TEST-DEMONSTRATED ADVANTAGES OF SOLID-OXIDE WATER ELECTROLYSIS FOR SCALED-UP HYDROGEN PRODUCTION ON THE MOON. D. C. Dickson[1], G. F. Sowers[1], C. B. Dreyer[1], G. Jackson[1], J. Schmit[2], N. Emadi[1], J. Schmidt[1], J.J. Hartvigsen[3], M. Hollist[3], [1]Colorado School of Mines (1500 W Illinois St, Golden, CO 80401, ddickson@mines.edu), [2]Lunar Outpost, Inc. (2830 East College Avenue, #106, john@lunaroutpost.com), [3]OxEon Energy LLC, 257 River Bend Way, Suite 300, North Salt Lake, UT, 84054.

Introduction: High-temperature, solid oxide electrolysis cell (SOEC) stacks with a thermally integrated balance of plant provide a potential pathway for scaling up production of hydrogen from water on the Moon. SOECs hold multiple advantages over lower-temperature proton-exchange membrane (PEM) and alkaline stacks [1]. SOECs can achieve lower specific energy in terms of kWh_{elec}/kg_{H2} (potentiall < 45 kWh_{elec}/kg_{H2}) because of the lower thermoneutral voltage for electrolysis and the lower area-specific resistance with high-temperature steam electrolysis [2]. However, SOEC operate at temperatures as high as 800°C, and as such, achieving low specific energy for SOEC systems requires tightly designed balance-of-plant with effective cxhaust heat recovery for efficient supply of high-temperature steam to the SOEC stack. This work presents a lab-scale demonstration of a 3-kWelec SOEC system in a cyro-vacuum chamber to simulate lunar-relevant conditions. Those test results have been used to calibrate SOEC system model to assess preferred system architectures and operating conditions of a scaled-up, lunar-deployed system.

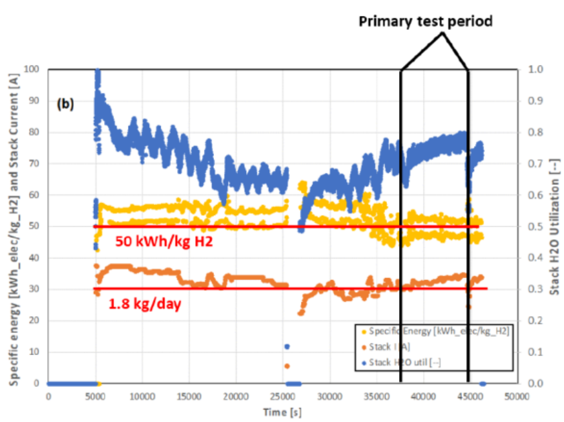

Figure 1. Plots of stack $\varepsilon_{H2O,util}$, system specific energy kWhelec/kgH2, and stack current for final SOEC system testing at vacuum..

Testing: The system was demonstrated on the lab-scale in a lunar-relevant cryo-vacuum environment at Colorado School of Mines in partnership with OxEon Energy LLC, with simulation modeling supporting the tests. [3] A solid-oxide 65-cell stack and supporting balance-of-plant (BOP) were fabricated, integrated, and tested in a cryo-vacuum chamber. Fig. 1 shows the final test of the system, demonstrating approximately 2 hr of H_2 production at a daily rate of >1.8 kg_{H2}/yr, under lunar-like conditions below 1 torr and -100°C, the latter generated by running liquid N_2 through the cryoshroud. Additionally, adding up the energy consumed by the SOEC stack, the stack heaters, and the steam generation, compression, and heat tracing in the BOP, the system was shown to use 48.8 kWh/kg_{H2} produced, achieving and surpassing target system energy efficiency. Finally, as part of an additional testing objective during an earlier test, O_2 product from the test was pressurized to approximately 2 bar for 20 min.

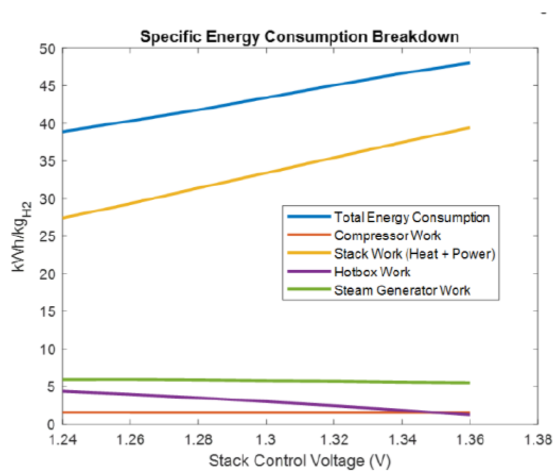

Figure 2. Plot of full system specific energy in kWh_{elec}/kg_{H2} (broken down by subsystem).

Modeling supporting the tests was benchmarked using these test results, in particular to account for stack cell voltage exceeding thermoneutral levels and the heat produced as a result. The results (Fig. 2) show stack hotbox heater work decreasing with increasing stack cell voltage, in addition to increasing rates of steam utilization $\varepsilon_{H2O,util}$.

Techno-economic Analysis: Parallel techno-economic analysis for a SOEC system, scaled up 258 times to a production rate of 169.2 mT_{H2}/yr, yielded an estimated development cost of \$160M and a production cost of \$108M (see Fig. 3), with overall system cost dominated by the SOEC stack and H_2-drying heat exchanger. This was done under the assumption that the SOEC stack component would consist of 15,000 individual cells assembled into units of 4 stacks of 100 cells each. This compared favorably to analysis done previously [4], and concluded that the cost of the system was in line with that required to keep the commercial business of an SOEC-based lunar-deployed hydrogen production system, using lunar water resources, viable.

Parameter	Current Estimate (target production rate)	Current Estimate (achieved production rate)	Previous Estimate (Sowers 2021)
Mass (kg)	8152	7383	4000
Average Power Consumption (kW)	1030	1030	1000
Development Cost ($M)	166	160	200
Production Cost ($M)	118	108	80
Launch Cost	No Change		

Figure 3. Current mass, power and cost estimates compared to previously published.

References: [1] Schmidt O. et al. (2017), *IJHE*, 42(52), 30470-92. [2] Lomax, B. A. (2022), *Nature Comm.*, 13, 583. [3] Dickson D. et al. (2021) *IEEE Aerospace*. [4] Sowers G., (2021) *New Space*, 9(2), 77-94.