Solid Oxide Fuel Cell Carbon Sequestration

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with Support of NiSource Energy Technologies

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PDP 36

Overview

- Timeline
  - –Project Start: November 6, 2004
  - –Project End: September 30, 2006
  - –21% Complete
- Budget
  - –Total Project: $2,452,700
  - –DOE Share: $1,962,155
  - –Contractor Share: $490,545

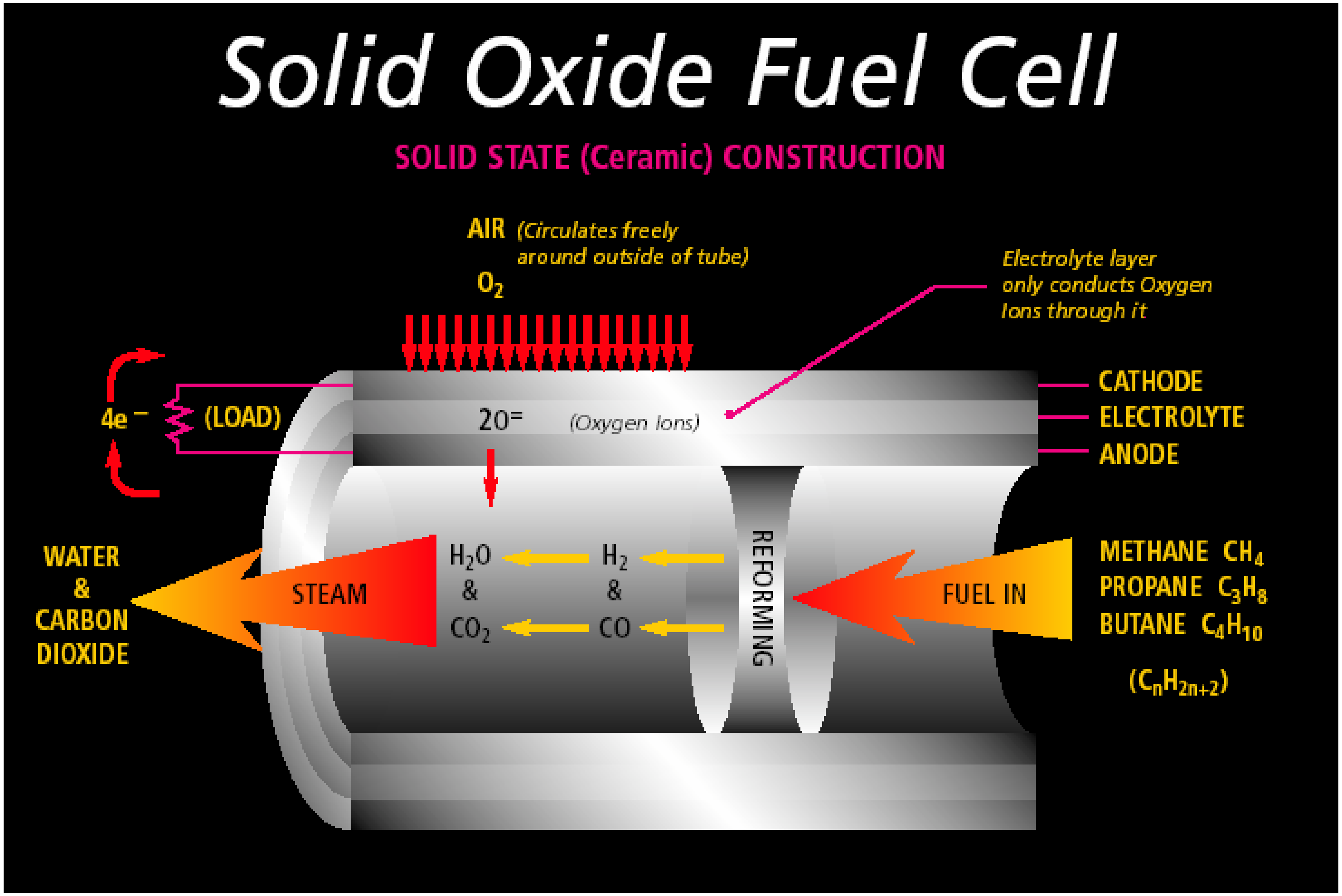
Project Objectives

- The objective of the project is to develop the technology capable of capturing all carbon monoxide and carbon dioxide from a natural gas fueled Solid Oxide Fuel Cell (SOFC) system.

