Settling the Eighth Continent — Three Steps to Mankind's Colonization of the Moon*

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Abstract

We are now on the threshold of not just visiting the moon, but establishing permanent self-sustaining colonies on the moon. There are three major conceptual leaps necessary in application of existing technologies to space exploration that will make this possible. Chemical rocket propulsion from Earth's surface to orbit is both expensive and limited, and this is the first hurdle that must be overcome. The second major leap must focus on available power in space once we can economically move mass to orbit. The third major paradigm shift for colonization of the moon without geographic restrictions is deployment of beamed power technology.

Access to space can be achieved if we discard our attachment to chemical rockets and recognize that nuclear thermal rockets can provide an order of magnitude improvement in performance and in launch-cost reductions. Another order of magnitude improvement can occur if we discard rockets altogether and rely on space elevators for movement of mass from Earth's surface to LEO.

Compact nuclear fission generators in the multi-megawatt range are the only near term practical source for high energy demand activities in space, such as manufacturing, mining, refining, and fuel production. A viable lunar colony must have abundant power available to produce water, breathing atmosphere and building materials from source materials that are similar to igneous rocks on earth. Solar power is not practical when it is limited by a 28 day-night lunar cycle, and the power density of solar energy is insufficient for the identified activities. Orbiting large solar arrays, manufactured in Earth or lunar orbit from materials mined from NEOs and with beamed power from these units to the lunar surface can be the transition technology between lunar surface-based compact nuclear fission power plants and ^{3}He fusion technology. The deployment of orbiting beamed energy technology to provide power anywhere on the Lunar surface, and ultimately, the establishment of ^{3}He fusion plants on the Lunar surface with power beamed to Lunar or earth orbit to support power demands on Earth and asteroid mining ventures in space could be a viable economic benefit to Earth's economy, linking the economic development of the Earth, NEOs, and the Lunar surface in an expanding triangle trade association that would be beneficial to all.

Selected References

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Settling the Eighth Continent

Energy Resources for Human Settlement in the Solar System and Earth's Future in Space

Three Steps to
Development of the Moon

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With Acknowledgement to N. Bakhtian and A. Zorn (2009)

AAPG Memoir No. 101

Energy Resources for Human Settlement in the Solar System and Earth's Future in Space

Editors; William A. Ambrose, James F. Reilly II and Douglas C. Peters

This AAPG Special Publication 101 is a comprehensive and integrated review of energy and mineral resources in the Solar System, including materials that can both sustain future manned expeditions and colonies in space and support Earth's energy and critical material challenges in the 21st century and beyond. …[it] , is a clear reflection of AAPG's vision of advancing the science and technology of energy, minerals and hydrocarbon resources into the future and supporting exploration and development of the ultimate frontier, beyond Earth's atmosphere.

Settling the Eighth Continent

- The Energy Industry exists and thrives on the frontier, and we, as professionals in the energy industry, explore in suspect terrain to find and develop valuable resources for our companies and our countries. The essence of our business, our expertise and our reason for being is to take calculated risks to gain a positive return.
- Why Explore the Eighth Continent?
- How shall we explore the Eighth Continent?

The Why is Economics

- Near Earth and Cis-Lunar Space is now a $4 Billion a year economy
- The Total Energy Industry segment is about $1 Trillion dollars per year worldwide
- Annual investments are in the range of $200 Billion per year
- Return on investments, for Lunar Energy, for Asteroid Mining, or for SPS Power Beaming can exceed $200 Billion in ten years or less.

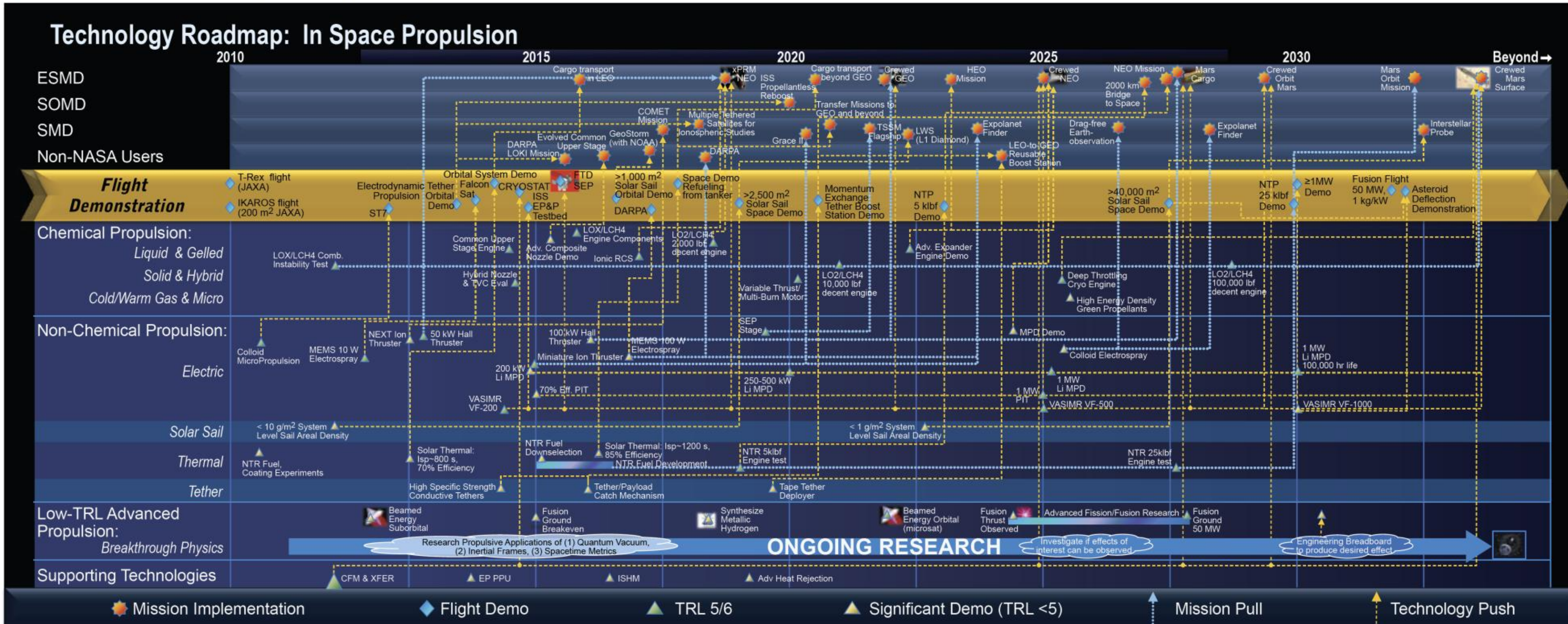
What is needed to make this a reality?

- **Propulsion Systems**. W*e must have better methods of moving materials from Earth's surface to orbit. (NTRs or space elevator)*
- **Power in Space.** *Solar power is useful, but weak and diffuse. We must have high-energy density sources of power for life support, mining and refining*. (compact modular fission reactors)
- **Infrastructure for power transmission**. *Excess power generation capacity becomes a marketable commodity, and beaming this power from the Moon to orbital facilities, or even to Earth's surface is not technically excluded, and supports a self-sustaining economy*. (microwave transmission is 85 % efficient, very close to long distance HV lines)
  - Excess Energy Production Capacity supports energy export
  - Materials refining provides local independence, lowers costs (ISRU)
  - Energy exports, either by beamed transmission, or shipment of H^3 to Earth benefits both permanent settlements on the moon and environment benefits for Earth
  - Unique capabilities of Space
    - Vacuum manufacturing, Intellectual Property, Communications, extra-earth monitoring, robotic-automation. Defense, national objectives, real estate

Keep in mind

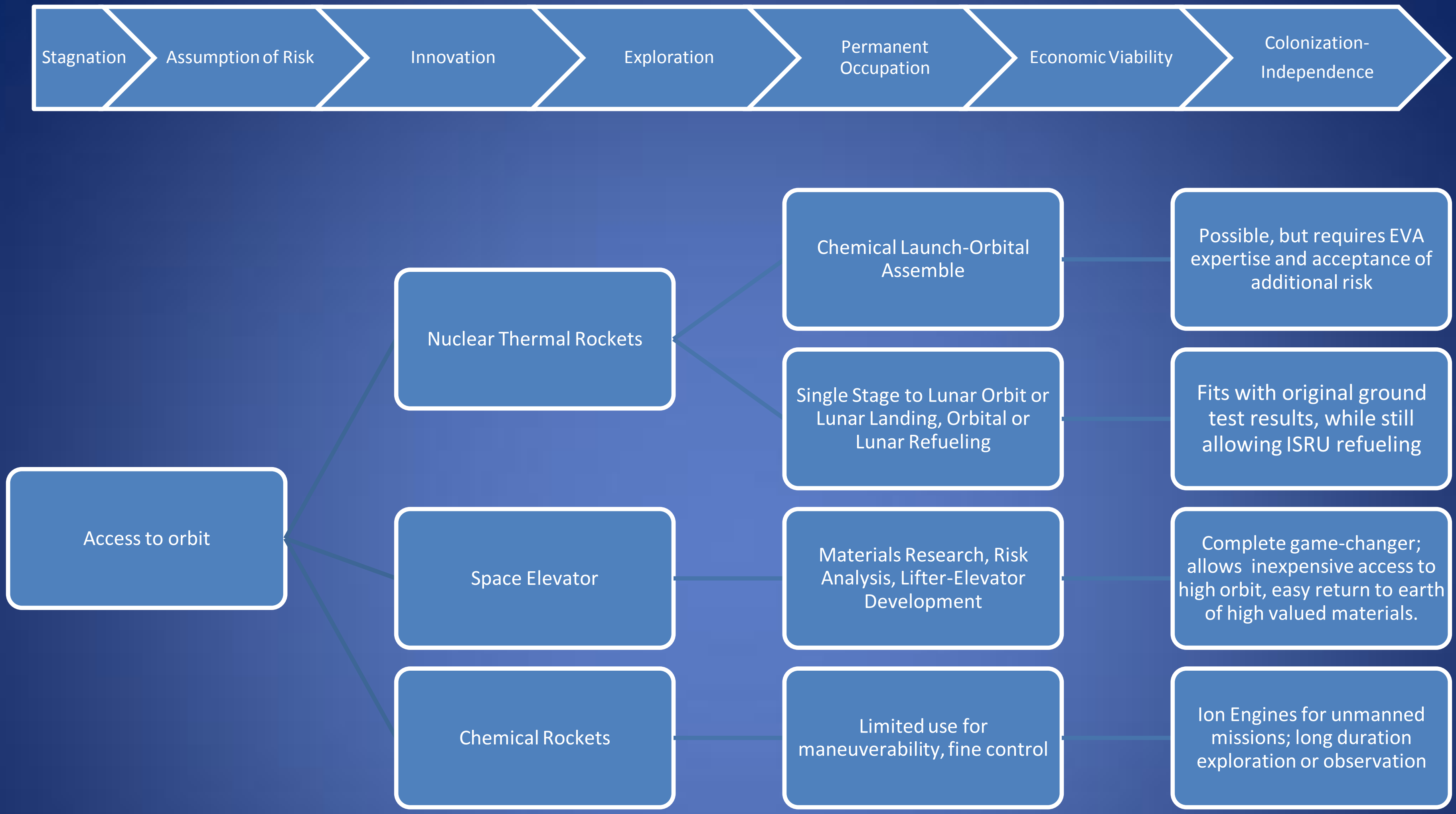
- It’s not that hard
- It’s not that expensive
- It does not take that long

Figure 2: *In Space Propulsion Technology Area Strategic Roadmap (TASR)*



Our capabilities, as exploration professionals, excel at understanding when enough is enough. We have proven the ion propulsion systems on Deep Space One; we have a little more work to do on the materials for Nuclear Thermal Rockets, but they are less than five years away, if we so chose.

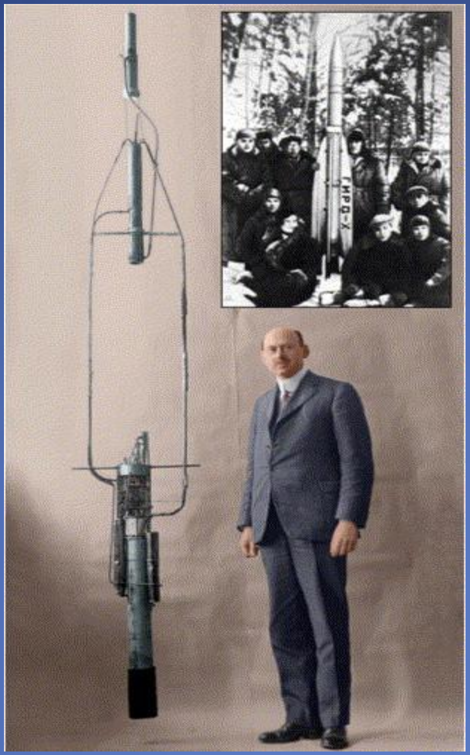
ITS NOT THAT HARD!



How do we move from the post-1972 stagnation of the US Space Exploration Program, to an active, goal-directed space utilization program?

Courage, Innovation, opportunity and economics.

There are better ways to travel.



Robert Goddard did not ask permission to test his rockets. Maybe we need to stop asking permission, and just get the job done?

Is Exploration an Illegal Act?

Pioneering achievements in rocketry came from dedicated individuals working initially without any significant government interest. This is Robert Goddard with one of his early inventions; the inset shows an early Russian club rocket.

