

## 1.5 Zero Emission Power Plants Using Solid Oxide Fuel Cells and Oxygen Transport Membranes

### Abstract

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### Abstract

Siemens Westinghouse Power Corp. (SWPC) is engaged in the development of Solid Oxide Fuel Cell stationary power systems. SWPC has combined DOE Developmental funds with commercial customer funding to establish a record of successful SOFC field demonstration power systems of increasing size. SWPC will soon deploy the first unit of a newly developed 250 kWe Combined Heat Power System. It will generate electrical power at greater than 45% electrical efficiency.

The SWPC SOFC power systems are equipped to operate on lower number hydrocarbon fuels such as pipeline natural gas, which is desulfurized within the SOFC power system. Because the system operates with a relatively high electrical efficiency, the CO<sub>2</sub> emissions, ~1.0 lb CO<sub>2</sub>/ kW-hr, are low. Within the SOFC module the desulfurized fuel is utilized electrochemically and oxidized below the temperature for NO<sub>x</sub> generation. Therefore the NO<sub>x</sub> and SO<sub>x</sub> emissions for the SOFC power generation system are near negligible. The byproducts of the power generation from hydrocarbon fuels that are released into the environment are CO<sub>2</sub> and water vapor. This forward looking DOE sponsored Vision 21 program is supporting the development of methods to capture and sequester the CO<sub>2</sub>, resulting in a Zero Emission power generation system.

To accomplish this, SWPC is developing a SOFC module design, to be demonstrated in operating hardware, that will maintain separation of the fuel cell anode gas, consisting of H<sub>2</sub>, CO, H<sub>2</sub>O and CO<sub>2</sub>, from the vitiated air. That anode gas, the depleted fuel stream, containing less than 18% (H<sub>2</sub> + CO), will be directed to an Oxygen Transport Membrane (OTM) Afterburner that is being developed by Praxair, Inc.. The OTM is supplied air and the depleted fuel. The OTM will selectively transport oxygen across the membrane to oxidize the remaining H<sub>2</sub> and CO. The water vapor is then condensed from the totally

oxidised fuel stream exiting the afterburner, leaving only the CO<sub>2</sub> in gaseous form. That CO<sub>2</sub> can then be compressed and sequestered, resulting in a Zero Emission power generation system operating on hydrocarbon fuel that adds only water vapor to the environment.

Praxair has been developing oxygen separation systems based on dense walled, mixed electronic, oxygen ion conducting ceramics for a number of years. The oxygen separation membranes find applications in syngas production, high purity oxygen production and gas purification. In the SOFC afterburner application the chemical potential difference between the high temperature SOFC depleted fuel gas and the supplied air provides the driving force for oxygen transport. This permeated oxygen subsequently combusts the residual fuel in the SOFC exhaust.

A number of experiments have been carried out in which simulated SOFC depleted fuel gas compositions and air have been supplied to either side of single OTM tubes in laboratory-scale reactors. The ceramic tubes are sealed into high temperature metallic housings which precludes mixing of the simulated SOFC depleted fuel and air streams. In early tests, although complete oxidation of the residual CO and H<sub>2</sub> in the simulated SOFC depleted fuel was achieved, membrane performance degraded over time. The source of degradation was found to be contaminants in the simulated SOFC depleted fuel stream. Following removal of the contaminants, stable membrane performance has subsequently been demonstrated. In an ongoing test, the dried afterburner exhaust composition has been found to be stable at 99.2% CO<sub>2</sub>, 0.4% N<sub>2</sub> and 0.6% O<sub>2</sub> after 350 hours online. Discussion of these results is presented.

A test of a longer, commercial demonstration size tube was performed in the SWPC test facility. A similar contamination of the simulated SOFC depleted fuel stream occurred and the performance degraded over time. A second test is being prepared.

Siemens Westinghouse and Praxair are collaborating on the preliminary design of an OTM equipped Afterburner demonstration unit. The intent is to test the afterburner in conjunction with a reduced size SOFC test module that has the anode gas separation features incorporated into the hardware.

