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In-situ resources on the Moon

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The paper gives an overview of potential materials and resources available on the Moon for future use within space exploration ventures or for export to Earth. It tries to critically assess the processing requirements and techniques as well as the corresponding utilization concepts and economics involved. The term “space resources” is understood in a broader sense: It covers materials, e.g., volatiles and minerals from the regolith, for production of propellants and life support consumables or for construction/manufacturing, and it includes also energy as well as the unique environment (vacuum, radiation, different g-level). The most obvious objective is to improve future human space exploration missions and their cost efficiency via increasing self-sufficiency and inherent safety (“living off the land”). Clearly, the on-site use of space resources aims at the support of space missions only and offers no argument or motivation in itself for space exploration activities (an often ignored fact). Propellant production on the lunar surface from in-situ materials is generally believed to be the most promising near-term application. Numerous processes have been proposed for the separation of oxygen (about 45 wt.%) bound very strongly in the minerals and glass of the regolith, but very few of them have been tested experimentally. Today, we are far from mastering the complex physical and chemical high-temperature processes involved in the reactions, multiphase flows, and phase changes. A significant effort is necessary to investigate promising processing concepts: first in small-scale terrestrial experiments and later scaled-up with consideration of lunar environmental constraints. Use of solar thermal technology seems ideally suited for these lunar facilities. From orbital missions (Clementine, Lunar Prospector) it is speculated that water delivered by cometary impacts is present in permanently dark polar depressions. If confirmed by robotic lander missions, a promising resource would be found (in addition to an interesting scientific phenomenon), but its exploitation might be difficult due to the harsh lunar polar environment. On the other hand, from the orbital measurements of the polar areas it can be deduced with some confidence only that enhanced hydrogen

is present (up to a few wt.%), which might be stored there from the solar wind. In this case oxygen would be missing and could be gained on the Moon only from the regolith.

In order to build up credible scenarios for in-situ resources utilization (ISRU), several activities must be initiated – mostly in parallel: 1) resources prospecting on the Moon to find the most interesting areas for volatiles extraction (including water in polar craters) and for oxygen production from regolith (e.g., ilmenite-rich mare or dark mantle deposits with glassy orange soil); 2) terrestrial laboratory experiments with simulated lunar soil to identify the most promising and efficient processes for production of lunar resources; 3) demonstration missions to the lunar surface to verify the developed concepts in the corresponding environment; 4) economic assessment of the concepts. This defines a roadmap for lunar ISRU, and corresponding ideas for activities and missions will be presented.