ADVANCEMENT OF ISRU TECHNOLOGIES AND SYSTEMS: WATER COLLECTION, PURIFICATION, AND ELECTROLYSIS. J. B. Holquist[1], C. J., Joyce[1], , T. Myles[2], D. Markham[2], T. Ebaugh[2], P. Tewes[1], and M. Rich[2], [1]Paragon Space Development Corporation (jholquist@paragonsdc.com, 3400 E. Britannia Dr., Tucson, AZ, 85706, USA) for first author, [2]Giner, Inc (tmyles@ginerinc.com, Auburndale, MA, 02466, USA).

Introduction: NASA has identified a critical need for the design, fabrication, and testing of in-situ resource utilization (ISRU) components to produce purified water, oxygen, and hydrogen on the Moon and Mars from regolith-based water-ice resources. Extended stays on the Lunar or Martian surface and human space exploration missions will require a readily available source of purified water. Once the water is purified, it can be used as a source of oxygen, (both as breathable air for habitat crew and as propellant oxidizer), and hydrogen as propellant fuel. In-situ purification and electrolysis of lunar water has never been done before. It presents unique challenges related to the hazardous, corrosive, and toxic gases that appear to be present with the lunar water and the lunar polar environment; as well as the typical constraints of systems launched to the lunar surface (mass, volume, power, autonomy, robustness, reliability, and lifetime). This technology development is vital to allow humans to achieve a sustainable presence on the Moon.

ISRU Technologies: Paragon Space Development Corporation (Paragon) has been advancing an ISRU system focused on processes, supporting subsystems, and components necessary for the capture, purification, and electrolysis of water to generate propellant and life support consumables. This presentation provides an overview of the ISRU system architecture that Paragon has been advancing over the last five years, along with the progress to-date of technologies and subsystems. Fig. 1 shows the major technologies and associated project names. The following is a breakout description of three separate projects led by Paragon to advance ISRU system technologies.

Non-Water Volatile Capture, Concentration, and Utilization: From the Lunar Crater Observation and Sensing Satellite (LCROSS) mission data analyses [1] [2], it was estimated that water-ice is distributed in regolith within Permanently Shadowed Regions (PSR) at concentrations of 5.6 ± 2.9% by mass. Further, it was observed that there may be a variety of non-water volatiles (NWV) co-located with water-ice in PSRs. These NWVs include, but may not be limited to, carbon monoxide, hydrogen, hydrogen sulfide, ammonia, sulfur dioxide, ethylene, methane, methanol, carbon monoxide, and mercury. Many of these substances would be expected to volatilize with the sublimation of water from lunar water extraction operations. Some of these NWVs pose such systematic hazards that it is advantageous to separate and handle them entirely before they reach downstream purification and processing equipment to mitigate risk to those downstream systems. However, simple, and specific removal of each NWV may allow the loss of potentially valuable resources. To this end, Paragon has been conducting system design, modeling, analysis, and technology trade studies (based on feasibility and value**)** to capture, concentrate, and utilize these NWVs through a NASA Small Business Innovative Research (SBIR) Phase I entitled, Ammonia and Volatiles Accumulation in Lunar Architectures for Non-water Capabilities furthering Human Exploration (AVALANCHE). By combining the potential AVALANCHE process technologies as risk mitigation strategies that simultaneously support capture and utilization, value can be added to ISRU architectures in both improving reliability and robustness of downstream systems as well as in generating consumable resources for sale or use with spacecraft and lunar surface habitation infrastructure.

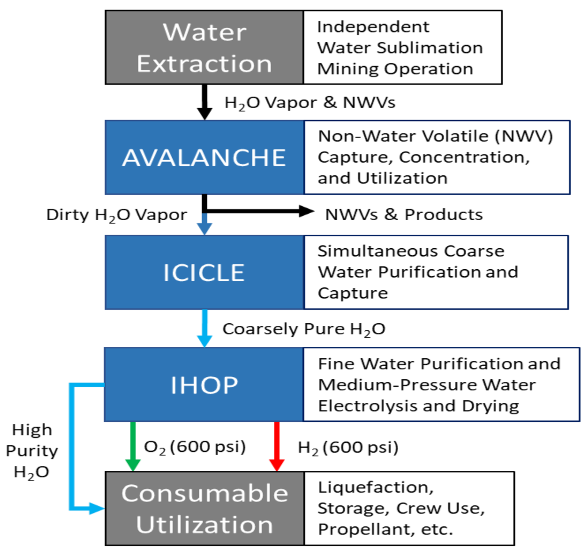

Figure 1. Paragon ISRU architecture major processes. Gray boxes: external up- or down-stream interfaces, blue boxes: Paragon project acronyms.