- In addition, the technology to electrochemically oxidize any remaining carbon monoxide to carbon dioxide will be developed.

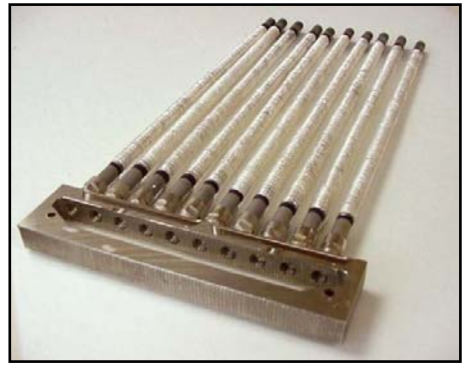
- Success of this R&D program would allow for the generation of electrical power and thermal power from a fossil fuel driven SOFC system without the carbon emissions resulting from any other fossil fueled power generation system.

How Acumentrics Fuel Cells Work



Acumentrics Fuel Cell Evolution

Stackable Single Chamber Manifold design



5 Watt
Tubes
Q2 2002

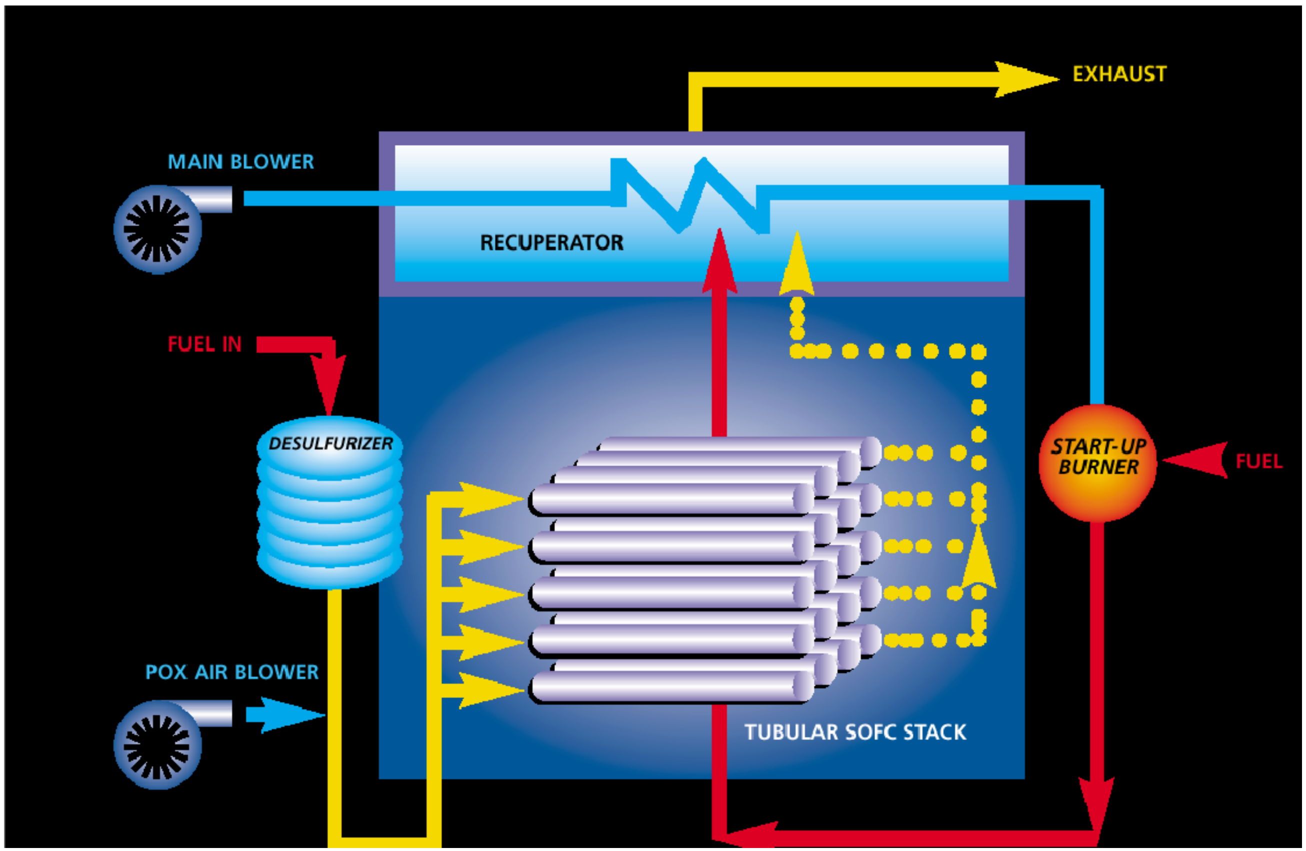
Stack Design Attributes

- Anode support tubes
- Brazed seals
- Stackable design
- Welded electric connections
- Low thermal mass
- Withstands heat expansion

High Power Anode Tubes

20 Watt
Tubes
Q3 2003

