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Space Resources, the Enabler of the Earth-Moon Econosphere (5)

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THE MOON AS AN EFFECTIVE PROPELLANT SOURCE: A COMPREHENSIVE EXERGY ANALYSIS FROM EXTRACTION TO DEPOT

Abstract

Establishing a permanent lunar base has gained increasing attention since it offers opportunities for international cooperation and the commercialization of space, forming the foundation and testing ground for a human existence independent from Earth. Essential to future missions beyond cis-lunar space is the exploration and in situ processing of the Moon's resources, especially the sustainable production of energetic resources and propellants. Utilizing in situ generated propellants can dramatically reduce transportation costs by removing the need to source propellants from Earth. Resources on the Moon are limited, and the extraction of available resources are energy-intensive processes demanding advanced techniques and technologies. Consequently, one of the biggest challenges lies in developing process architectures with a positive energy balance, for which comprehensive analyses are still missing. The focus currently lies on the extraction of water ice from lunar regolith and the production of hydrogen and oxygen through water electrolysis. However, alternative fuel and process options may reduce the energy cost while providing equivalent energetic revenue. In this paper, exergy analyses of in situ extraction methods are conducted to investigate whether the required energetic budget allows sustainable implementation. The analysis includes extraction methods and propellant options to reveal the extent to which alternatives to hydrogen are feasible. Exergy analyses determine thermodynamic losses of energy flows and indicate options for process optimization. The exergy destructed represents the margin of improvement within the process architecture and thus reflects the process's thermodynamic and economic value while allowing a more distinct examination of energy use. Assuming the availability of water and carbon dioxide ice in permanently shadowed regions, the analysis shows that choosing methane instead of hydrogen in combination with oxygen as propellants can reduce the required energy input by up to a third. An example mission allows to directly compare the operating cost of the extraction processes for the different propellant options. The mission entails a spacecraft propelled by a liquid bipropellant engine utilizing the extracted propellant and transporting a payload of the same propellant to a depot located in lunar NRHO (Near-rectilinear halo orbit). Although abundant in space, the results suggest that hydrogen may not be the only or even energetically cost-effective resource for developing cislunar and Martian space infrastructures. Likewise, sustainable extraction of propellants suitable for current and future propulsion systems will foster humanity's reach further into the solar system.