# SCALED-UP USAGE OF SOLID-OXIDE ELECTROLYSIS CELL (SOEC) TECHNOLOGY FOR PRODUCTION OF ROCKET FUEL ON THE MOON BASED ON EXPERIMENTALLY BENCHMARKED MODELS

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## Background

- A major NASA in-situ resource utilization (ISRU) technology development goal is to develop more energy-efficient systems for **splitting water into $H_2$ and $O_2$ in a lunar environment.** (e.g., PSRs)
- High-temperature ($T$ > 700℃) solid oxide electrolysis (SOEC), with a well designed balance-of-plant (BOP), requires **lower specific energy consumption** ($kWh_{elec}/kg_{H2}$) than legacy alkaline or PEM electrolysis systems [1].
- The lab-scale, 2 $kg_{H2}$/day SOEC system below was successfully tested at School of Mines (Fig. 1). [3] Based on these tests, Cantera simulation models were created, using the configuration in Fig. 2. [2]
- These benchmarked models were scaled up to simulate a **160 ton/year $H_2$ production system, using lunar water.**

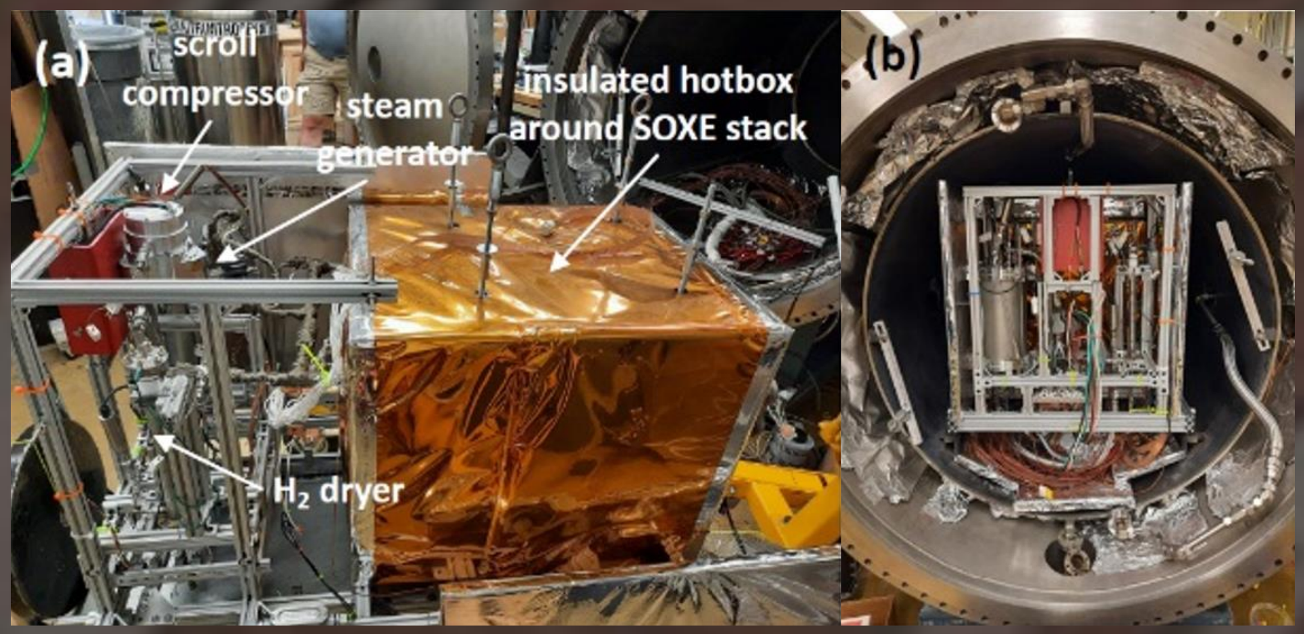


**Fig. 1.** a) Lab-scale electrolysis system. b) BOP and SOXE stack hotbox inserted into the vacuum chamber with the main door open before testing.