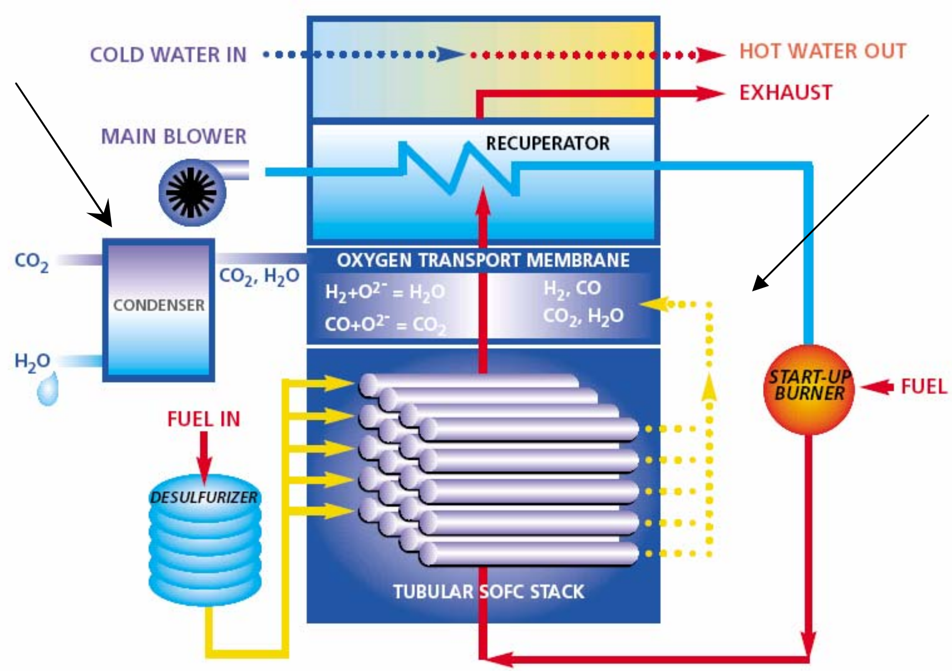
Acumentrics Tubular SOFC System Overview



In the existing generator design, the non-electrochemically used fuel is combusted with the air and exhausted to the atmosphere

Conceptual layout of a CO_2 Sequestered SOFC Generator

The CO_2 & H_2O are then passed across a condensor removing the water leaving a pure CO_2 stream



In the conceptual design, the non-electrochemically oxidized fuel is passed to a set of ceramic membranes which fully oxidize the remaining fuel.

Approach

- There are two key developments needed to successfully complete this research:

1. Develop the capability to capture the electrochemically utilized fuel gas.
2. Complete the oxidation of the spent fuel to result in an exhaust stream containing only carbon dioxide and steam.