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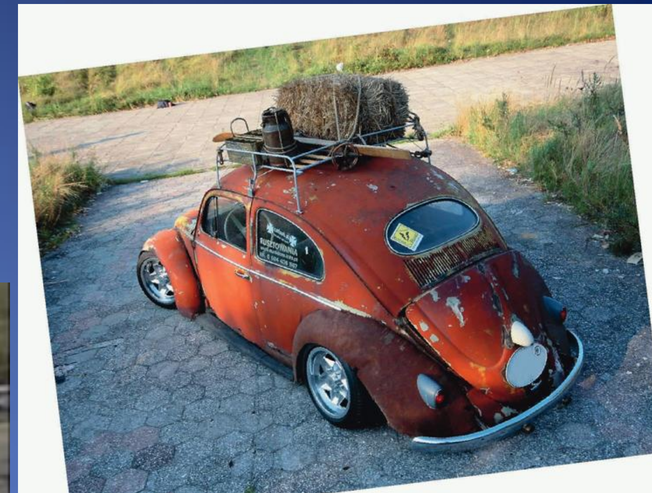
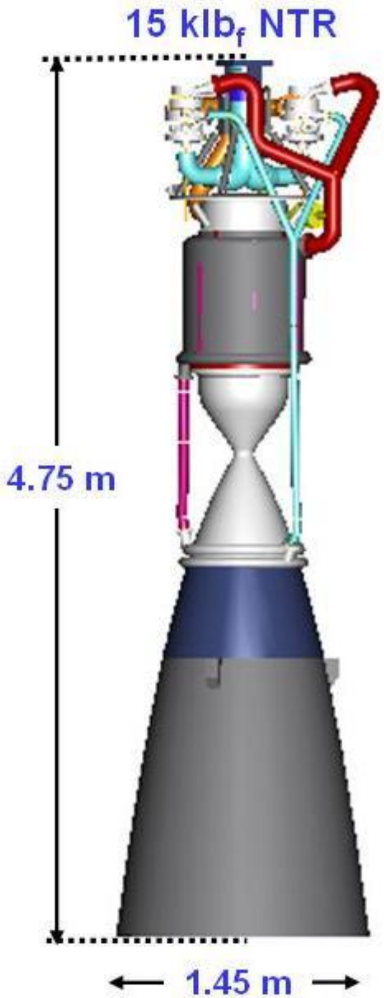
http://dx.doi.org/10.1016/j.actaastro.2006.01.004

Energy Density Matters



Companies with active space-related business: Space X, Scaled Composites, Armadillo Aerospace, Bigelow Aerospace, Plus the existing defense contractors, Lockheed-Martin, Boeing, British Aerospace among many others

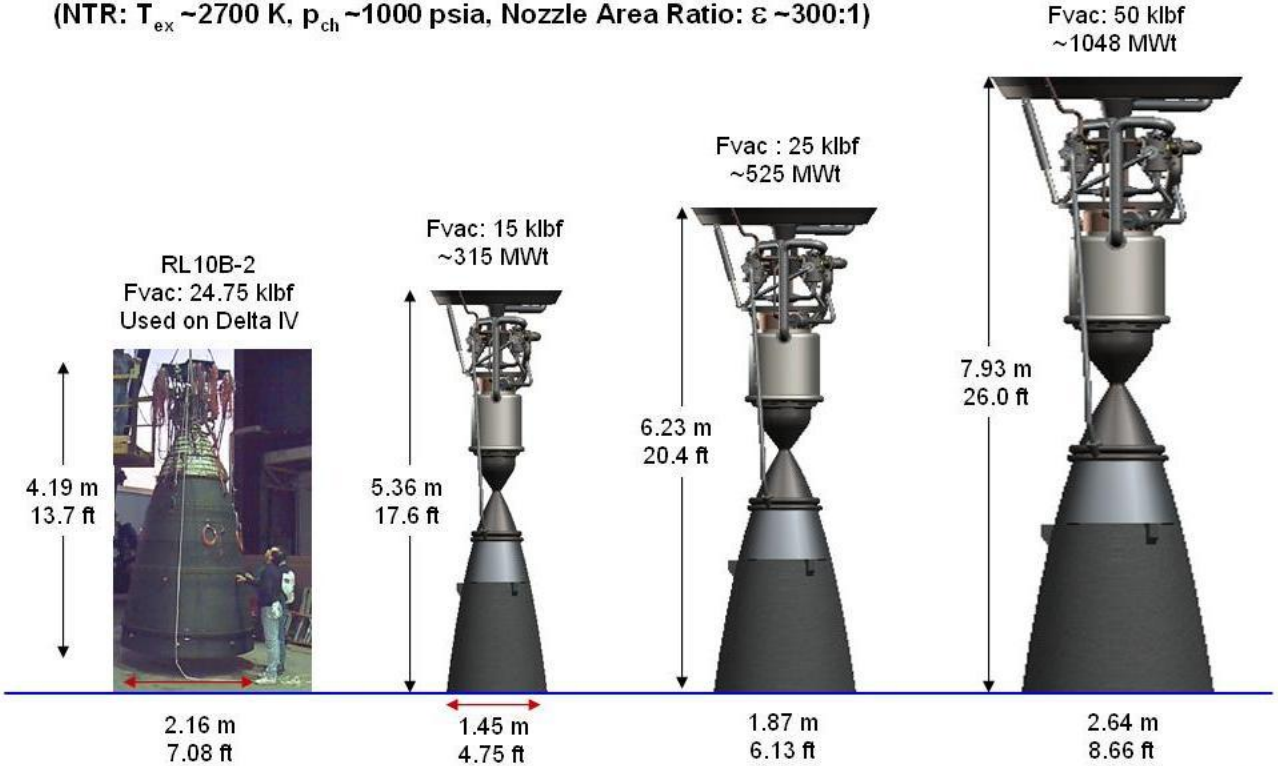
Benefits of NTP for NEO Intercept / Human Exploration Missions

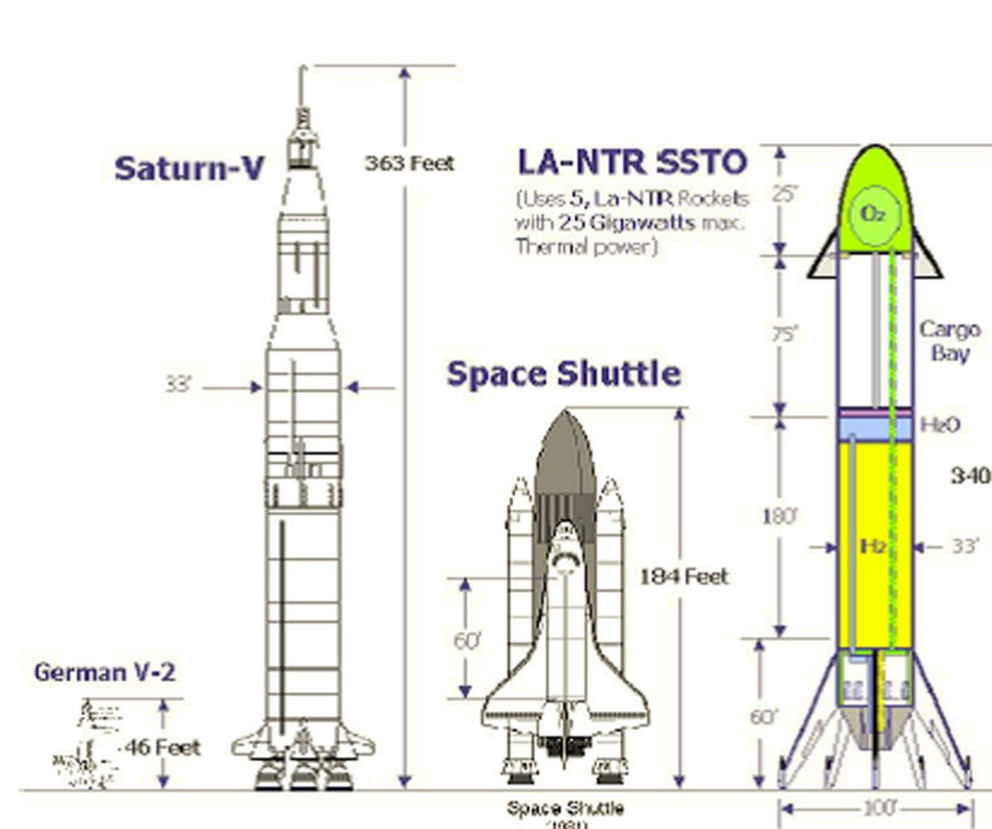


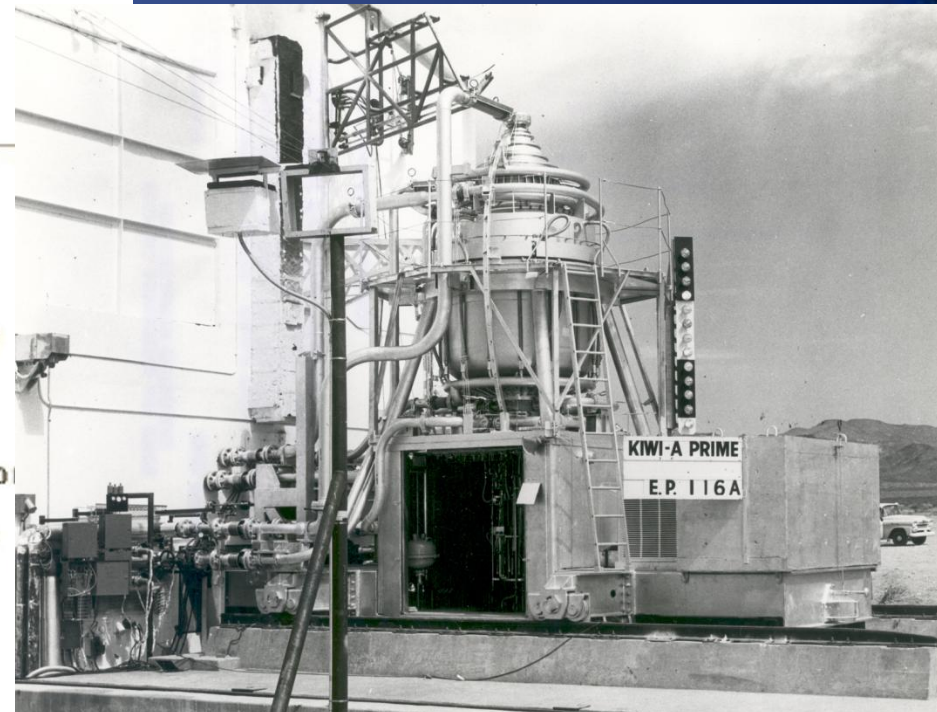
- NTP engines have negligible radioactivity at launch / simplifies handling and stage processing activities at KSC -- *Shortens prep & launch times*
- High thrust / Isp NTR uses same technologies as chemical rockets/stages (*e.g., Ares-V "core" stage uses a 10 m D, ~44.5 m L Al/Li LH_2 tank*)
- Short burn times (< 60 mins); rapid LEO departure & acceleration to V_i
- NTP achieves higher V_i than CP for given payload and LEO launch mass
- *NTP allows a viable response / NEO intercept capability even when the detection range (R_D) is small (~1 AU or less) & response times are short*
- *NTP may be the only option available to deflect high velocity LPCs if R_D is limited to ~4 AU from Earth (T_i~100 days, R_i is ~0.54 AU, t_d ~2 weeks)*
- *With no payload, an expended NTP stage (~34 t) can also be used as a KE interceptor providing impact energies of ~4.8 kT for NEO deflection*
- NTP can be developed in ~10 years after ATP. Small engine size (~15-25 klb$_f$) could be key to reducing time, cost to develop, ground test and fly
- Small engines can be used individually or in clusters to maximize mission versatility -- for robotic science and NEO intercept & deflections, also for human Moon, Mars and NEA missions

Size Comparison of Pratt Whitney Rocketdyne RL10B-2 Chemical Engine and Different Thrust Level NTR Engines

(NTR: T_{ex} ~2700 K, p_{ch} ~1000 psia, Nozzle Area Ratio: ε ~300:1)







In 2004, a detailed review of the potential for a man-rated NTR was completed and concluded that Nuclear Thermal Rocket engines could be ready for active use in 5 years….from 2004. (Davis, E. W., 2004 Advanced Propulsion Study. Special Report AFRL-PR-ED-TR-2004-0024Air Force Research Laboratory, Air Force Material Command Edwards Air Force Base, Ca. 103 pgs.)

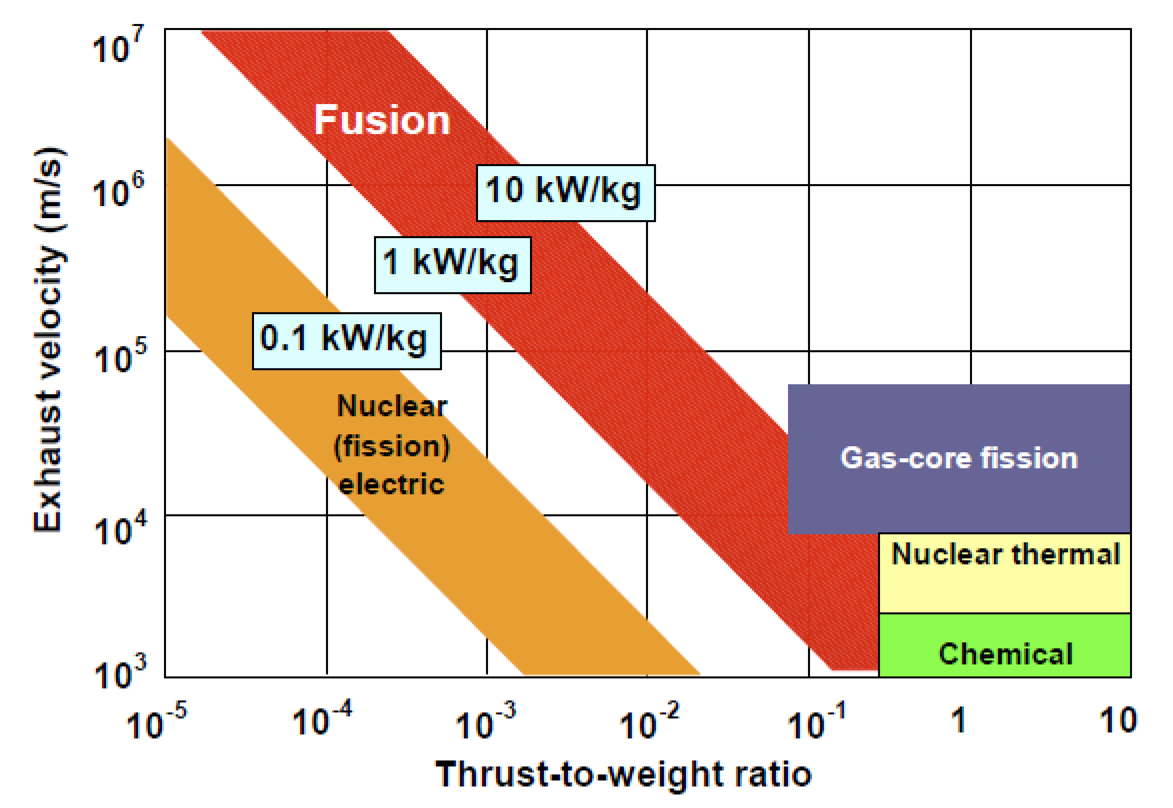


Table 1. Key Fusion Reaction Rates vs. Ion Temperature.