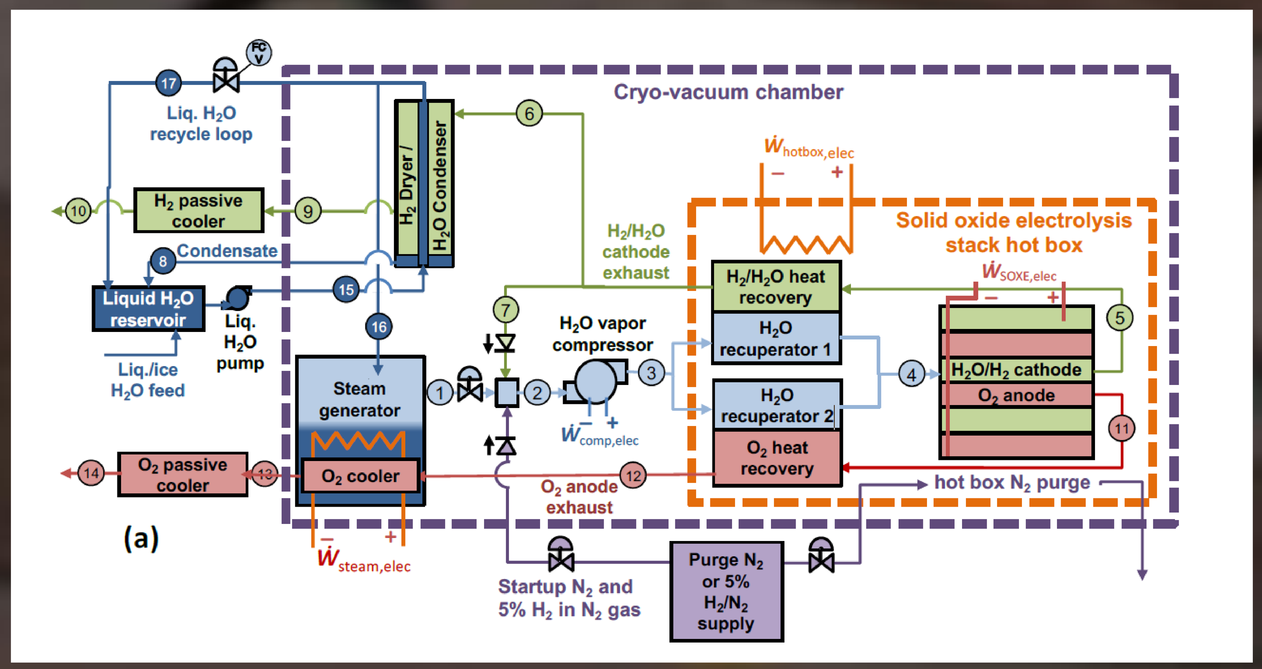


**Fig. 2.** Process flow diagram of the integrated SOXE system with the BOP as designed for the final full system demonstration

## Scale-Up Methodology

- Individual SOXE stacks comprised 100 cells of stabilized zirconia electrolyte between nickel cermet cathodes and manganite Perovskite anodes.
- To **scale up production** to **160 ton/year,** trade studies were performed that indicated the following optimal architecture:
  - **250 SOEC stacks** arranged in quad-stack configuration (See Fig. 3)
    - Single-layer configuration to ensure uniform stack pressure.
    - Recuperator heat exchangers for each stack—Maximize heat transfer (and therefore energy savings) with minimal mass penalty.