Technical Accomplishments
1. Capturing Utilized Fuel

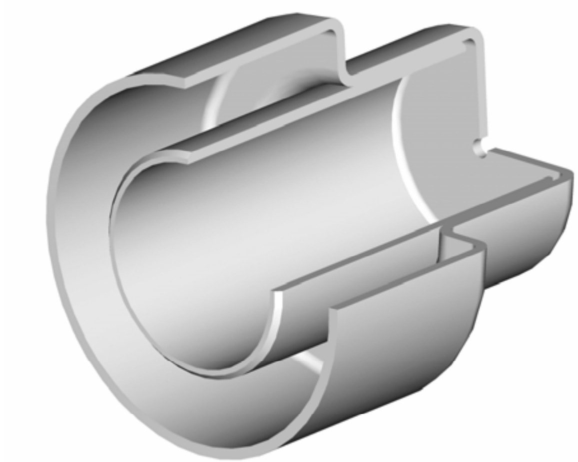
- A double chamber manifold has been developed building on the single chamber design.
- An ability to close the normally open end of the cell has been proven by two concepts- brazing and isopressing.

Double Chambered Manifolds

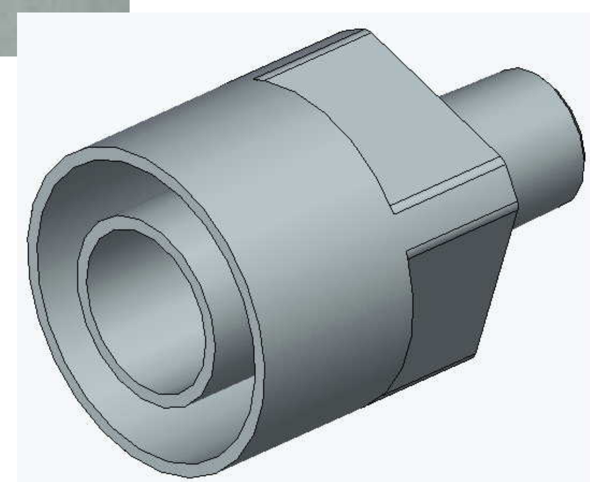
Fuel Inlet Cavity

Spent Fuel Cavity

Cap Designs



The existing cap designs allow for fuel delivery through an injector tube while providing the negative connection for the fuel cell.

