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LUNAR POLAR ICE EXTRACTION TECHNIQUES ASSESSED TOWARDS POWER AND INFRASTRUCTURE REQUIREMENTS

Abstract

The emerging cis-lunar economy, including crewed lunar missions and permanent settlement will require self-sustaining operations as the cost of resupplying resources from Earth is unfeasibly high. In-situ resource utilization (ISRU) will be a key enabler in this regard. In particular, the presence of water ice on the Moon offers promising prospects for in-situ propellant production, water and oxygen supply. Water ice is most abundant in permanently shadowed regions (PSR) at the lunar South pole with temperatures averaging around just a few Kelvin.

This paper classifies and compares various mining techniques to extract water ice from PSRs. These include thermal mining solutions based on the principle of water ice sublimation by utilizing solar mirrors, high power lasers or microwave heaters and afterwards capturing the vapor in a cold trap. Other techniques include filtering/grain-sorting techniques as well as chemical reduction of lunar regolith. The classification also considers key infrastructure along the value chain of ISRU, namely logistics and supporting technologies to enable mining operations, raw material transport, storage and refining. Using weighted criteria, the study conducts a system-level tradeoff analysis. High energy efficiency and easy access pose one of the greatest challenges for conducting mining operations and depend on the applied techniques. Upfront, the technology readiness level (TRL) is estimated as well as the expected development time. Other criteria include cost per kilogram, mass requirements, upfront investment cost, thermal operational stability, water ice retrieval rate, and the complexity of infrastructure needs. One of the key factors for sustained long-term operations is the low-cost, low-energy scalability of mining technology.

Based on the technology review, this paper aims to derive long-term operational scenarios comparing different concepts of operations in an integrated space resources value chain. Depending on the considered mining, the scenarios outline the potential evolution of prototypes, preliminary study missions towards long-term scalable applications of these techniques. Lastly, the paper provides recommendations for proposed water ice mining missions highlighting potential challenges and risks for sustained mining operations.