COMPARATIVE ASSESSMENT OF DELIVERING CONSUMABLE RESOURCES VERSUS IN-SITU RESOURCE UTILIZATION FOR MOON AND MARS HABITATS LIFE SUPPORT SYSTEMS. W. West[1], M. Heldmann[1], T. Scull[1], D. Samplatsky[1], G. J. Gentry[2] , M. Duggan[2], K. Klaus[2], [1]Hamilton Sundstrand Space Systems International (HSSSI), A UTC Aerospace System Company, Windsor Locks, Connecticut, [2]The Boeing Company, Houston, Texas

Introduction: Life support consumables are a significant mass driver in human spacecraft and exploration surface habitats. Loop closure through regenerative systems greatly reduces resupply needs. Utilization of local resources could further reduce resupply needs. This study seeks to quantify the basic resupply needs of surface habitats on the moon and Mars, identify candidates for early In-Situ Resource Utilization (ISRU) and compare these results to determine crossover points where early ISRU could potentially become attractive.

General Assumptions: Based on the NASA Baseline Values and Assumptions Document (BVAD) the authors selected a crew of four astronauts to inhabit both the lunar and Mars habitats [1]. A single habitat is assumed to be used and is is 85 m^3 (3000 ft^3) in volume and is operated at 77 kPa (10.2 psia) (assumed by the authors). It provides living quarters and includes all the basic life support functions typically expected of a habitat, such as Atmosphere Control & Supply (ACS), Temperature & Humidity Control (THC), Fire Detection & Suppression (FDS), Atmosphere Revitalization (AR), Water Recovery Management (WRM), and Waste Management (WM).

Venting of waste gasses and leakage of atmosphere from human habitats on both the moon and Mars is, for this study, considered acceptable without limitation. One pedestrian airlock is envisioned along with one rover docking port. When a rover is docked to the habitat the vestibule allows for shirt sleeve access to the rover interior and the suit ports located on the rover. The rover supports open-hatch habitat 77 kPa (10.2 psia) ops when docked but operates at 55 kPa (8 psia) (assumed by the authors) when operating independently or can be isolated as a pre-breathe airlock prior to a Pedestrian Surface Excursion (PSE), formerly referred to as an Extra Vehicular Activity (EVA) while docked to the habitat.

Nominal PSEs in the vicinity of the habitat will occur from the rover suit ports while the rover is docked to the habitat. Similarly, during a rover based excursion, PSEs will be conducted from the rover suit ports. While the rover is away from the habitat the remaining crew members can access the outside via the habitat pedestrian airlock, or if rover or suit maintenance or other contingency is required the pedestrian airlock can be used. Surface excursion rates for PSEs local to the Habitat by two crew were analyzed for rates of 2 per week and 7 per week for both lunar and Mars missions. These are less than the maximum 14 per week frequency called out in the BVAD, which the authors considered conservative for this analysis, since more PSEs result in larger water resupply needs. Oxygen, water and food are provided to the rover from the habitat in support of the RSE.

Venting and Leakage: Spacecraft pressurized cabins experience air leakage overboard through hatch seals and other hull penetrations. The leakage rate can be modeled as proportional to the cabin pressure and volume. Some air is also vented overboard during airlock and rover operations. Venting of gases overboard, both intentionally and unintentionally, is unavoidable as a practical matter for spacecraft and habitat life support but results in a reduction in life support loop closure and requires make-up of gas.

Venting on planetary surfaces presents additional concerns with contamination of the environment. Several life support technologies in this assumed Environmental Control and Life Support Systems (ECLSS) architecture vent gases. From a planetary protection standpoint for the purposes of this study it is assumed that nominal ISS type venting is acceptable from lunar and Mars surface habitats and no extreme measures need to be taken to avoid venting.

Habitat Leakage - Deep space missions and crewed habitats will operate at lower pressures to minimize air losses, reduce structural weight of the pressure enclosure and reduce or eliminate prebreathing time for PSEs. Lunar and Mars habitats should therefore have lower leakage rates than ISS.

Airlock Losses - For every local habitat PSE via the pedestrian airlock, the airlock will be pumped down by air save pumps to preserve most of the air, with the remainder vented overboard. Air loss is a function of the size of the airlock, the minimum air save pressure and number of airlock uses.

Rover Vestibule Losses - For every rover departure, the vestibule will be pumped down by air save pumps to preserve most of the air, with the remainder vented overboard. Rover vestibule volume is assumed to be equivalent to an ISS vestibule defined by the trapped volume between two attached elements, and usage is equivalent to rover excursion assumption of 1/month.