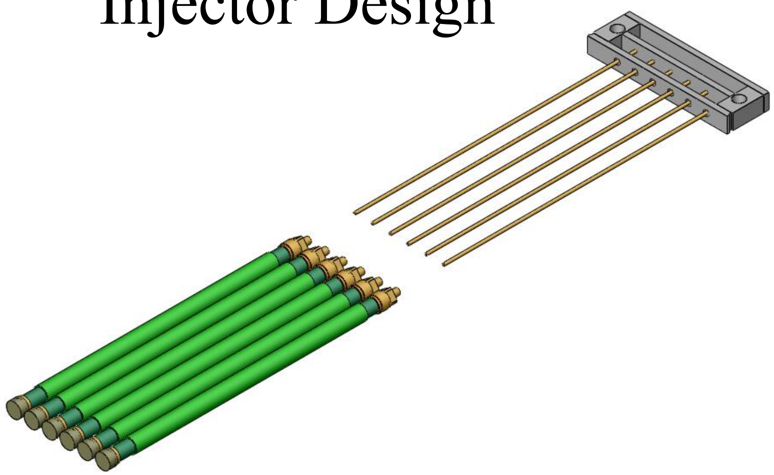


Injector Options

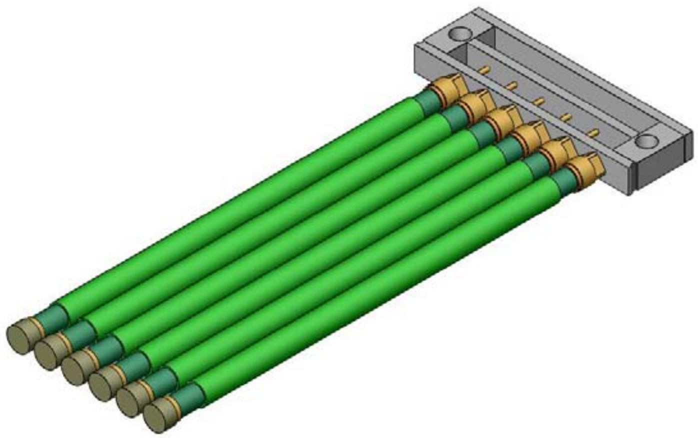
- Utilized to deliver fuel to the opposite cell end
- Contains an orifice for flow uniformity

