Clean Energy Systems Integration Lab

Washington State University

Test-Stand Development

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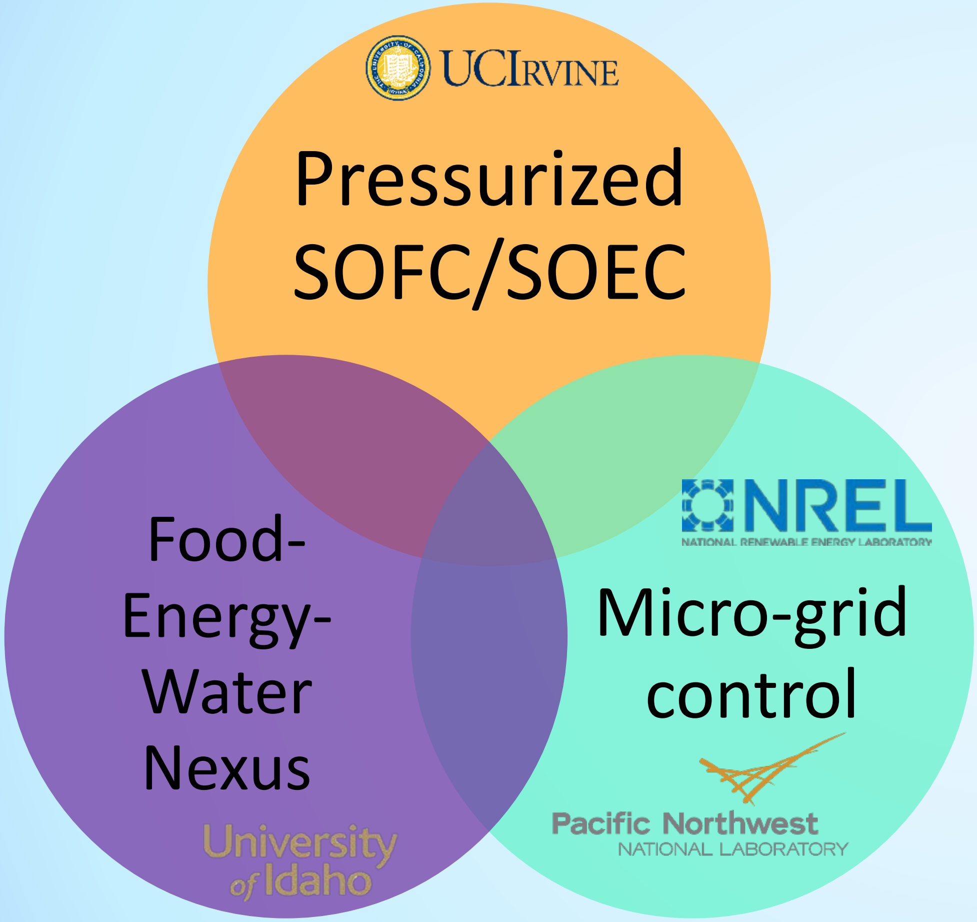
Washington State University

- Land grant Institution founded in 1890
- 29,686 Students (20,043 at Pullman Campus)

Set among the scenic Palouse hills

CESI Lab



How does pressurization affect performance?

Are there alternative system configurations that enable pressurized operation?

How do we incorporate the slower transients of high temperature fuel cells with energy storage to meet local demands

What role can solid oxide technology and the hydrogen economy play in sustainable systems

Overview

» Why Pressurized SOFC/SOEC?

- > Higher FC operating voltage (also with pure O_2 cathode)
- > Potential for low energy H_2 recovery, ammonia co-production, integrated carbon capture & liquefaction
- > Reduce/eliminate high temperature air heat exchangers (with pure O_2 cathode)
- > Potential for continuous H_2 production in both modes (integrate with H_2 liquefier being developed at WSU)

