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LUNAR WATER ICE MINING SYSTEM ARCHITECTURES OPTIMIZED TOWARDS POWER AND INFRASTRUCTURE REQUIREMENTS

Abstract

The emergence of a cis-lunar economy requires key infrastructure and self-sustaining operations as the cost of resupplying resources from Earth is unfeasibly high. In-situ resource utilization (ISRU) will be a key enabler for permanent lunar settlement. The discovery of water ice deposits on the Moon offers great potential for in-situ propellant production, water and oxygen supply. Water ice is most abundant in permanently shadowed regions (PSR) near the lunar poles where temperatures can drop to -250C.

This paper proposes water ice mining system architectures and aims to assess the technical and economic feasibility of these techniques for in-situ propellant production within an integrated ISRU ecosystem. Initially, the study classifies and compares mining techniques to extract water ice from PSRs considering technology readiness level (TRL) and expected development time. Mining techniques 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 are based on filtering and grain-sorting as well as chemical reduction of lunar regolith. The classification also considers key infrastructure along the value chain of ISRU, including logistics and supporting technologies to enable mining, refining and long-term storage.

Using weighted criteria, a trade study compares system-level architectures, with a primary focus on power and infrastructure requirements. High energy efficiency, accessibility to PSRs and stable thermal control to endure extreme temperatures are among the greatest challenges. System trades also compare mass budget, thermal operational stability, water ice retrieval rate, and the complexity of infrastructure needs. Further, the study assesses the economic feasibility of each architecture in terms of cost per kilogram, upfront investment cost and return on investment. The derived architectures have output capacities large enough to enable propellant production for direct launch from the Moon. System dimensioning optimizes the ratio of energy input versus mining output. The most feasible architecture enables long-term self-sustaining operations and energy-efficient scalability within a greater ISRU ecosystem.