Double Manifold Configuration

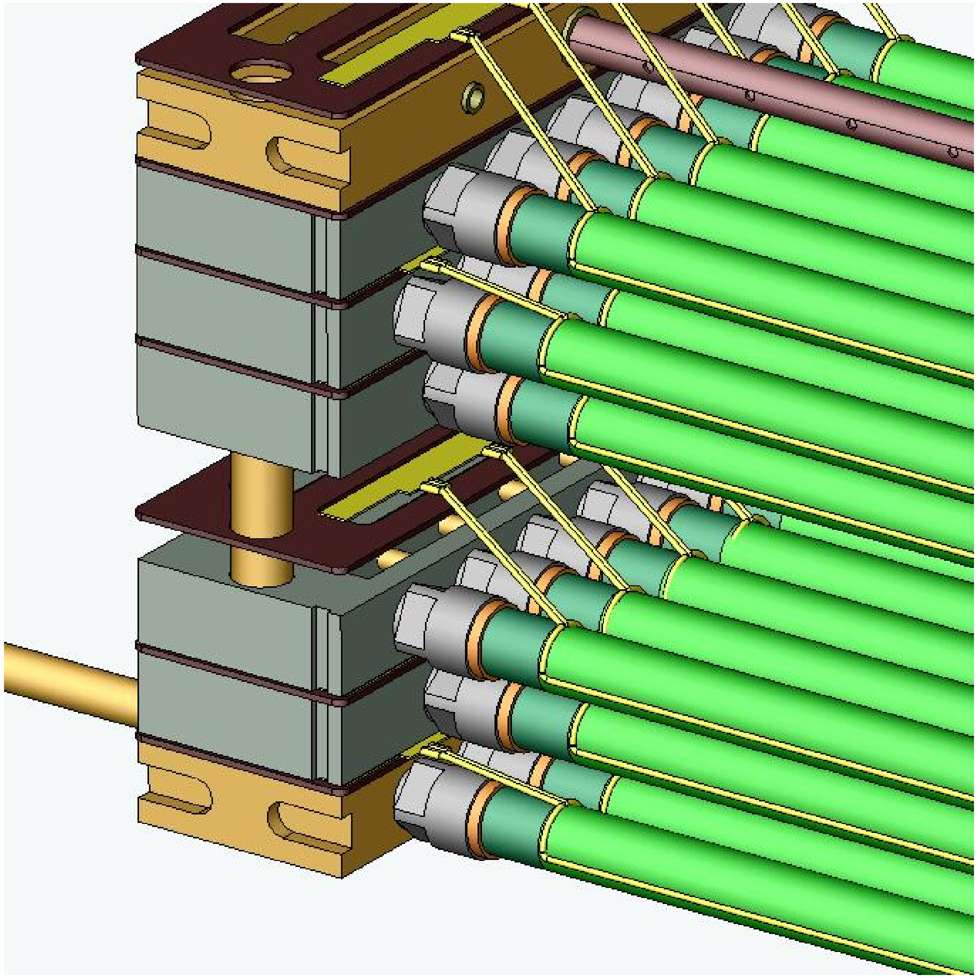
Injector Design



6 Cell Manifold Design



Double Manifold Stack Configuration



Closed End Formation - Braze Caps

Closed End Formation - Isopressing

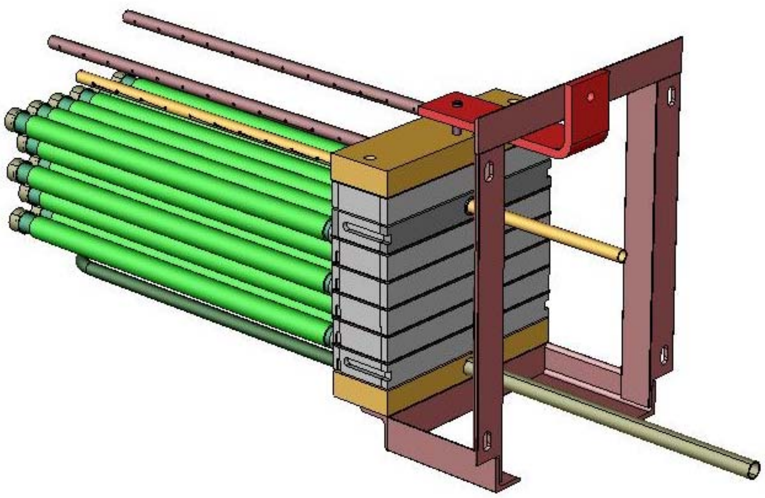
- This tube has been manufactured by isopressing the anode powder in a mold with an integral closed end

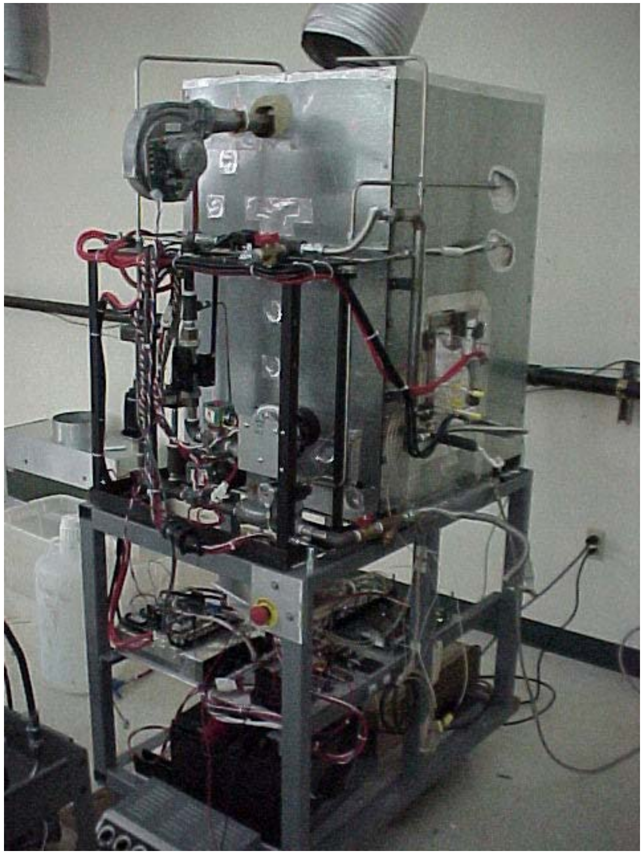
Proof Fuel Sealing and Capture

- Develop test rig to check internal fuel sealing at high temperature
- Make additions to current rig: gas sampling port (determine inlet/exhaust compositions), and an oxygen sensor (determine how much fuel escapes).
- Develop new software for test rig
- Make necessary preparations for extended run times

Spent Fuel Capture Test Stands

- Manifolds and current interconnects can be tested in these devices
- Up to six manifolds can be bundled together to form a mini stack





Spent Fuel Oxidation Test Chambers

Technical Accomplishments
2. Oxidation of Spent Fuel

$$CO + H_2 + 2O^{2-} \rightarrow CO_2 + H_2O + 4e^-$$

Possibilities…

A. Mixed ionic electronic conductor (MIEC) coating
B. Dual phase composite
C. Single material MIEC

A. Mixed Ionic electronic conductor (MIEC) coating

Concept: By applying a thin film of a MIEC material onto a standard Acumentrics anode tube, a viable afterburner cell may be possible

- Oxygen Transport Membrane I (OTM I) and Oxygen Transport Membrane II (OTM II) are materials that both exhibit mixed ionic/electronic conduction.