$D + {}^{3}He \rightarrow p\ (14.68\ MeV) + {}^{4}He\ (3.67\ MeV)$	
$D + T \rightarrow n\ (14.07\ MeV) + {}^{4}He\ (3.52\ MeV)$	
$D + D \rightarrow n\ (2.45\ MeV) + {}^{3}He\ (0.82\ MeV)$	(50%)
$\rightarrow p\ (3.02\ MeV) + T\ (1.01\ MeV)$	(50%)
$p + {}^{11}B \rightarrow 3\ {}^{4}He\ (8.68\ MeV)$	
${}^{3}He + {}^{3}He \rightarrow 2\ p + {}^{4}He\ (12.86\ MeV)$	

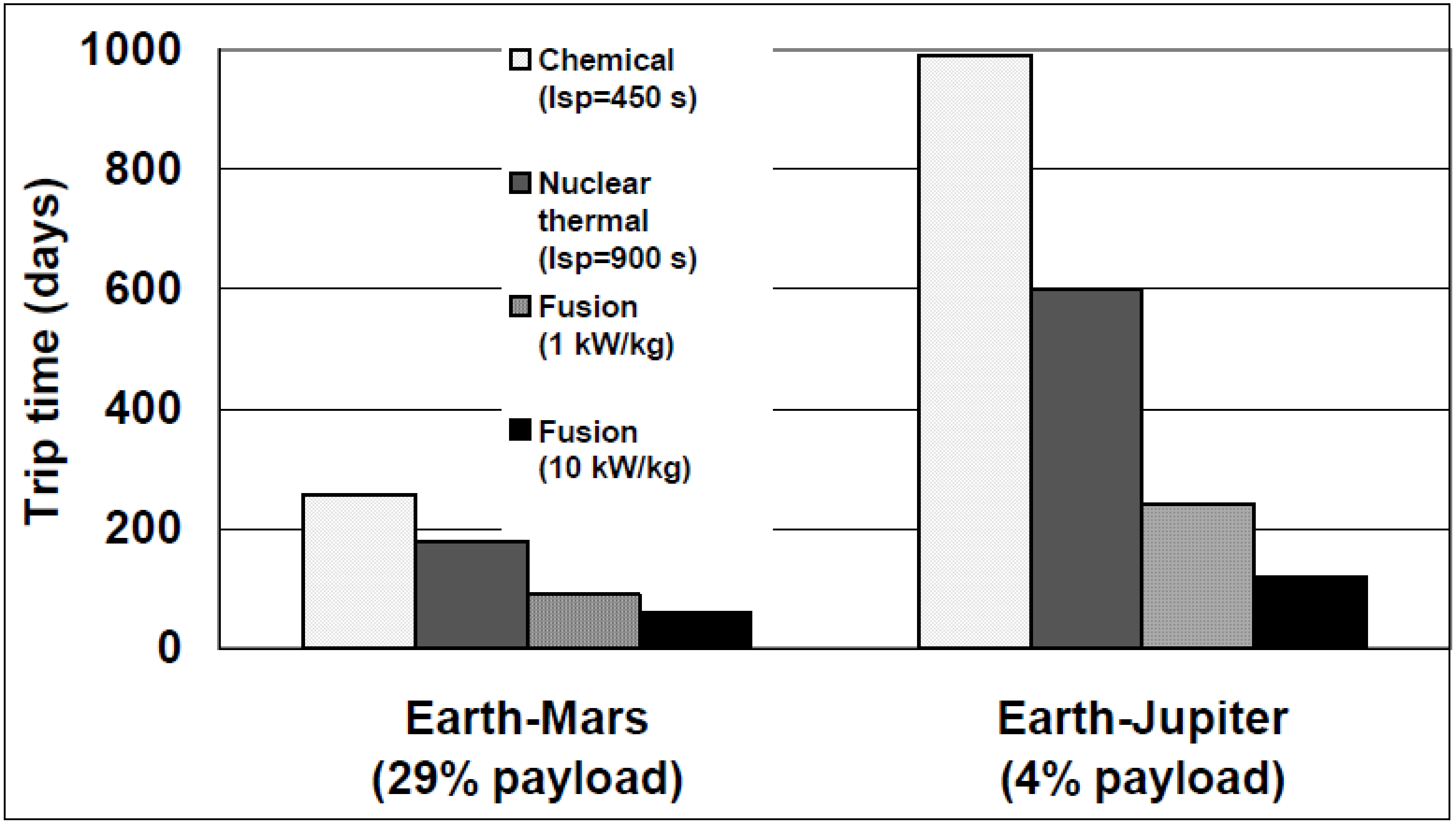
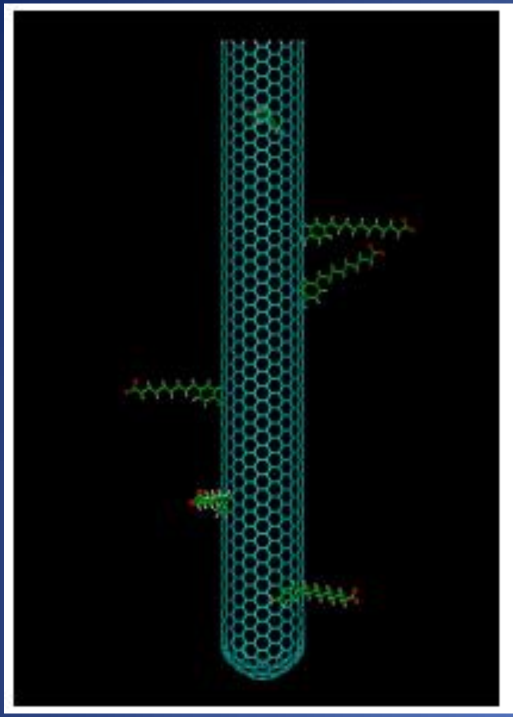


Figure 4. One-way trip time for the same payload fraction comparison of fusion, nuclear-thermal, and chemical propulsion.[17]



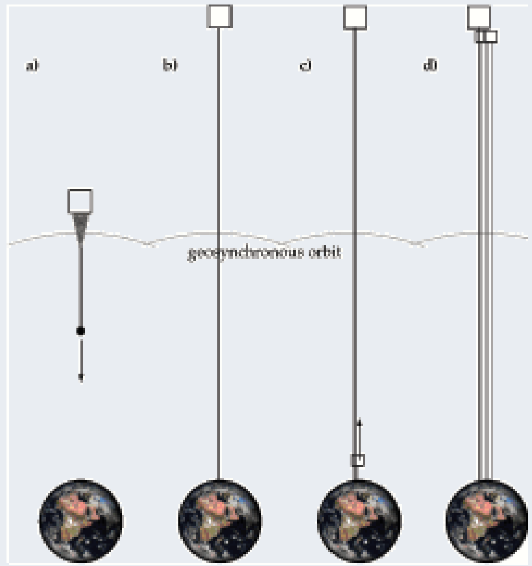
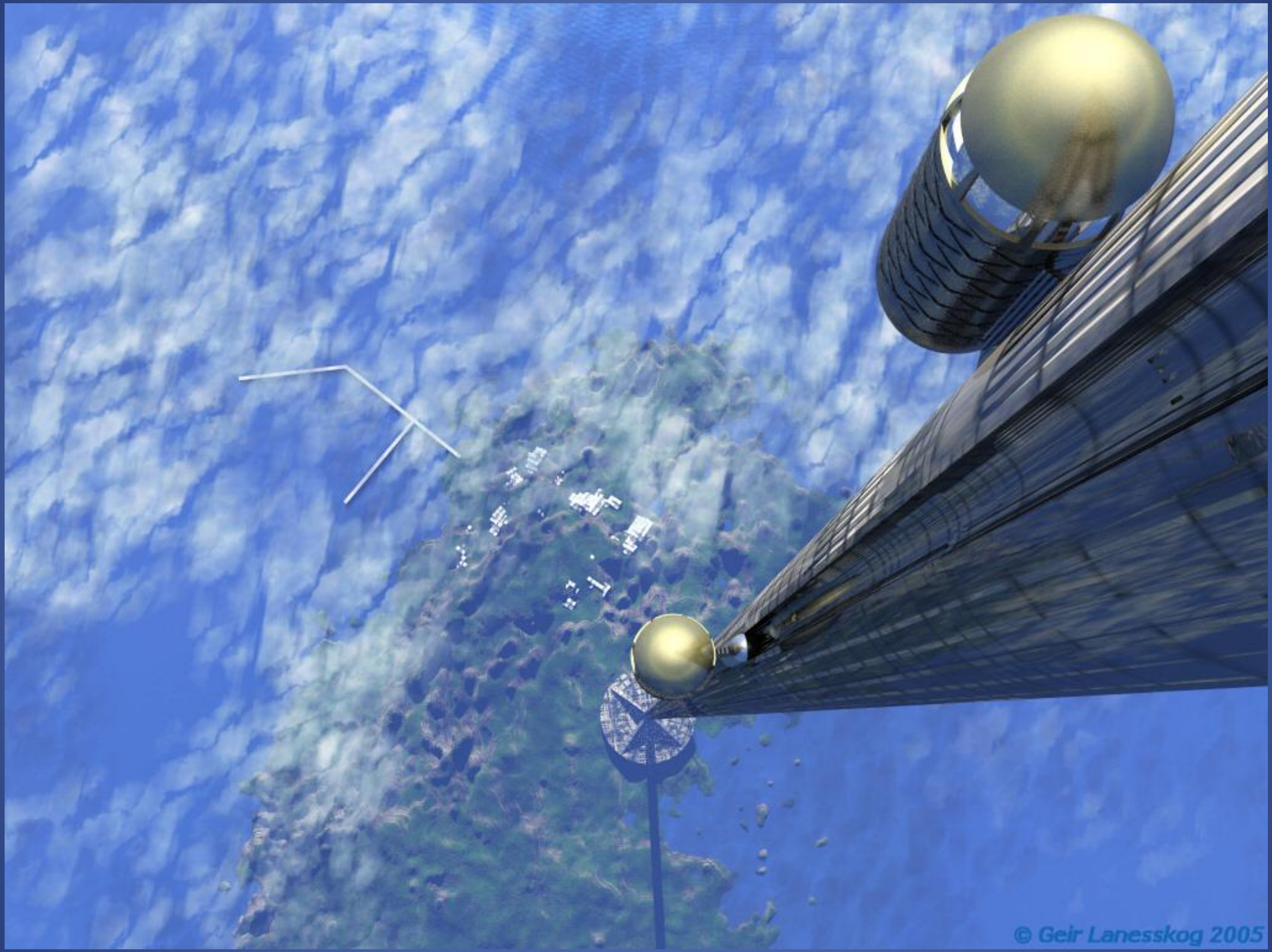
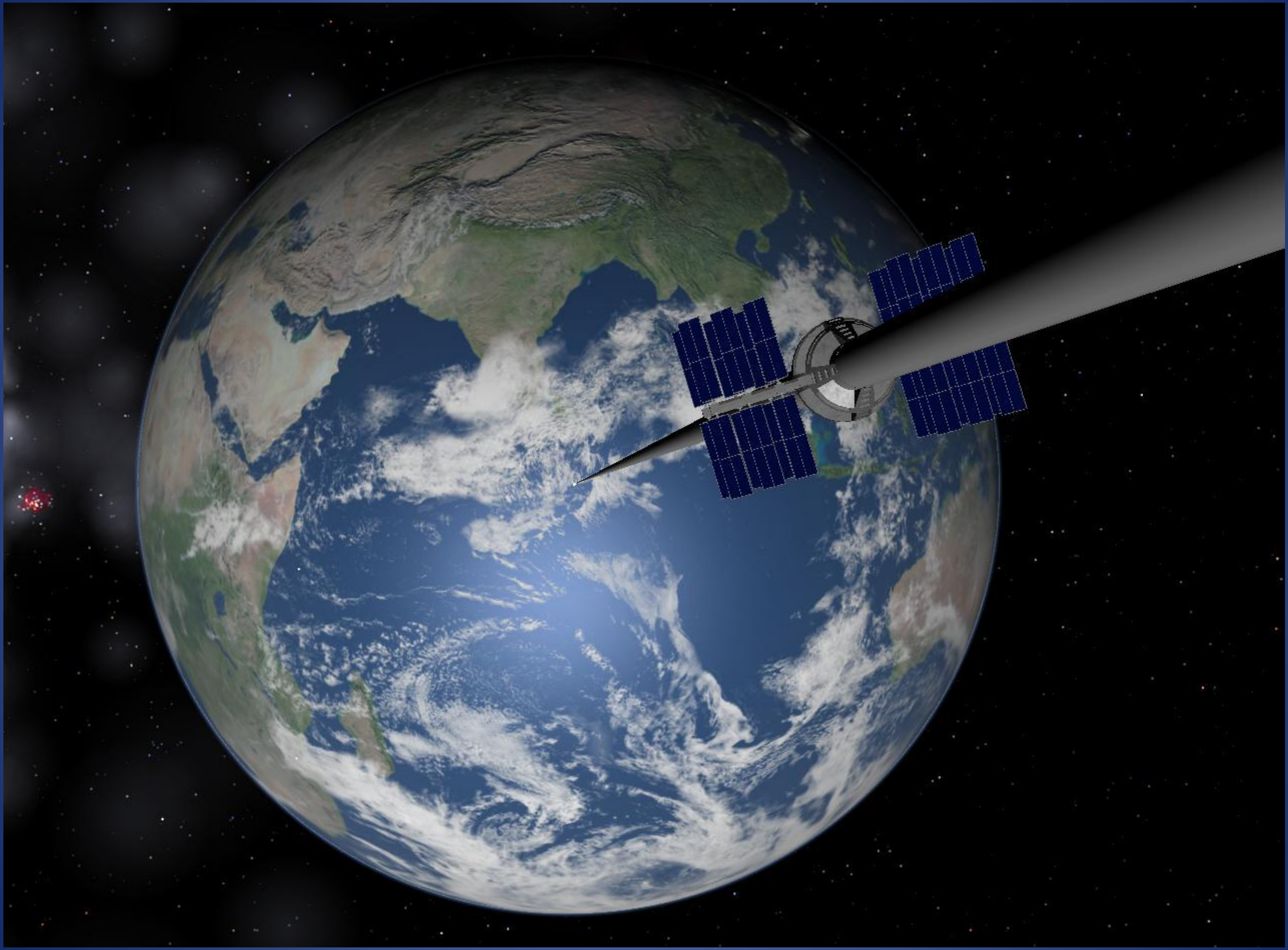


