Space Resources and Mining: Current Objectives, Plans, and Missions

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Why are Space Resources and Their Use Important?

There are many reasons why people and nations want to explore space, and there are many different ways in which space can be explored. A critical interface linking both the 'why' and the 'how' of space exploration is the identification, extraction, and use of resources in space. In both NASA's Journey to Mars: Pioneering Next Steps in Space Exploration released in October of 2015 and the Global Exploration Roadmap released in August 2013, the ability to find, quantify, extract, process, and use space resources was identified as a critical objective by NASA and over 14 other space agencies for achieving affordable and sustainable human exploration beyond Earth's orbit, encouraging and creating new commercial entities and markets based on space activities, and increasing the terrestrial economy and quality-of-life benefits for all humankind.

Robotic and especially human space exploration up to this point in time can be considered to be 'Earth reliant' in that everything needed to support and enable the mission is launched from Earth. The past Apollo missions to the Moon and the International Space Station currently in orbit above the Earth all rely on hardware, habitats, power, transportation, and life support consumables sent from Earth to keep the crew alive and working. As the distance from Earth increases, the cost of transportation and the risks due to failures and logistics disruptions also increases. By using resources found at the site of exploration to make mission critical consumables (such as propellants, fuel cell reactants and life support commodities), spare parts, and infrastructure needed to support surface activities (such as landing pads, roads, habitats/shelters, and power/thermal systems) commonly referred to as *In Situ* Resource Utilization, a significant amount of launch mass and cost can be saved and risk reduced. The ability to do these things also changes how exploration is performed from Earth Reliant to NASA's goal of 'Earth Independent' exploration.

After the US Apollo program was over, people began to recognize that it had been an inspiration for a generation of young students to go into Science, Technology, Engineering and Math (STEM) fields, and that the US industry and economy had significantly grown and lived off these students and the technological advances made to achieve these missions for decades. Space exploration should no longer be focused solely on scientific advancement or national pride, but for economic growth and population standard of living advancement. Considering the economic value of human exploration and how it could expand the economy of the US was brought to full light in a speech by John Marburger, the director of US Office of Science and Technology Policy under George W Bush at the Goddard Symposium in 2006. In his speech he highlighted that the ultimate goal was not to just Explore space but to Use space for the benefit of mankind. He further stated that the use of off-planet resources, in this case from the Moon, should be a critical architectural consideration for human space exploration to make it more affordable and sustainable. This could be achieved in two ways. The first is to start by encouraging and commercializing the extraction and production of transportation and life support related products from space resources, which could than lead to other resource uses once an affordable transportation architecture is established. The second is to encourage the spin-in of terrestrial technologies into space applications and spin-off of space technologies into terrestrial applications to increase the efficiency and profitability of terrestrial industries.

What is Needed and What is Currently Going On with Space Resources?

As with terrestrial mining, for ISRU and space mining to be implemented there needs to be confidence in the availability of the resource(s) of interest, the extraction and processing systems used, and the quality and availability of the product generated. To achieve this confidence, NASA is currently pursuing multiple paths simultaneously.

The first path is understanding what resources and products can have the greatest impact on near-term and long-term human exploration missions. By performing studies of human missions to the Moon, Mars, and other destinations with and without the use of space resources and products, a return-on-investment assessment can be performed for the cost and mass of the hardware and infrastructure needed to create the product vs bringing the product from Earth. Past studies have shown that making propellants for transportation systems provides the biggest mass reduction, while construction and manufacturing with in situ materials can significantly reduce the risk to the crew.

The second path is developing technologies and capabilities to perform the resource extraction and processing tasks identified in the first path. NASA is currently pursuing development of technologies for conversion of carbon dioxide into oxygen, the excavation, processing, and extraction of water and other volatiles from extraterrestrial regolith on the Moon and Mars, and the chemical conversion of carbon dioxide and water into oxygen and rocket fuel (methane) at human mission relevant scales. NASA is also pursuing development of technologies for construction and manufacturing through additive manufacturing techniques with Earth and in situ derived feedstock materials.

The third path is to perform missions to better characterize potential resources in space as well as demonstrate critical technologies and capabilities to gain confidence in ISRU. For the Moon, NASA is developing several CubeSat orbital missions (Lunar Flashlight, LunaH-MAP, and Lunar IceCube), specifically aimed at trying to better locate where water-ice might be found and how much water-ice might be available. To provide ground truth to the measurements taken by past, current, and these planned orbital missions, NASA is working on Resource Prospector, a lunar rover and instrument suite targeted for launch in the early 2020's. For Mars, NASA is developing a small experiment to acquire, pressurize, and process the atmosphere on Mars to make oxygen. Called MOXIE, this experiment is manifested to fly on the Mars 2020 rover.

To promote involvement of terrestrial industries into these efforts, NASA has recently released two solicitations for public-private partnerships with NASA. The first solicitation is a Broad Area Announcement aimed at developing critical components and subsystems that can be used in oxygen and propellant production on the Moon and Mars (https://www.fbo.gov/notices/34eb0ba219ff3a8d97c9c4b2c9302bf1). The second is a Tipping Point solicitation (80HQTR18NOA01-18STMD_001) asking for proposals to develop technologies and systems that enable new in-space capabilities for future NASA missions, and that have viable commercial applications in ISRU.