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

Abstract

Larry A. Shockling, Phd (larry.shockling@swpc.siemens.com, 412 256 2275)
Keqin Huang, Phd (keqin.huang@swpc.siemens.com, 412 256 2323
Thomas E. Gilboy (tom.gilboy@swpc.siemens.com, 412 256 1227)
Siemens Westinghouse Power Corporation
Stationary Fuel Cells
1310 Beulah Rd.
Pittsburgh, PA 15235

G. Maxwell Christie, Phd (max_christie@praxair.com, 716 879 7739
Troy M. Raybold, Phd (troy_raybold@praxair.com, 716 879 2346)
Praxair, Inc.
175 East Park Drive
Tonawanda, NY 14150

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_2 emissions, ~1.0 lb CO_2/ kW-hr, are low. Within the SOFC module the desulfurized fuel is utilized electrochemically and oxidized below the temperature for NOx generation. Therefore the NOx and SOx 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_2 and water vapor. This forward looking DOE sponsored Vision 21 program is supporting the development of methods to capture and sequester the CO_2, 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_2, CO, H_2O and CO_2, from the vitiated air. That anode gas, the depleted fuel stream, containing less than 18% (H_2 + 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_2 and CO. The water vapor is then condensed from the totally

oxidised fuel stream exiting the afterburner, leaving only the CO_2 in gaseous form. That CO_2 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_2 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_2, 0.4% N_2 and 0.6%O_2 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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National Energy Technology Laboratory

Zero Emission Power Plants with OTMs

Stationary - Fuel Cells

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.

Zero Emission Power Plants with OTMs

Stationary - Fuel Cells

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

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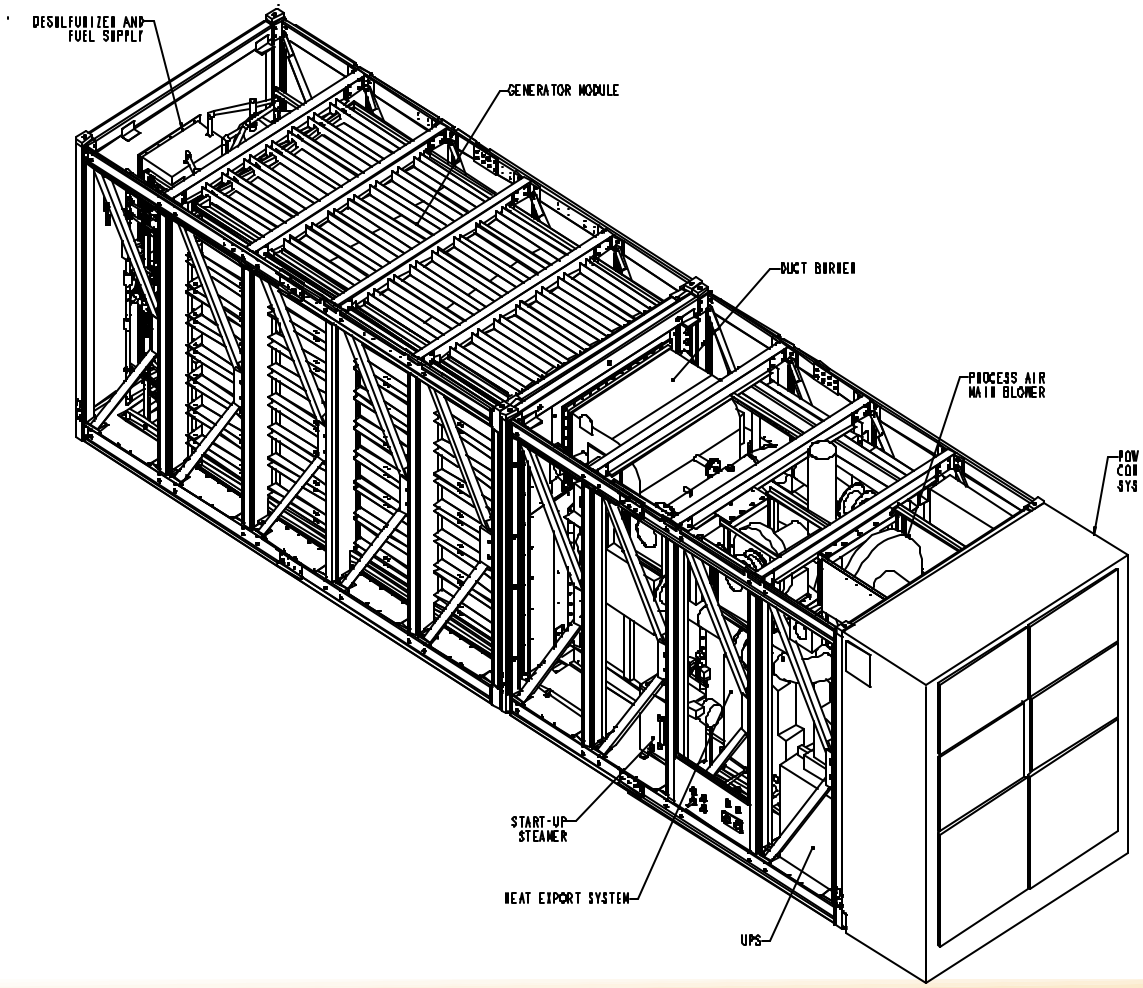
SWPC 250 kWe CHP System