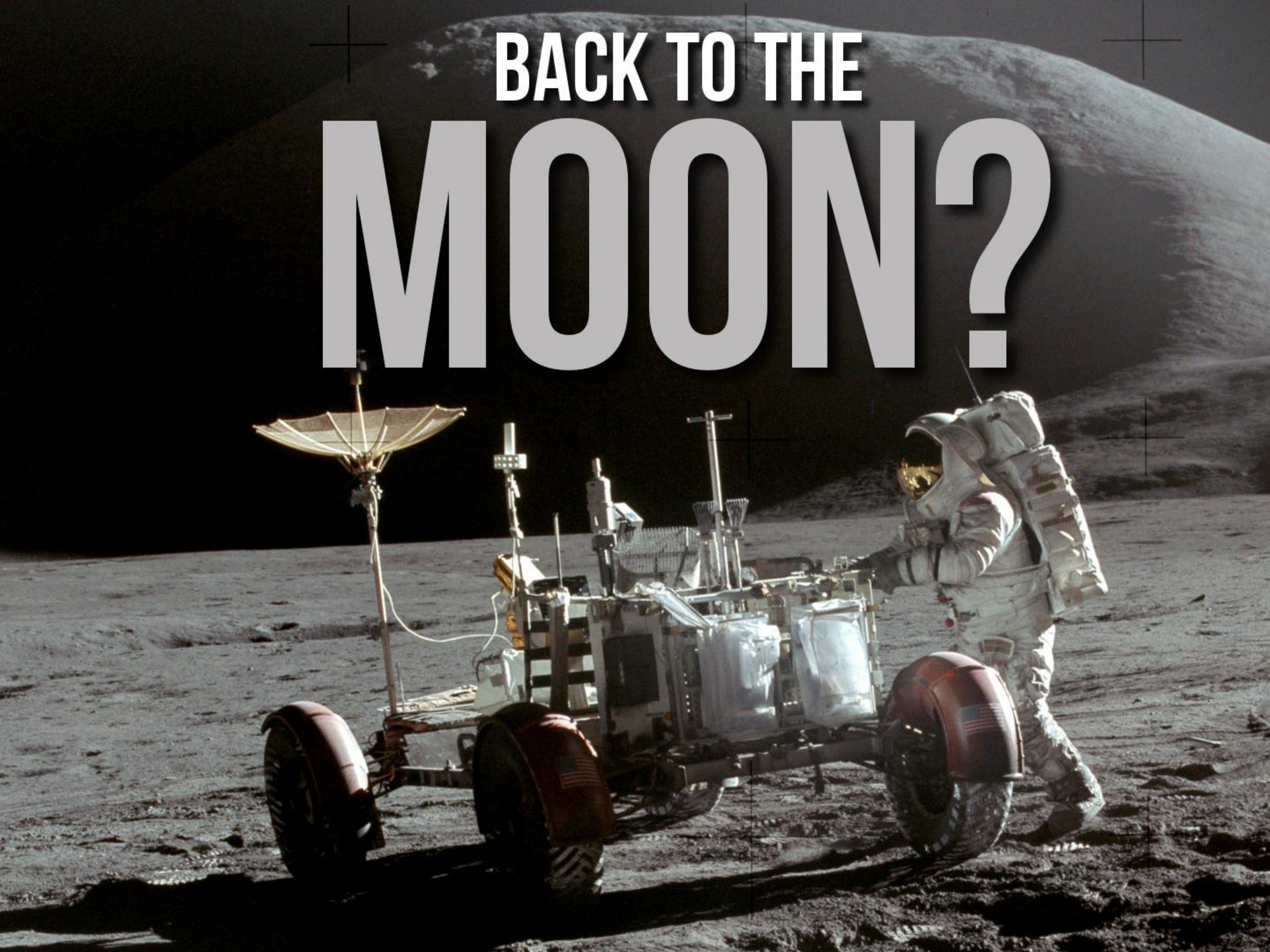
Fig 1.3: Illustration of the deployment scenario for the space elevator. A) A spacecraft is sent to geosynchronous orbit where it begins deploying a small cable. As the cable is deployed the spacecraft floats outward. B) When the end of the cable reaches Earth it is retrieved and anchored. C) Climbers are sent up the initial cable to strengthen it. D) A usable, high-capacity cable is completed.

If there is a concern regarding NTR technology, then, consider the current research related to Space Elevators. We are at most, two decades away from materials that have the capabilities of supporting a + 130GPa support structure over 150- 40,000 kilometers long.


© Geir Lanesskog 2005



BACK TO THE MOON?

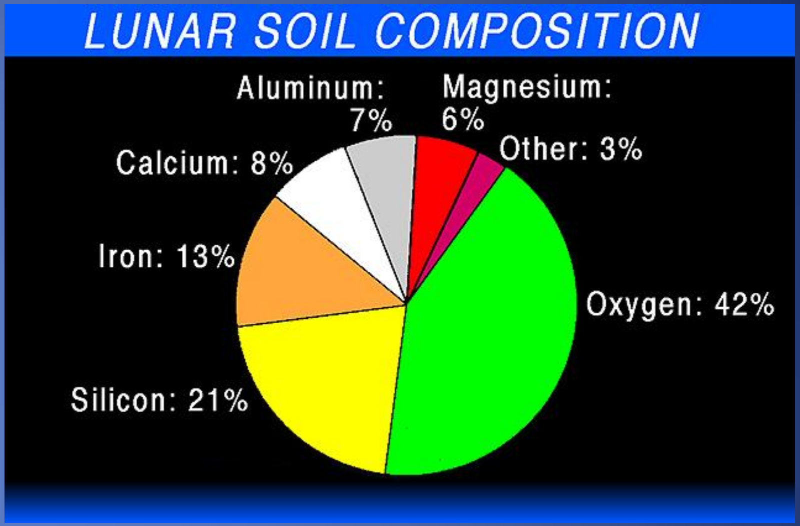


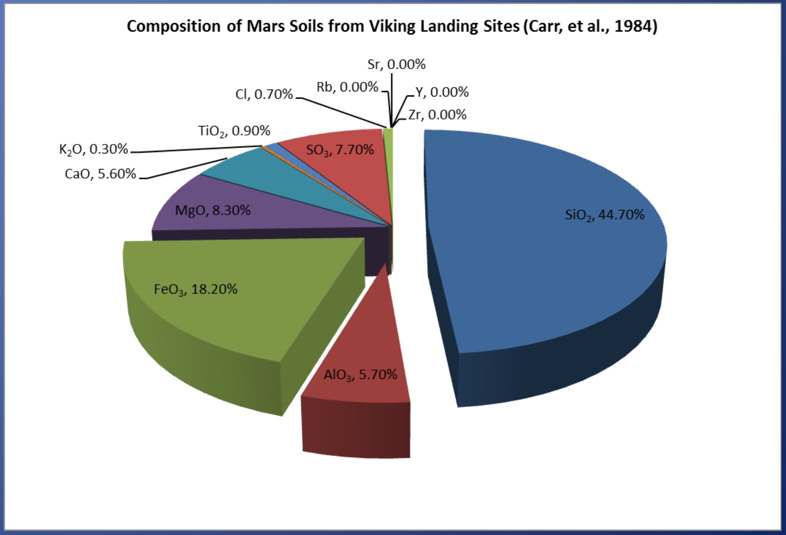
Businesses actively engaged in preparing for space resource exploration and exploitation

1. Planetary Resources (Focus on near earth asteroids)
2. Shackleton Energy Company (Focus on mining the Moon)
3. Stott Space, Inc. (Focus on Near Earth Asteroids)

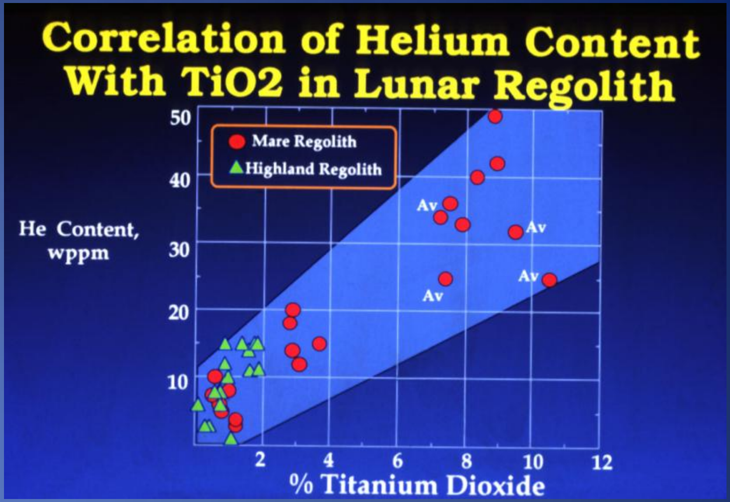
Are these the next Exxon, Chevron and Shell companies of the World?

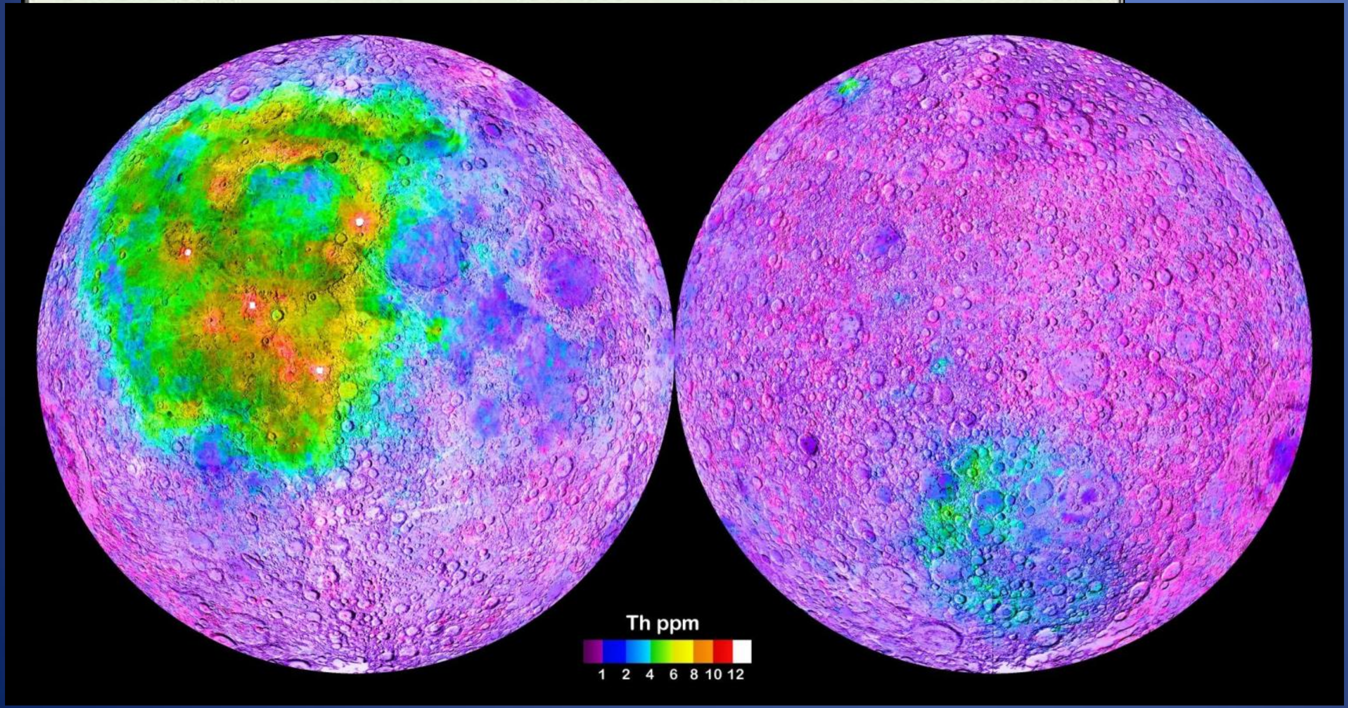
Estimated Value of a Typical 1 Kilometer Diameter M Class Asteroid	
Element	**Value if sold at today's market price**
Semiconductors	
Phosphorous (P)	1.24E+08
Gallium (Ga)	4.98E+10
Germanium (Ge)	3.45E+11
Arsenic (As)	1.29E+07
Selenium (Se)	3.15E+09
Indium (In)	3.97E+08
Antimony (Sb)	4.11E+05
Tellurium (Te)	1.13E+08
Platinum and Precious Metals	
Ruthenium (Ru)	1.46E+11
Rhodium (Rh)	6.61E+11
Palladium (Pd)	5.52E+10
Silver (Ag)	7.59E+08
Rhenium (Re)	1.98E+10
Osmium (Os)	2.25E+11
Iridium (Ir)	1.13E+12
Platinum (Pt)	3.33E+12
Gold (Au)	3.89E+10
Other Important Metals	
Copper (Cu)	1.60E+09
Cobalt (Co)	1.71E+11
Titanium (Ti)	1.35E+09
Chromium (Cr)	8.64E+09
Nickel (Ni)	1.55E+10
Molybdenum (Mo)	4.32E+05
Total	**6.20E+12**
Value	**$6.2 trillion**





Comparison of Terrestrial and Lunar REE Abundances	Lunar KREEP Basalt 15386 REE Abundance (ppm) typical	Apollo 16 ultra-KREEP REE Abundance (ppm) high	Bulk Continental Crust REE (ppm)	8.9% REO Mountain Pass Mine Molycorp	15.4% REO Mount Weld Mine Lynas Corp
Yttrium (Y)	240.9	na	24	70.0786	0
Lanthanum (La)	84.1	282	30	25656.9378	33493.383
Cerium (Ce)	213.1	733	60	37690.1472	61456.1825
Praseodymium (Pr)	30	na	6.7	3118.0705	7000.7476
Neodymium (Nd)	125.6	460	27	8546.5632	24427.326
Samarium (Sm)	36.5	127	5.3	690.7824	3014.7779
Europium (Eu)	2.78	5.36	1.3	76.8604	589.1652
Gadolinium (Gd)	43.9	na	4	154.4328	0
Terbium (Tb)	7.51	27.4	0.65	0	90.9807
Dysprosium (Dy)	45.7	na	3.8	0	166.3834
Holmium (Ho)	10.3	na	0.8	0	0
Erbium (Er)	28.3	na	2.1	0	0
Thulium (Tm)	3.97	na	0.3	0	0
Ytterbium (Yb)	26.2	77	2	0	0
Lutetium (Lu)	3.59	10.9	0.35	0	0
TOTAL REE (ppm)	**902.45**	Aprox 4000	**168.3**	**76003.8729**	**130238.9463**



