With Endpoints Defined, an ISRU Roadmap Takes Shape. Gary Rodriguez[1], Frederick Slane[2], Lee Johnson[3] and Richard Westfall[4].

Space Exploration is dominated by two realities: gravity and the rocket equation. Until one or both of these is somehow diminished in stature we will have to be clever if we are to afford extensive space exploration. Initial exploration identifies the coarse distribution of resources in a new frontier and is supported by the determined investment of a collection of enterprises (often through their governments). Follow-on exploration is required to locate specific feedstocks and is supported by the very activities which exploit and add value to the indigenous resources (usually through well-capitalized companies). Space exploration is sufficiently expensive that the cost of transport must be leveraged from the start, and since we've already conducted the initial exploration with the Apollo, Clementine and other Lunar orbital survey programs, adopting a follow-on exploration model would seem appropriate.

The *in-situ* Resource Utilization (ISRU) approach is to *live-off-the-land*, a concept familiar to those who have endured survival training in Boy Scouts or special ops. Many lessons were taught in these exercises, and success was enjoyed by those who could close the gap between their environment and an advantageous change to that environment with the least expenditure of energy.

A vigorous ISRU effort results in less *matériel* being launched into space, and a significant fraction of what does get launched are tools for manipulating the target environment. The ISRU work is of three distinct types: science, civil engineering and ISRU-manufacturing. Scientific sampling engages the smallest quantities of a planetary surface and civil engineering the largest. The highest complexity and added value are inherent to manufacturing and ore beneficiation.

The success of any vigorous Space Exploration program lies with the fabrication of products outside of Earth's gravity well. Such a place, rich with resources, energy and practical proximity to the Earth is the Moon. The Moon is well-positioned as a literal stepping-stone to Mars, Jupiter and beyond. It is on and near Luna that we can fashion products which have inherent mass and bulk from rocks, dirt and energy. Manufacturing the massy and bulky hardware and expendables from indigenous space resources eliminates launching production uphill from Earth's gravity well.

The exploitation technologies which are used to develop the Moon's resources should be sufficiently low-tech that early generations of Lunar ISRU factories can build them. This is where the rocket equation will yield to the logistics equation. Envisioned on a distant horizon, a shipyard can be built in a distributed fashion on the Lunar surface and in Lunar orbit, which will provide a focus for our near-term ISRU projects, and eventually (and inevitably) provide the largest fraction of the needs of Lunar habitation, development and exploration.

The pinnacle of this effort will be the ability of the CisLunar economy and infrastructure to construct and commission a series of flotillas to transport mankind in a robust way to Mars.

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