Zero Emission Power Plants with OTMs

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Conceptual Design of SOFC and OTM Modules

- Process exhaust of CHP250 system is primarily O_2, N_2, H_2O, and CO_2, with trace amounts of CO, NOx, and SOx
- The CHP250 SOFC power plant operating on natural gas and generating electricity at >45% electricity efficiency will emit <1.2 lbs CO_2/kWh.
- For a Zero Emission power plant, we must segregate the CO_2

Zero Emission Power Plants with OTMs

Stationary - Fuel Cells

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_2 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

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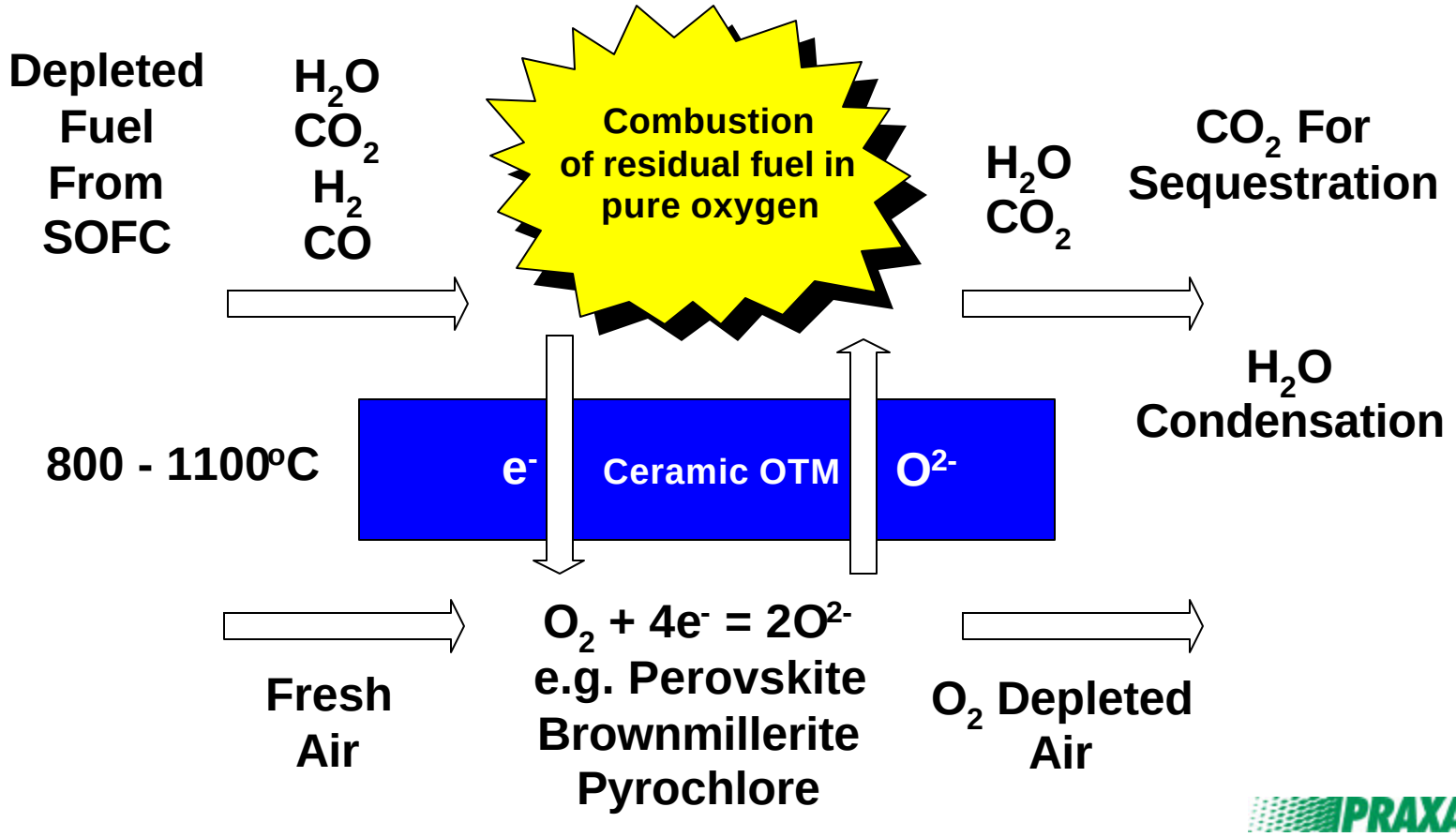
Principle of OTM Afterburner Operation