- Powders of each were formulated into slurries for such coatings

A. MIEC coating

OTM I

- Coating showed pitting after application
- Pitting caused cracks in coating when fired
- OTM I coatings were unsuccessful

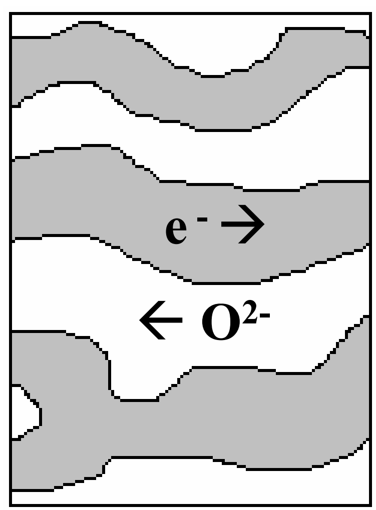
OTM II

- Formed dense, leak-tight coatings when sintered at temps $\geq$ 1500 °C
- Sintering problematic - coatings were prone to pin holes
- OTM II coatings were however largely successful

B. Dual Phase Composite

- Afterburner Cells with a combination Electrolyte/Silver Coating

Dual Phase Membrane



B. Dual Phase Composite

Concept: YSZ electrolyte is used in combination with silver to create a MIEC, which acts as an internal short

Two methodologies were used to create such a composite

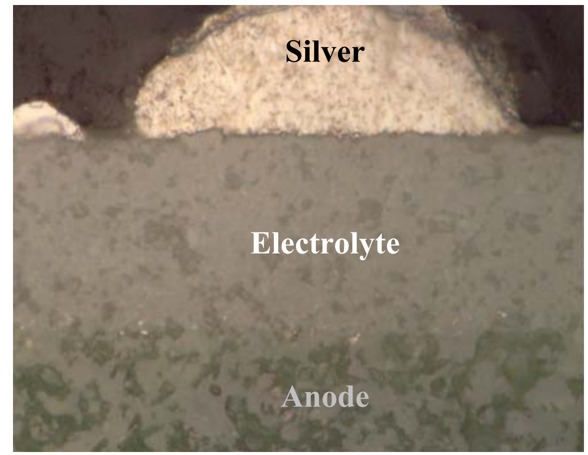
I. *Application of silver ink to a porous YSZ coating followed by a firing and reduction step*

II. *Reduction of YSZ coated tube, followed by application of silver ink (no subsequent firings)*

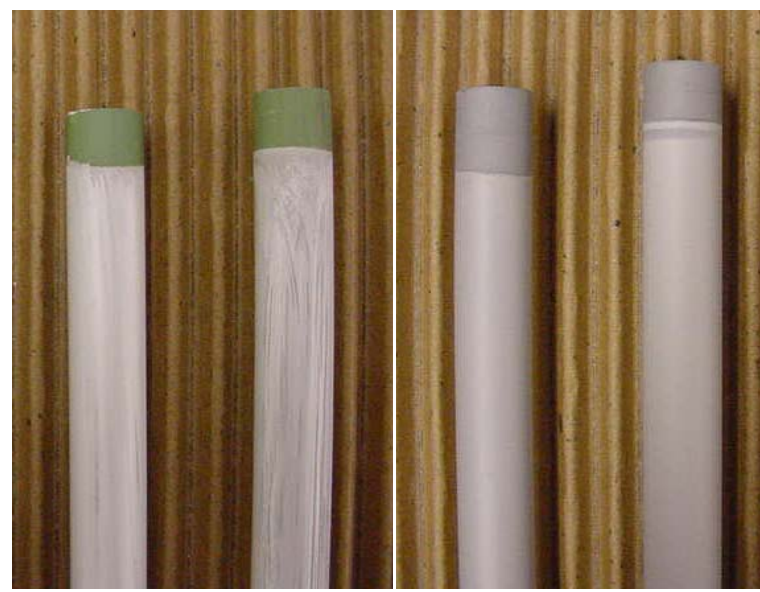
B. Dual Phase Composite

I. Application of silver pre firing and reduction

After multiple firings of multiple Ag coated tubes the Ag does not appear to have successfully penetrated the electrolyte



