LUNAR PROPELLANTS AND "GATEWAY" SPACE TRANSPORTATION ARCHITECTURES

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We have been examining the use of propellants derived from the Moon, Mars and Phobos/Deimos in the context of "gateway" space transportation architectures such as those studied recently by the NASA Exploration Team. Gateway architectures us stations at Lagrangian points, such as the Earth-Moon L-1 point between the Earth and the Moon, as operationally important nodes from which missions can be launched to the Moon, Mars, Earth-Sun L-2, and various Earth orbits. Similar applications may be found for the Sun-Mars L-1 point. The addition of propellant obtained from resources in space can have a significant role in such architectures, where they can substantially reduce the quantity of propellants that must be transferred from Earth. This would lead to the development of propellant depots at L-1 and potentially in other Earth orbits.

Hydrogen and oxygen are the principal propellant resources of the Moon. Hydrogen is ubiquitous at low concentrations (50 ppm) in the lunar regolith and can be removed by heating at modest (800 degrees C). That could be done most places on the Moon. Oxygen can be obtained by hydrogen reduction of ilmenite or pyroclastic glass, found in mare regions. Recently, data from the Lunar Prospector mission have indicated that hydrogen is enriched toward the lunar poles and may be in the form of water ice deposits within permanently shadowed craters. Such water could be removed by mild heating, though operations within these very cold places may be significantly more difficult than those in more typical lunar environments.

Even if water is found in polar craters, hydrogen (or equivalent water) concentrations are expected to be low, implying the need for excavation of substantial to huge quantities of regolith in proportion to the amount of propellant produced. We have developed a concept for a continuous excavation device, a lunar bucket-wheel excavator, which in principle can be highly productive (mass excavated/mass of excavator). This system can be designed at scales that are compatible with current robotic mission capabilities for the Moon, which can deliver 200 kilograms of payload to the Moon using a Delta-class launcher from Earth.

We have been examining alternative heating mechanisms for the extraction of volatiles from the regolith. Heat transfer to the regolith is an important parameter. In low pressure systems where thermal convection is inefficient and conduction dominates, the amount of time required to heat material to a given temperature can be quite long. This necessitates large containment systems. If more rapid heat transfer methods can be developed, the scale of extraction reactors can be reduced and the total system mass will be less.

Power availability is key to the thermal extraction of hydrogen or ice from regolith. Roughly 200 times as much energy is required to extract a given amount of hydrogen from lunar regolith (at 50 ppm H_2) as is needed to extract ice at 1% concentrations (higher concentration, less heating for water). However, as energy on the Moon becomes less expensive, the difference in system cost become less important. For that reason, we have been involved in studies at the University of Houston that could lead to the production of photovoltaic cells on the Moon from lunar resources and could eventually significantly reduce the cost of energy on the Moon. It might also be possible to utilize lunar materials to produce solar concentrators that could be utilized for thermal extraction systems. If nuclear reactors are built for the Moon, and waste heat is available, it could also become possible to economically extract hydrogen directly from the lunar regolith.

We have analyzed potential economic benefits for the use of lunar propellants in Earth-Moon space. In one architecture, an orbital transfer vehicle would be based in Earth-Moon L-1, where it would be fueled with hydrogen and oxygen derived from the Moon. This vehicle would fly to low Earth orbit, rendezvous with a communication satellite, deliver it to geostationary orbit, and return to L-1 for refueling. This would appear to be economically competitive at the predicted scale of geosynchronous orbit activity in the next 10-20 years, depending on the actual market scale, the financial approach, the technologies for extraction and production of propellants, and the concentrations of extractable ice or hydrogen that can be discovered in lunar exploration programs. Other L-1 applications, such as the use of lunar propellant in a human Mars exploration program, could contribute to the demand and provide additional economic incentives.