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Zero Emission Power Plants with OTMs

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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_2 analyzer.

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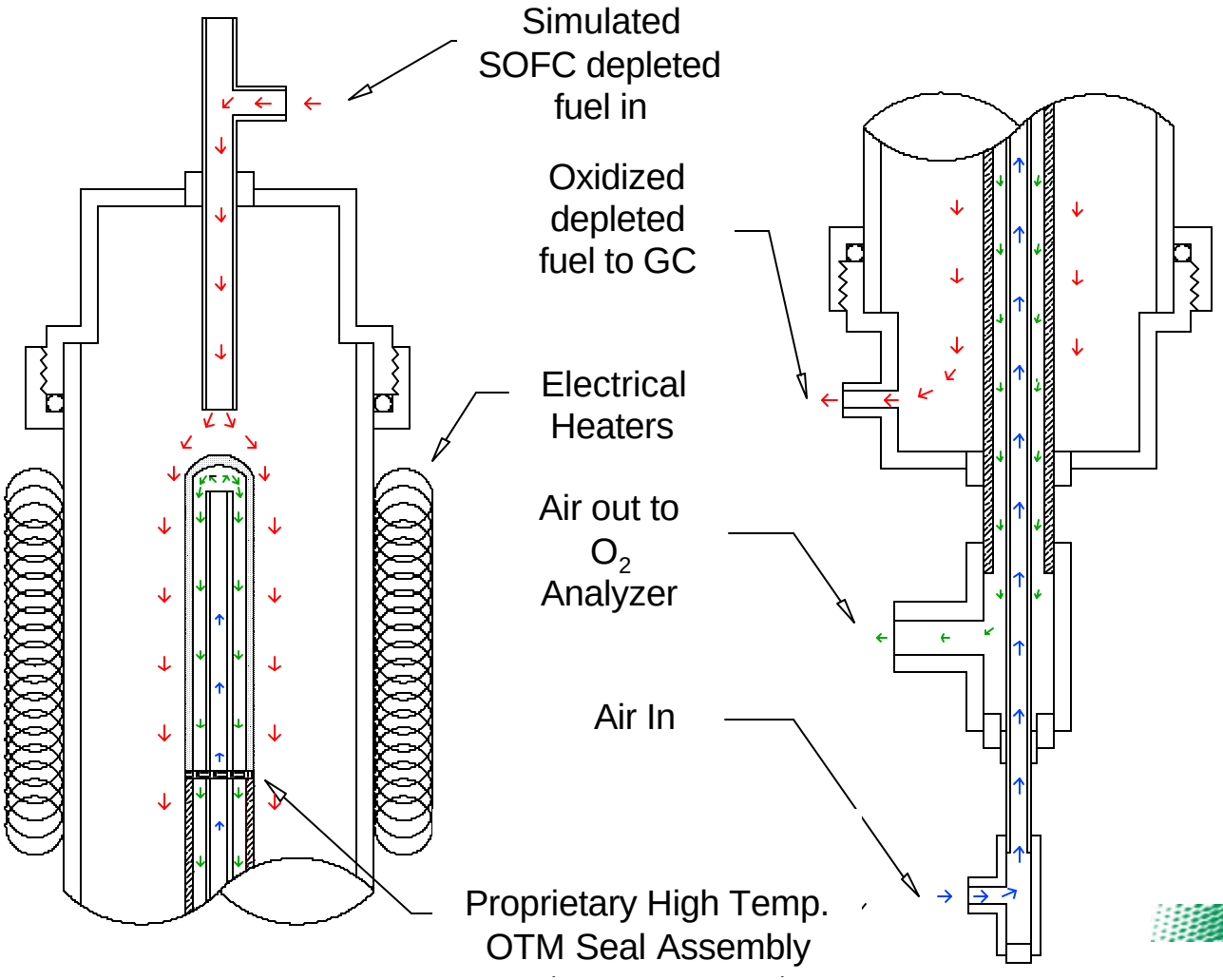