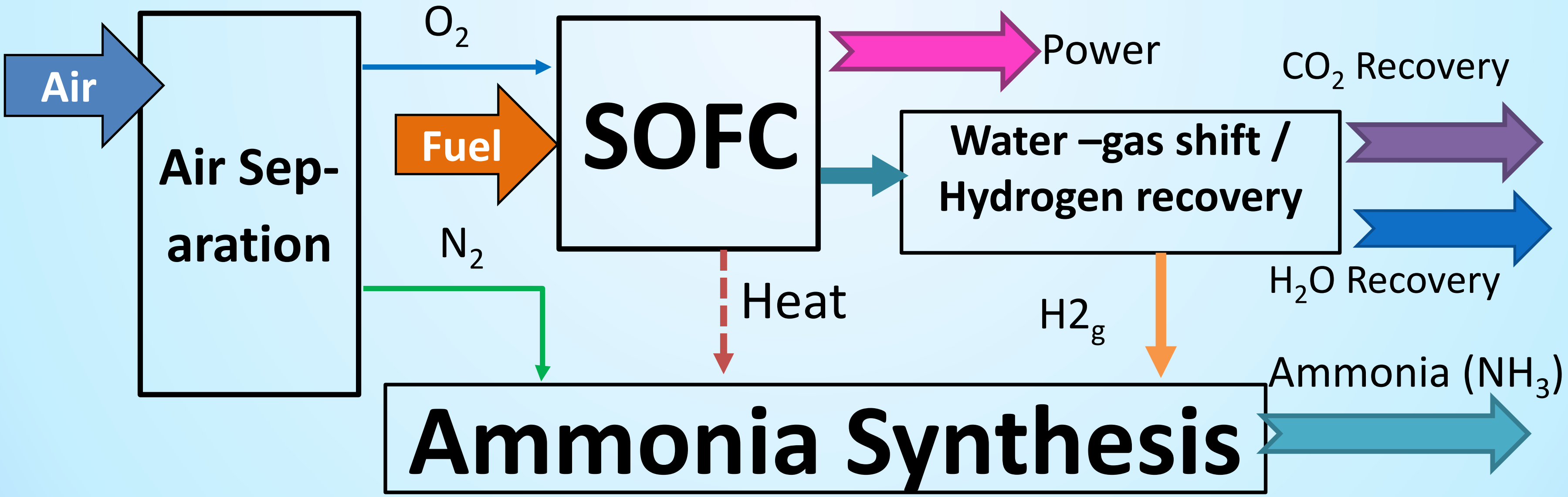
» What will CESI lab test?

- > Pre-commercial SOFC cells (100mm X 100mm) at 0-150psig
- > Operation at elevated pressure with pure O_2 cathode
- > Indirect/direct internal reforming
- > Participation of CO in electrochemistry
- > O_2 purge cycle for closed-end cathode (requires additional hardware installation)

Ammonia Co-Production

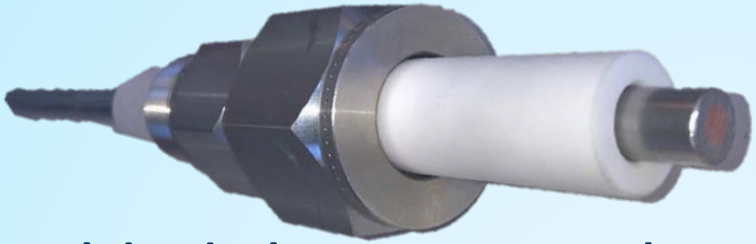
<u>Oxy-FC can provide ultra-efficient, carbon neutral, fertilizer production</u>

- Pressurized, pure O_2 cathode and higher anode H_2 concentration increases efficiency
- Waste heat captured in chemical potential of H_2
- Air separation yields O_2 for FC and liquid N_2 for the carbon liquefaction and H_2 recovery
- Exhaust N_2 and H_2 streams pass over a catalyst bed to form NH_3 (Haber-Bosch)
- Ammonia production consumes 5% of the world's natural gas (<50% efficient)
- Combined system co-produces electricity + ammonia + liquid CO2 at +80% efficiency

