DEVELOPING THE RESOURCES OF THE SOLAR SYSTEM

by
The Space Resources Roundtable, Inc.

Submitted to the NRC Solar System Exploration Decadal Study

Permanent human habitation of space requires knowledge of the resources available from the Moon, Mars, and asteroids. This paper presents a near-term strategy for exploring for resources that is compatible with the main science goals of solar system exploration.

Strategy

We propose missions to the Moon, Mars, and asteroids. The missions share two common elements: (1) They land on the planetary bodies and characterize the surface and subsurface environments. (2) The data returned will be of immense value to both science and resource exploration.

Moon

Lunar Prospector data show conclusively that lunar polar regions are enriched in hydrogen. We do not know the precise form of the hydrogen (H, H_2O[ice], H2O[bound], CH_4, organic compounds, etc.), its distribution in the regolith, or its precise location (permanently shadowed craters or over a broader region). The presence of water ice would enable more economical human exploration of space and allow us to address important science questions such as the compositions of comets. To understand the concentration mechanisms, sources of hydrogen, and composition and total inventory of the deposits, a dedicated mission is essential. Such a mission would characterize the locations of the hydrogen deposits from orbit and, most important, make detailed *in situ* measurements of representative deposits. Sub-surface sampling is essential. It should reach a depth of at least a meter (ideally to the base of the regolith, several meters).

Recommendation: Give high priority to a mission that combines orbital and landed components to study lunar polar regions.

Asteroids and Martian Moons

Asteroids provide vital information about processes in the solar nebula, accretion mechanisms, asteroidal aqueous and igneous processes, and the impact record in the asteroid belt. They will also be important sources of fuels and material (regolith for shielding, precious metals for industrial use, organic compounds for polymer production) for use by humans in space. As for scientific studies, resource prospecting requires missions that characterize the composition and physical properties of a number of types of asteroids. Such missions must include orbital and surface measurements, and sample returns.

Recommendation: Missions to at least three types of asteroids (at least one of which appears to be water-rich and carbonaceous), with detailed imaging from orbit, surface sampling, and sample return.

Mars

A unifying theme of the Mars Exploration Program is to understand the distribution and history of water. Water is also essential for permanent settlements on Mars. We support missions that determine the surface and subsurface distribution of water, with emphasis on deep drilling (a few hundred meters). Deep drilling will characterize the chemical, mineralogical, and physical properties of the Martian subsurface, an essential step toward determining how to recover deep water and for understanding the planet's formation and evolution.

Recommendation: land a spacecraft equipped with a drill capable of retrieving samples for in situ analysis and/or sample return from depths of more than 100 meters.

Other Opportunities

There are opportunities on science missions to enhance both the overall scientific return and our understanding of resource utilization. *In situ* analyses, especially of the physical and geotechnical properties of the surface, help us understand mining and materials processing. Sample return missions allow us to devise methods to extract commodities from planetary surfaces. Such experiments can also benefit future scientific missions. For example, the ISRU experiment that was to fly on the 2003 Mars lander mission was designed to extract fuel from the Martian atmosphere. This could have made a sample-return mission less costly and more capable.

Recommendation: Allocate space, power, and mass on planetary missions for dual-use payloads that perform both science and applied science measurements, or that enhance future science missions.

Rationale

Need for Resources in Space

Permanent settlements will require use of materials from the Moon, Mars, and asteroids to build and maintain the infrastructure and generate products for export. Prospecting for these resources and devising mining and processing techniques are crucial steps in human migration to space. This must begin now, long before settlement and the establishment of industrial complexes.

Resources Recognized in Strategic Planning

Paving the way for human space missions is listed in the strategic plan developed by the Office of Space Sciences: "Identify locales and resources for future human habitation within the solar system." Another goal is closely aligned with the search for resources in space: "Make the solar system part of the human experience in the same way Earth is, and hence lay the groundwork for human expansion into the solar system." One of the four major goals of the Mars Exploration Program is to "Prepare for human exploration." Thus, our priorities should be based in part on the ways in which near-term robotic missions will facilitate future human exploration.

Targets for Resource Exploration

The Moon will play a central role in human expansion into space. Many studies have been made of its resource potential (e.g., oxygen extraction from volcanic glass and ilmenite), but one type of resource has not been characterized sufficiently: potential water ice deposits at the poles. If the observed hydrogen enrichments signal the presence of ice, there could be vast amounts of fuel available to support development of the Moon and cis-lunar space. It is essential to characterize the nature and distribution of the deposits and to design and develop extraction techniques.

Asteroids and the Martian moons will be most important as sources of water, which could be used for fuel and life support throughout the inner solar system. Thus, we must identify water-rich near-earth asteroids and characterize their surface properties in sufficient detail to design and develop extraction systems.

Mars is a long-range target for human exploration and settlement. We will need numerous indigenous resources, but the most important is water. Water is essential for life support and fuel. Consequently, we must determine the accessibility of water in surface and subsurface environments. This is also essential for answering central scientific questions: Was there, or is there, life on Mars? For both resource exploration and science, we must follow the water.

These bodies offer more than sources of fuel and material for human habitation of space. They have unusual environments compared to Earth, which will provide opportunities to develop new, unintuitive techniques to extract resources. Such new techniques may lead to new, environmentally friendly ways to extract and process resources on Earth.

The Space Resources Roundtable, Inc.

The Space Resources Roundtable is a non-profit organization whose vision *is to promote the development and utilization of space resources for the benefit of humanity.* Its members constitute a broad spectrum of technically-oriented, professional space experts: planetary geologists, mining engineers, aerospace engineers, energy specialists, economists, and space legal experts. Its Board of Directors currently has six members:

Michael B. Duke, President (Colorado School of Mines
G. Jeffrey Taylor, Vice-President (University of Hawaii)
Alex Ignatiev, Treasurer (University of Houston)
Robert Wegeng, Secretary (Pacific Northwest National Lab)
Sanders Rosenberg, Director (In-Space Propulsion, Ltd)
Frank Schowengerdt, Director (Colorado School of Mines)

Contacts:
Michael Duke, mduke@mines.edu
G. Jeffrey Taylor, gjtaylor@higp.hawaii.edu