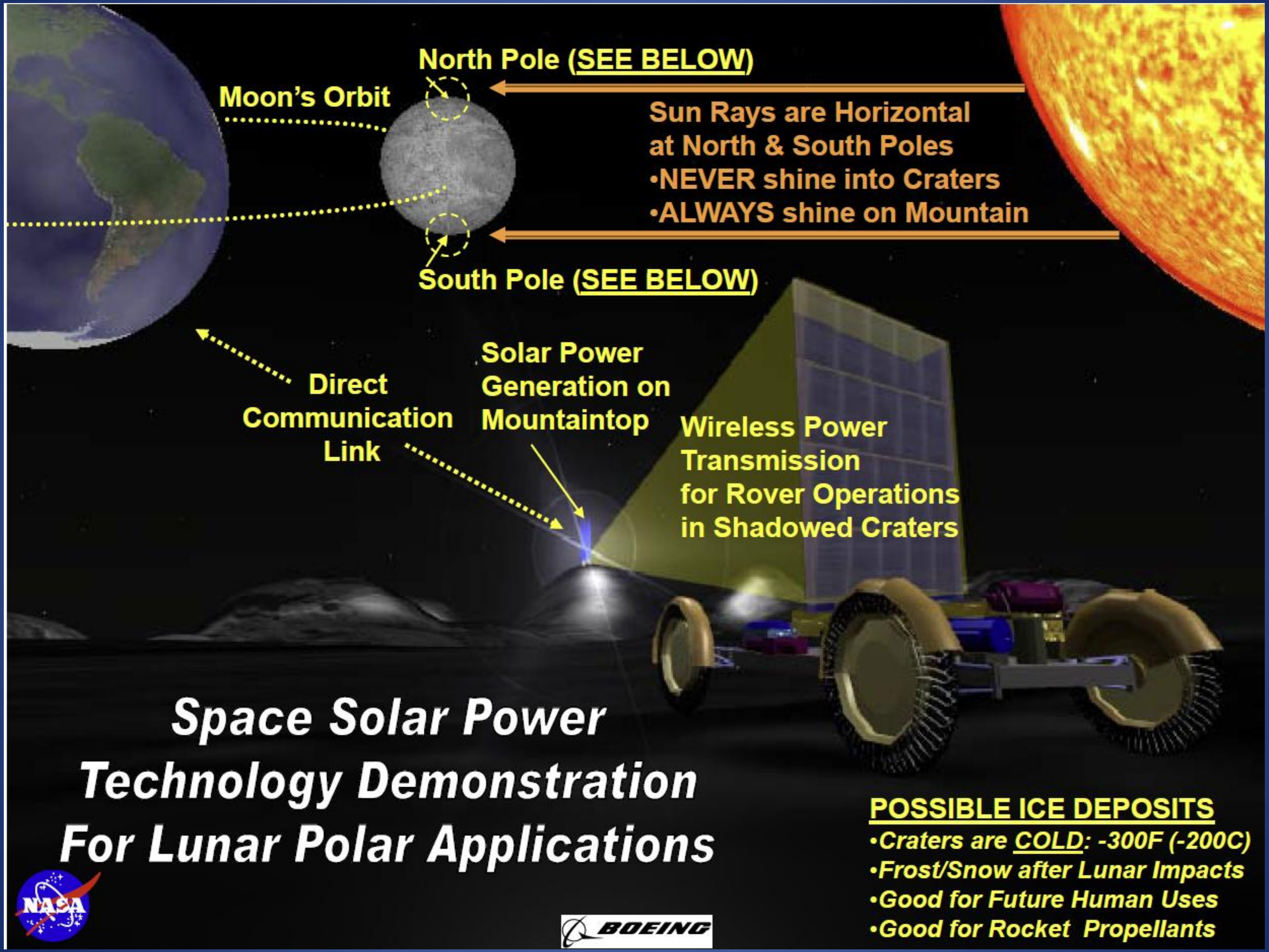


Rare Earth Elements, Helium-3 and Thorium Content of Lunar Regolith

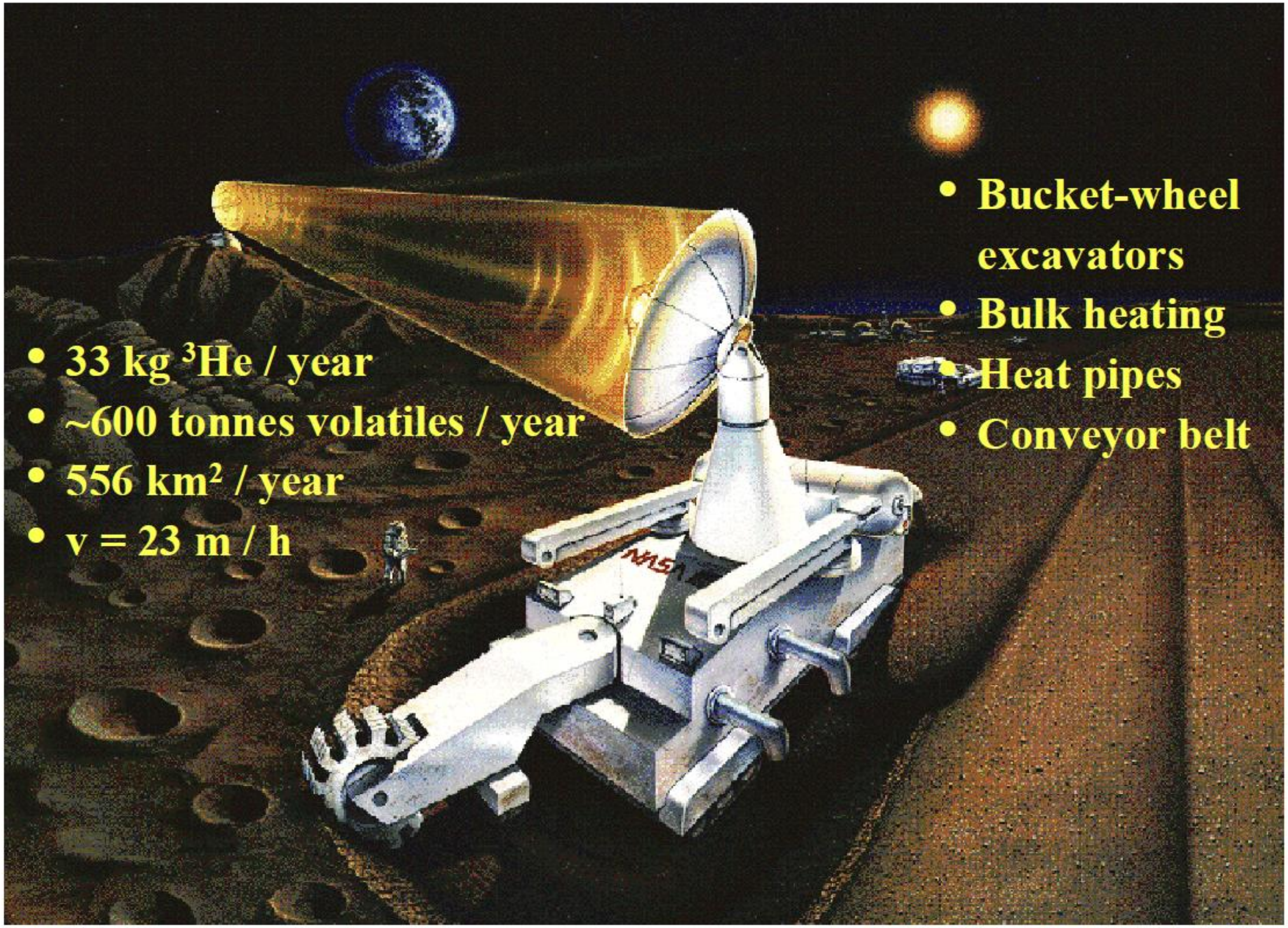
Spudis, P. Ambrose, W.

Lunar Resources (Courtesy of Ambrose, W.)

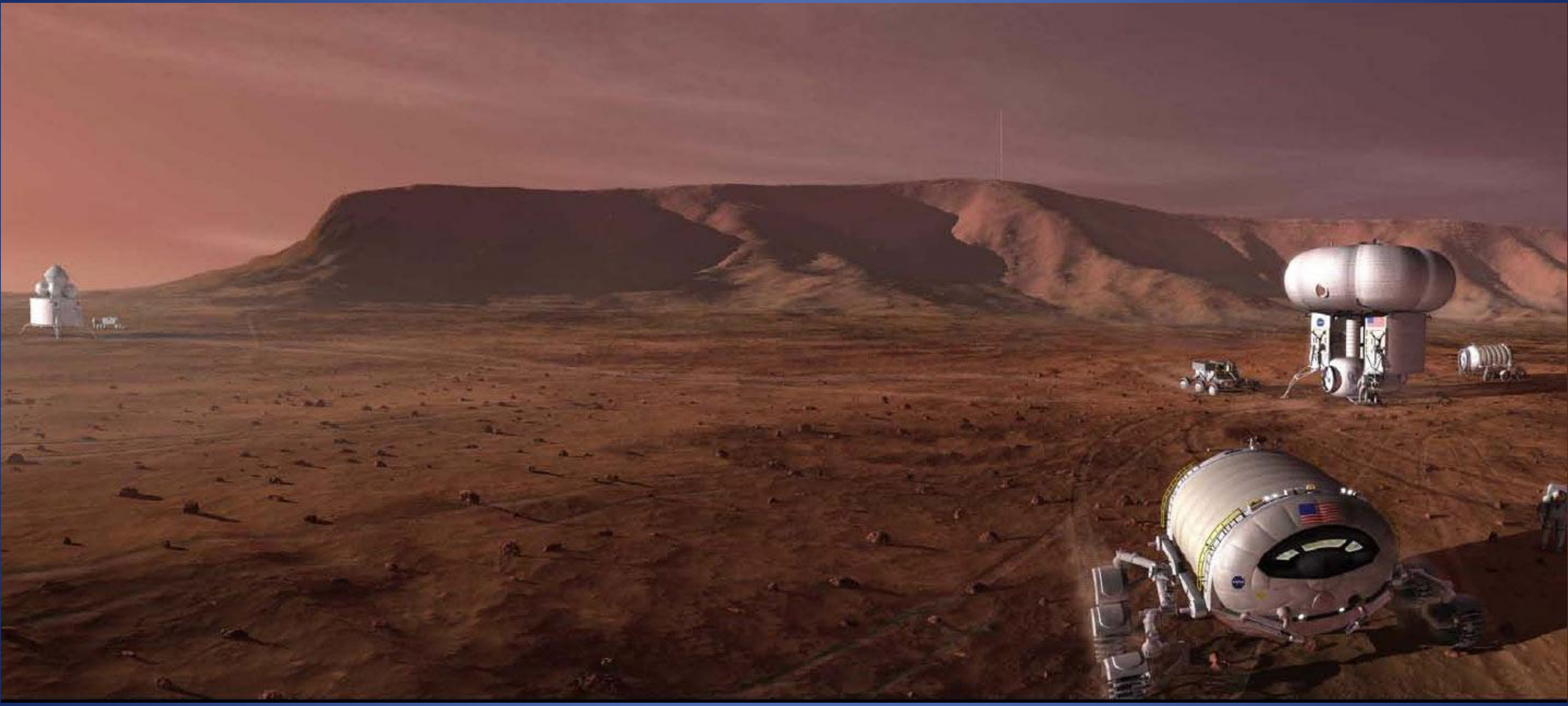
Resource	Use	Occurrence
Helium-3	Energy	Mature regolith
Hydrogen	Propellant, water	Mature regolith, poles
Oxygen	Propellant, air/water	Global
Nitrogen, carbon	Food and plastics	Breccias/regolith
Metals/bulk regolith Iron Titanium Aluminum	<u>Construction</u> Moon base Shielding Roads Solar power facility	Regolith, mare


North Pole (SEE BELOW)
Moon's Orbit
Sun Rays are Horizontal
at North & South Poles
•NEVER shine into Craters
•ALWAYS shine on Mountain
South Pole (SEE BELOW)
Direct
Communication
Link
Solar Power
Generation on
Mountaintop
Wireless Power
Transmission
for Rover Operations
in Shadowed Craters
Space Solar Power
Technology Demonstration
For Lunar Polar Applications
POSSIBLE ICE DEPOSITS
•Craters are COLD: -300F (-200C)
•Frost/Snow after Lunar Impacts
•Good for Future Human Uses
•Good for Rocket Propellants
NASA
BOEING

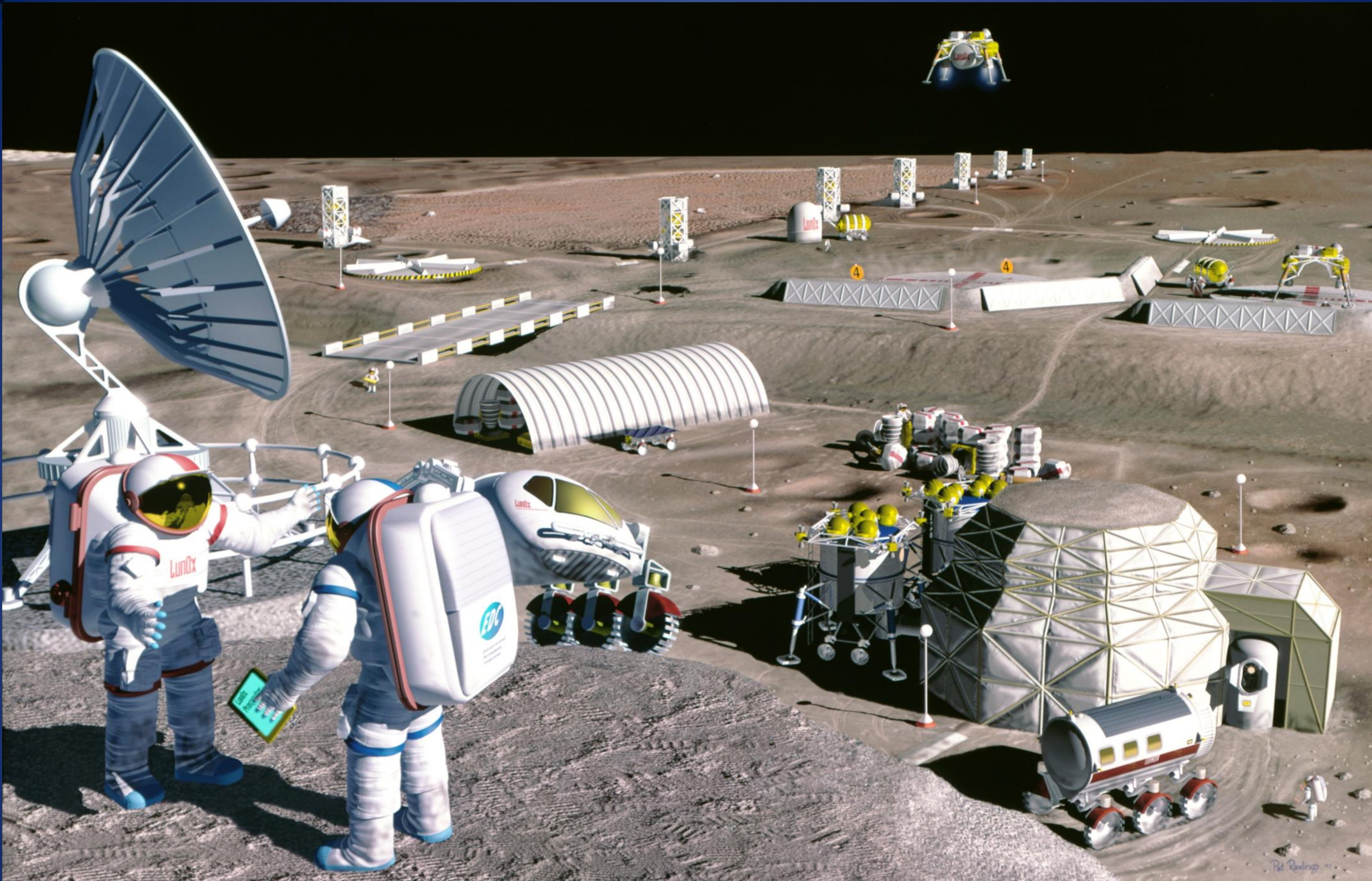
Well-Developed Terrestrial Technology Gives Access to ~10^9 kg of Lunar ^3He