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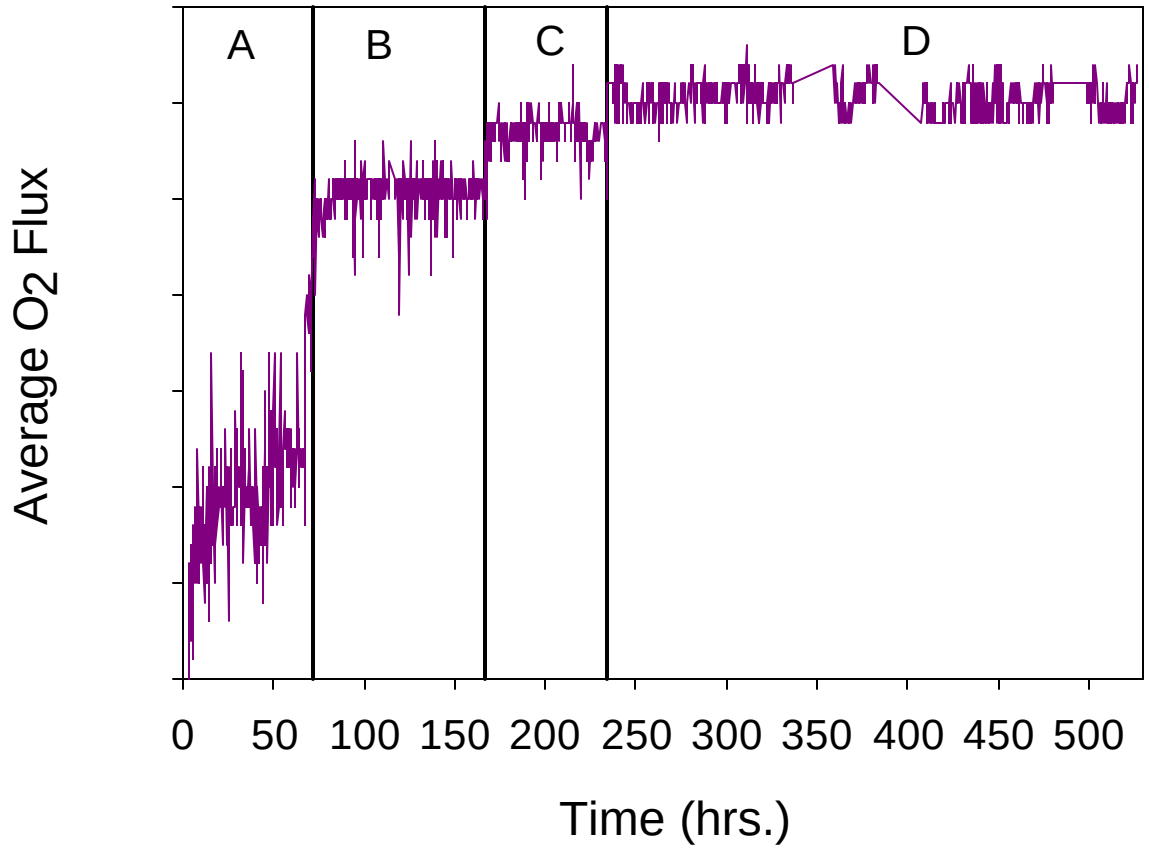
Fabricate OTMs and test in SOFC depleted fuel - Short tubes



