In-Situ Resource Utilization For "OSAM" Logistics and Space Development

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Space Assembly – Instruments, Spacecraft, Equipage, Etc., i.e. ISS

Space Service – Refueling, Batteries, Sensors, Repairs, Enhancement, Etc.

Space Manufacturing – of “everything”, increasingly via printing

Major Benefits

- **Reuse, repurposing of space debris**
- **ISRU, Earth Independence, “living off the land”….**
- **Increased instrument capability, aperture**
- **Greater capabilities than could be shrouded for launch [i.e. telescopes, artificial gravity systems]**
- **Major Cost Savings, especially with respect to ISRU and life extension/ capability improvements**

Applicable Technologies

- **AI/ Robotics/Autonomy**
- **Nuclear batteries, up to 22 KWs/Kg of isotope, 1% the weight of a nuclear reactor, scalable from sensors to tens of MWs, Can power everything space – propulsion, habitats in space and on body, ISRU, manufacturing, on body transportation…….**
- **Sensors, navigation, communications**
- **Joining, magnetics, electrostatics**
- **Printing manufacture**
- **Tethers for fuel-less transport in Earth environs, cleaning up space debris, orbit raising**
- **Structural engineering, trusses, etc.**

Resources in Space

- **Vacuum**
- **Low temperatures**
- **Solar energy**
- **Solar and galactic radiation**
- **Micro gravity**
- **Minerals, volatiles, oxides, etc., on planets, moons, asteroids, meteorites, dust**
- **Magnetic fields**
- **Photons**
- **Gravity fields**
- **“Position,” the source of the economic value of the current commercial space Industry**
- **Interstellar space, the rest of the galaxy and universe**
- **Vast to unimaginable space**

Why Go There?

- **Exploration and science**
- **Space solar power**
- **Space mining**
- **Space manufacturing**
- **Colonization**
- **Tourism**
- **Asteroid defense, national defense**
- **Unique biologics**
- **Positional utilities**

Space Manufactured Products

- **Crystals**
- **Semiconductors**
- **Microencapsulation**
- **Fibers, fiberoptics**
- **Pharma**
- **Human organs**
- **Metal alloys**
- **Equippage for space operations**

Humans-Mars, Visits-to-Colonization

- **Until recently, Humans-Mars was far more Expensive….**
- **The Musk reusable rockets have and will reduce much the costs of space access**
- **Nuclear batteries could power high thrust MHD, 6,000 secs of Isp, 200 day round trips, essentially solving the radiation/ GCR and micro g health issues**
- **Need to reduce the tonnage of requisite equipage/ supplies from Earth**
- **Mars has massive resources, Therefore ISRU, In Situ Resource Utilization, Earth Independence**

Benefits of ISRU

- **Is an absolute necessity for Colonization**
- **Possibly enabling for serious "Commercial Space", not just commercial execution of Government functionalities, and beyond orbital "Positional Earth Utilities"**
- **Enables demonstration of reliability, functionality, systems performance years before the humans arrive at on planet conditions, greatly increases possibility of mission success and improves overall safety**
- **Provides reusability, the huge cost benefits of robotic systems , cost reductions for future missions**

Potentially Supplied by ISRU

- **Habitats**
- **Return Fuel, on planet fuel, entry, descent and landing fuel**
- **Life support [water, O2, atmospheric N2, Food, thermalization, pressurization, dust protection]**
- **Radiation Protection**
- **Devices from regolith mineral volatile extraction and synthetic biology via printing and bio-fabrication**
- **Equipage [from printed plastics derived from H20 and CO2]**

Water

- **Very little water in the atmosphere, but estimates indicate much of the water that was ever on Mars is still there…..**
- **Massive amount of water ice at north pole region, many Km thick, enough to put an ocean on a flat mars 350 meters deep, Melt**
- **Major quantities of Water ice and water adsorbed on minerals in the regolith, from some 3% at the equator [up to 8+% localized] to some 40% plus at 60 degrees North etc., Can microwave/ heat to produce water vapor, capture and store as ice in “container”**
- **A solar “tent” could produce sufficient heat to vaporize the regolith water ice**
- **Also available from Sulfates [22% H2O], Silicates etc. ,bound up chemically**
- **Large crater near equator purportedly has an “Ice Lake” the size of Lake Huron with similar or greater depth under some regolith**

Oxygen

- **Some in the atmosphere**
- **Much available from water**
- **Much available from the highly oxidized regolith, some suggest that if add water to regolith produces Oxygen**
- **Much chemically bound in various oxides**
- **Much available from atmospheric CO_2 [CO_2 From cooling or compression]**

Minerals/ Materials Available From the Regolith/ Atmosphere

- **Nickel**
- **Titanium**
- **Iron**
- **Sulfur**
- **Magnesium**
- **Calcium**
- **Phosphorus**
- **Chlorine**
- **Bromine**
- **Aluminum**
- **Silicon**
- **Oxygen**
- **Hydrogen**
- **Carbon**
- **Nitrogen**
- **Sodium**
- **Manganese**
- **Potassium**
- **Chromium**
- **Deuterium**