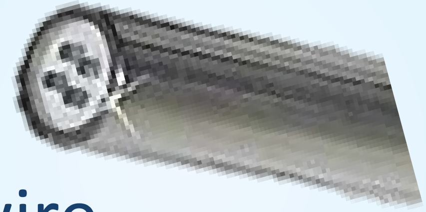


Electrical Components

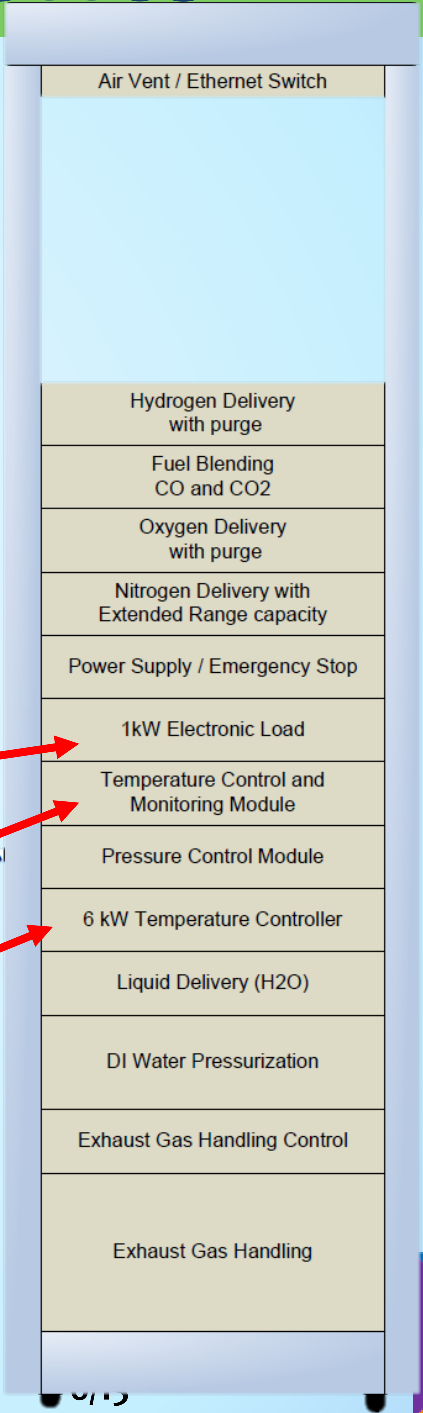
- Copper cored electrodes



- Shielded thermocouples



- Shielded voltage wire
  - Missile wire rated to 2000F
- 1 kW Load bank
  - 200 amps
  - 10 voltage measurements
- Humidifier Control
- Furnace Control



Gas Handling Components

» Cathode:

- > 150psig rated MFC for N_2 delivering 0.2→10slpm
  - + Expandable to 125slpm
- > 150psig rated MFC for O_2/Air delivering 0.2→10slpm

» Anode

- > 150psig rated MFC for H_2 delivering 0.1→5slpm
- > 150psig rated MFC for CO & CO_2 delivering 0.002→0.1slpm

» Humidifier

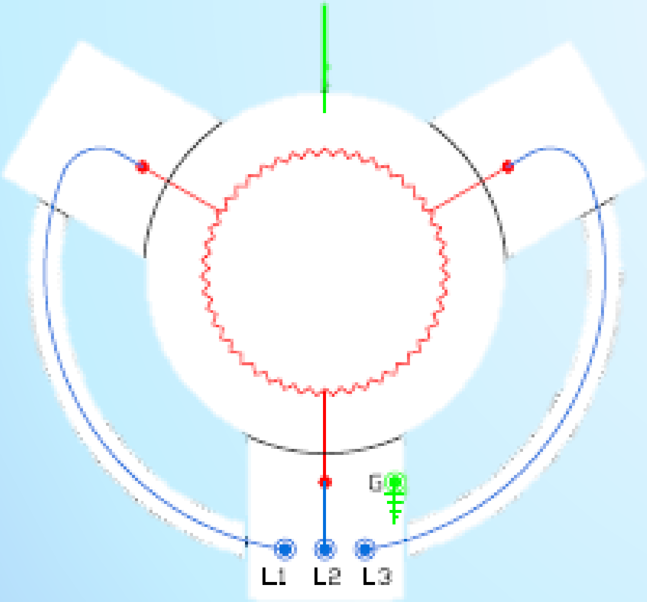
- > Pressurized D-I water reservoir and liquid MFC for H_2O delivering 0.2→10gpm