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***Vision 21 Program Review Meeting***  
**November 6, 2001**

**U.S. Department of Energy**  
**National Energy Technology Laboratory**

## PROGRAM OBJECTIVES

- System Study to set cost and Oxygen Flux targets for OTMs
- Select and characterize OTM materials
- Fabricate OTMs and test in SOFC depleted fuel
- Conceptual design of the SOFC and OTM modules

Siemens Westinghouse Power Corp. and Praxair, Inc are collaborating on this DOE sponsored project.

Each has made progress in the respective areas.

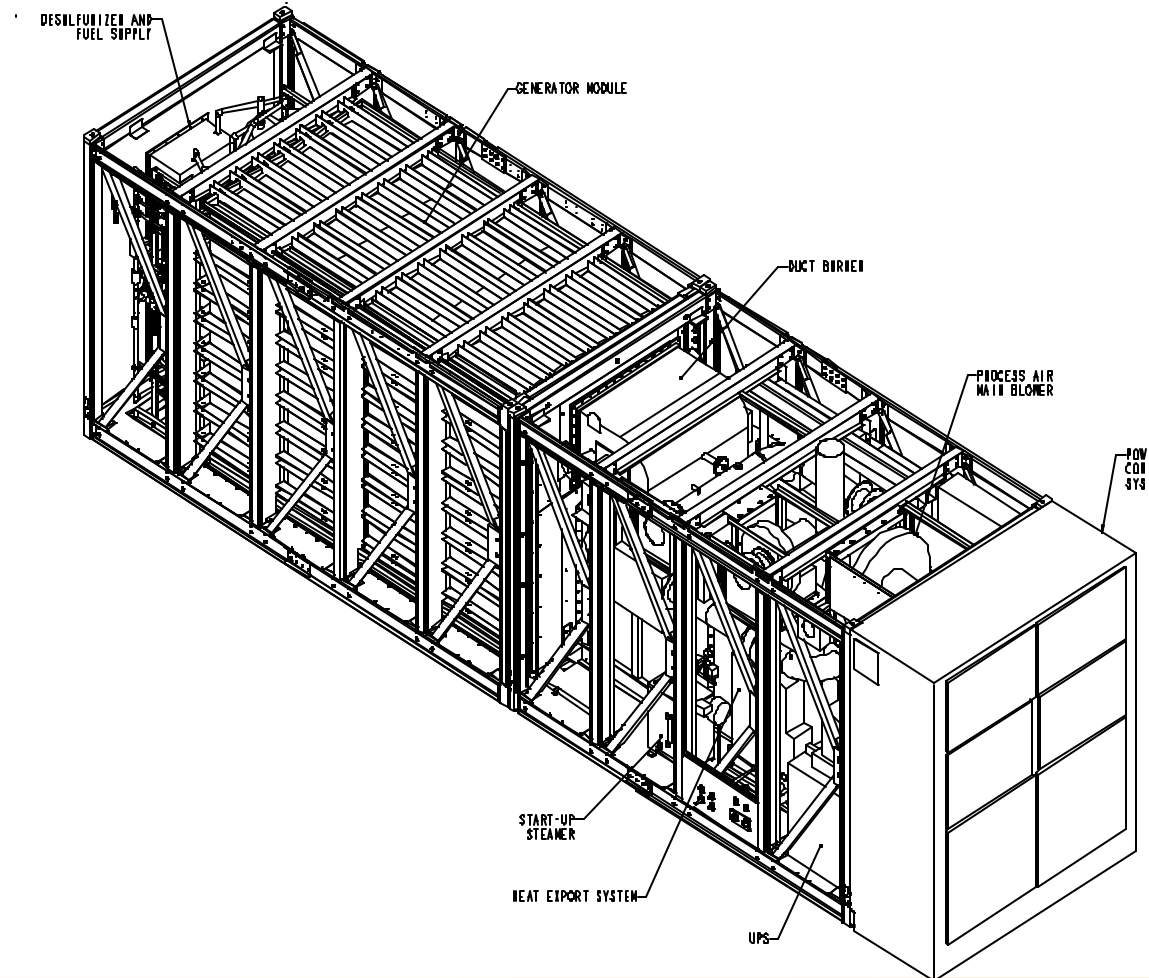
## Conceptual Design of SOFC and OTM Modules

- The basis for the Zero Emissions (ZE) plant is the SWPC 250 kWe Combined Heat Power (CHP250) System
- CHP250 incorporates production design closed end tubular 150 cm active length SOFCs
- CHP250 utilizes the proven SWPC “seal-less” generator module design with Anode and Cathode gases merging into a common pressure effluent.
- CHP250 is a packaged system incorporating a complete BOP system.

