Asteroid Mining: Why and How?

By Michael Buet, CTO – KESE, LLC and Robert Frantz, PhD, CFO – KESE, LLC

The development of Space Industrialization and large-scale human tourism, habitation in orbit and in space, is hampered by the high cost of launching materials into low Earth orbit (LEO) using existing launch vehicles (@ ~ $10,000 per kg). Even using the next generation of launch vehicles from Space X, Boeing, and Sierra Nevada, we still look at ~ $5,000 per kg. Consider that payloads are only about 5% of the entire mass of a rocket on the launch pad and that 80% of the propellant in that rocket is expanded during the first 80 seconds of flight, just to extract the 5% of that initial mass out of Earth's gravity well into LEO! At that cost, putting a pioneer family into orbit with a ton of supplies would cost more than $7 million each, many orders of magnitude higher than the pioneers paid two centuries ago to come to America or to go "conquer" the West.

Although the Moon appears to be the logical first goal for space mining, basic thermodynamics tells us that it is actually more difficult and more costly to go in and exploit Moon-based materials than asteroids. In space, all that really matters is energy expenditures from a limited source (no re-fueling stations in space yet…): that is called changes in velocity (Delta-V or ΔV), and the Moon, even though it is only 1/6th of Earth's gravity (1/6th g), still exerts a significant gravitational pull that is large enough to require fuel and specialized motors and equipment to land and take off. For most Near-Earth Orbit asteroids (NEOs), that adds up to more ΔV than is needed for asteroid exploitation, which makes asteroids a better choice, particularly because we already have all the technology to do so now, vs. the necessary huge new technology development efforts needed to do the same from the Moon.

The solar system's asteroid belt is essentially an inexhaustible source of all the metals, minerals, water, gasses and organic compounds we need to support life in large human colonies in outer space within the solar system (Figure 1).

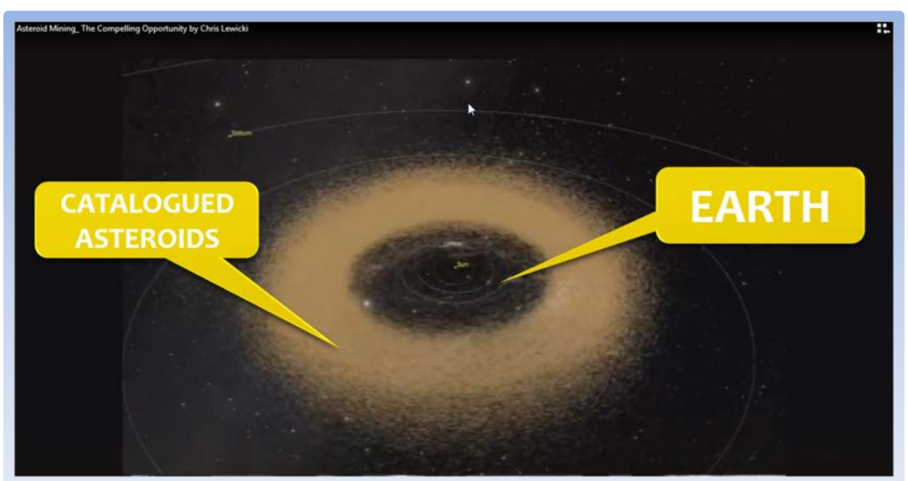

Figure 1: Earth Sits at the Center of a Vast Ocean of Resources

At present, there are three companies dedicated to asteroid mining and to jump-start the 21st-Century industrialization of space:

1. Planetary Resources is headed by an ex-JPL engineer and is supported by several multi-billionaires, including a Google founder, Microsoft founder, and Warren Buffett. Their business model is to send thousands of small, inexpensive reconnaissance Arkyds Cubesats (Figure 2) and land them on the asteroids they deem the most valuable, hence claiming sole mining rights to these asteroids for their exclusive billionaire funders "club". They estimated the Wall Street value of a 1-km-wide metal-rich asteroid at approximately $1 trillion.

