Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

L. J. Karr[1], M. S. Paley[2], M. J. Marone[3], W. F. Kaukler[4] and P. A. Curreri[1], [1]NASA/MSFC, Huntsville, AL 35812, [2]AZ-Technology, 7407 Old Madison Pike, Suite 300, Huntsville, AL 35806, [3]Mercer University, Dept. of Physics, Macon, GA 31207, [4]University of Alabama in Huntsville, Huntsville, AL 35899

In order for humans to explore beyond Low Earth Orbit both safely and economically, it will be essential to learn how to make use of *in situ* materials and energy in an environment much different than on earth. Precursor robotic missions will be necessary to determine what resources will be available and to demonstrate the capabilities for their use. To that end, we have recently been studying acidic Ionic Liquid (IL) systems for use in a low temperature (< 200° C) process to solubilize regolith, and to extract, as water, the oxygen available in metal oxides. Using this method, we have solubilized lunar regolith simulant (JSC-1A), as well as extraterrestrial materials in the form of meteorites, and have extracted up to 80% of the available oxygen. Moreover, by using a hydrogen gas electrode, we have shown that the IL can be regenerated at the anode and metals (e.g. iron) can be plated onto the cathode. These results indicate that IL processing is an excellent candidate for extracting oxygen *in situ*, for life support and propulsion, and for extracting metals to be used as feedstock in fabrication processes.

We have obtained small amounts of meteorite materials believed by meteoriticists to have originated from our moon, Mars, and the asteroid Vesta, and were able to solubilize those using acidic IL systems. From the Vesta meteorite, we were able to extract about 60% of the available oxygen as water. *As far as is known, this is the first time that extraterrestrial/earth "hybrid" water has been obtained.* NMR analysis provided proof that the liquid retrieved is indeed water. We have also been able to electro-plate nickel and iron contained in meteorite material. By varying voltage they can be plated separately (electro-winning), and we plan to soon have sufficient quantities to form usable parts utilizing the additive manufacturing process.

IL processing of regoliths for oxygen and metal extraction has a number of advantages over other methods. An important advantage is that ILs are much "greener" and safer than conventional chemical reagents (e.g., volatile organic solvents, corrosive acids), primarily because they have very low vapor pressures, and they can exhibit good stability in harsh environments (extreme temperatures, hard vacuum, etc.). Furthermore, regolith processing can be achieved at lower temperatures than other processes such as molten oxide electrolysis or hydrogen reduction, thereby reducing initial power requirements. Efficiency of oxygen production is much greater than for hydrogen reduction because all metal oxides can be utilized. Since we have shown that the ILs can be regenerated and reused, the expense of shipping large quantities (up-mass) can be mitigated.