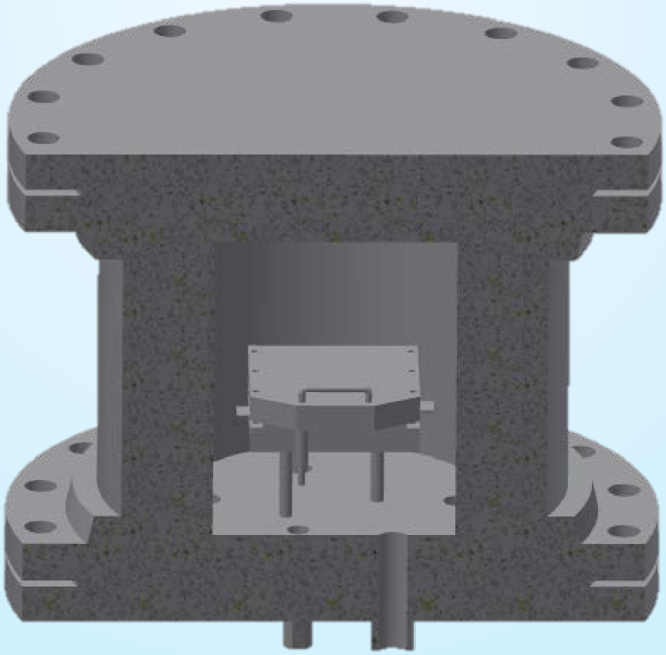
» Gas cabinets / regulators

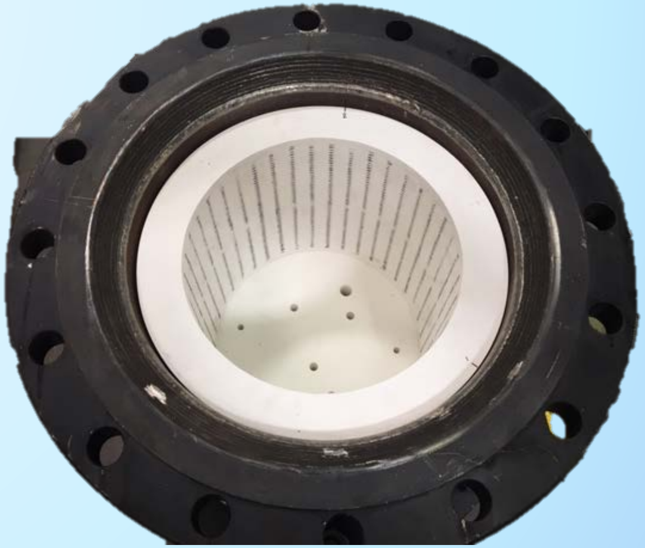
- > 4 X GasGaurd bottle cabinets with continuous exhaust
- > 3 X dual bottle 200 psig regulators with automatic switchover
- > 1 X 200 psig regulator for inert & control air

Heating and Humidification

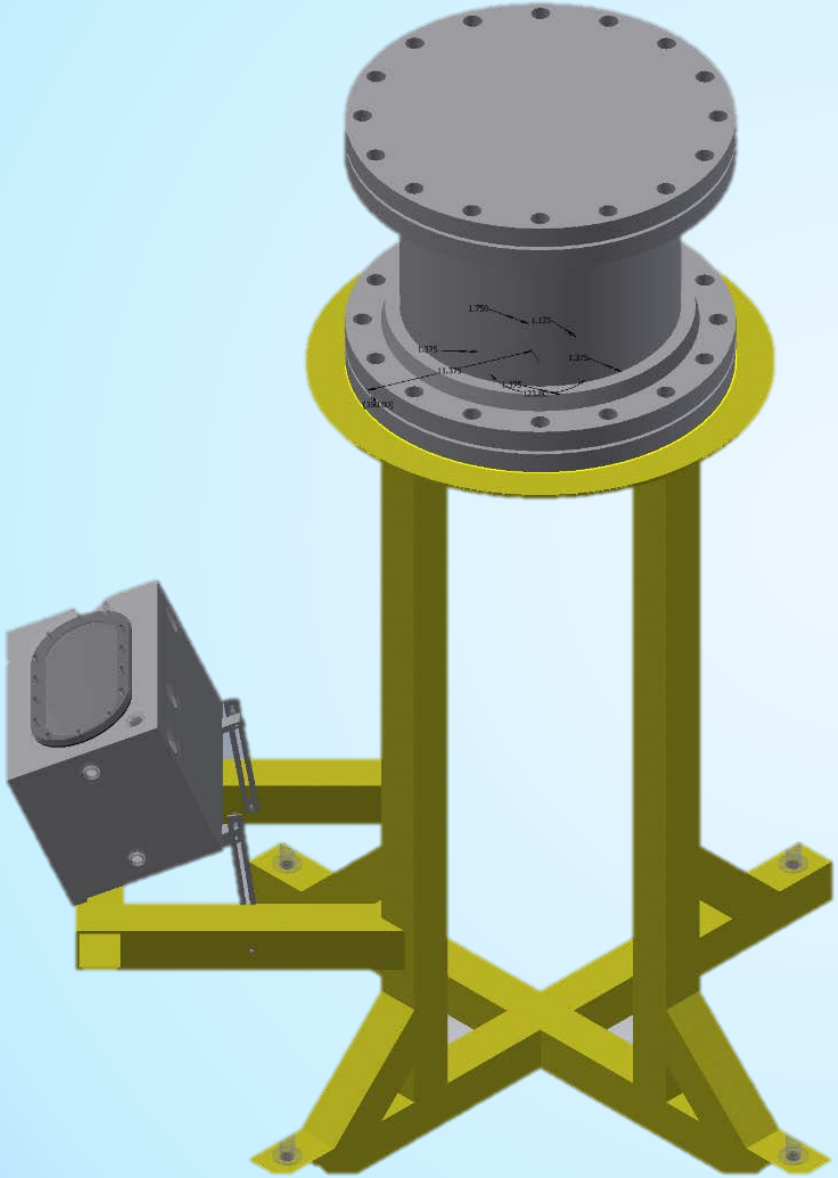
- 6kW furnace rated to 1000°C and 150psig
  - Top-hat style so top+ sides lift off to expose working area
  - Bottom mounted to stand
- 1 kW anode humidifier