Figure 2: PR Arkyd Cubesat

Planetary Resources then plans to tow these most valuable asteroids and place them in orbit around the moon for later exploitation (Figure 3). This will also require extensive new space-tug and propulsion technologies development to achieve and mandates a return to manned expeditions to the Moon, with manned space stations in orbit around the Moon, ~400,000 km away from Earth, way outside the Earth's protective Van Allen magnetic belts, fully exposed to deadly cosmic radiation and solar flares.

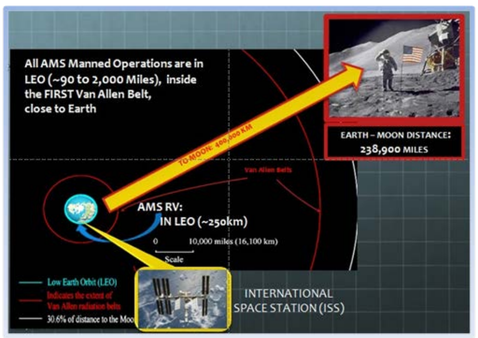

Figure 3: PR Cis-Lunar Captured Asteroid Orbit vs. AMS

2. Deep Space Industries is headed by a very knowledgeable Australian mining and radioactive materials industry expert and PhD in Asteroid Mining, Dr. Marc Sonter. DSI is supported by Australian mining concerns and private funding: it plans to do essentially the same thing as Planetary Resources (Figure 4).

Figure 4: DSI 's Asteroid Tug

3. Kepler Energy and Space Engineering (KESE) is headed by several veterans of the Aerospace Industry. It aims to return ~ 40 metric tons of raw asteroid regolith to LEO (250 km from Earth, the same as the ISS) by the end of the decade using the "keep it simple" principle: KESE plans to make full use of existing proven space technologies and hardware from the Dawn, Hyabusa, and Rosetta Missions, which can be very easily adapted to Cornucopia (Figure 5).

Figure 5: KESE 's Asteroid Mining System

The KESE spacecraft system architecture and proposed hardware components (Figure 6) will result in a complete robotic asteroid mining system (AMS) that is named "Cornucopia," for the mythic Horn of Plenty. Cornucopia is specifically designed to return large amounts of marketable materials from near-Earth asteroids into LEO as quickly as possible. The goal is to energize the Space Industrialization in LEO by providing enough raw materials for the development of in-space manufacturing, producing building materials, propellants, radiation shielding, etc. The goal is also to extract valuable minerals like rare earths, gold, and platinum group metals (PGMs) for Earth consumption. Based upon our very large analytical database from meteorites, which are pieces of asteroids that landed on Earth, all these valuable basic compounds are found in abundance in asteroids and will provide the significant revenue stream needed to support the entire enterprise.[1]

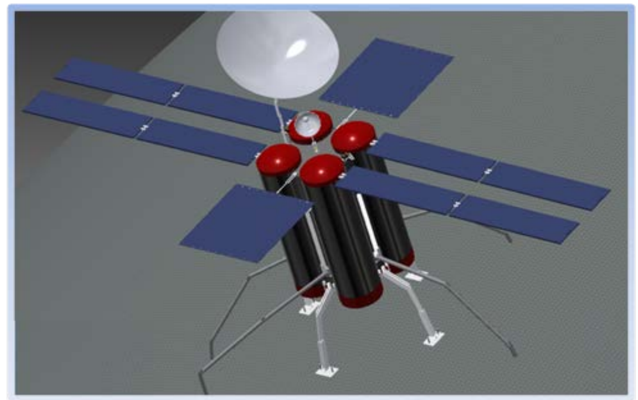

Figure 6: KESE 's "Cornucopia"

Several technology developments in many different fields have all come together to make it possible now to begin the development of asteroid resources for space development. The Japanese Hayabusa spacecraft mission[2] to the Apollo asteroid Itokawa demonstrated the basic capabilities needed for asteroid mining. The NASA Dawn mission demonstrated long-term space operation of advanced ion rockets. Advances in solar cells driven by terrestrial applications have greatly increased the efficiency of using solar power and asteroid regolith has been transformed into useful forms needed for space manufacturing using solar power and additive manufacturing.