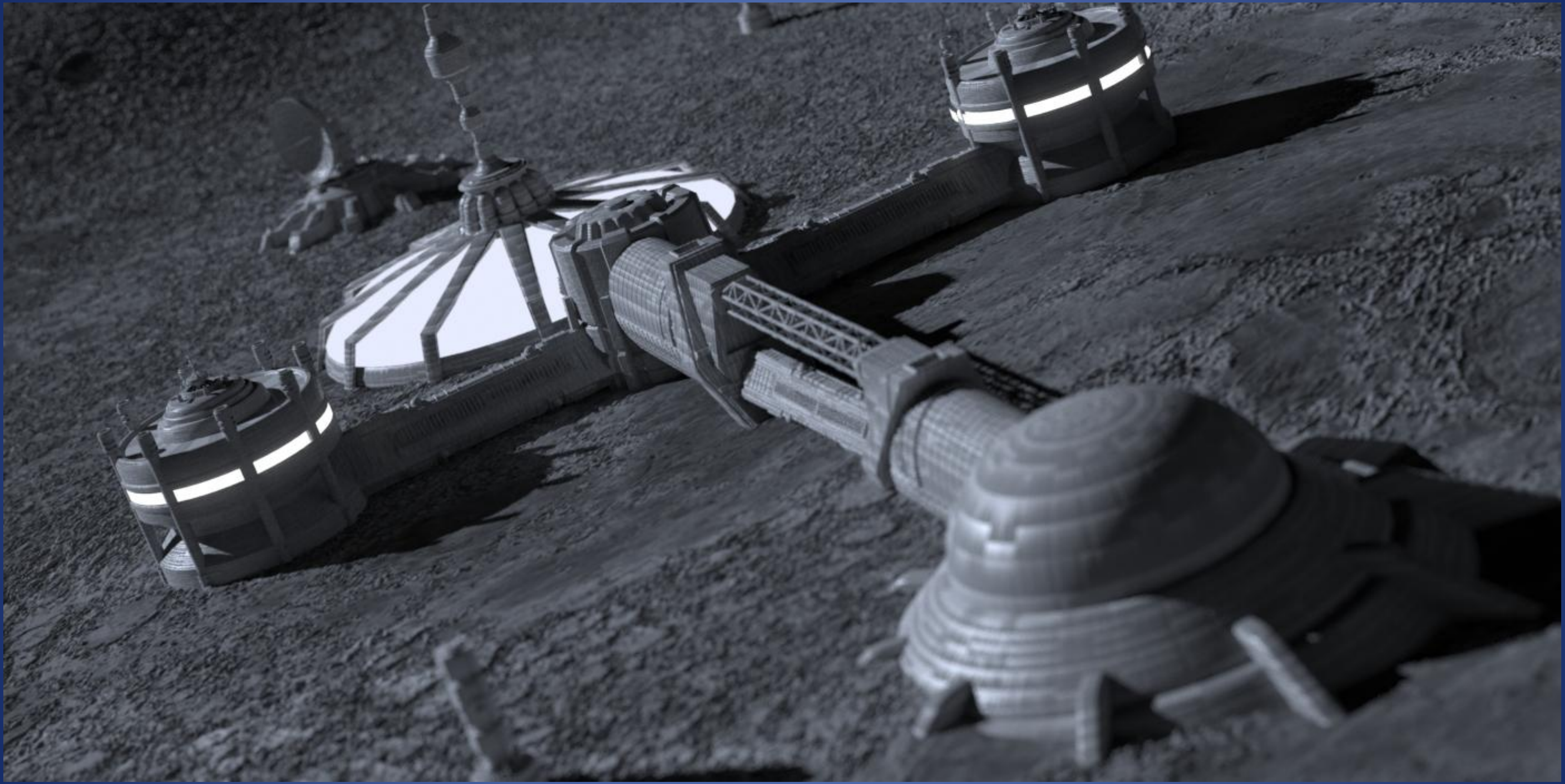
We are already operating ROVs on Mars, why not on the Moon?
Light Speed Constraints must be overcome by having humans on site



Human Exploration of Mars is necessary, for now. You can’t send a computer to do a human’s job. Yet.


LunOx
EDC

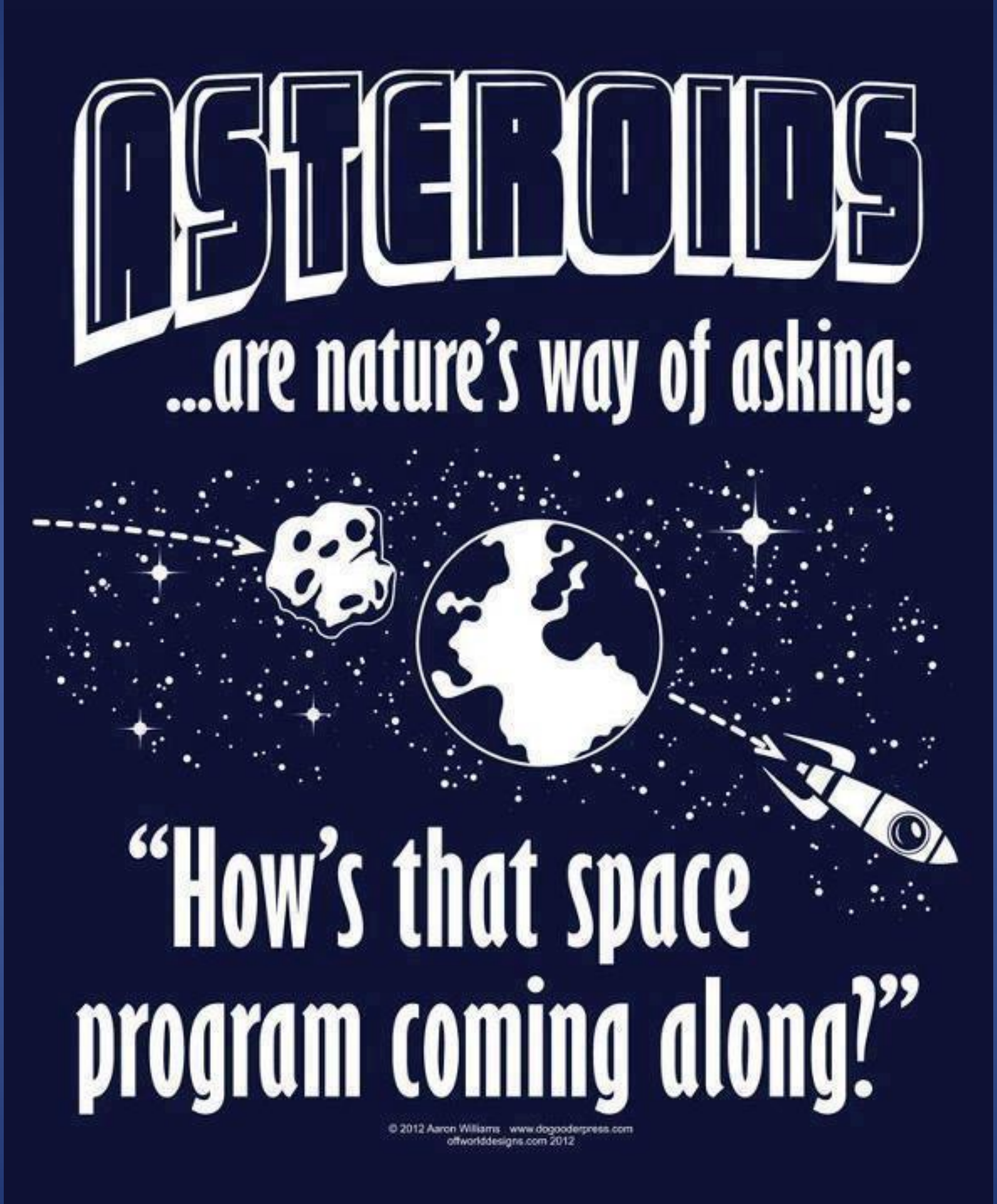

We need to keep in mind the hardships that our ancestors faced when first arriving in the New World



Permanent habitations will be efficient and comfortable. They will be the new permanent home for the explorationists in our societies.

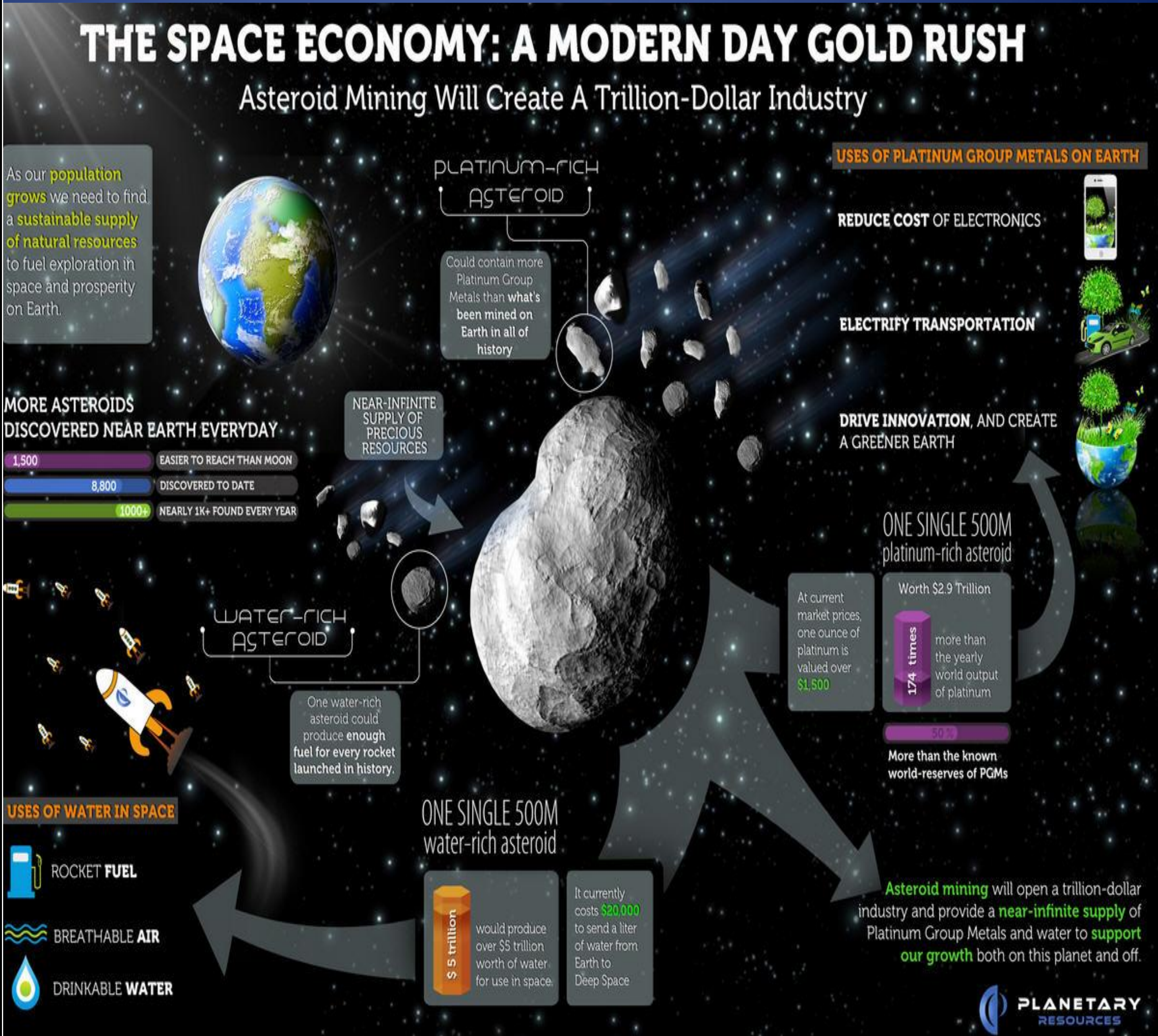
Fireball Streaking over Russia
This photograph of the meteor streaking through the sky above Chelyabinsk, Russia, on Feb. 15, 2013, was taken by a local, M. Ahmetvaleev. The small asteroid was about 56 to 66 feet (17 to 20 meters) wide.