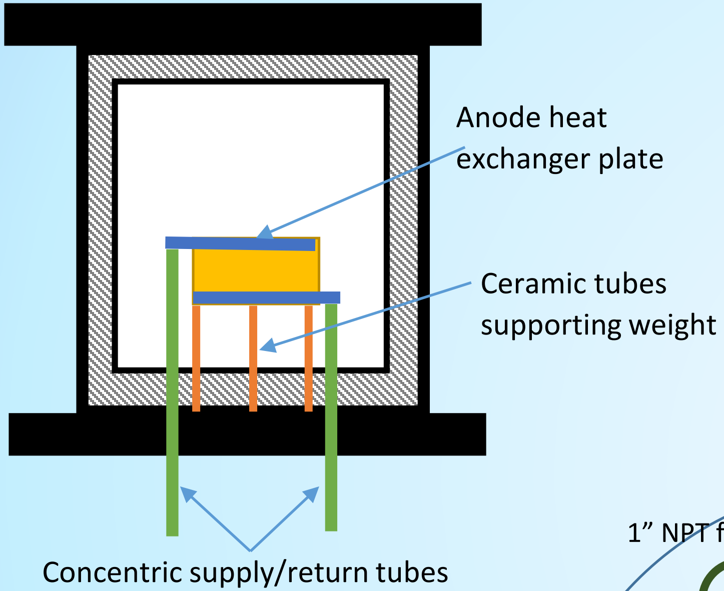
Furnace Stand & Exhaust Cooling

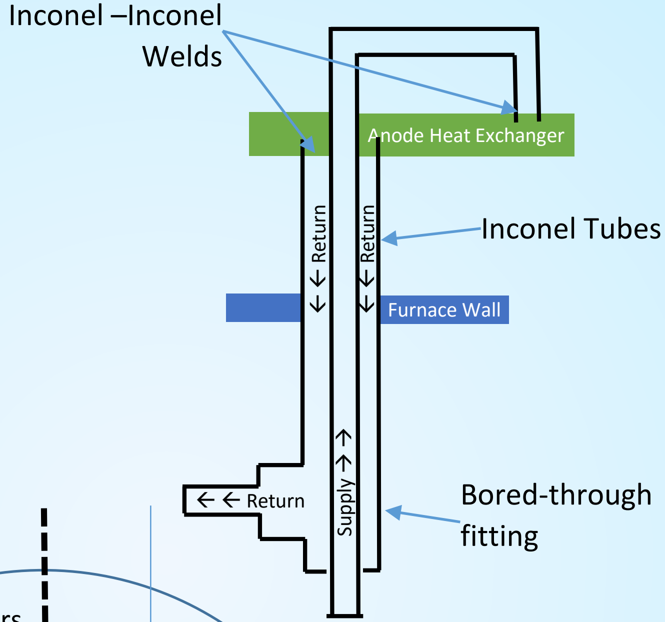


Fittings & Pass Throughs

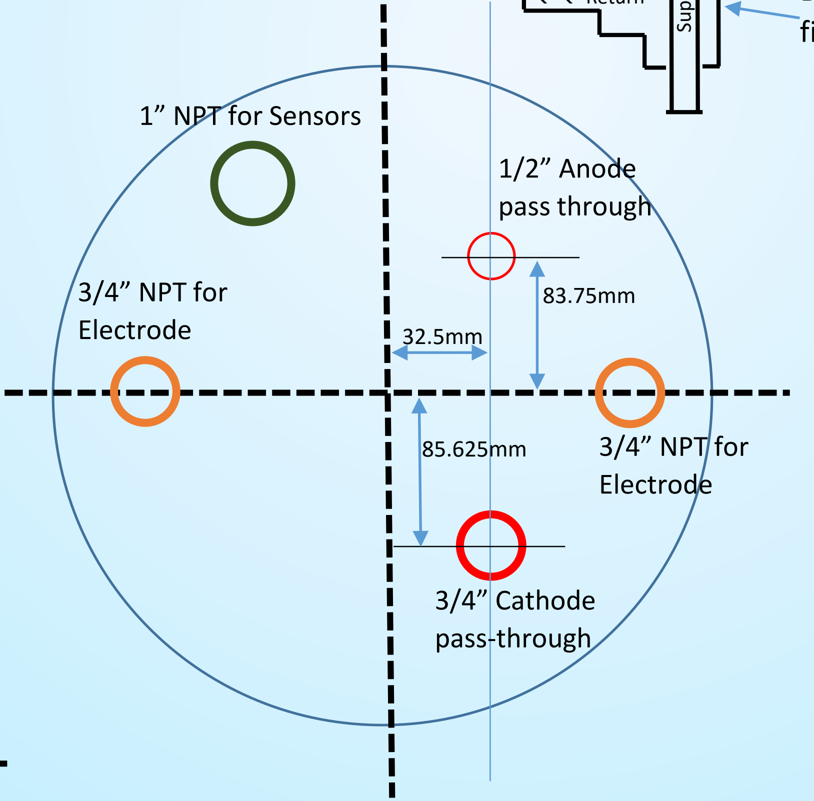
High Pressure Furnace

Test volume: Diameter = 300mm
Height = 300mm





- 5 pass throughs in bottom of furnace

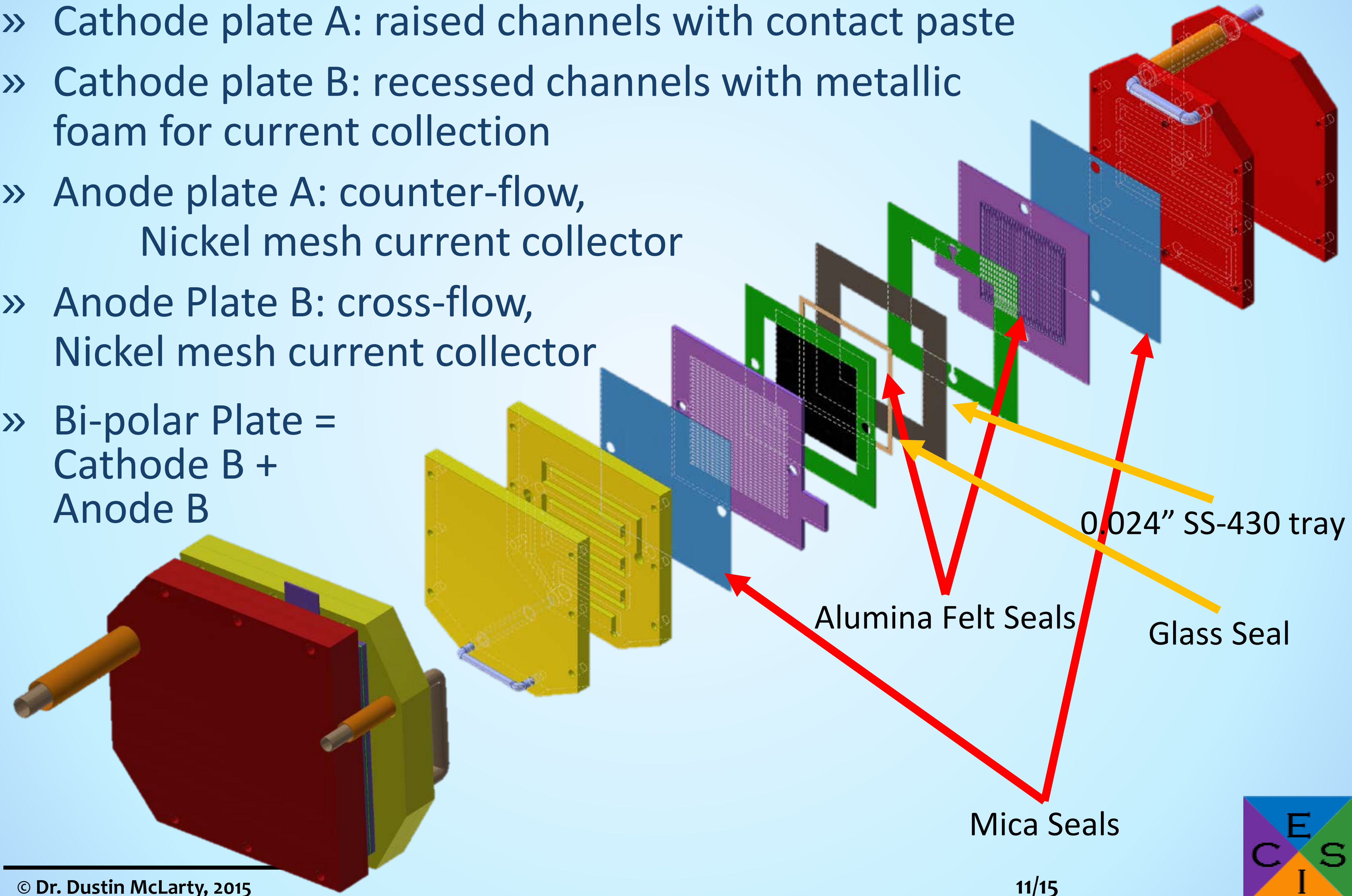


Aerospace multi-sensor pass through

- Sensor diameter 0.1”
- Pressure rating 150psig
- Up to 28 sensors

