Technical and Economic Restraints on Resource Development on the Moon, Mars, and the Asteroids

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Abstract

As humans prepare to take the next great leap into space, prioritizing the Moon, Mars, or the asteroids is still under debate. Lunar missions will prove scientific and exploration technologies, provide life support for human settlements, and extract water-ice, helium-3, and minerals for rocket fuel, power, and infrastructure. Metals and platinum-group elements (PGEs) may reside in impact breccias and layered mafic intrusives. Thorium occurs in late-stage melts with KREEP (Potassium/Rare-Earth-Elements/Phosphorus). Knowledge gained from developing lunar resources can be applied to future missions to Mars in the 2030s. Proponents of going to Mars argue that lunar missions from low-earth (LEO) to low-lunar (LLO) orbit involve an inefficient gravity well, requiring excessive fuel. Mars is rich in atmospheric carbon and mineral salts in evaporites. Oxygen and methane can be synthesized from the Martian atmosphere. Near-Earth Objects (NEOs) can also provide fuel, life-support materials, and construction metals. More than 20,800 were identified by September 2019, and 897 are >0.6 mi (>1 km) in diameter. Some contain PGEs and REEs (rare-earth elements) for advanced technology. Strategic minerals, although not rare on Earth, are geographically limited. Extracting them in space would foster off-world commerce and long-term investments in space. Space activities have been performed by large government agencies for seven decades because of technical complexity and high capital expenditures. Maintaining a sustainable presence in space is no longer aligned one-dimensionally with geopolitics but rather profitable ventures in communications, Earth observation, and manufacturing. Recent miniaturization of electronics and competition between commercial launch providers have exponentially increased the capabilities of on-orbit

assets while reducing costs. In 2018, the global satellite industry was worth $360 billion, with government space agencies accounting for <25%. New technology development to serve the satellite industry include orbit-changing tug services, on-orbit refueling, orbital manufacturing and assembly, deorbit services, and materials recycling. As these technologies become routine, delivering materials to supply business growth in space will be critical. Successful assessment of consumable materials that can be sourced from outside Earth's gravity well will enable scientific exploration and economic expansion into the Solar System.

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