Mars Oxygen and Methane System (MOMS). M. Hollist[1], T.Hafen[2], J. Pike[3], J. Elwell[4], J. Hartvigsen[5], and S. Elangovan[6], OxEon Energy, 257 River Bend Way, Suite 300, North Salt Lake, UT, 84054, [1]michele@oxeonenergy.com, [2]tyler@oxeonenergy.com, [3]jenna@oxeonenergy.com, [4]jessica@oxeonenergy.com, [5]jjh@oxeonenergy.com, [6]elango@oxeonenergy.com

Introduction: The OxEon team provided the Solid Oxide Electrolysis Cell (SOEC) for the MOXIE (Mars OXygen In-situ resource utilization Experiment) project for the Perseverance Rover. The SOEC stack on Mars successfully operated 16 times meeting all the operational objectives and producing propellant quality (>99.6% purity) oxygen by electrolyzing Mars atmosphere CO_2 and represents the first ISRU (In-Situ Resource Utilization) demonstration on another planet.[1] ISRU presents the opportunity to reduce payload and launch costs by utilizing resources already available on the moon and Mars. Since MOXIE, the SOEC stack using identical set of materials has been successfully scaled by 35x and incorporated into breadboard demonstration systems for propellant production on both the moon and Mars.[2],[3] Additionally, materials development since MOXIE has resulted in improved performance and capabilities of the nickel-based cathode material.[4] With the support of NASA, OxEon is continuing SOEC materials and hardware development to design, build, and operate a propellant production system capable of producing methane and oxygen from Mars H_2O and CO_2 referred to as MOMS: Mars Oxygen and Methane System.

Materials Development: Remote operation of the SOEC system for Mars and Lunar applications imposes a significant demand for performance stability and reliability. Each of the materials sets used in the construction of stacks are evaluated for potential improvement for robust operation. The redox tolerant fuel electrode previously developed under a NASA SBIR project has continued to be utilized for redox capability but also due to its ability for higher conversion of CO_2 when compared to the heritage (MOXIE) fuel electrode. Optimization of the redox tolerant fuel electrode is ongoing but recent materials development has also focused on electrolyte quality and air electrode treatment for improved long-term cell stability.

Developments in air electrode treatments have shown that the initial performance of the electrode can be fully recovered, even after 5,000 hours of operation (Figure 1). Baseline electrode treatment results in full performance recovery and improved stability. A modified treatment applied to an air electrode symmetric button cell (half-cell) has demonstrated full performance recovery again, and with significantly improved stability. The 0.4-volt hold used for the test (OCV = 0 with air on both sides) results in fuel cell mode of operation for one air electrode and electrolysis mode of operation for the opposite air electrode. Typically, an initial break-in period of about 300 hours is required before reaching stabilized performance. After three thermal cycles to room temperature, around 800 hours test time to verify cycling stability, the cell was cooled for baseline treatment. The cell was re-heated and tested for an additional 4,800 hours until the previous stable performance of 0.3 A/cm^2 was reached (not shown), at which point the cell was cooled for the modified treatment. The performance once again recovered and the cell stabilized slightly below 0.4 A/cm^2, showing a marked improvement over untreated air electrode and baseline treatment.

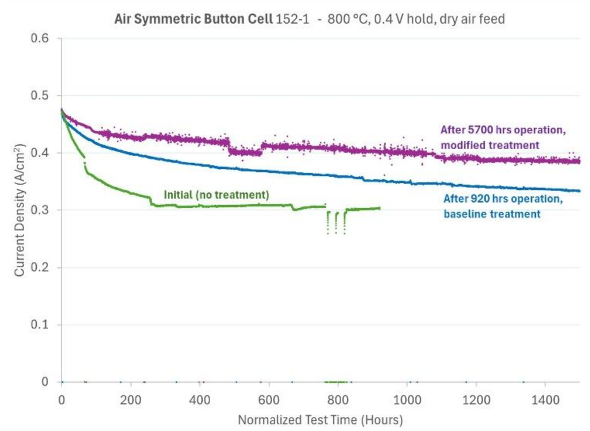

Figure 1. Button Cell stability test data superimposed for three different treatment regimes.

Test Validation: This improved materials set will be incorporated into full-size SOEC cells and stacks for quantitative and long term verification testing. Testing will evaluate degradation, performance, and coking resistant properties. A 5,000-10,000 hour long-term test, scheduled to begin in Q2 2025, is planned to monitor performance stability. A series of shorter length tests, scheduled to begin in Q4 of 2025, will operate stacks at various operating voltages, including voltages above the point where carbon is expected to form (via electrolysis of CO to quantify the coking resistant limits of the redox tolerant cathode material set. Stack testing with the redox tolerant cathode has demonstrated brief periods of operation above the voltage where carbon is expected to form (see Figure 2), but requires longer run verifications before establishing a nominal operating condition for scaled up demonstration hardware.