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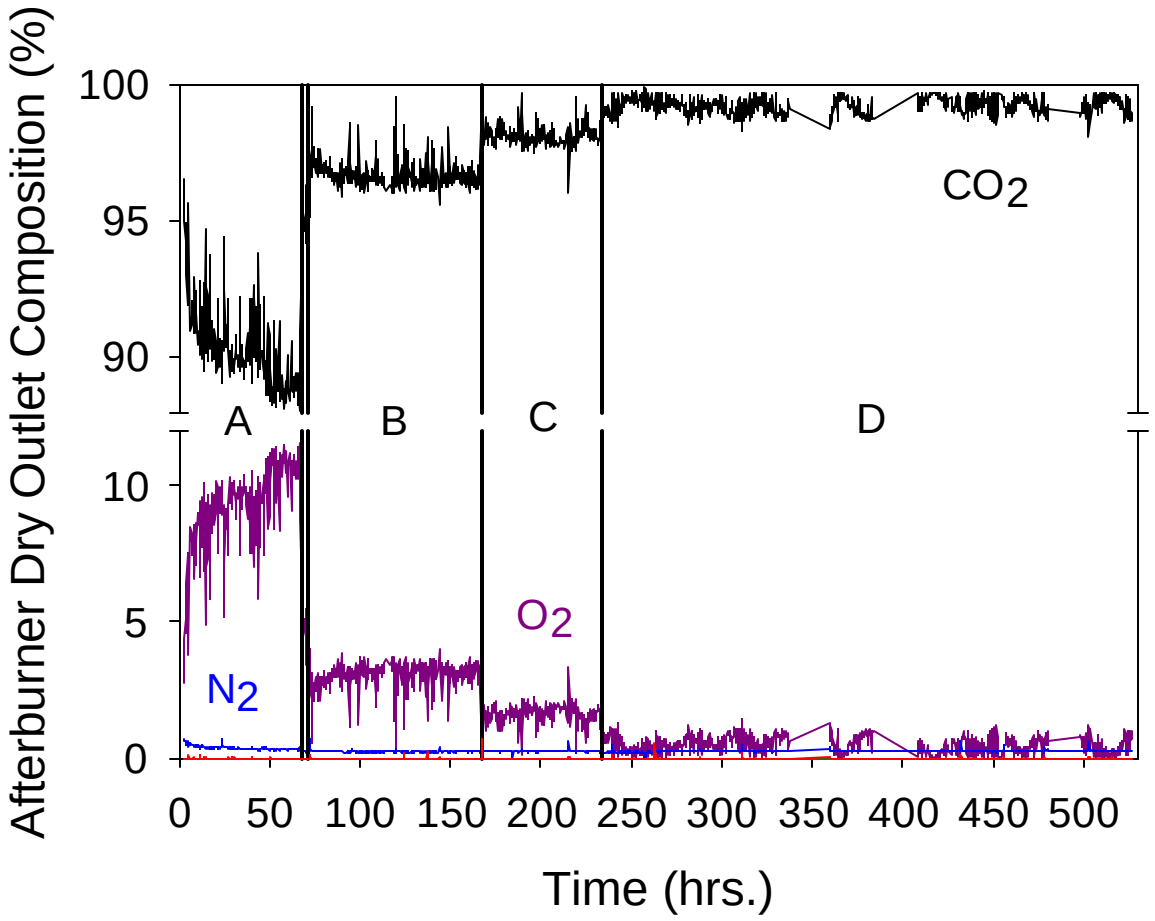
Fabricate OTMs and test in SOFC depleted fuel - Short tubes