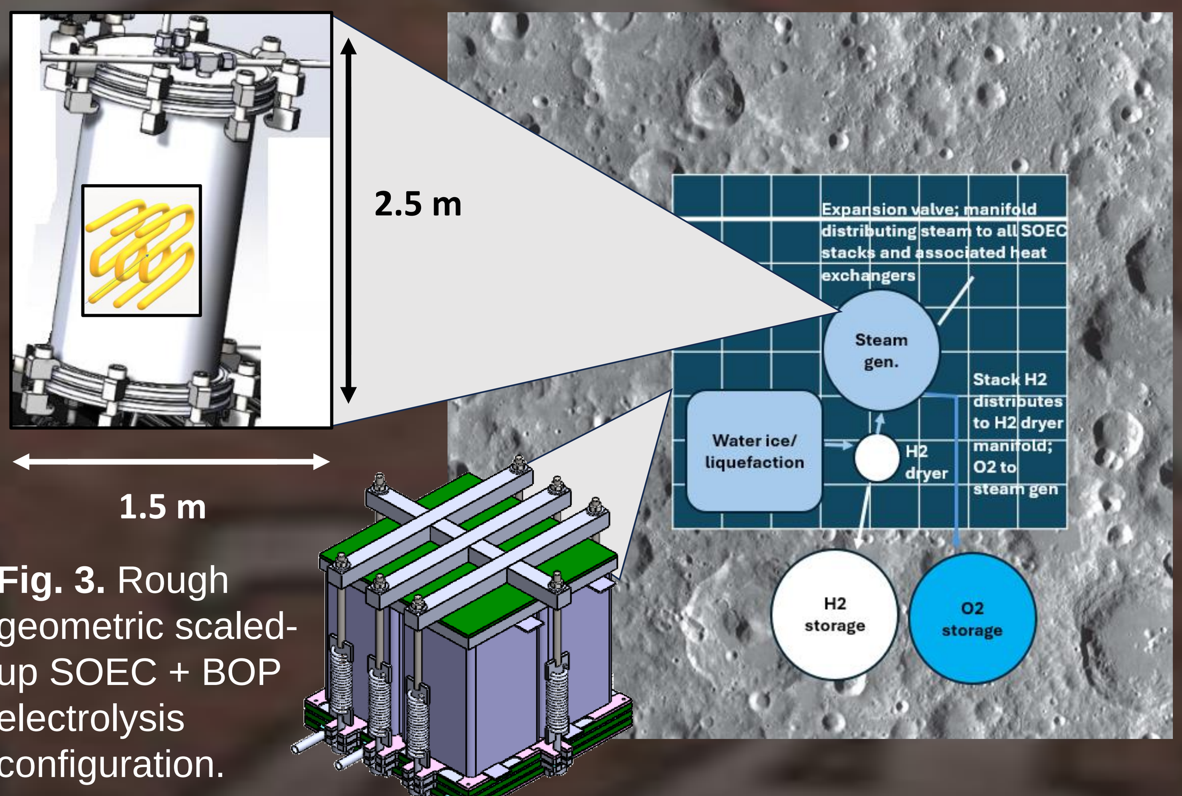


**Fig. 3.** Rough geometric scaled-up SOEC + BOP electrolysis configuration.

  - **One single steam generator** (~ 1.5 m diameter x 2.5 m height) to feed the SOEC stacks and cool the $O_2$ exhaust from the stacks.
  - **No steam compressor!** Control pressure with steam gen saturation pressure and expansion valve. For the following reasons:
    - Reliability—Lab experience has demonstrated compression to be the most risk-prone component of the BOP
    - Energy savings with compressor are minimal.

## Results

- Scaled up results, for $H_2$ production and specific energy consumption, are shown in Fig. 4 as a function of steam saturation temperature and lunar water mass input, with stack voltage assumed thermoneutral.