Image Credit: Copyright M. Ahmetvaleev


ASTEROIDS
...are nature's way of asking:
"How's that space program coming along?"
© 2012 Aaron Williams www.dogooderpress.com
offworlddesigns.com 2012

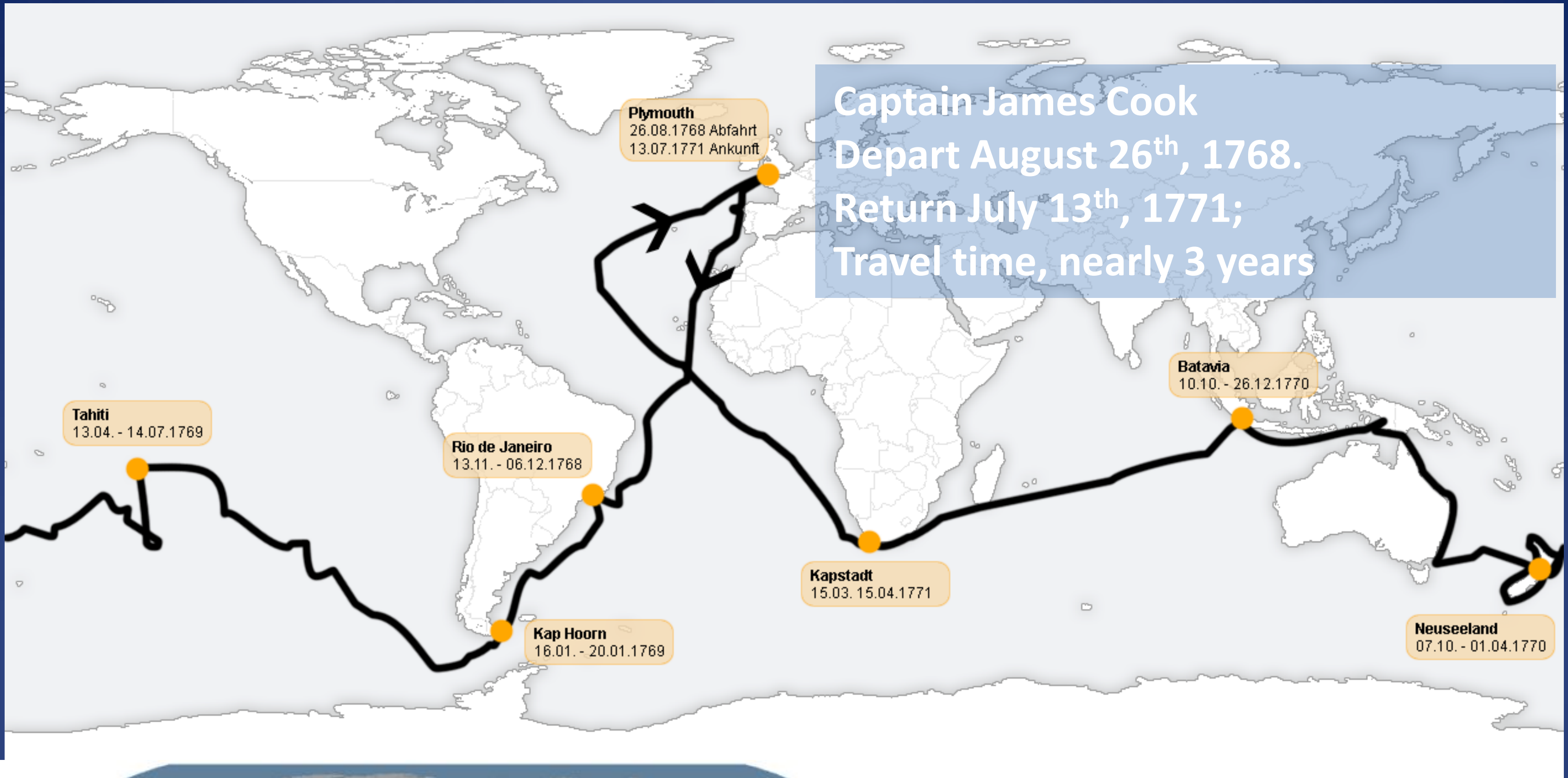
Significant attention has been directed toward mining the asteroids recently, but we have known of their value for more the 75 years

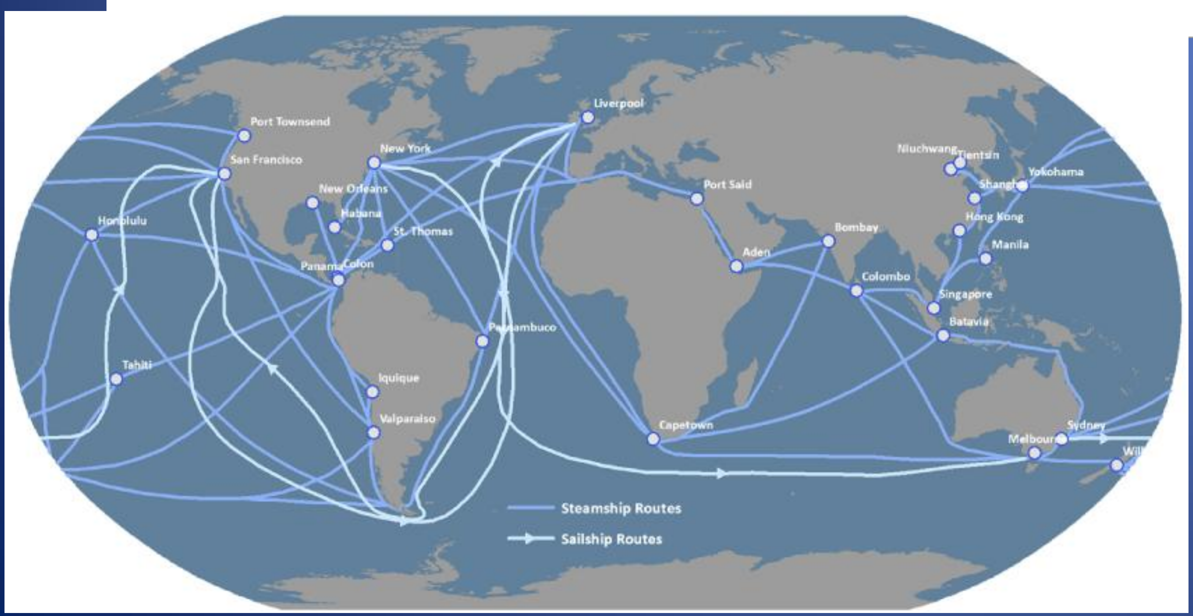
Estimated Value of a Typical 1 Kilometer Diameter M Class Asteroid	
Element	**Value if sold at today's market price**
Semiconductors	
Phosphorous (P)	1.24E+08
Gallium (Ga)	4.98E+10
Germanium (Ge)	3.45E+11
Arsenic (As)	1.29E+07
Selenium (Se)	3.15E+09
Indium (In)	3.97E+08
Antimony (Sb)	4.11E+05
Tellurium (Te)	1.13E+08
Platinum and Precious Metals	
Ruthenium (Ru)	1.46E+11
Rhodium (Rh)	6.61E+11
Palladium (Pd)	5.52E+10
Silver (Ag)	7.59E+08
Rhenium (Re)	1.98E+10
Osmium (Os)	2.25E+11
Iridium (Ir)	1.13E+12
Platinum (Pt)	3.33E+12
Gold (Au)	3.89E+10
Other Important Metals	
Copper (Cu)	1.60E+09
Cobalt (Co)	1.71E+11
Titanium (Ti)	1.35E+09
Chromium (Cr)	8.64E+09
Nickel (Ni)	1.55E+10
Molybdenum (Mo)	4.32E+05
Total	**6.20E+12**
Value	**$6.2 trillion**



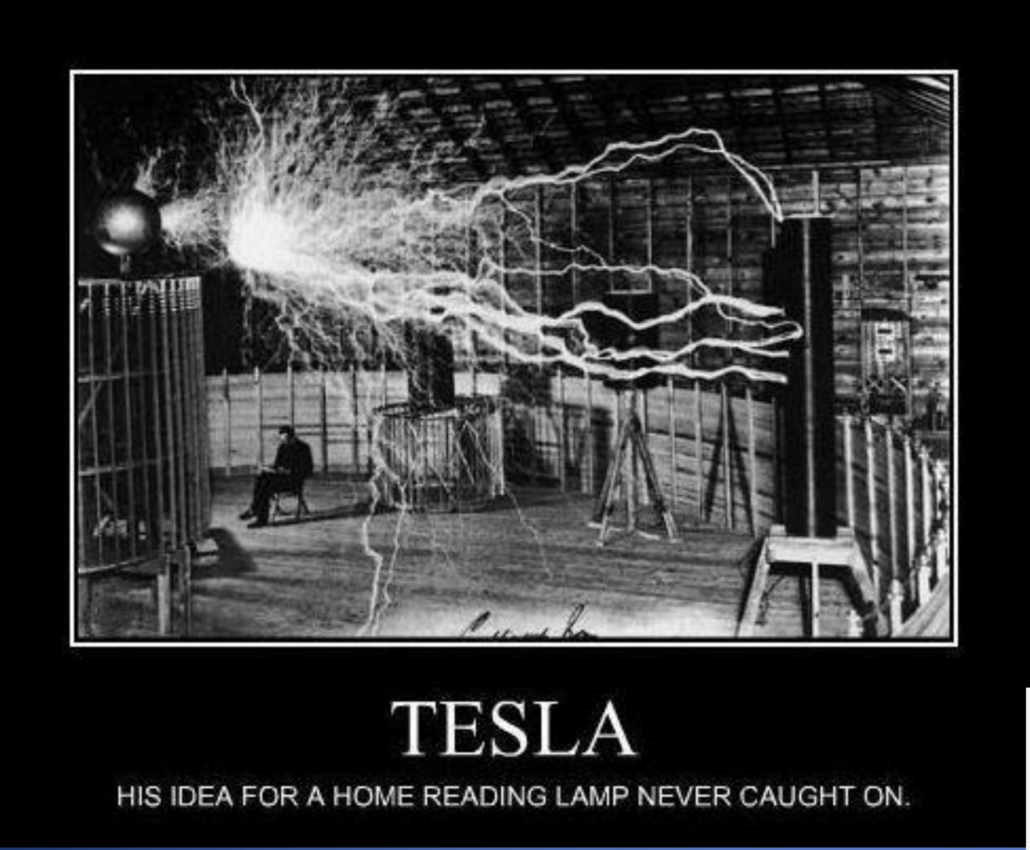
The Sooners, the California Gold Rush, the attraction of Yukon Gold have all been motivating factors for “pushing the envelope” and seeking new opportunities.

Captain James Cook
Depart August 26th, 1768.
Return July 13th, 1771;
Travel time, nearly 3 years



