Space Resource Enabling Technology Development at the Colorado School of Mines.

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Introduction: Technologies related to in situ resource utilization (ISRU) must be developed to make extraterrestrial colonies, research stations, and economic enterprises possible. At the Center for Space Resources in the Colorado School of Mines, key enabling technologies for lunar ice mining, regolith 3D printing, and in-situ geophysical investigation are being actively developed. In the past year, the Center for Space Resources has taken several TRL 1 ISRU technologies to TRL 4 and 5, and continue their development alongside corporate and government partners. This presentation will give an overview of the recent work done in the four previously mentioned key technology areas.

Lunar Ice Mining: The Center for Space Resources (CSR) has developed an ice extraction method called thermal mining. Methods for extraction of lunar permanently shadowed region (PSR) ice can be grouped into two classes: extraction based on bulk physical removal of icy regolith as solid material from the ground and extraction based on in situ sublimation of ice that allows regolith to remain in place. Recent findings have proven the existence of ice up to 30% by weight in the PSRs. Thermal mining is ideal for this scenario as ice is efficiently sublimated by applying heat directly to the surface of the PSR and the near subsurface (fig 2), then directing vapor to cold traps to freeze for transport to a processing system.

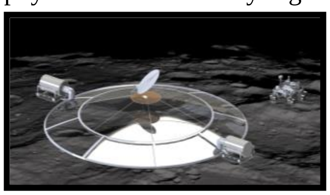

Figure 2: Thermal mining concept art.

3D Printing: Additive manufacturing (AM) will be a key ISRU technology for producing parts astronauts will use to survive, from mechanical tools, to habitats to launch vehicles. A single AM system can produce complex, organic shapes as easily as simple parts, allow for system simplification, reduce failure modes, and eliminate storage and logistical concerns as parts are produced on an as-needed basis. CSR is pursuing development of this technology on multiple fronts: concentrated solar regolith AM in a simulated lunar environment, and large-scale, regolith-based structure printing. Though concentrated solar regolith AM and other directed energy methods have been tested, testing as seen in figure 3 has rarely been done within a simulated lunar environment of vacuum, high temperature, and high energy particles. CSR is defining the parameter space for regolith printing with the goal of immediate applicability to precursor AM testing missions on the lunar surface.

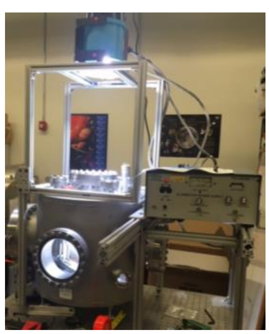

Figure 3: Regolith 3D printing using a solar simulator.

Geophysical Testing: Many surfaces found on the Moon, asteroids, Mars, moons, and other planetary bodies are covered in fine granular material known as regolith. Increased knowledge of the physical properties of extraterrestrial regolith surfaces will help advance scientific knowledge of these bodies as well as the development of exploration (e.g. instrument and robotic) and ISRU systems. CSR has developed a novel system, called the ISRU Experimental Probe (IEP, fig 1), supporting studies of dry and icy regolith from -196 to 150 °C and pressure from laboratory ambient pressure to 10-7 Torr. CSR has also built a room-sized regolith simulant filled test bed for larger scale geophysical property investigation and rover drive testing. Commercial partners such as Lunar Outpost (fig 4) have begun testing in the large regolith bed in preparation for lunar launches in the next five years.

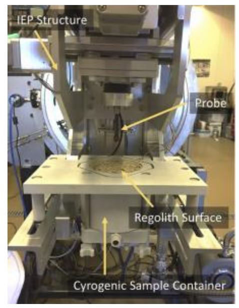

Figure 1: IEP with sample.

Figure 4: Lunar Outpost rover testing in CSR test bed.

Conclusion: The Center for Space Resources is developing technology to enable resource extraction, manufacturing, and fundamental science for the advancement of space exploration and ISRU capabilities. CSR is working to bridge the technical gap from the current global dream of practical, economically viable ISRU to its widespread use in the future.

References: SRR presentation/abstract for Thermal Mining (Dreyer, Sowers and Williams, 2018)

Commercial Lunar Propellant Architecture (Kornuta et al., 2018) www.isruinfo.com/docs/Commercial%20Lunar%20Propellant%20Architecture.pdf

Li S, Lucey PG, Milliken R, Hayne P, Fisher E, Williams JP, Hurley DM, Elphic RM (2018a) Direct evidence of surface exposed water ice in the lunar polar regions, Proc. Nat. Acad. Sciences 115 (36), 8907-8912, https://doi.org/10.1073/pnas.1802345115.