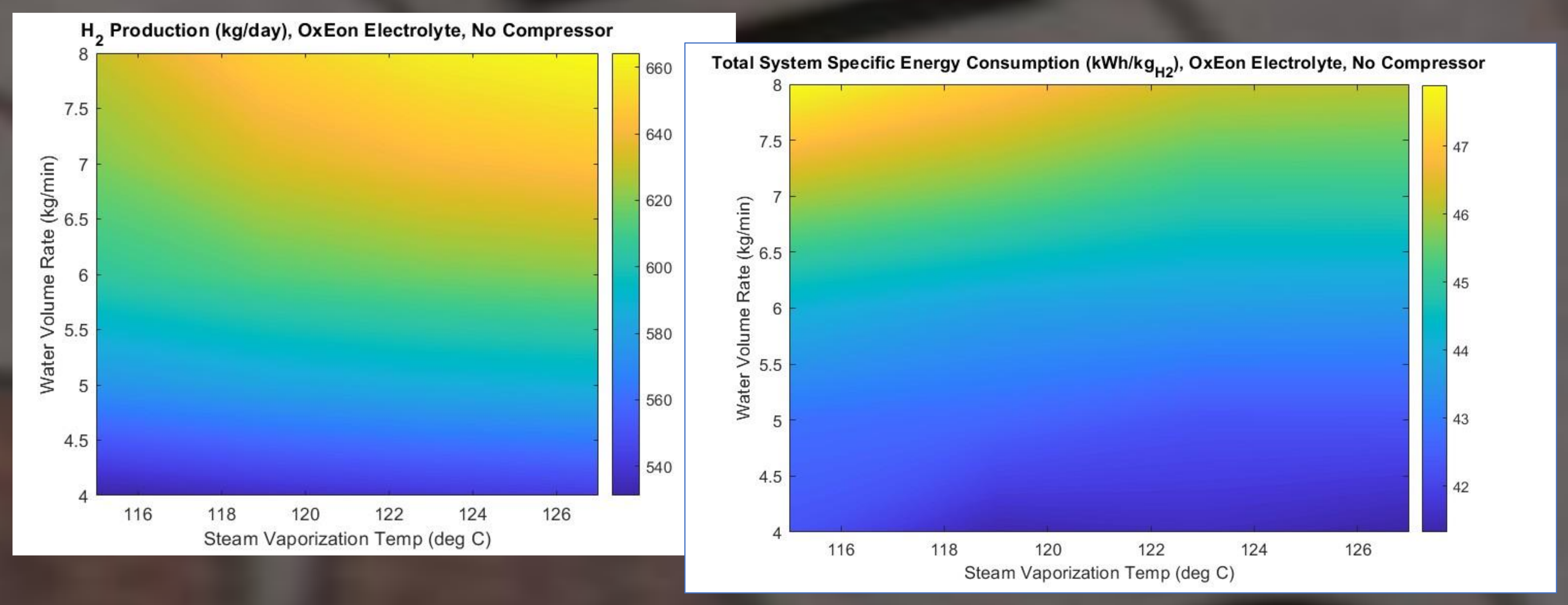


**Fig. 4.** $H_2$ production rate (kg/year) and system specific energy consumption ($kWh/kg_{H2}$) as function of steam saturation temperature (deg C) and water input rate (kg/min)

| Mass (kg) | | | | | | | |
|---|---|---|---|---|---|---|---|
| H2 exhaust heat exchangers | O2 exhaust heat exchangers | SOEC electrolysis stacks | H2 dryer | Steam generator | Hotbox insulation | | Total system mass (kg) |
| 710.7 | 631.7 | 5955.0 | 358.1 | 741.3 | 94.2 | | 8491.0 |

**Fig. 5.** Mass breakdown of SOEC fuel production system.

- These results indicate a system capacity for **~200 tons of $H_2$/year** production.
- These results indicate a trade-off between energy efficiency and $H_2$ production rate, holding water input rate (i.e. lunar water extraction rate) constant.
- Mass breakdown of system (Fig. 5) indicates a total lunar fuel production system mass of **8.5 metric tons**.

### Acknowledgments

This work was a follow-on to work performed under a NASA Space Technology Research, Development, Demonstration, and Infusion-2019 (SpaceTech-REDDI-2019) grant under NASA Research Announcement (NRA) 80HQTR19NOA01. I would like to thank the NASA Tipping Points program, as well as my advisors, Gregory Jackson and Christopher Dreyer, as well as Dr. George Sowers and Neal Sullivan, my PhD committee members.

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**References:** [1] Schmidt O. et al. (2017), *IJHE,* 42(52), 30470-92. [2] Dickson D. et al. (2021), *IEEE Aerospace.* [3] Dickson D. et al. (2023) *ECS Transactions, 111(6), 925.* [4] J. H., et al. (2021), *ECS Meeting Abstracts* (1, pg. 194).