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Zero Emission Power Plants with OTMs

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Fabricate OTMs and test in SOFC depleted fuel - Short tubes

- Demonstrated OTM oxidized depleted fuel gas composition of 99.2% CO_2, 0.2%N_2, 0.6%O_2 .
- H_2 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.

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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_2, 1%N_2 & 4%O_2.

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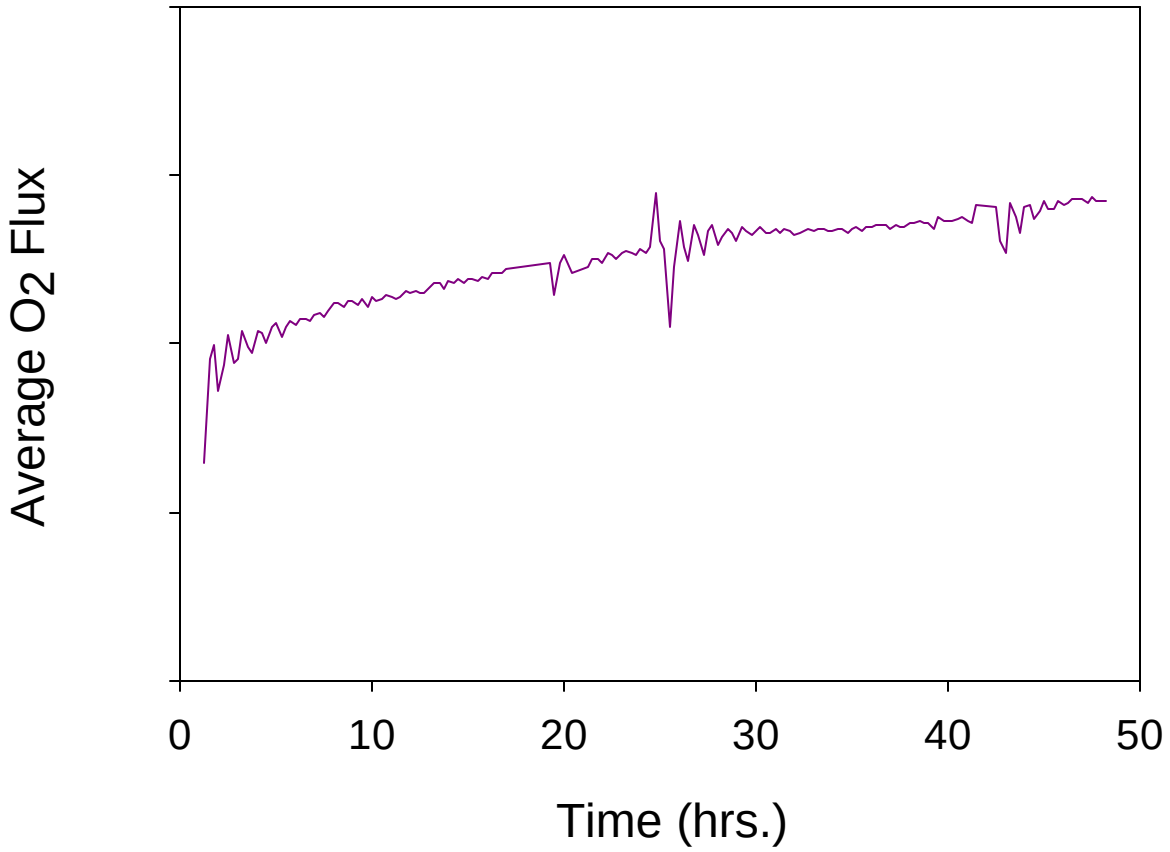
Fabricate OTMs and test at SWPC in SOFC depleted fuel - long tubes



