

## Baseline Forecast: The Harvesting of Space Resources

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This assignment explores the expected future of the domain covering the harvesting of space resources. Because that topic is, literally, infinite, I focus on the specific aspect of exploiting material resources from asteroid or comet bodies classified as Near Earth Objects (NEOs). The time frame will be twenty years -- about 2033. This length of time is dictated, again, by the immaturity of the domain. It will probably take that long before many of the interesting activities come fully into play, even if all goes according to the plans offered by the involved organizations.

By 2033, humanity is routinely present in Earth orbit, largely due to the foresight of the space mining companies. The two primary players, both established in the early 2010s, began launching numerous, relatively inexpensive probes (costing perhaps between a few million dollars to a few tens of millions each) seeking suitable prospecting candidates around 2015<sup>(1)(2)</sup>. By 2020, a number of possibilities had been identified from the, by then, over 20,000 near-earth asteroids (NEA) discovered in the 40 years since 1980.<sup>(3)</sup> While some of these proved unsatisfactory "dry holes", others panned out, driving the dispatch of robotic or tele-operated swarms of mining craft. These in turn began returning not precious metals, but rather frozen water in increasing amounts, first by the hundreds, then the thousands of tons worth to the vicinity of Earth.<sup>(4)(5)</sup> The first return of materials was no sooner than 2027 -- twelve years after the initiation of the prospecting project in 2015<sup>(18)</sup>. Although this seems like a long time, the investors in the asteroid mining companies have always been well aware of the greater return-on-investment period.<sup>(6)</sup> It was acceptable if the success of the venture would result in a strong strategic or marketing position for the companies. Too, the parallel to deep-sea drilling -- and many mining ventures -- was recognized: an activity that would require a large capital outlay initially, followed by a long project life, heavily reliant on robotic technology that must work reliably yet autonomously.<sup>(7)</sup>

Water, though a simple chemical and cheap on Earth, has benefited all aspects of the expanding space frontier. Its availability greatly reduced the cost of the increasingly frequent orbital activities of both governments and commercial enterprises: extended tourist stays in orbit; satellite rebuilding and refueling; orbital debris reduction;<sup>(8)</sup> and manned space stations. Even the preparation for the first Chinese manned moon mission in 2030<sup>(9)</sup> chose practicality over politics and launched with a minimum of fuel and "topped off" in Earth orbit with propellants cracked from asteroid water before embarking on its historic mission.

Plentiful water has provided the "ore" which, once separated into hydrogen and oxygen, using limitless solar power, is available as a high-efficiency propellant. This has reduced launch costs as much as 90%, depending on the mission, since operational fuel no longer needs to be lifted from Earth.<sup>(10)</sup> The number of people working in orbit for longer than brief stays has increased significantly; the 10,000 pounds of water needed for each human per annum<sup>(11)</sup> is also already present where it's needed: in orbit. Finally, organizations launching habitants and components for deep-space missions have also found it cheaper to buy water ice in orbit and save launching the equivalent amount of material to use as necessary radiation shielding (since several centimeters of water is sufficient to protect against both solar radiation and against cosmic rays).<sup>(12)</sup>

The availability now, in 2033, of abundant water for fuel, shielding and personal consumption, is fortuitous. The current goal for a US manned expedition to orbit Mars (announced in 2012 for "the 2030s")<sup>(13)</sup> might launch this year during the first of the two windows in the 2030s (2033 and 2035). If so, it could be provisioned by the mining organizations with all its water needs. This will alleviate launch costs somewhat, though they will still be high, given that only water and not metal has been exploited so far from asteroid resources. The reduction in cost might even drive a re-assessment of the mission profile, if it can contribute toward a mission that includes an actual landing, instead of just an orbit around the planet. While a Mars landing would still likely unlikely (since its expense has always seemed to vary tremendously: anywhere from \$20 to \$100 to \$450 billion), perhaps a Martian moon landing would be more attractive. An altered profile that restates the Mars mission away from a surface landing instead to a landing and tele-exploration from a manned station on the Martian moon of Deimos would drop the overall mission cost considerably.<sup>(14)</sup>

By 2025, favorable circumstances allowed the mining organizations to shift their attention to a new target resource: metal-rich asteroids.<sup>(6)</sup> There was a plentiful supply of the propellant necessary for moving about the space around Earth at reduced expense; experience with water extraction and processing had provided lessons improving the remote mining technology; bodies high in metals had already been identified by prospecting spacecraft during their search for water-bearing chondrite asteroids; and the companies were flush with revenue generated from the sale of depot water, or fuel from it, to spacecraft operators.

By 2033, the products of mining for metals haven't made it back to Earth yet; however, the mere possibility of the imminent arrival of billions or trillions of dollars worth of metals has already begun to have an economic effect. Prices have already begun to drop as buyers anticipate a vastly increased supply;<sup>(15)</sup> investors likewise have already begun to flee the precious metals for other investment commodities that will presumably maintain their value, such as industrial metals, diamonds, carbon credits, and agricultural products like sugar.

This prospect was not unanticipated. Even early in the Space Age it was recognized that the introduction of large amounts of new resources could affect the global economy. Fortunately, at least one of the mining companies had made it clear from its founding that it welcomed the fall in prices that their metals would cause, since it would open wide the possibility of new technology based on the materials that could never have been feasible had the prices of the needed metals remained high.<sup>(16)</sup> The analogy is the history of aluminum. In the mid-19th Century, it was regarded as more precious than gold.<sup>(17)</sup> Only after the element became extremely cheap, thanks to the development of efficient smelting processes, did it become a widely used building material and alloy component. The increase in palladium, platinum, iridium, and other metals will act similarly: initially depressing their prices drastically, but eventually creating greater demand within new products which previously could not have afforded to incorporate one or more of the elements.

In summary, the expected future of space resources is one of enabling many other aspects of future civilizations within the next twenty years -- from the innovation of new products no longer constrained by material costs, to the more affordable expansion of humans' presence and activity beyond low earth orbit.

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