Simultaneous Coarse Water Purification and Capture. Many proposed and in-development lunar water extraction technologies leverage the sublimation of water to separate it in a gaseous state from regolith [3] [4] [5]. This inherently makes a second phase change of water, such as condensation or deposition, necessary to trap and collect the water for delivery to downstream processing systems. Paragon's ISRU Collector of Ice in a Cold Lunar Environment (ICICLE) is a technology being developed under a NASA Phase II SBIR to cold trap water from a wide range of potential lunar ice mining techniques, while simultaneously coarsely purifying the water through a process described as “freeze distillation.” The ICICLE technology is a thermally controlled cold trap for capturing water vapor through selective deposition from a mixed stream of both water vapor and NWVs. By controlling the internal pressure and temperature such that only water vapor deposits and NWVs remain in a gaseous state, the NWVs can be rejected in the exhaust to vacuum of the flow-through system while water is retained in a solid state – reducing the potential for NWVs to interact with water as it would in a condenser through aqueous phase solubility. This process has been analytically and experimental investigated in previous works [6] [7] and recent progress has demonstrated the water collection process at Technology Readiness Level (TRL) 4 using a prototype and relevant process conditions (partial pressure of water vapor less than the triple point of water and surface temperatures below -25ºC) [8]. A picture of frost grown inside the ICICLE prototype is shown in Fig. 2, below.

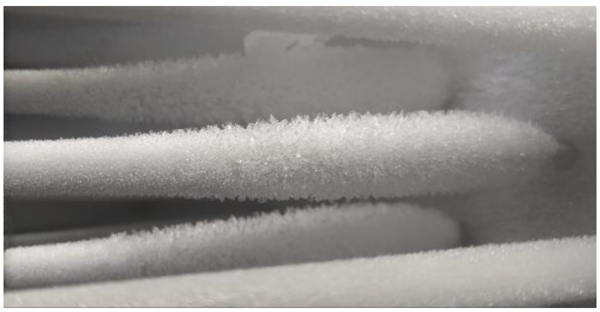

Figure 2. ICICLE cold trap TRL 4 prototype internal frost growth at relevant conditions.

Water Purification and Electrolysis: Paragon and partner Giner, Inc. (Giner) have been developing and testing key components and assemblies in the ISRU-derived water purification and Hydrogen Oxygen Production (IHOP) subsystem over the last 4 years [9] [10] [11] funded under a NASA Game Changing Development (GCD) NextSTEP-2 award and supported by internal research and development (IR&D) from both Paragon and Giner. IHOP is a multi-step water purification assembly (“Water ISRU Purification Equipment”, WIPE) coupled with an electrolyzer assembly (“Hydrogen Oxygen Production Equipment”, HOPE) capable of generating relatively dry H_2 and O_2. The IHOP subsystem is designed to process 1.34 kg/hr of water and multiple strings of IHOP can be utilized in parallel to meet desired processing rates. The primary components of the IHOP subsystem being advanced to TRL 5 are Paragon’s Ionomer-membrane Water Processing (IWP) technology and Giner’s lightweight aerospace electrolyzer technology, along with advancing the subsystem to TRL 4 through laboratory testing.

To-date, the testing that has been accomplished with the IHOP subsystem and components is: stress testing of a single IWP component module with a full suite of expected NWVs with water quality analysis [9]; full suite, nominal contaminant load testing of the WIPE assembly over 3 weeks of cumulative run time with water quality analysis, full-scale flow rate, and near-ideal water processing efficiency (negligible loss) [10]; 6,000 hours of endurance testing with the electrolyzer at 40 bar pressure, freeze-thaw cycle testing of the electrolyzer, and initial HOPE assembly operation for 200 hours at full-scale steady state H_2 and O_2 production rate. Integrated subsystem testing, pairing WIPE and HOPE assemblies together will begin soon.

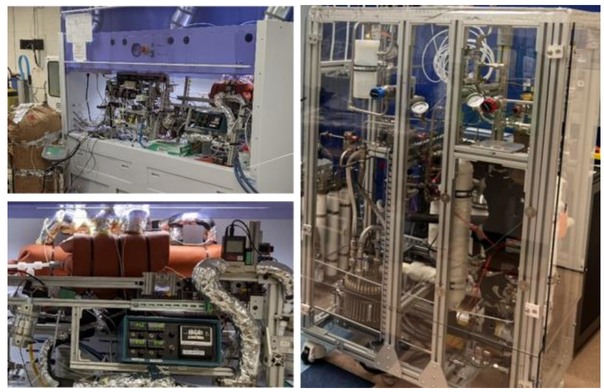

Figure 3. IHOP subsystem: top left: WIPE assembly, bottom left: IWP component, right: HOPE assembly.

Summary: Paragon’s strategic involvement in the lunar ISRU of water-ice resources uniquely positions the company to take the next steps to develop solutions for collecting, purifying, and electrolyzing lunar water, along with capturing and utilizing the NWVs that are co-located with water, to generate propellant and life support consumables for sustainable human surface activities and space exploration. The approach taken emphasizes modularity in the architecture and a holistic view of handling all potential contaminants that may be present with lunar water-ice resources.

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