[Sample] Uses for Martian CO_2

- **Nuclear shielding**
- **Metal fuel cells**
- **O_2 production**
- **C for carbon nanotubes, other materials/ organics**
- **Pressurized rockets**
- **CH_4 fuel production**
- **In-atmosphere solar pumped CO_2 laser**
- **Polyethylene production**

ISRU Via Synthetic Biology

- **Lynn Rothschild et al [Ames Research Center]**
- **Metals extraction from regolith via biological processes**
- **Printing fabrication via Enzymes**
- **Biological precipitation**
- **Nitrogen fixing Cyanobacteria**
- **Microbial cellulose for wide variety of products**
- **Bio Plastics**
- **Biocomposites**
- **Food**

Food

- **Via Extremophiles, Genomics and Synthetic Biology – Plants for Planets. Will need to reduce CO2 partial pressure – grow in a protected atmospheric environment using sunlight or morph to take the CO2**
- **Reprocess solids, grow mushrooms for protein, insects [excellent source of essential fats], Cyanobacteria/ Spirulina [CO2 + Sunlight], printed food**

ISRU “Benefits”

- **Much improved Reliability across the board including redundancies, checkout at on planet/ body conditions**
- **ISRU produced equipage [from devices working over long times sent via inexpensive “Slow Boats”]**
- **Reduces up-mass in Low Earth Orbit and costs much for the Human Campaign**
- **From NRC review of Space Tech Roadmaps “Use of Martian derived Propellants could reduce launch masses by over 60%” … “A Game Changer for Exploration”**

From DRA-5
“Notable Advantages of ISRU”

- **O2 production for ascent and consumables**
- **Reduced initial mass in low earth orbit and reduced number of Launches**
- **Reduced lander size and volume**
- **Greater surface exploration capability**
- **Life support redundancy**
- **Lower risk via fewer launches**
- **Lower life cycle cost**

Mars/ Humans ISRU Bottom Line[s]

- **Mars , in terms of resources, is a VERY Rich planet, especially wrt water and Carbon – the essentials, plus much else.**
- **[Pregame] ISRU is doable, affordable and would greatly reduce Humans-Mars mission costs & MLEO and greatly improve safety**
- **Serious ISRU changes much the mission architecture**
- **The technologies required are either here or available soon enough to execute in a timely fashion**

BTW

- **The ISRU arrivals, daily construction activities/ progress will be a 24/7/365 [5 senses going forward] Virtual Reality experience for everyone……..We can send a robotic reporter to chronicle all this.**

DRA-5 Conclusions

- **“Need to Dramatically decrease the total mass that must be launched into LEO and transported to the Martian Surface”**
- **“Reducing launched mass is an overarching need for long term self sufficiency and acceptable operations cost”**
- **“….Critical to decreased mass are surface nuclear power, ISRU and radiation shielding”. The latter available via ditch and bury under some 4 meters of regolith an expandable habitat**

Orbital Debris Cleanup

- **Are within a very few collisions from closing out LEO**
- **Folks are lofting tens of thousands of new LEO satellites, having increasing trouble finding launch windows through the current debris, debris cleanup needs to be added to detect and avoid**
- **Cleanup Issues include ownership of debris and cost, including fuel**
- **An affordable way forward is to utilize powered tethers to fuel-lessly do the cleanup AND put in a space junk yard, repurpose/ remanufacture, including ISS eventually**
- **Power tether from either a nuclear battery or solar PV**

Autonomy

- **The costs of humans in space are orders of magnitude greater than robotics**
- **OSAM space operations require trusted autonomy**
- **Trusted autonomy must operate successfully in the presence of unknown unknowns, which requires an AI that conducts issue evaluation, ideation of solution spaces, and triage/ execution**
- **There are now three successful approaches to machine ideation. They largely mimic the operation of the human subconscious, evaluation of huge numbers of quasi-random combinatorials.**

Why Autonomous Systems?

- **Autonomous systems could, now or going forward [compared to Human operation]:**

- Know far more

- Be less Expensive

- Exclude operational human error

- Have far less latency, provide new functionalities

- Have far longer duty cycle, provide size reduction[s]

- Be faster, more efficient,

- Be more durable, and “patient”

In general, operate at far less cost and for conditions and performing functions where and in a manner that humans could not

Some Observations/Projections

- **We have been executing in space assembly since the 1960s, in space servicing more recently and starting into in space manufacturing now that the costs of space access are decreasing**
- **There are massive resources on Mars, much less on the moon, and then there are asteroids. ISRU is essential for colonization.**
- **Studies indicate that, thus far, space ISRU/ space resources are critical for in space, on other bodies but the cost comparison between utilization near earth vs earth sourced is not favorable**
- **Space servicing is successful, aided by initial design that accommodates such, the outlook is servicing becoming the usual way of doing things**
- **Space manufacturing enabled by less expensive space access should develop well.**

What is Needed For Spacefaring

- **Solutions to space debris**
- **Solutions to human space-related health issues**
- **Inexpensive space access, in progress**
- **Reliability and safety improvements**
- **Detailed mapping of space resources**
- **Solar and nuclear power**
- **Solutions to legalities with respect to ownership and space debris**
- **Trusted autonomy**
- **Closed business cases**