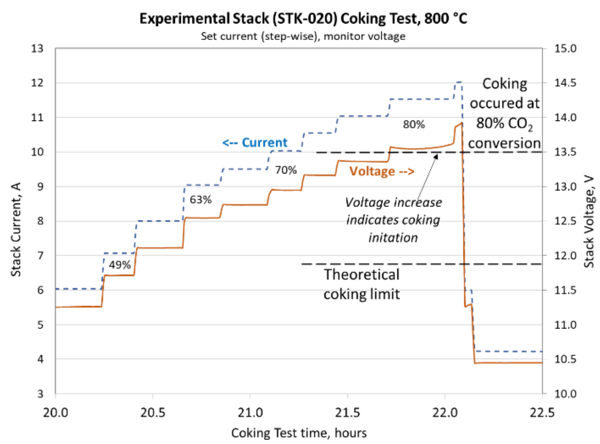

Figure 2. Carbon formation resistance testing with redox tolerant cathode.

Hardware Demonstration: For this effort, SOEC hardware scaled up from the MOXIE program and incoprporating subsequent materials improvements will be integrated with a methanation reactor to demonstrate a aystem capable of producing oxygen and methane from Martian environmental conditions (Figure 3).

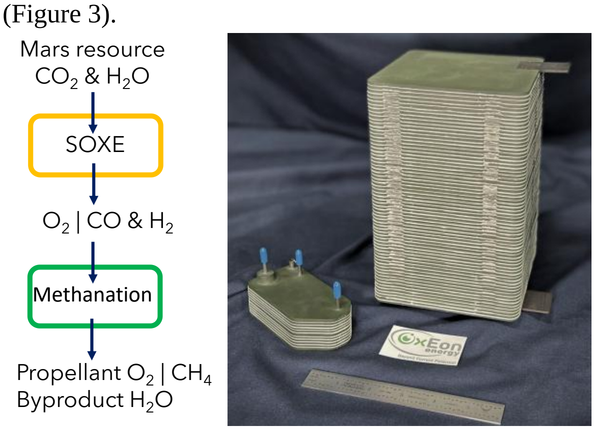

Figure 3. Concept for Mars ISRU for propellant production (left) and scaled SOEC device (right).

The goals include producing high-purity oxygen and methane at specific pressures and production rates. Before final hardware design, key technical objectives will be addressed through the materials improvements and testing described in the previous sections. A process simulation will be developed and informed by testing results to allow the mapping of stack operation performance, and development of process models for CO_2 collection and H_2O removal. The aim is to achieve a high conversion yield of CO_2 to CH_4. The final hardware deliverable would be compatible with Lunar ISRU operation as well, supporting NASA's Moon-2-Mars architecture to advance and implement technologies for ISRU systems for both lunar and Mars surface.

The program's Key Performance Parameters (KPPs) include operation of an integrated breadboard system capable of 1) producing at least 1 kg/hr high purity O_2 with a goal of 3 kg/hr, 2) production of O_2 at a pressure of at least 2 bar with a goal of 4 bar, and 3) overall feed CO_2 conversion to CH_4 of at least 60% with a goal of 80% conversion. All of the KPPs for the program will require system and materials developments to improve on the SOEC demonstration systems tested to date.

References: [1] Hoffman, J.A., Hecht, M.H., Rapp, D., Hartvigsen, J.J., SooHoo, J.G., Aboobaker, A.M., McClean, J.B., Liu, A.M., Hinterman, E.D., Nasr, M., "Mars Oxygen ISRU Experiment (MOXIE)—Preparing for human Mars exploration," *Sci. Adv.*, **8**, https://doi.org/10.1126/sciadv.abp8636 (2022).

[2] Hartvigsen, J., Elangovan, S., Elwell, J., Hollist, M., Lasen, D., Hafen, T., Calus, D., Valdez, S., Gomez, A., Czernichowski, P., Yarosh, A., Pike, J., and Davis, N., "Scale Up and Coupling of the MOXIE Solid Oxide Electrolyzer for Propellant Production on Mars," *51st International Conference on Environmental Systems*, Minneapolis, Minnesota, ICES-2022-280, https://hdl.handle.net/2346/89749 (2022).

[3] Hollist, M., Hartvigsen, J., Elwell, J., Elangovan, S., Gomez, A., Claus, D., Wilson, M., Jackson, G., Dreyer, C., Sowers, G., Dickson, D., Schmit, J., and Emadi, N., "Solid Oxide Electrolysis Based Lunar PSR Ice Processing System for Propellant Hydrogen and Oxygen Production," *51st International Conference on Environmental Systems*, Minneapolis, Minnesota, ICES-2022-280 (2022).

[4] 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," *51st International Conference on Environmental Systems*, Minneapolis, Minnesota, (2022).