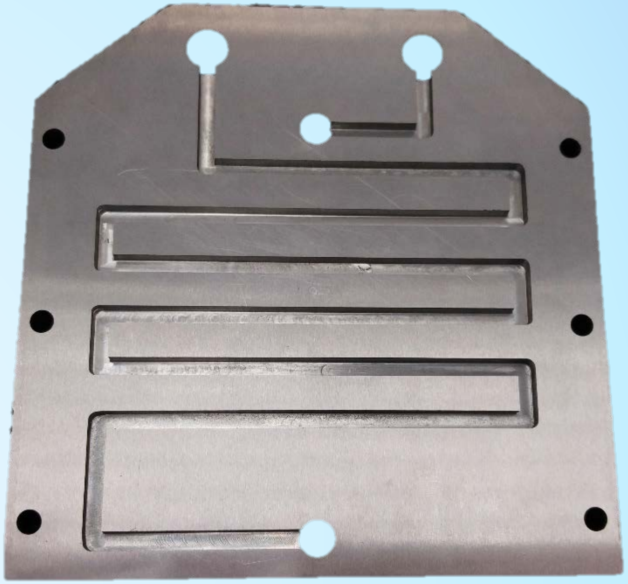
Stack Arrangement

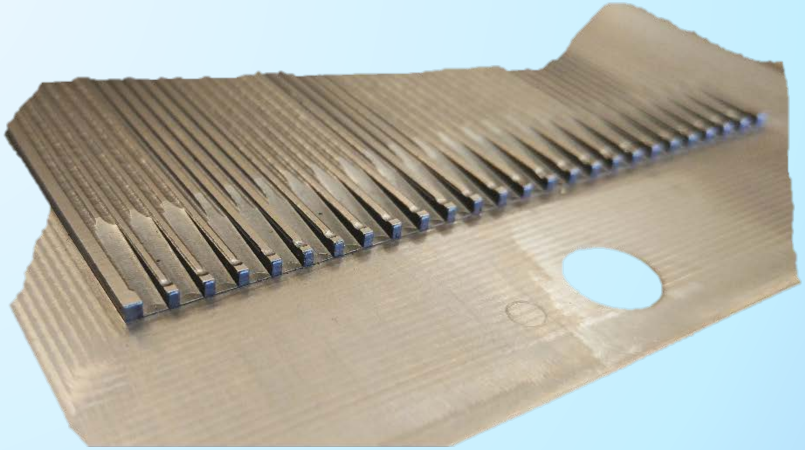
- Cathode plate A: raised channels with contact paste
- Cathode plate B: recessed channels with metallic foam for current collection
- Anode plate A: counter-flow,
  Nickel mesh current collector
- Anode Plate B: cross-flow,
  Nickel mesh current collector
- Bi-polar Plate =
  Cathode B +
  Anode B

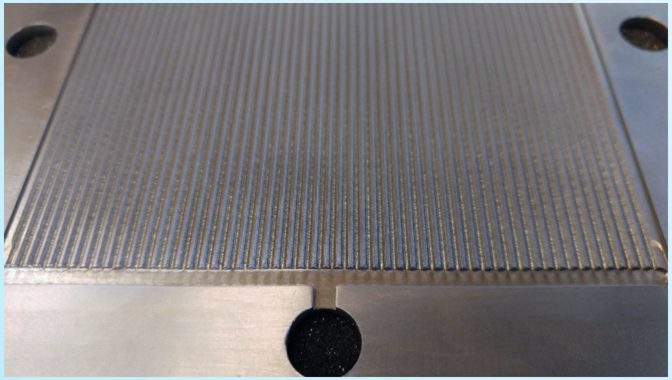


Machining and Post-Treatment

- Anode & Cathode heat exchangers machined from ½" Inconel plate
  - Plates aluminide coated & brazed together
  - Post-machining of a moat to create a strong Inconel-Inconel weld
- Anode A & B, Cathode A & B, and bi-polar plates machined from 0.12" SS-430
  - Anode plates aluminide coated via thermal spray
  - Cathode plates spinel coated with Mn1.5Co1.5O4
- Water-jetting process for small anode/cathode channels to reduce machining time



