Solid oxide cell technology for propellant and power production. J. Elwell[1], M. Hollist[2], J. Hartvigsen[3], and S. Elangovan[4], OxEon Energy, 257 River Bend Way #300, North Salt Lake, UT 84054, [1]jessica@oxeonenergy.com, [2]michele@oxeonenergy.com, [3]jjh@oxeonenergy.com, [4]elango@oxeonenergy.com

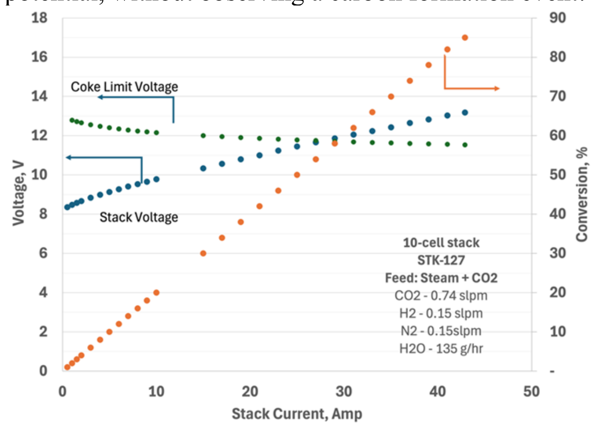
Introduction: OxEon Energy's Solid Oxide Cell (SOC) stack in the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) demonstrated the production and collection of 99.9% pure O_2 from Martian atmospheric CO_2 in a 0.5% scale device aboard the Mars Perseverance Rover. [1] The United States National Aeronautics and Space Administration (NASA) has continued to fund research for SOC technology for space applications including materials development and demonstration systems incorporating scaled SOC stack devices for both Lunar and Martian applications.

The use of Martian and Lunar resources such as atmospheric CO_2 and permanently shadowed region (PSR) ice respectively represents a significant opportunity to reduce the cost of launch from earth, enable propellant production for space refueling, allow for life support of manned missions, and generate power for surviving the Lunar night. OxEon has two current hardware development efforts using SOC technology for space applications.

Propellant production: The Mars Oxygen and Methane System (MOMS) can produce oxygen and methane by electrolyzing Martian environmental resources. Final demonstration hardware will produce high-purity oxygen and methane at pressures up to 4 bar and an oxygen production rate of 1-3 kg/hr.

Remote operation of the SOC systems imposes a significant demand for performance stability and reliability. One of the biggest SOC operational challenges during the MOXIE program was the lack of a redox tolerant cathode which resulted in a system with a recycle loop to ensure the feed stream contained a small amount of reducing CO. Materials development work has since developed a redox tolerant cathode capable of extreme redox cycling and thermal cycling. [2] Recent testing has also evaluated a new electrolyte composition for increased performance, long term durability, and phase stability. A Long-term (5000+ hours) SOC stack test is underway on the latest material set to evaluate long term performance stability.

The improved SOC materials are also being evaluated for carbon resistance properties. To date, three short SOC stacks (10-cells) have undergone a performance mapping sweep in coelectrolysis mode to quantify the extent of operating voltage and feed conversion possible without creating carbon in the stacks. Each test demonstrated up to 85% CO2 and H2O feed conversion, up to the thermal neutral voltage of 1.32 V/cell which is 0.2 V/cell over the carbon formation potential, without observing a carbon formation event.

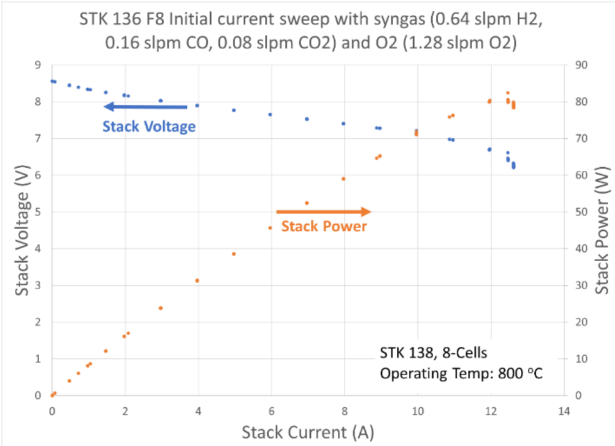


Power production: The Sustained On Orbit Propellant Enabled Ruggedized Solid Oxide Fuel Cell (SOOPER SOFC) system will be designed and tested to generate 2-kW power to demonstrate electrochemical conversion of propellants into direct current electricity. System feeds will be CH_4 and O_2.

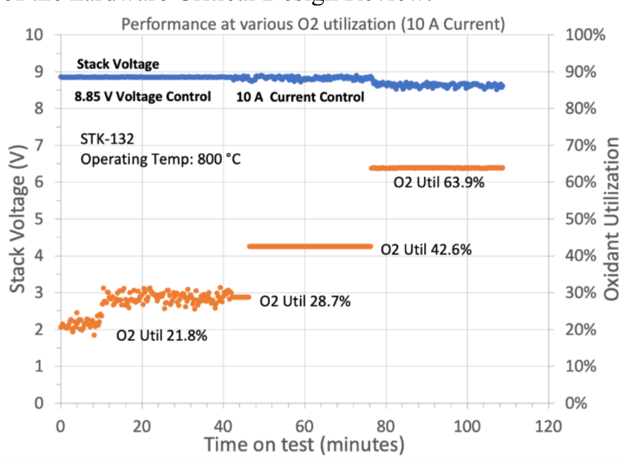
The objective of this work is to advance the SOC power generation system to TRL 6 through a structured development and testing campaign. A Key Performance Parameter for the effort is operation of the system with CH_4 and O_2 for power production. Running an SOC stack in fuel cell mode with only the stoichiometric O_2 required for reaction will require careful operating considerations to address the thermal management. Initial simulation and prototype testing indicate that operating at a lower current density reduces the heat flux within the stack to a level that can be thermally managed by convective and radiative heat transfer from the stack to the thermal stack enclosure.

Early technology verification of this operating approach has been conducted with two short stacks (8 and 10-cell) to allow for operating considerations and performance mapping to be researched ahead of full system design. The two test stacks underwent a standard IV sweep with a CO and H_2 mixture to simulate methane reformate. The fuel flow was set to demonstrate at least 70% fuel utilization at a target stack current between 10-12 A. The oxygen flow was initially set to four times the amount required for the electrochemical reaction to ensure that the stack operation would not be oxygen limited. The initial concept operation was able to successfully demonstrate 85% fuel utilization and a power generation of about 10 W/cell.

This information will be used to help size the final demonstration hardware.



In addition to the initial power sweep to demonstrate high fuel utilization, each stack went through a series of oxidant flow reductions to demonstrate higher oxidant utilization. It was observed with both stacks that oxidant utilization could only reach ~50% at constant fuel utilization before stack performance dropped due to leaking at the stack manifold interface. The oxygen stack delivery is a design item that has been flagged for additional testing and improvements ahead of the hardware Critical Design Review.



Conclusion:

The TRL for SOC space applications continues to advance with the development of demonstration hardware containing mission scale sized stacks with 35 times the production capacity as the device used in the MOXIE program. SOC technology has the capability for both in situ resource utilization for propellant production as well as power generation. Additionally, SOC can operate reversibly to provide both propellant and power production with the same device for additional functionality and applications.

References:

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[2] Hafen, T., Rane, T., Larsen, D., Pike, J., Hartvigsen, J., Elwell, J., and Elangovan, S., "Solid Oxide Electrolysis Cathode for Increased Robustness for ISRU Application," in *51st International Conference on Environmental Systems*, St. Paul, 2022.