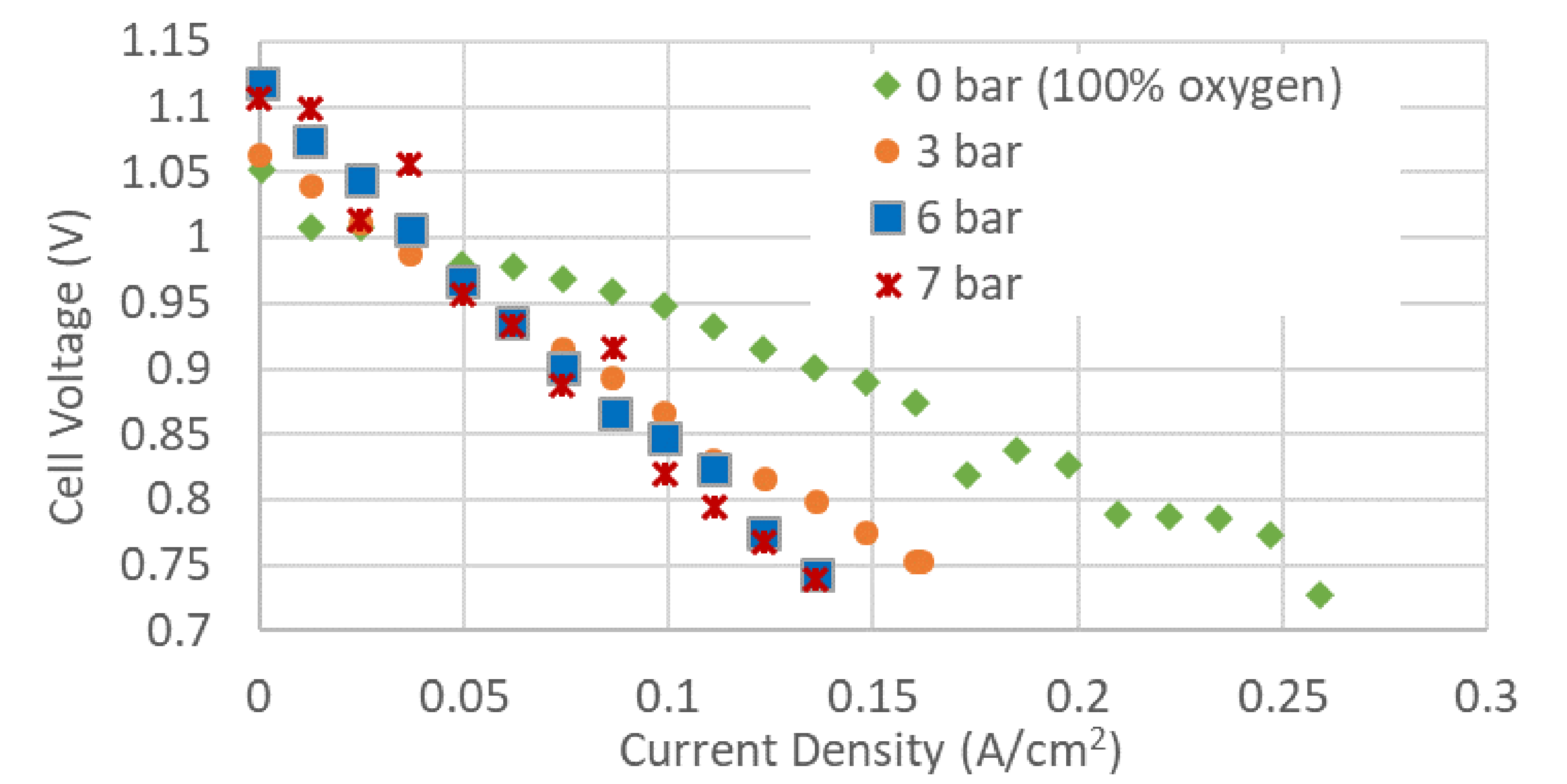


Current Degradation With Time



- Significant degradation, which slowed slightly after 200 hrs.
- Chrome volatilization suspected

Direct Internal Methane Reforming



- The fuel inlet gas composition was 0.3 slpm H_2, 0.1 slpm N_2, 0.45 slpm H_2O, and 0.15 slpm CH_4, for a total anode flow rate of 1 slpm.
- A brief period without steam after atmospheric testing significantly degraded cell performance.

Conclusions

- Pressurization may be key to unlocking SOFC potential
- WSU has developed new testing capabilities
- Demonstrated 61% performance improvement
- Degradation needs further investigation
- Complete direct internal reforming is possible at pressure

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