Recent additive manufacturing/3D printing experiments have already demonstrated the capability of generating structural material directly from unrefined regolith, as shown in Figure 7. Therefore, it may not even be necessary to refine the raw regolith material to create the basic building blocks of space structures in space. A simple interlocking building block design may be all we need to create a massive basic habitat with a radiation-protective shell, made of raw regolith in orbit.

[1] Brad Blair, "The Role of Near-Earth Asteroids in Long-Term Platinum Supply," EB535 Metals Economics, Colorado School of Mines, May 5, 2000.
[2] Hitoshi Kuninaka et al., "Hayabusa Asteroid Explorer Powered by Ion Engines on the way to Earth," IEPC-2009-267, 31st International Electric Propulsion Conference, Ann Arbor, MI, 20-24 Sep 2009.

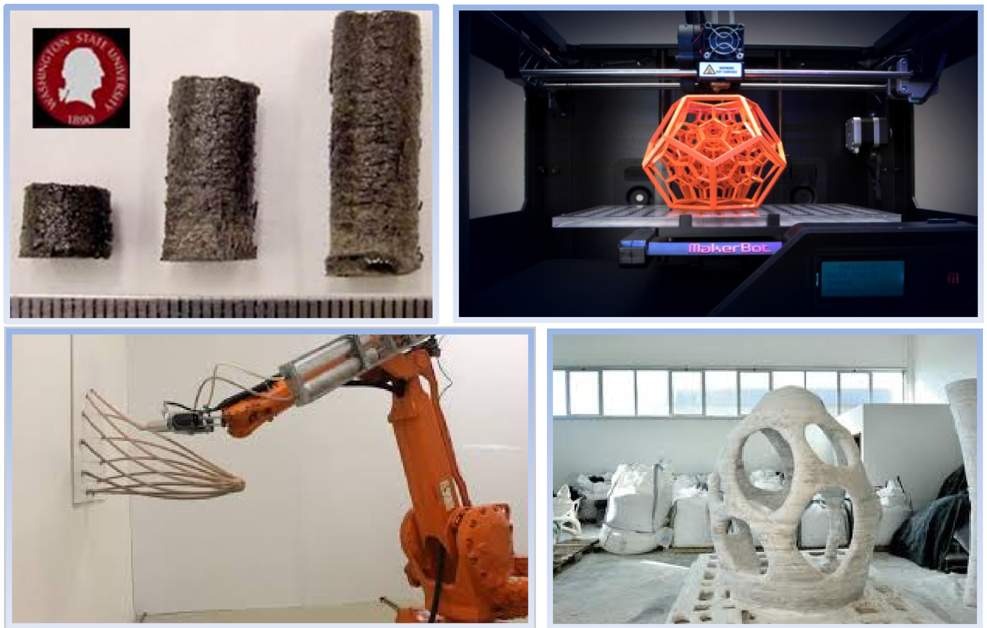

Figure 7. 3D-Printed Tubes Directly from Raw Lunar Regolith Simulant + 3D Printers

The Cornucopia mission plan has the goal of returning several tons of marketable asteroid regolith by the end of the decade, at a projected cost of less than $400 million. An unexpected potential application is that the in-orbit ore-processing system can also be used to recycle the thousand tons of high-grade aluminum in upper stage debris in LEO.[3] This material is worth at least the current launch cost of $5,000 per kg, or $5 billion.

During the 1970s, NASA supported many studies[4] on space colonies and organizations such as the L5 Society (a precursor to the National Space Society), which developed plans for large space colonies at the Earth-Moon L5 Lagrangian point. But building colonies for 10,000 people using Earth and even lunar materials would be prohibitively expensive and is not within the technical capabilities of NASA or the private industry, even to this day, unless we first start bringing raw materials to LEO to build those space structures and spacecraft from space-based materials.

