Introduction to a Bosch Process Architecture for ISRU and Terrestrial Applications. B. M. Compton[1] and T. J. Giesy[2], [1]NASA Glenn Research Center (21000 Brookpark Rd, Cleveland, OH – Beau.M.Compton@nasa.gov), [2]NASA Marshall Space Flight Center (4600 Rideout Rd Huntsville, AL – Timothy.J.Giesy@nasa.gov).

Introduction: In-Situ Resource Utilization (ISRU) is an enabling component of NASA's goal for a sustainable presence on the Moon and beyond. Commodities such as oxygen and carbon that can be produced in-situ reduce the mass required to launch from Earth. Oxygen production is at the forefront of this goal as it can be used for life support and as a propellant. Carbon powder is useful for the carbothermal reduction process that produces oxygen[1]. To create both of these commodities, a new NASA project is studying the Bosch process, which involves reacting CO_2 and H_2 to create carbon powder and water that can be electrolyzed into oxygen and hydrogen. The process is also being studied for CO_2 reduction on Earth.

Experiment Design: The Carbon Utilization Technology for Lunar and Atmospheric Systems (CUTLAS) project is advancing the TRL of three key technologies to enable the Bosch process for ISRU and terrestrial applications. The first is a Rapid Cycle Adsorption Pump (RCAP) which uses zeolite as an absorbant to capture CO_2 from the atmospheres of Mars and Earth. The RCAP cycles the temperature of the zeolite to capture and release pressurized CO_2. A sub-scale sorption pump was tested in a simulated Martian environment and compared with a preliminary model. RCAP is also being tested in a terrestrial environment where CO_2 and humidity levels are varied. CUTLAS will include design, fabrication, and testing of a terrestrial-scale sorption pump based on the sub-scale results.

The second technology developed is a solar concentrator. Because the Bosch process reactors operate above 500 °C, a solar concentrator could provide the required thermal energy with minimal power required. Solar concentrator technology is not new, and CUTLAS is testing with a previously fabricated sub-scale unit to gain an understanding of scale, efficiency, and temperature gradient sensitivity for this new application. A terrestrial-scale solar concentrator is also being designed.

The third technology advanced under CUTLAS is a carbon formation reactor (CFR). The Bosch process is most efficient when split into two separate reactors [2]. While both reactors are necessary for oxygen production on Mars, only the second reactor, the CFR, is necessary for the lunar carbothermal reduction process. Previous work is scaled for environmental control and life support systems (ECLSS) on the International Space Station to support four crew members. For ISRU use on the lunar surface, the carbon removal and catalyst application systems need to operate in low gravity and be automated. CUTLAS is developing an ISRU-scale CFR that demonstrates this required automation. Additionally, a 10x scale CFR is being designed for terrestrial carbon capture.

Integrated sub-system testing is also underway. The two sub-scale reactors are to be integrated and tested at Marshall Space Flight Center. This will demonstrate the carbon production at steady state conditions for both reactors. A solar concentrator will be integrated and tested with a sub-scale CFR at Glenn Research Center. This will demonstrate the ability for the solar concentrator to sufficiently heat the reactor, and evaluate the effects of the temperature gradient.

Current Results:

Results are available for sub-scale testing of the RCAP in a simulated Martian environment (7 torr, 100% CO_2). Results of other technology advancements will be published throughout the lifecycle of CUTLAS. Results thus far have been unexpected, and improvements to the technology are in work for future testing. Using approximately 200 g of zeolite 13X, the maximum average CO_2 capture rate was 1.57 g/hr at a cycle time of 186 minutes. The equipment available and the sub-scale test setup limited the RCAP bed to a moderate temperature cycle (3 °C to 32 °C). A wider temperature range from planned equipment upgrades should allow for more efficient CO_2 capture. Cycle time was varied to optimize the average CO_2 process rate. While a longer cycle time allows a more extreme temperature gradient, there is also a point of diminishing returns when rate of CO_2 capture decreases and a new temperature cycle should be initiated. Furthermore, when compared to isotherm data for a similar zeolite, there appeared to be a consistent offset. This suggests results were affected by water contamination, a lack of performance of this particular zeolite, or that an equilibrium was not reached, which will be investigated in the next round of testing. Future tests will require better heat transfer and a more extreme temperature differential.

References:

[1] Hintze P. E. et al. (2016) "Self-Cleaning Boudouard Reactor for Full Oxygen Recovery from Carbon Dioxide," *46th International Conference on Environmental Systems*. [2] Abney M. B. et al. (2012) "Series Bosch Development," *42nd International Confer-*

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