# Solid Oxide Fuel Cells in UUV (Unmanned Undersea Vehicle) Applications

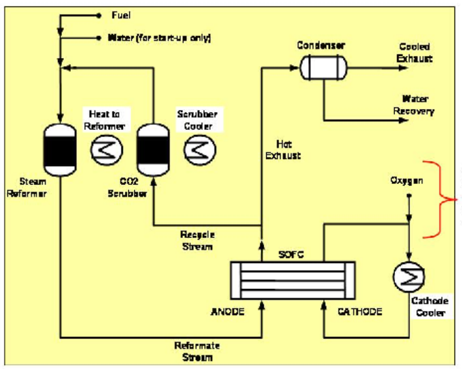
NEWPORT

## NUWCDIVNPT INVESTIGATORS

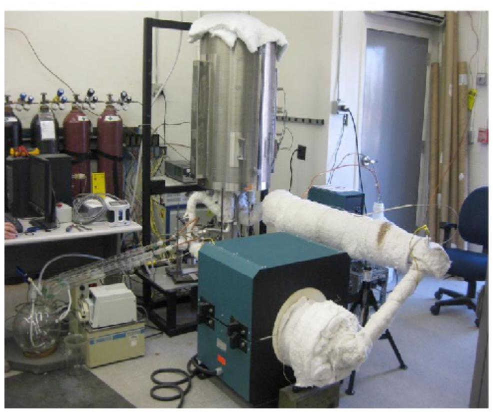
A. Alan Burke, Ph.D.
Louis G. Carreiro, Ph.D.

## INTRODUCTION

- The U.S. Navy is currently investigating SECA solid oxide fuel cells for the propulsion of Unmanned Undersea Vehicles (UUVs).
- Key goal is to operate a SOFC power source on logistic (military) fuels in an air-independent environment.
- A UUV power source will consist of a SOFC stack(s), fuel processor, carbon dioxide scrubber, balance of plant components and fuel / oxidant storage.




- SOFCs offer several distinct advantages over rechargeable battery technology:
  - potential for achieving specific energy greater than 300 Wh/kg.
  - capable of utilizing energy-dense fuel (extended mission time)
  - "gas and go"—allowing a UUV to be re-launched at short notice.
  - self-sustaining while supplying heat to reforming processes.



Experimental Set-up at NUWCDIVNPT

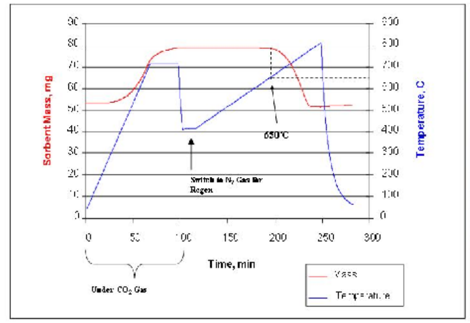
## APPROACH

- Test SECA SOFC Stacks under pure oxygen and reformate conditions
- Isolate effects of pure oxygen, using only hydrogen/nitrogen mixtures as fuel
- Reformate studies conducted with major system components
- Evaluate SOFC stacks and balance of plant components for UUV application

**R&D Dynamics**

U.S. DOE-sponsored SBIR

Phase II prototype matches 21" UUV design goals




**TDA Research**
**$CO_2$ Sorbent**

Removes $CO_2$ from exhaust gas of SOFC via an active sorbent, calcium oxide, which is chemically converted to calcium carbonate at high temperature.

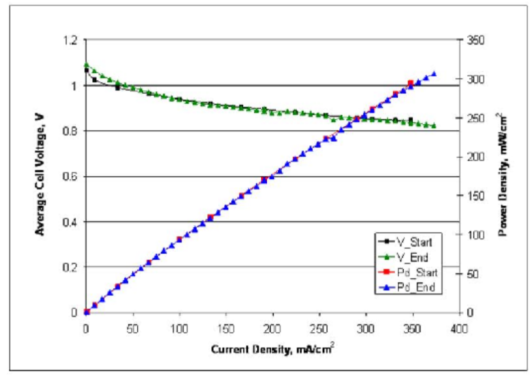
**Over 50% mass gain demonstrated**

$CaO + CO_2 \rightarrow CaCO_3$ + HEAT (178 kJ/mol)

## RESULTS

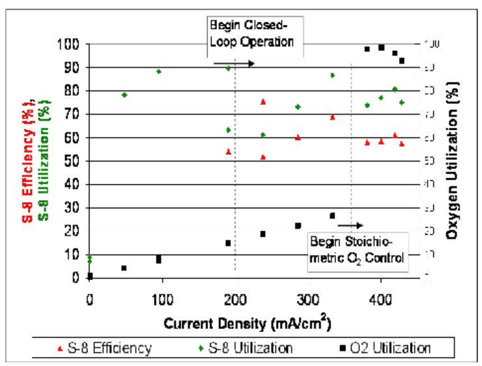
- Delphi Corporation and Versa Power Systems have been tested at NUWCDIVNPT's facility
- Up to 10% Power gain seen by using pure $O_2$ vs. Air
- 30-Cell Delphi Stack integrated with
  1) InnovaTek's Steam Reformer
  2) TDA Research's $CO_2$ Sorbent
  3) R&D Dynamics' High Temperature Blower
- Benchmarks achieved in first Demo:
  -> 75% S-8 Utilization
  -> 90% Oxygen Utilization
  -> 50% Efficiency ($P_{SOFC}$ / S-8 LHV)
  -> 1 kW
- Degradation Rate: 2-3% / 100 hour mission

All achieved simultaneously in initial proof-of-concept study (several hours of operation).

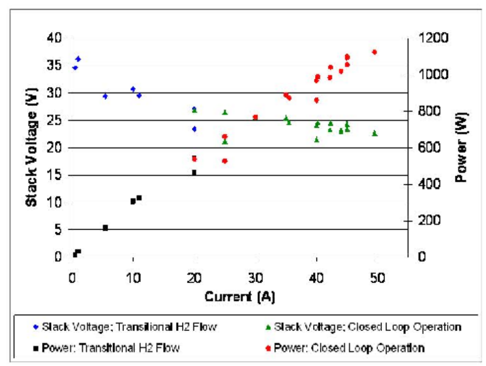



**28-cell Versa Power Systems SOFC Stack**

IV Plot at the beginning versus the end of test. At beginning, the flows were 20 L/min $H_2$, 16.3 L/min $N_2$ with 3% water vapor at the anode and 16.3 L/min pure oxygen at the cathode. At the end, the flows were 20 L/min $H_2$, 7.2 L/min $N_2$ with 3% water vapor at the anode and 10 L/min pure oxygen at the cathode. There was negligible change in the average cell performance over the timescale tested (~100 hrs).




Data acquired in conjunction with the IV-plot shown in figure to the right; above 200 mA/cm² there is fully closed-loop operation and above 350 mA/cm² there is stoichiometric oxygen control.




IV plot of 30-cell Delphi Stack during transition from cylinder gas to closed-loop, anode recycle operation. Power exceeded 1 kilowatt.

## CONCLUSIONS

- SOFC technology has the potential to greatly increase UUV mission time compared with current rechargeable battery technology.
- NUWCDIVNPT is collaborating with DOE & industry to evaluate technologies for undersea power systems
- Main challenges for UUV application:
  - Oxygen Storage
  - Sorbent Regeneration
  - Start-up
  - Thermal Management