# Zero Emission Power Plants with OTMs



## SWPC 250 kWe CHP System



## Conceptual Design of SOFC and OTM Modules

- Process exhaust of CHP250 system is primarily O<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, and CO<sub>2</sub>, with trace amounts of CO, NO<sub>x</sub>, and SO<sub>x</sub>
- The CHP250 SOFC power plant operating on natural gas and generating electricity at >45% electricity efficiency will emit <1.2 lbs CO<sub>2</sub>/kWh.
- For a Zero Emission power plant, we must segregate the CO<sub>2</sub>

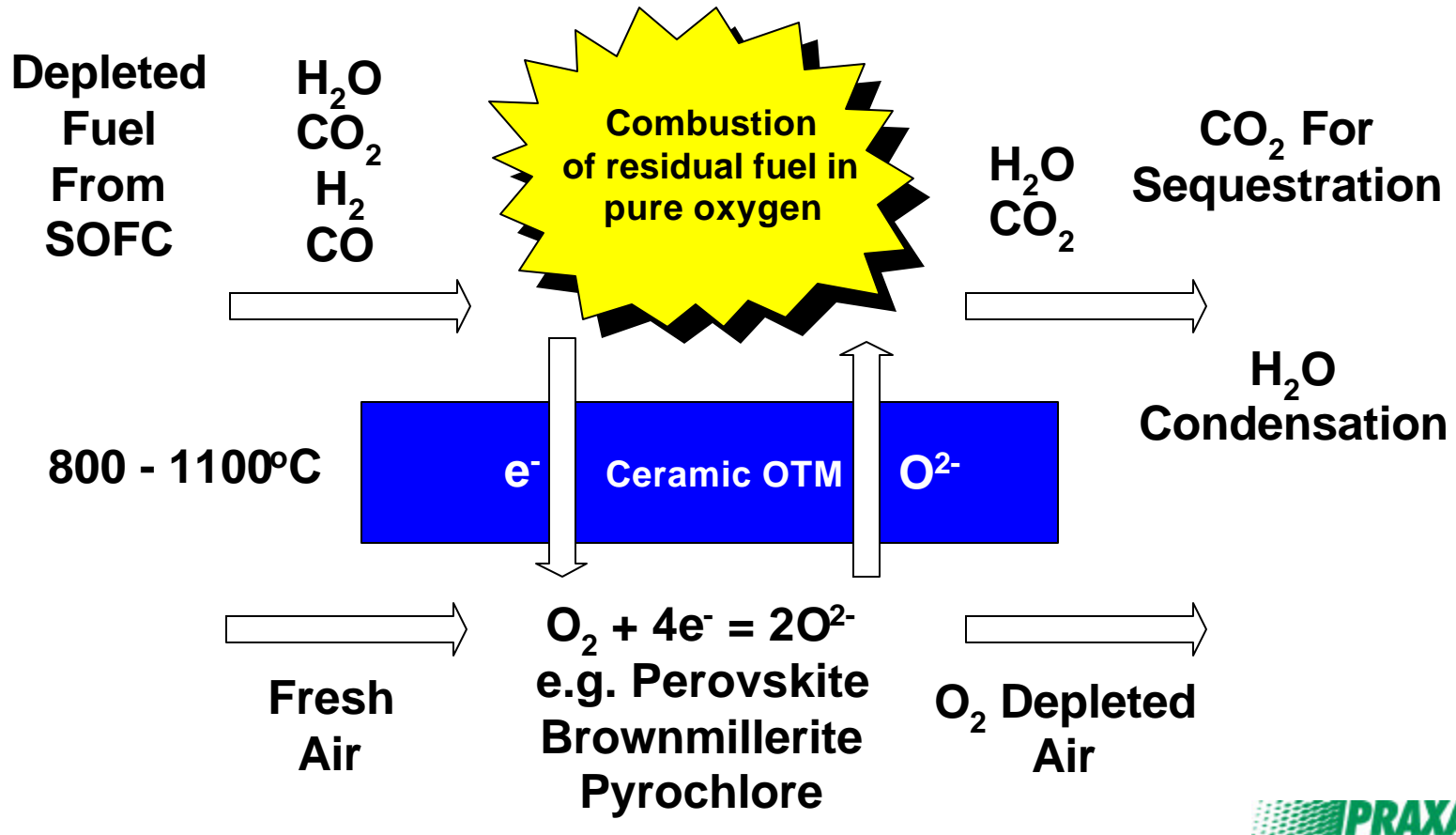
## Conceptual Design of SOFC and OTM Modules