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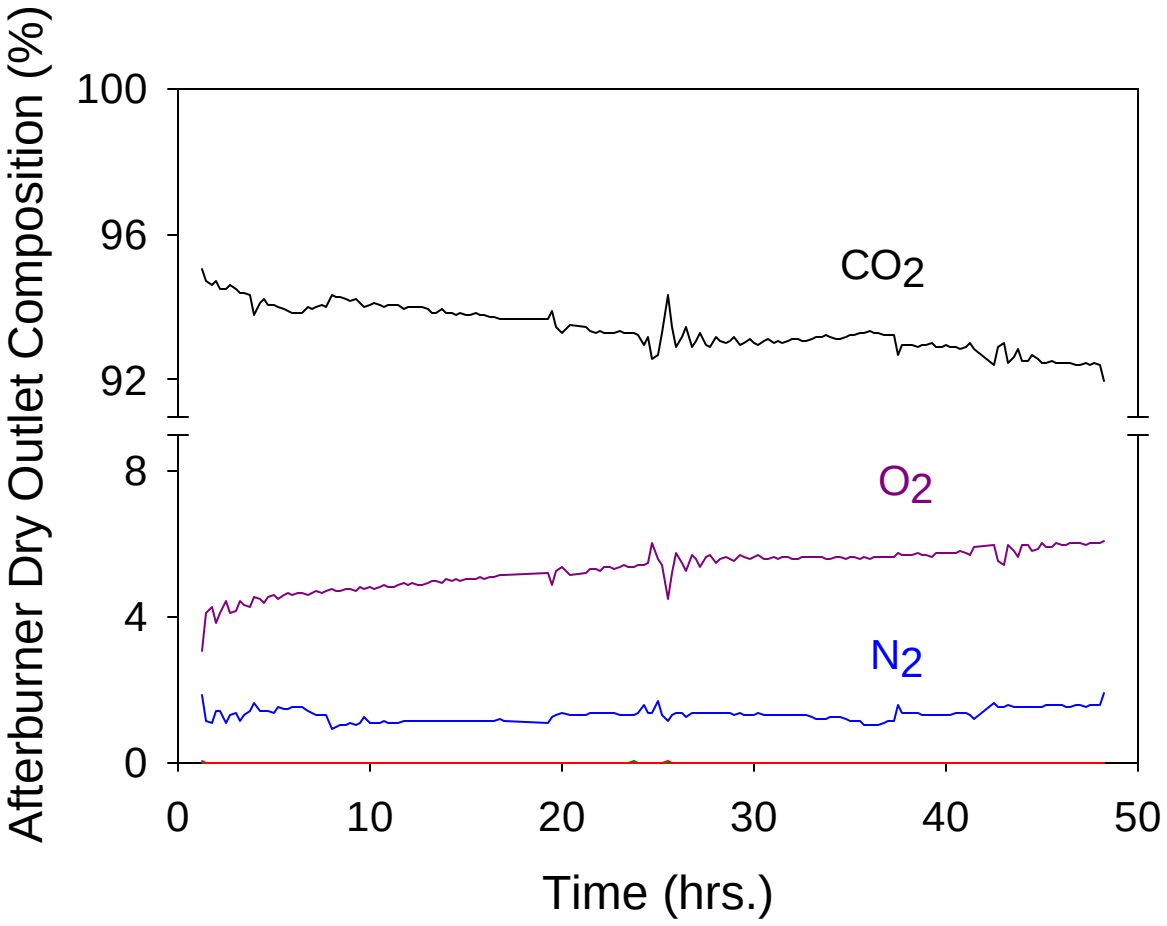

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Future Work

- 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

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