- Tubes after first Ag firing (left)
- Tubes after reduction firing (right)



Cells are "leak-tight", but still need to be tested to see if electrical short is created

B. Dual Phase Composite

I. Application of silver post firing and reduction

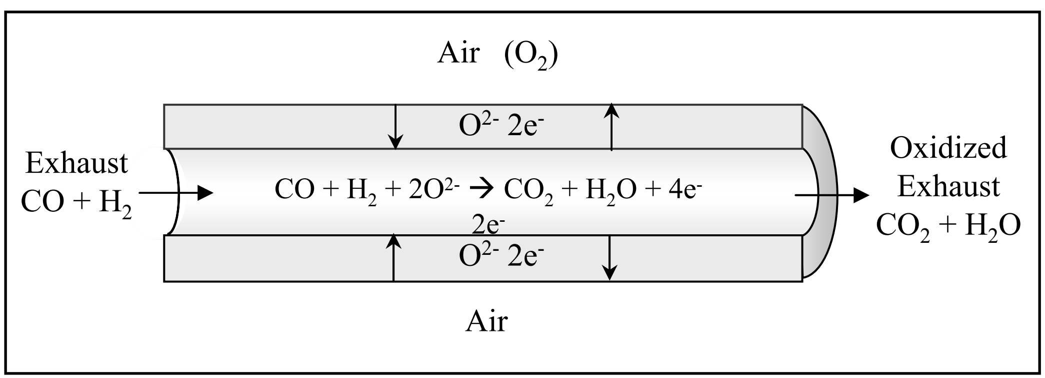
- Lowered silver to anode resistance
- Leak-tight
- Further testing is necessary


Silver Coating

C. Single Material MIEC

Concept: Use a single material which acts as a mixed ionic/electronic conductor.

- OTM III exhibits high oxygen fluxes and high electronic conductivity.



C. Single Material MIEC

Foreseeable
Advantages & Disadvantages

- Theoretical 100% fuel utilization
- Requires low surface area
- Shorter production time - dealing with one material

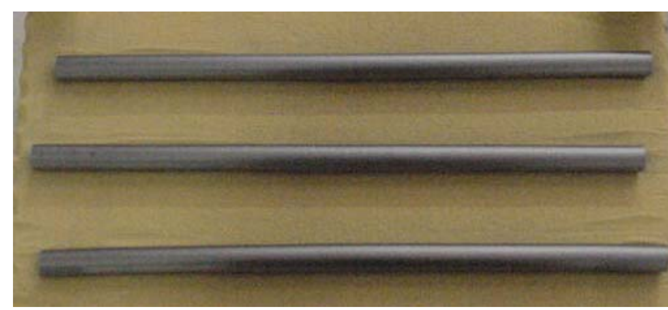
- Difficult to extrude
  - Must be thin enough for oxygen ions to diffuse through
  - Thick enough to support itself

C. MIEC Single Material

OTM III Tube

- Appropriate mixture combination (powder, binder, water) for successful extrusion
- Sintering temperature of 1325 ˚C necessary for sufficiently dense “leak-tight” tubes

- Sensitive to binder burnout
- Good conduction
- Yet to be seen if it can survive dual atmosphere (air & spent fuel)



Future Work

- Developments
  1. Fuel Capture
     - Complete build of the test rigs for manifolds and mixed conducting materials.
     - Test and demonstrate the capability to capture all fuel effluent
  2. Spent Fuel Oxidation
     - Successfully Produce an OTM II coated tube suitable for cell testing
     - Electrical testing for heat-treated silver coated tubes
     - Cell testing for non-heat-treated silver coated tubes
     - Determine whether OTM III tubes can survive the dual atmosphere environment of air and SOFC exhaust

- Complete the conceptual design of a carbon sequestered generator
- Complete a 2000 hour endurance test