- SWPC is developing a SOFC module design that maintains the anode gas effluent separate from the cathode gas effluent, thus facilitating CO<sub>2</sub> capture.
- The anode gas effluent will be directed to an AfterBurner module containing OTMs to finish the depleted fuel oxidation
- Praxair and SWPC are collaborating on the design of the OTM module to facilitate the incorporation into the overall design and operation of the CHP250 ZE power plant
- A sub-module bundle test of the proposed module designs is planned



# Zero Emission Power Plants with OTMs

## Principle of OTM Afterburner Operation



# Zero Emission Power Plants with OTMs

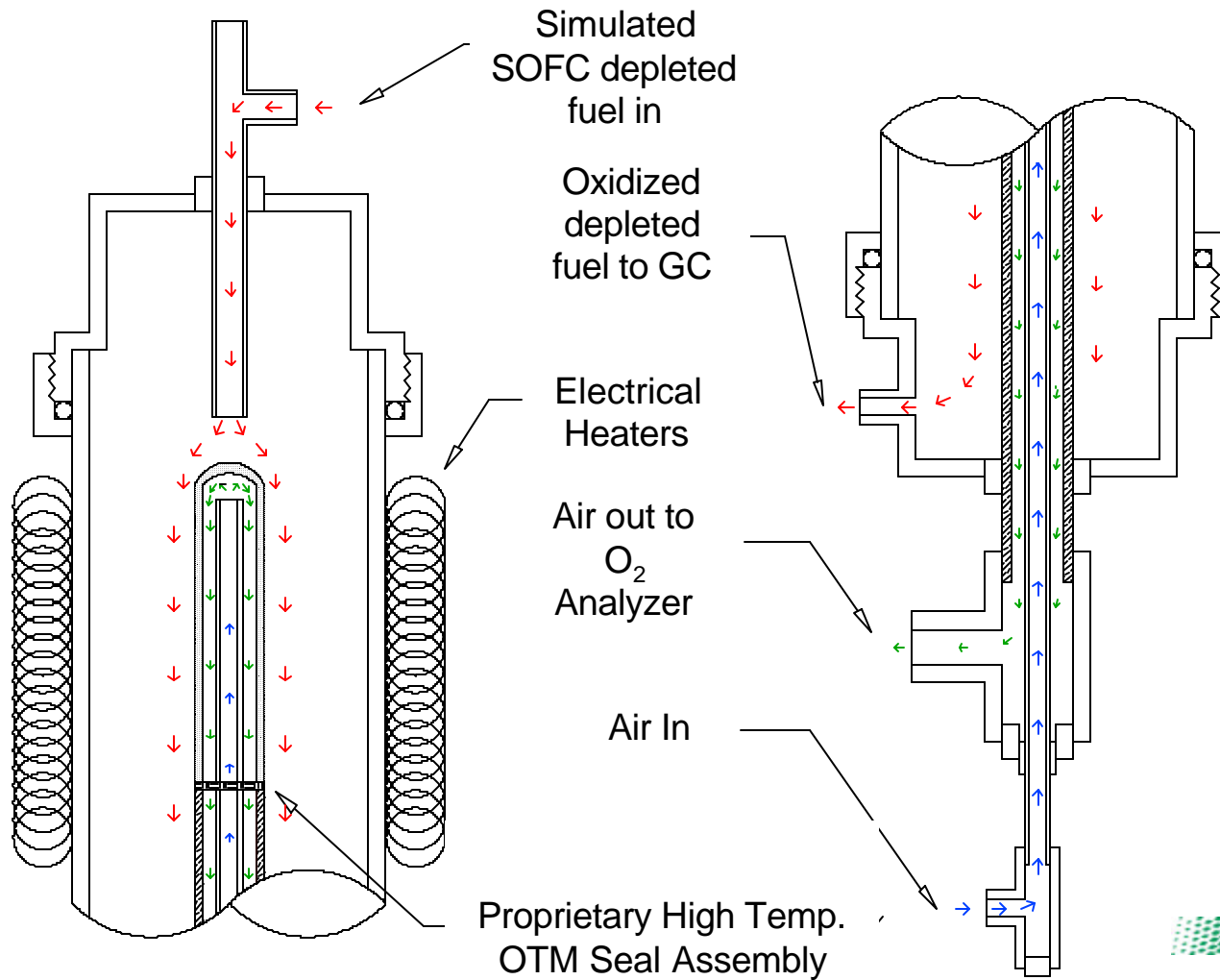


## **Fabricate OTMs and test in SOFC depleted fuel**

- 2 Short (15 - 40 cm) OTM lab-scale reactors designed and constructed at Praxair.
- Air supplied to inside of closed-one-end OTM tube via a feed tube.
- Ceramic OTM tube sealed to metallic pipe via proprietary high temperature seal assembly.
- Sealed OTM tube located inside larger diameter shell in electrically heated furnace.
- Simulated SOFC exhaust directed to outside of OTM tube.
- OTM exhaust gas composition analyzed by GC. Depletion of air monitored by O<sub>2</sub> analyzer.



