In-Situ Resource Utilization Human Exploration Requirements. W.E. Larson, NASA-KSC, NE-I2, Kennedy Space Center, FL 32899, william.e.larson@nasa.gov ,

Introduction: From the dawn of human space exploration, we've carried every resource required, food, water, oxygen, fuel, etc., on our launch vehicles. As such, we had to build the massive Saturn V to land man on the moon. If NASA is ever going to establish a sustained presence beyond low earth orbit and even venture to the surface of Mars, the architectures for human space exploration missions must fundamentally change. Just like Lewis and Clark utilized the natural resource at their disposal when the explored the western United States, NASA must learn to utilize the resources found at exploration destinations. While the resources used by Lewis and Clark, water, air, flora and fauna, are familiar to us all, the resources we can utilize on planetary bodies are not as obvious to the public. However, space resources are plentiful and can be harvested through relatively straightforward chemical processes.

Resources of Interest: Picking the resources of interest is pretty straight forward. Clearly astronauts need oxygen to breath and water to drink. Some of this can be supplied by closed loop life support systems that we are starting to be test on the International Space Station. However, closing the loop 100% is difficult and there's always the chance that this system could fail, so an alternative source of oxygen and water is needed. Additionally, there are losses associated with airlock operations and leakage. The Constellation program estimates that a crew of four would needed a metric ton of oxygen each year to make up for losses at a lunar outpost. Saving a metric ton of launch mass a year is certainly a good goal, but the real benefit of using in-situ resources is in the production of propellants for our Ascent Vechicles.

The majority of the mass of any launch vehicle is made up of propellant. While the design of the vehicle and its purpose will vary, the propellant fraction of mass for most vehicles is that roughly 80% of the mass is related to propellant. So if our architectures start flying with empty Ascent Vehicle tanks, we can save a huge amount of launch vehicle mass. A variety of architecture studies have shown a reduction of initial mission launch mass from 3.5 to 5 times. Considering that it is estimated that the cost to put a kg on the lunar surface and return it to earth costs in the vicinity of $100,000, reducing the launch mass by a factor of 3.5 results in a huge cost savings.

Extracting Resources of Interest: Producing oxygen and fuel on planetary bodies in most cases requires thermo-chemical processes. On Mars, we have an atmosphere that we can process to produce oxygen and fuel, but producing fuel will also require that we process the soil to extract the hydrogen we need to produce methane fuel from what is likely hydrated minerals. On the moon, we have no atmosphere and therefore must extract the oxygen need from the regolith. NASA is investing in three different technical approaches to extract the oxygen bound up in the lunar regolith. However all of these processes are very energy intensive. At this point in time, our prototype systems take in the neighborhood of 400 kWh per kg of oxygen produced annually. One of the reasons we consume so much energy, is that much of the regolith we are heating in our reactors is inert. That is, the chemical process we are employing can't extract oxygen from all of the minerals in the regolith. Energy is a very precious commodity on a space mission, so to make space resouce utilization practical we need to drive down the energy cost of extracting resources.

The mining industry is very familiar with this problem of uninteresting materials mixed in with the element of interest. There are a variety of beneficiation processes employed terrestrially to improve the yield of the extraction processes. If we can develop beneficiation techniques that can help us enrich the regolith for the minerals of interest we can significantly drive down the energy cost of utilizing space resources.

NASA's current beneficiation development focus has been to enrich the iron oxide content of the soils being loaded into our reactors. That is because the one of our chemical processes, called hydrogen reduction, primarily extracts oxygen from the ilmenite found in the lunar regolith and the iron oxides found in lunar glasses. In some places on the moon the fraction of reducible ilmenite in the regolith is below 5%. So to get the oxygen we end up wasting energy heating a mass that is largely inert.

Clearly, effective beneficiation techniques could have a real impact on the energy cost of oxygen via hydrogen reduction as well as other processes. But it is important to keep in mind that there is also a mass and power cost of employing a beneficiation system. So any process employed must be low mass, low power and reliable. That is why very creative beneficition solutions will be required.