The methods for utilizing those materials “in-situ” were not as advanced as they are now: Today, we have at our disposal modern carbon fiber composites and in particular, additive manufacturing/3D printing. Using advanced propulsion, solar power, miniaturized and highly reliable electronics, and simple mining techniques, we believe

[3] J. Pearson, E. Levin, and J. Carroll, “Affordable Debris Removal and Collection in LEO,” IAC-12-A6.6.7, 63rd International Astronautical Congress, Naples, Italy, 2012. www.star-tech-inc.com/papers/Affordable_Debris_Removal_IAC_2012.pdf

[4] John Billingham, William Gilbreath, and Brian O’Leary, eds., “Space Resources and Space Settlements,” NASA SP-428, technical papers from the Ames 1977 summer study (Washington, DC: NASA, 1979).

that it is now possible to retrieve asteroid materials at a low enough net cost to make possible the large-scale space industrialization in Earth orbit.

We must start building in space for space from space-based materials if we are to start colonizing space.

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About the Authors: Michael Buet has a long career track record in cutting-edge aerospace, high tech semiconductors, and manufacturing technologies. His career spans from AT&T Bell Labs in fiber optics and other high-tech aerospace and undersea technologies development, to LORAL Electronics, MESA-TEK Instruments, Harvard Custom Manufacturing of satellite and rotary aircrafts wiring harnesses, to DeCrane Aerospace and Global Aeronautica (Alenia/Boeing alliance) on the initial efforts for the Carbon Fiber Reinforced Polymer (CFRP) body and electrical assembly of the new Boeing 787 in Charleston, SC. Michael also holds five USPTO patents ranging from chemicals recovery to semiconductor manufacturing tools. Michael has the breadth of experience and skills needed to apply his lifelong experience at creating and developing new ideas and fostering new technologies, then successfully transitioning R&D into production. Michael will be heading the technical staff of the Alternative Energy and Aerospace Research Center (A.E.A.), the high-tech incubator portion of the Japsers Crossings Project (see www.jasperscrossing.com).

Robert L. Frantz has completed multiple careers. Serving in the United States Marine Corps for 20 years, he was a combat veteran of the Vietnam War, where he served as a fighter pilot. Following this career, he flew as a commercial pilot for United Airlines and retired after 16 years as a Captain. In his third career he served as a university administrator and as a professor in business administration, specializing in distance education, both as a professor and as an online administrator. He served for ten years on the board of the Distinguished Flying Cross Society (.org) where he held positions of President and COB. He is also the COB for Ashburn Institute (.org) and has promoted international integration through the organization's graduate-level scholarship endowment.

His 22 years of nonprofit work has also included extensive volunteer work in Africa in technology infrastructure development and education delivery through distance learning. Additionally he volunteered for nine years at the Smithsonian Air and Space Museum working in fundraising/development and nine years at the same time with the Airline Pilots Association (on loan from United Airlines), where his duties included serving on the President's Commission for Airline Safety.

His education includes a BA, University of Minnesota and an MS, University of Southern California. He completed his doctoral course requirements and comprehensive exam at a Virginia business international graduate school earning the distinction of ABD (all but dissertation). He then transferred his doctoral work to Kepler Space University in

California and successfully defended his dissertation receiving a Doctor of Philosophy in Earth and Space Science. He is about to complete a second PhD with American University Girne, a European-accredited university located in North Cyprus. He co-founded Kepler Space Institute, a U.S. nonprofit corporation, along with Dr. Bob Krone and Walter Putnam. He is currently the Director for Strategic Planning for Intrepid Sports Development, which is developing 265 acres at Exit 8, I-95 in South Carolina, along with the Alternative Energy and Aerospace Research Center in close cooperation with Michael Buet (see www.jasperscrossing.com). He is also a co-founder of Kepler Energy and Space Engineering, LLC, which will be the key component of A.E.A.

Editors' Notes: This second paper on mining asteroids develops on the authors' previous contribution in the Fall 2013 issue of the *Journal of Space Philosophy* (Article # 13). We are again grateful for the combined skills of Dr. Robert Frantz and Michael Buet, which have led to the further development of their proposals for capturing the resources of asteroids for Earth needs*. **Bob Krone and Gordon Arthur***.