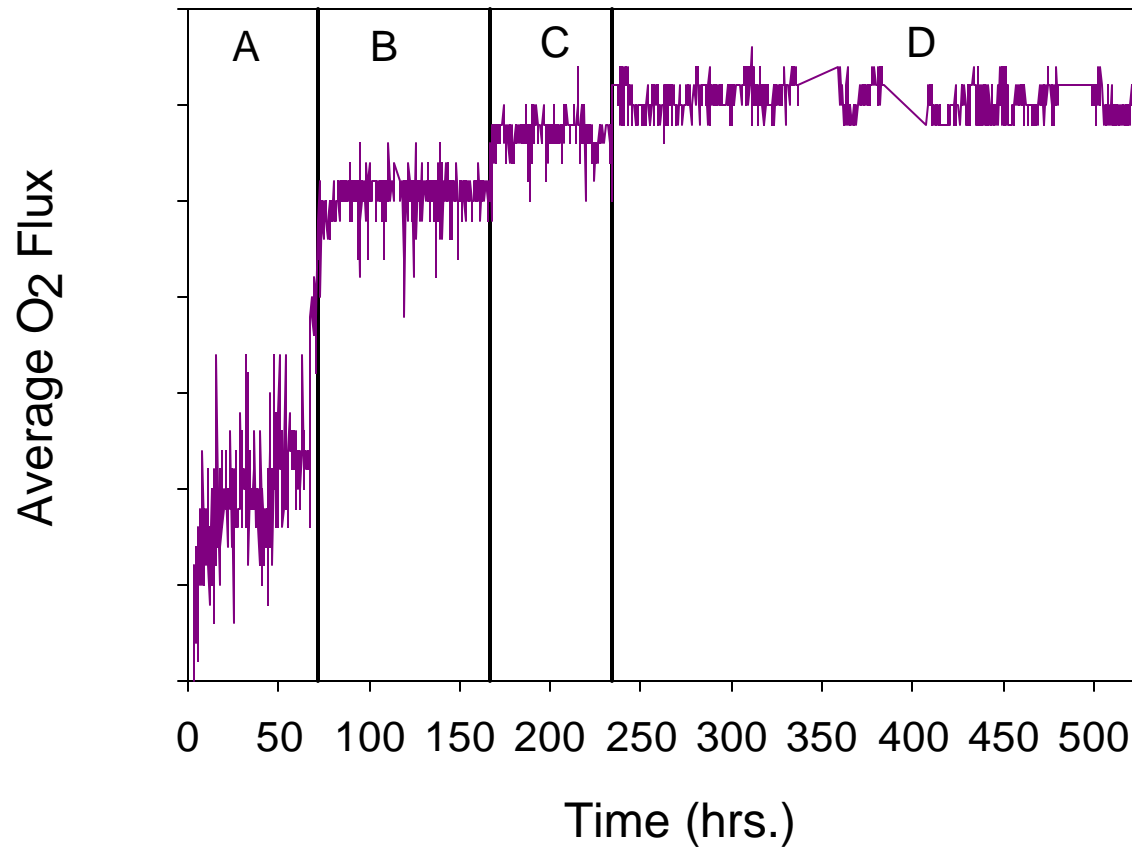
# Zero Emission Power Plants with OTMs



# Zero Emission Power Plants with OTMs

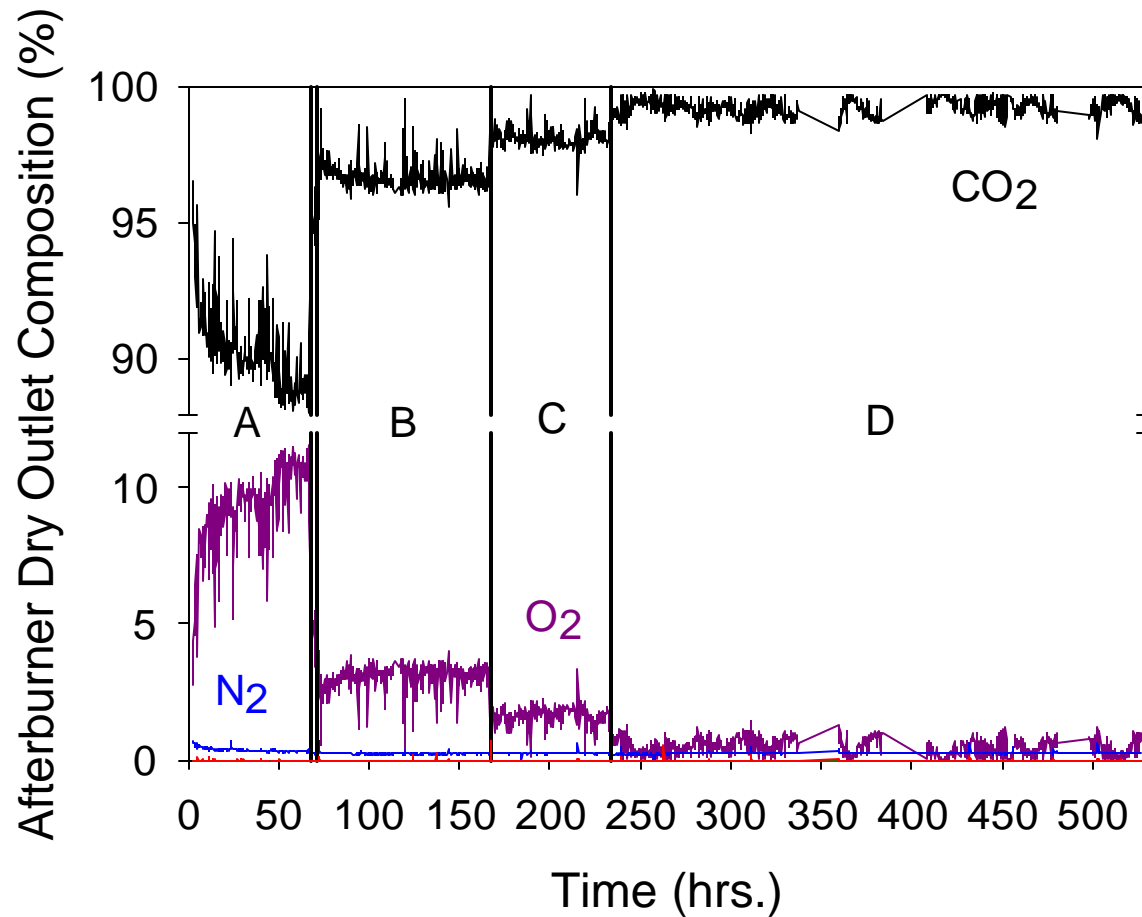


## Fabricate OTMs and test in SOFC depleted fuel - Short tubes



# Zero Emission Power Plants with OTMs

## Fabricate OTMs and test in SOFC depleted fuel - Short tubes



# Zero Emission Power Plants with OTMs



## **Fabricate OTMs and test in SOFC depleted fuel - Short tubes**

- Demonstrated OTM oxidized depleted fuel gas composition of 99.2% CO<sub>2</sub>, 0.2%N<sub>2</sub>, 0.6%O<sub>2</sub> .
- H<sub>2</sub> and CO below GC detection limit (< 10 ppm)
- Demonstrated OTM stability > 650 hrs (Ongoing)
- Future work to address OTM oxidized depleted fuel gas composition as a function of temperature and fuel flow rate and ability of membrane to withstand thermal and chemical shocks.