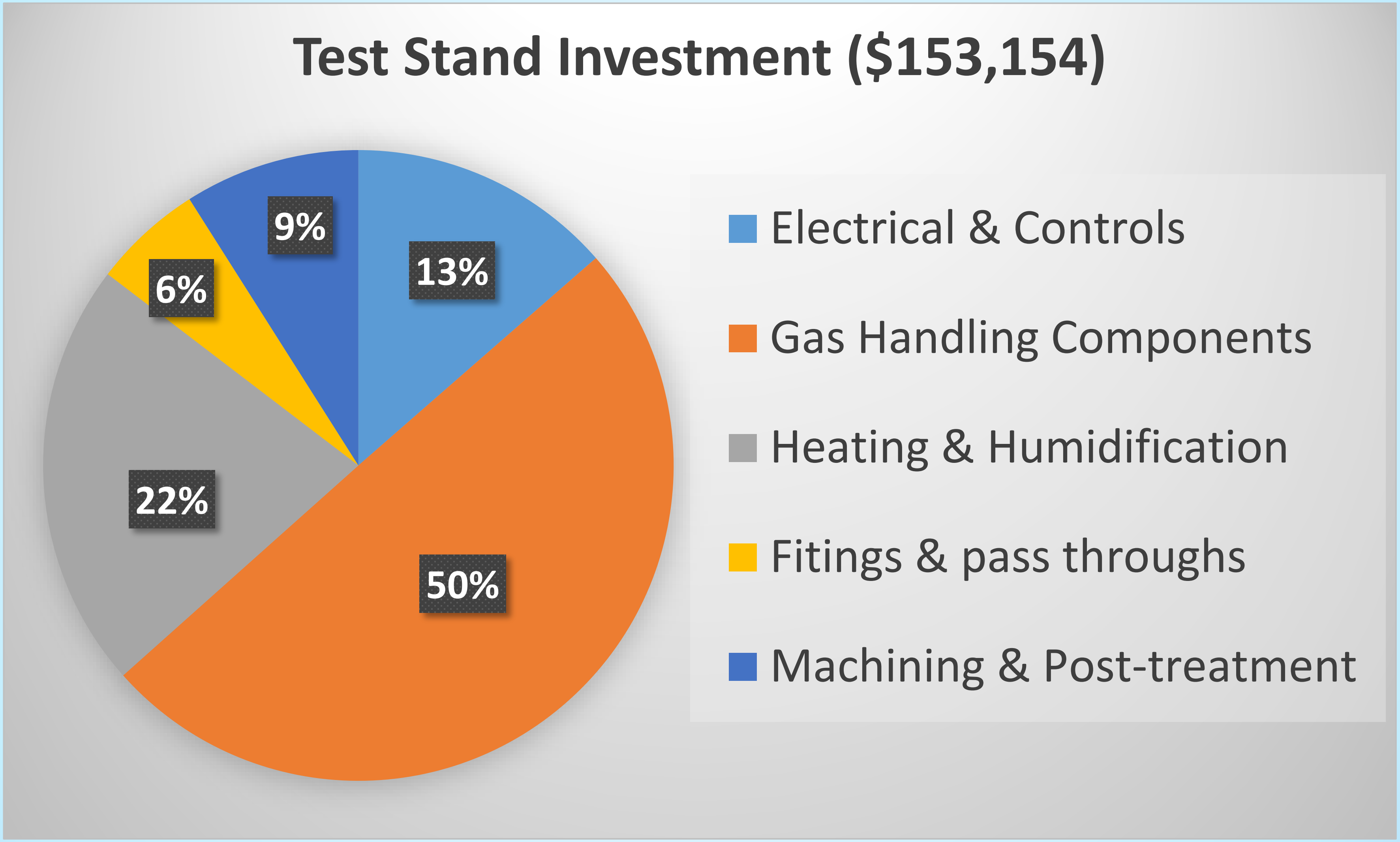




SOFC Materials

Support	Anode	Cathode	Thickness (µm)	Rated Voltage @ 0.5A/cm^2	Cell Cost
Electrolyte	NiO-GDC	LSM-GDC	250	0.7	$360
Electrolyte	Ni-YSZ	LSM	150	0.73	$225
Electrolyte	Ni-YSZ	LSM	150	0.75	$250
Electrolyte	Ni-GDC	LSCF	160	0.8	$280
Anode	3 layers	2 layers	700	0.85	$160
Anode	GDC	LSC	250	0.9	$270

Cost Summary



Conclusions

- Pressurized SOFC/SOEC has a number of applications
  - FC-GT hybrids
  - Oxy-FC with ammonia co-production
  - Electrolysis with methanation
- Published data for pressurized operation is scarce
- CESI lab's test stand will evaluate commercial scale cells and small stacks up to 1kW at up to 150psig, and test with a pure O_2 cathode
- Off-the-shelf furnace + pressure vessel is extremely expensive and large, custom option may actually save costs
- Water-jet machining is a good option for lab test interconnects, but commercialization requires stamping
- Mass flow controllers rated for 150psig are the bulk of the test stand cost
- There is considerable spread in the cost to researchers of pre-commercial SOFC