

Asteroid Mining: Methods and Opportunities for Serving In-Space and Terrestrial Markets

Several companies backed by significant wealth plan to prospect, extract, and utilize asteroid resources for markets in space and on Earth. Deep Space Industries Inc. and Planetary Resources Inc. are the leading examples. These companies have determined that it is technically feasible, using present technologies, to recover multi-hundred tonne parcels of regolith from highly accessible Near Earth Asteroids (NEAs) and return these payloads to Earth orbit for processing and use in orbit.

The potential markets for products from the processing of asteroidal material include propellants, for orbit maintenance for space stations and commsats, and for tug operations (removal of commsats to graveyard orbits; orbit transfer ops); metals for construction of national or commercial space stations and solar power satellites; silicon for fabrication of PV cells for use in space; and Platinum Group Metals, obtained as by-product of metal extraction, for export to Earth. .

All products for in-space use have a potential value to the purchaser which approaches the cost of launching them from Earth, i.e., the 'airfreight cost'. This approaches \$25,000/kg to Geostationary orbit, or an implicit minimum value of \$25 million per ton for volatiles.

Some 900 NEAs are identified annually, with the known total exceeding 9,000 out of several million projected to exist. Some are small enough that they can be brought to convenient orbits near Earth to be worked over several years. Others are so large they pose civilization-ending risks. The development of an asteroid mining industry will give mankind the tools to neutralize these planetary hazards.

Deep Space Industries is developing a fast paced, staged and sequential program, including early flyby and rendezvous missions, and subsequent sample return missions, intended to rapidly demonstrate materials return from a NEA; methods for extraction of water, other volatiles, nickel-iron metal, and other metals, including PGMs; and an innovative manufacturing process based on 3D printing concepts, that outputs complex metal parts from asteroidal feedstock.

Success in accessing the unlimited resources of interplanetary space will indeed open the 'final frontier' to the mining and metallurgical industries and present the ultimate answer to the 'Limits to Growth' paradigm.

The founders of Deep Space Industries include **Rick Tumlinson**, **David Gump** and **Kirby Ikin** who have almost a century of combined space commerce experience. Collectively they've won dozens of NASA contracts, carried out events on the International Space Station for corporate sponsors, developed breakthrough initiatives to extend the life of commercial commsats, created private-sector space suits, and led some of the first commercial lunar robotics and crewed space station projects. They have led global space associations, published books on space enterprises, and laid the groundwork for NASA's multi-billion dollar program to supply the International Space Station commercially via SpaceX and other firms.

The team also includes **Dr. Marc Rayman**, *the world's top asteroid mission program manager*, whose DAWN mission is now exploring two of the solar system's largest asteroids and whose Deep Space 1 comet probe was a breakthrough in propulsion and on-board AI. **John Mankins** directed NASA's \$850 million advanced technology program, helped create the now standard NASA Technology

Readiness Level (TRL) concept, and led essential research into Solar Power Satellites over a 25-year career with the space agency and JPL.

Mark Sonter combines experience in planning, permitting, and management of large and complex terrestrial mining projects with funded research into the development of asteroid resources.

Stephen Covey directed R&D for Applied Innovation Inc. and will chair the Asteroid track at the 2013 International Space Development Conference.

Dr. Christopher Cassell and **James Luebke** are engineers with decades of experience at some of the world's largest aerospace corporations, with expertise in trajectory design and the integration of satellites whose total value is well into the billions.

Daniel Faber is a champion of cubesats and innovation tech. He has founded companies to exploit innovations in mining, medical imaging, and space operations, including the design and fabrication of key components for spacecraft. **James Wolff** is one of the central players in the new world of "Makers" and "Hacker Spaces." He develops rapid-prototyping technologies, displayed at Makerfares, Google conferences, and rapid-prototyping conferences.