Venting of CO_2 and CH_4 - The Sabatier reaction converts carbon dioxide and hydrogen to water and methane. If the hydrogen is carefully managed, every mole of hydrogen generated can be used to produce one mole of water. Since only half a mole of carbon dioxide is needed for this reaction, the excess carbon dioxide is vented overboard with the waste methane [2].

PSE Losses - The PSE suits themselves will also lose oxygen and water vapor. The suit ECLSS technologies will not have the same level of loop closure as the habitat. Metabolic levels vary depending upon the mission. Walking on a surface, collecting carrying samples and equipment could result in higher metabolic levels for the habitat PSEs.

Rover Losses - While in the rover, the crew's metabolic levels would be the same as those in the habitat. The ECLSS level of loop closure in the rovers is assumed to be less than the habitat. Rovers vent carbon dioxide overboard equal to 2 crew metabolic rate for duration of RSE minus PSE (at which point standard PSE losses are counted). Rovers leak air at 0.1 kg/day (0.22 lb/day). Air loss due to suitport cycling in support of remote & local PSEs is 0.36 kg/PSE (0.8 lb). Rovers vent humidity condensate along with the CO2, while waste water & solids are retained for return to the habitat for processing and disposal.

Analysis of Mission Resupply Needs: Starting from the data and assumptions, analysis was performed to determine summary resupply needs for both water and inert gas while varying percentage of water in food (0% and 50%) and number of surface excursions per week (2 and 7) The variable values were chosen to bound the solution set.

Another potential resource demand and associated resupply need is emergency reserves of consumables. In addition to the water usage, water (and other resources will need to be stockpiled to provide resource supplies during periods of maintenance and repair of the systems. Additionally, habitat inflation could be performed with ISRU resources as well. Based on this analysis, the only difference between lunar and Mars habitat and crew consumables needs is the length of stay time the resupply must satisfy.

Results: Basic ECLS system architecture for lunar and Mars habitats is almost identical as one might expect given that the equipment needs to support human life are identical and from a habitat design perspective there is little to differentiate a lunar habitat resupply need from a Martian habitat resupply need. Comparing the calculated resupply needs to the assumed ISRU systems masses provides the crossover point at which ISRU system mass becomes less than the supplied consumable mass.

With assumptions regarding delivered food water content, water recovery through processing and losses overboard, the water balance can be slightly negative or highly negative. One somewhat surprising source of water loss turns out to be the sacrificial cooling of the PSE suits. If one looks to improve initial water supply condition over time, say start out with a 1 month supply but provide tankage for 3 months and have the water mining system fill up the remaining tanks early on, the crossover point becomes immediate and underscores the value of ISRU water mining.

Lunar and Mars base water recovery requirements will ultimately be driven by the water content of the food. If food is supplied in a form that has about half of the final water content at consumption (the remaining half added during food preparation) then about 77% water recovery is required to result in no water resupply requirement, not accounting for EVA losses. For both lunar and Mars habitats the oxygen loss is assumed to be replenished from the High Pressure Oxygen Generator Assembly (HPOGA). Initial and subsequent resupply of nitrogen is required for both the lunar and Mars habitats. With no known inert gas supply to take advantage of on the moon, ISRU does not look feasible for inert gas replenishment for a lunar habitat. However, with relatively abundant and accessible amounts of inert gasses in the Martian atmosphere ISRU becomes value-added on Mars at the point where the processing equipment equals the weight of resupply gas (plus tankage). Basic crew needs and anticipated frequent work outside the habitat drive tremendous logistics challenges for mission planners.

Conclusions: Efforts must be made to reduce basic ECLS system weight and volume for a Mars mission. Loop closure is challenging, costly and ultimately not as value-added as reduction of initial systems weight and development of ISRU technology can be. This analysis comparing resupply needs to ISRU systems masses shows that ISRU systems could break even within the first surface mission in terms of launch mass. If similarity of design and purpose can be determined, lunar base water ISRU systems can be readily adapted for a Mars mission. Investment in technologies for lunar and Mars ISRU systems must begin soon to be at an acceptable TRL level for baselining systems when needed for a lunar base, and to better inform long term planners for a Mars mission.

References: [1] *NASA Life Support Baseline Values and Assumptions Document* NASA/TP-2015-218570. [2] Samplatsky, D., Grohs, K., Edeen, M., Crusan, J., Burkey, R., Development and Integration of the Flight Sabatier Assembly on the ISS, *AIAA-2011-5151 ICES Portland, OR*.