# Zero Emission Power Plants with OTMs

## Fabricate OTMs and test at SWPC in SOFC depleted fuel - long tubes

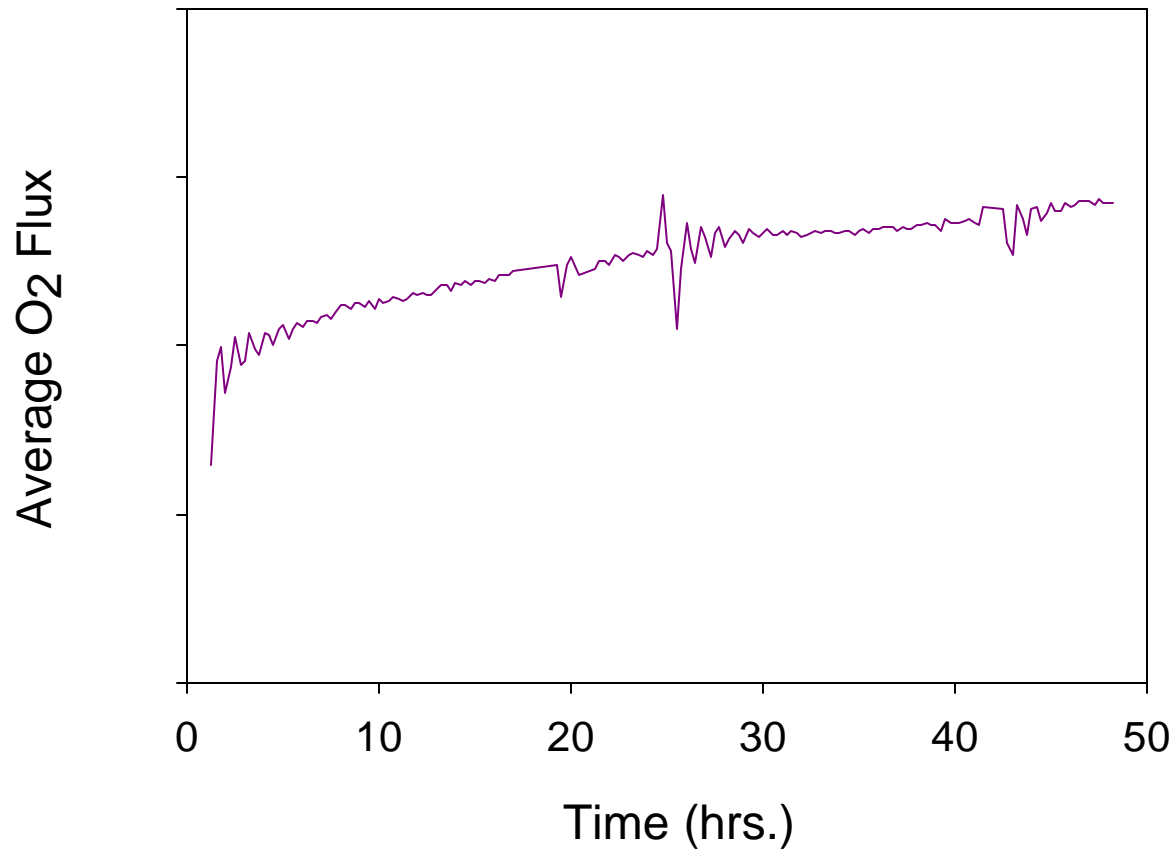
- Full size SOFC single tube test facility re-designed to test commercial demonstration sized OTM afterburner tubes.
- Measured oxygen flux comparable to short-tubes.
- Current ongoing test: OTM dry exhaust gas composition is stable at 95% CO<sub>2</sub>, 1%N<sub>2</sub> & 4%O<sub>2</sub>.