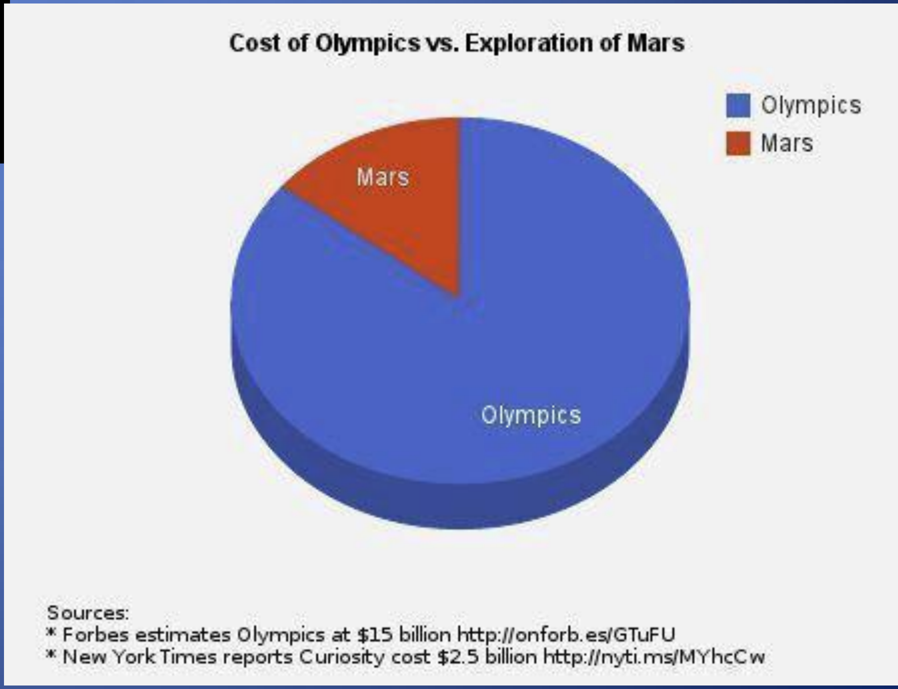


World Trade Routes 19th Century

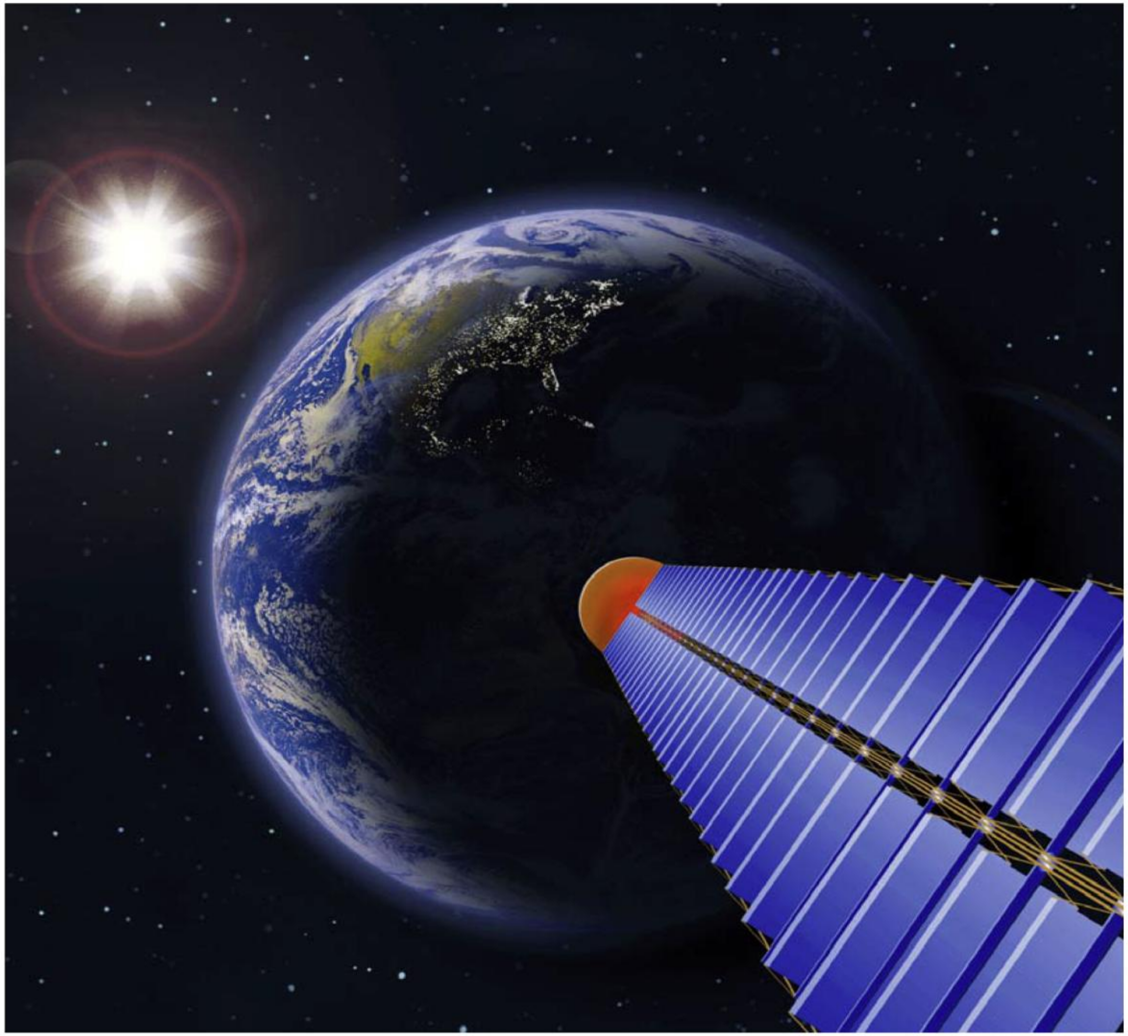


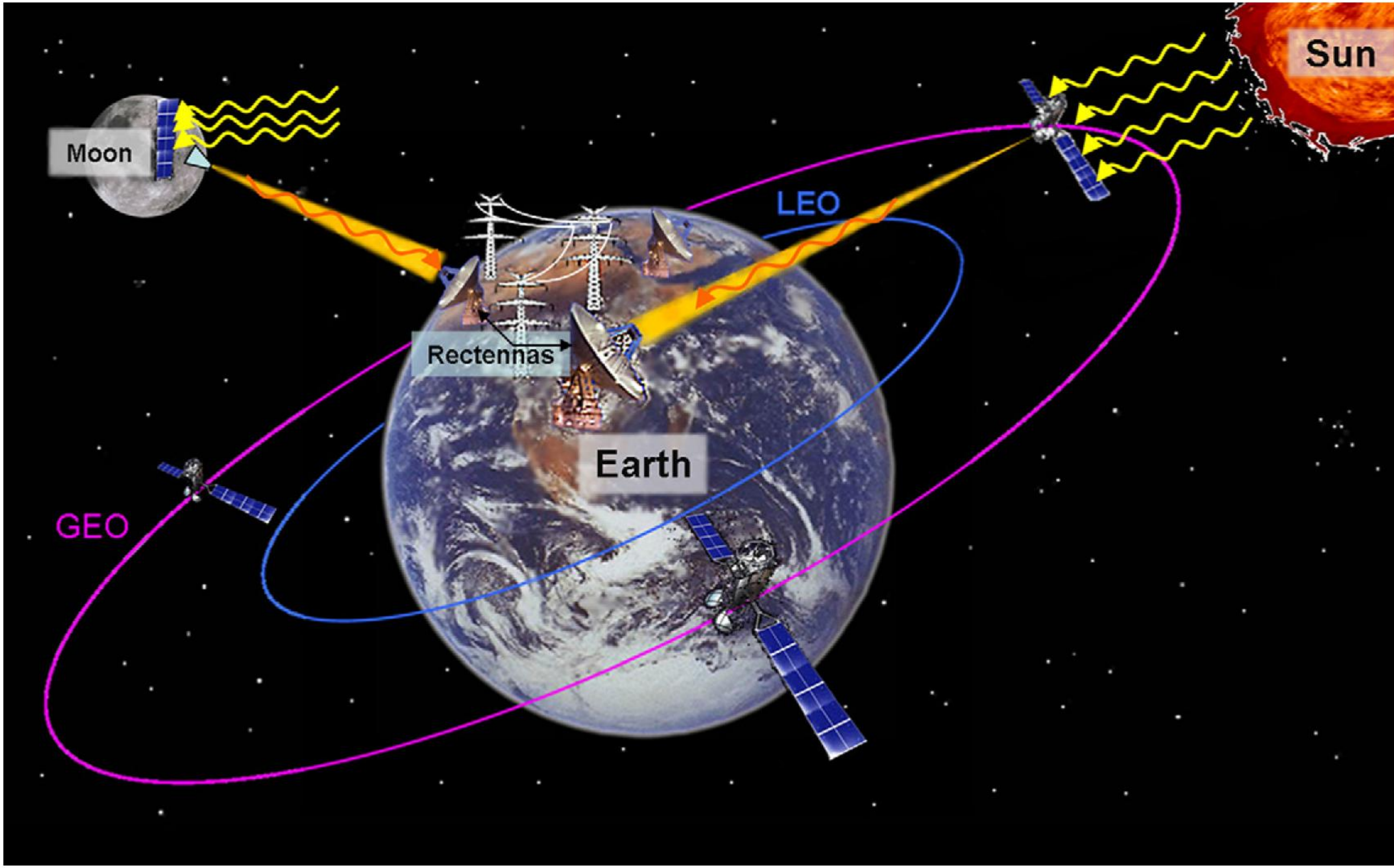
Its not that hard, it doesn't cost that much, and it doesn't take that long.

So, while we are in space, let's beam power back home, to earth orbit, or to earth's surface. The benefits are substantial, and the economics are competitive.



- “Sun-Tower” Design based on NASA Fresh Look Study
- Transmitter Diameter: 500 meters
- Vertical “Backbone” Length: 15.3 km (gravity gradient)
- Identical Satellite Elements: 355 segments (solar arrays)
- Autonomous Segment Ops:
1) Solar Electric Propulsion from Low Earth Orbit
2) System Assembly in Geostationary orbit
- Large Rectenna Receivers: Power production on Earth




Sun
Moon
LEO
Rectennas
Earth
GEO

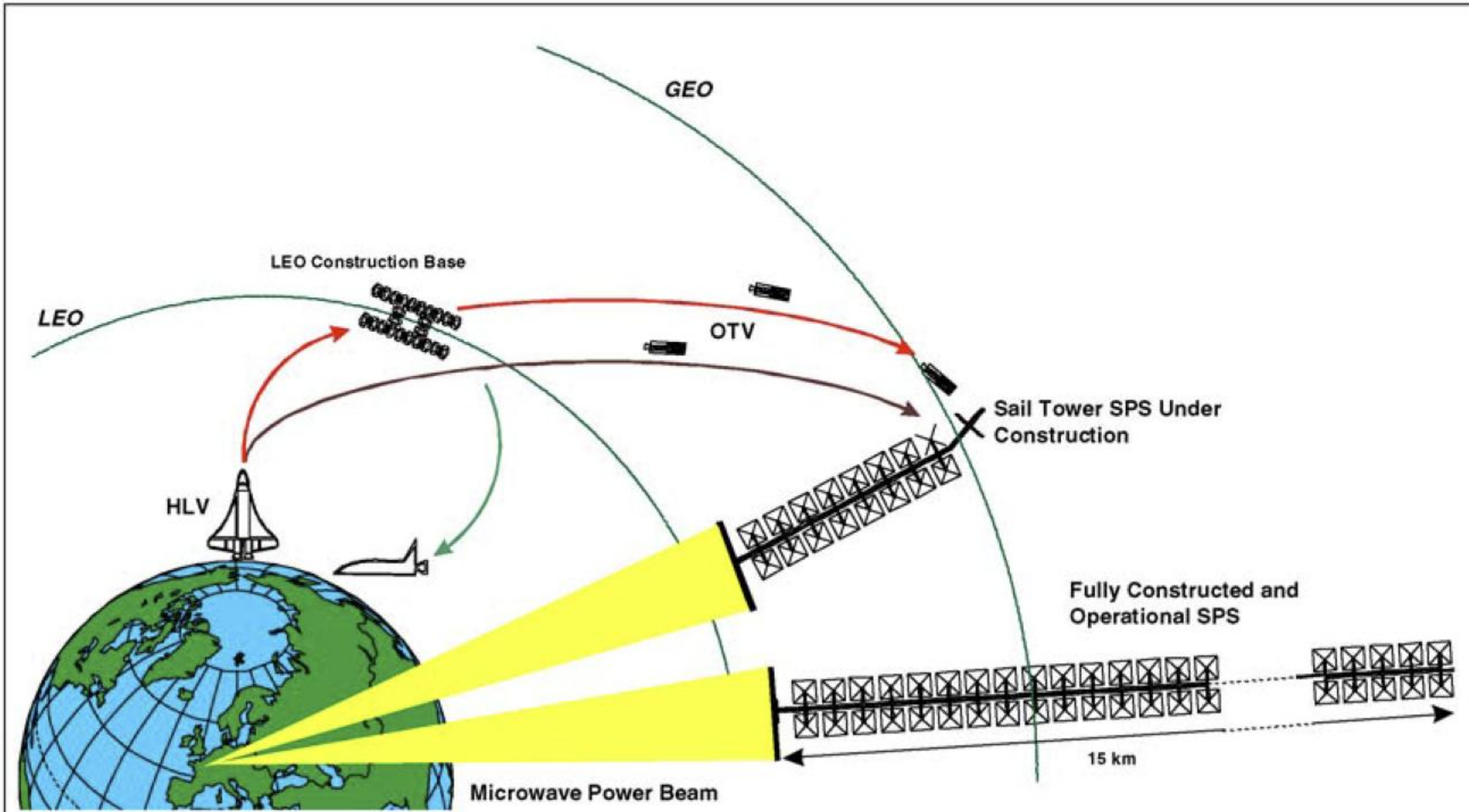


Fig. 9. ‘European Sail Tower SPS’ transportation scenario (DLR), not to scale.

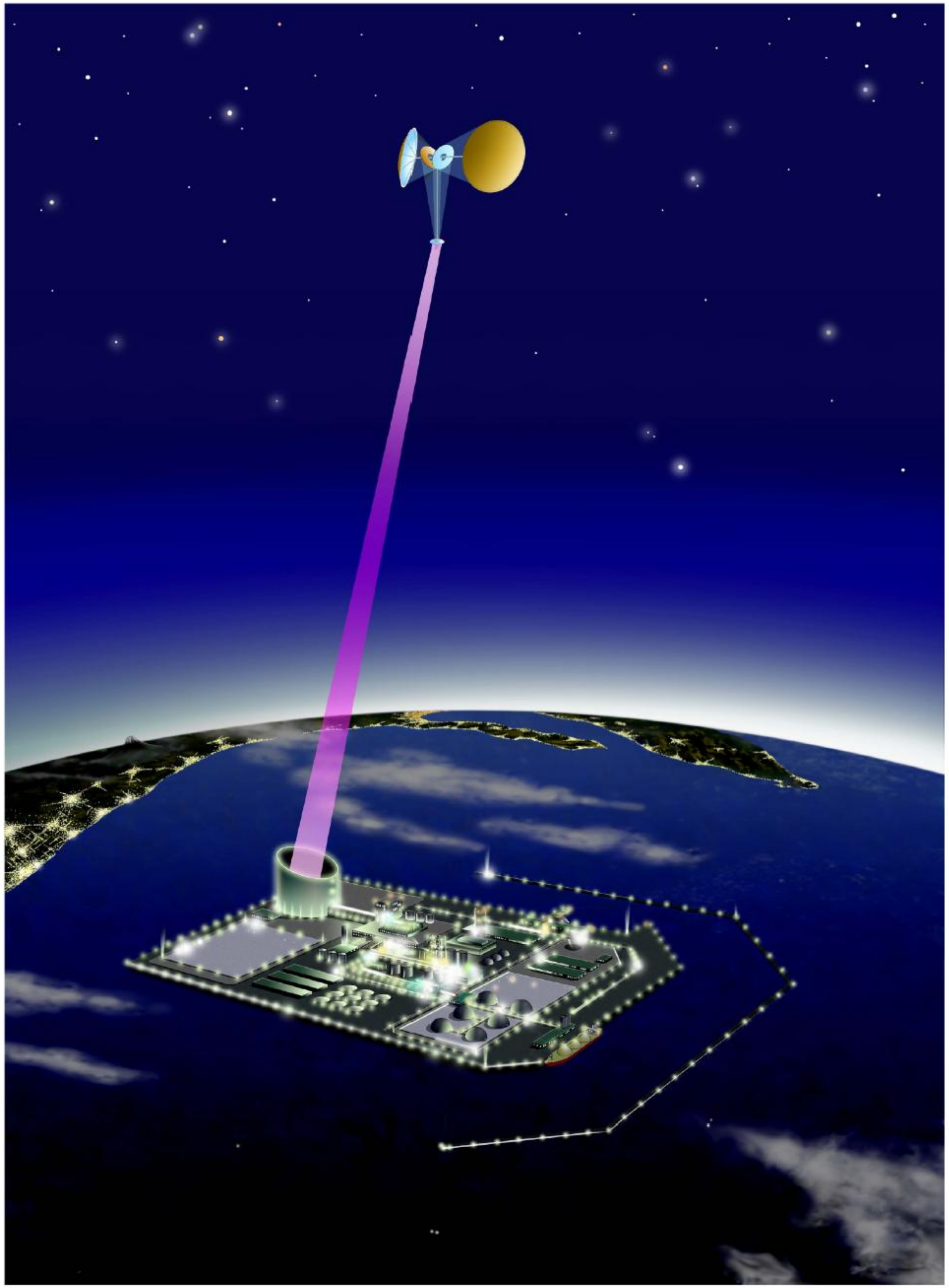


FIG. 7: JAXA L-SPS system diagram. (source: JAXA)

Japan Space Agency (JAXA) is aggressively working on Space-based Solar Power Stations.

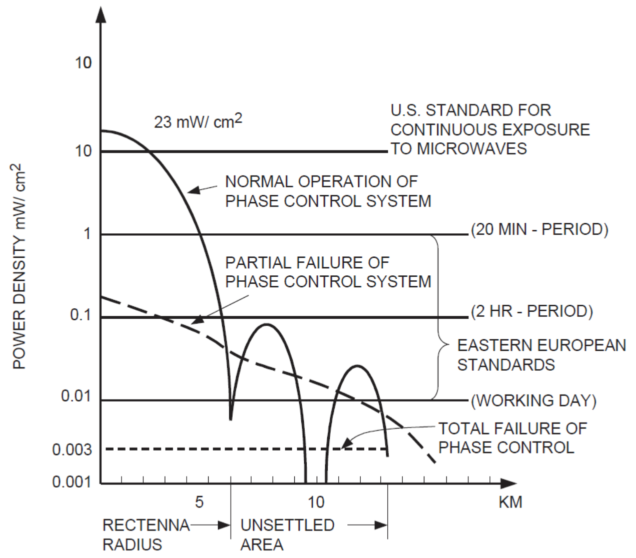


Fig. 4. International standards for continuous microwave radiation exposure.

Fig. 5. Ground receiving rectenna (artist's view).

Installed Cost ≈ Range $1,000 to $2,700 /KW

Production (wholesale) Cost ≈ $0.05-0.07 /KWhr

(Glaser, P. 1993)
(Seboldt, W. 2004, Criswell, 2013)

Keep in mind

- It’s not that hard
- It’s not that expensive
- It does not take that long

- The most successful commercial space applications, such as satellite communications, remote monitoring, direct-to-home TV and satellite radio, have been successful not because they’re space-based, but because they provide a service that is better and/or less expensive than competing options.

- Space-based mining and power generation are cost-competitive now, lacking only our courage to develop propulsion systems to take us to space. And, once there, why return, when all the resources necessary are already there.

AAPG Memoir 101 *Energy Resources for Human Settlement in the Solar System and Earth's Future in Space* defined the opportunities, we, as energy and exploration professionals, have before us as we move from admiring space to occupying space.


Good Luck in your new adventures