# Zero Emission Power Plants with OTMs



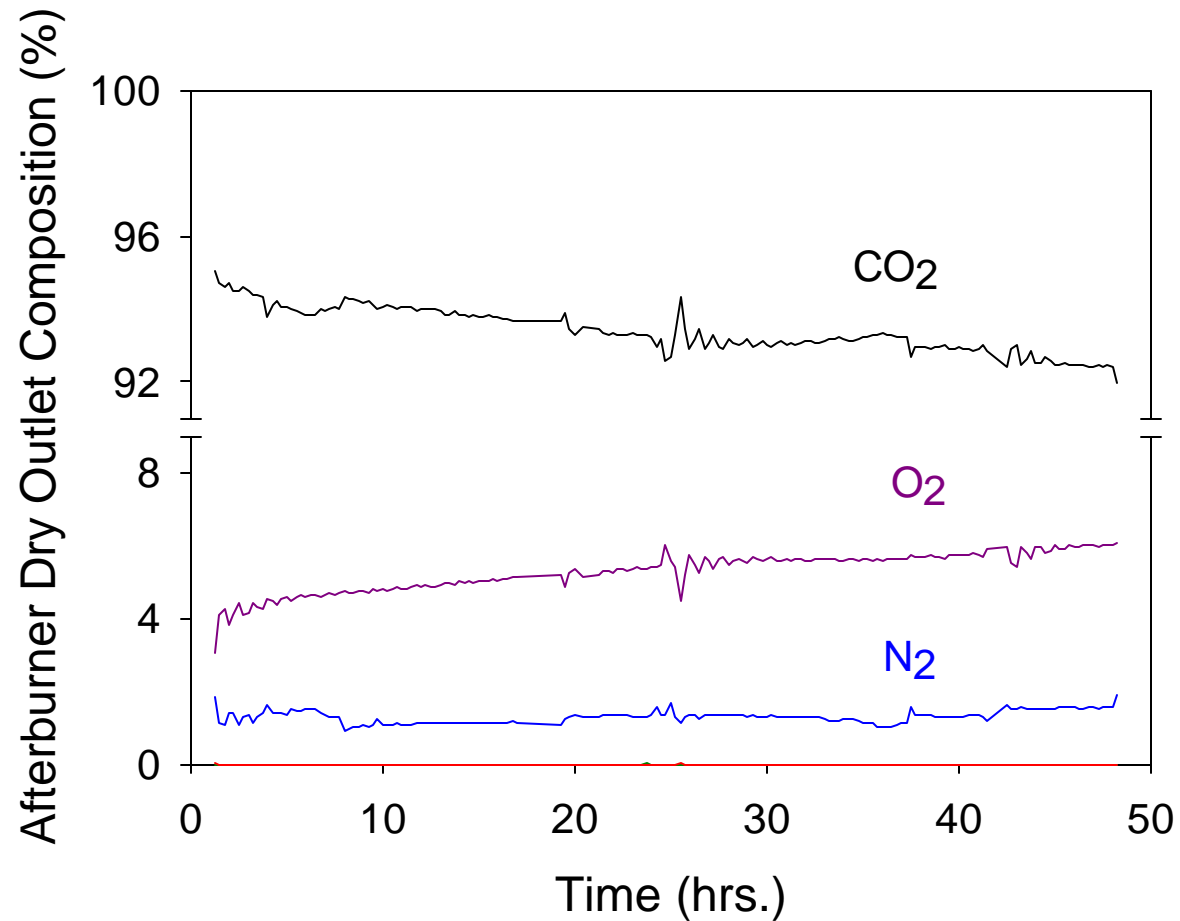
**Fabricate OTMs and test at SWPC in SOFC depleted fuel - long tubes**





# Zero Emission Power Plants with OTMs

**Fabricate OTMs and test at SWPC in SOFC depleted fuel - long tubes**



## Future Work

- Finalize preliminary design of the OTM afterburner for the sub-module bundle test.
- Development of process flow diagrams for integration of the SOFC stack with the OTM afterburner bundle.
- Develop strategies for operation of the integrated SOFC / OTM system.

# Zero Emission Power Plants with OTMs



“This material was prepared with support of the U.S. Department of Energy, under Award No. DE-FE26-00NT40765. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the DOE”