Robotic, Self-Sustaining Architecture to Utilize Resources and Enable Human Expansion throughout the Solar System

SRR / PTMSS

Golden, Colorado

June 4-7, 2012

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NASA / Kennedy Space Center

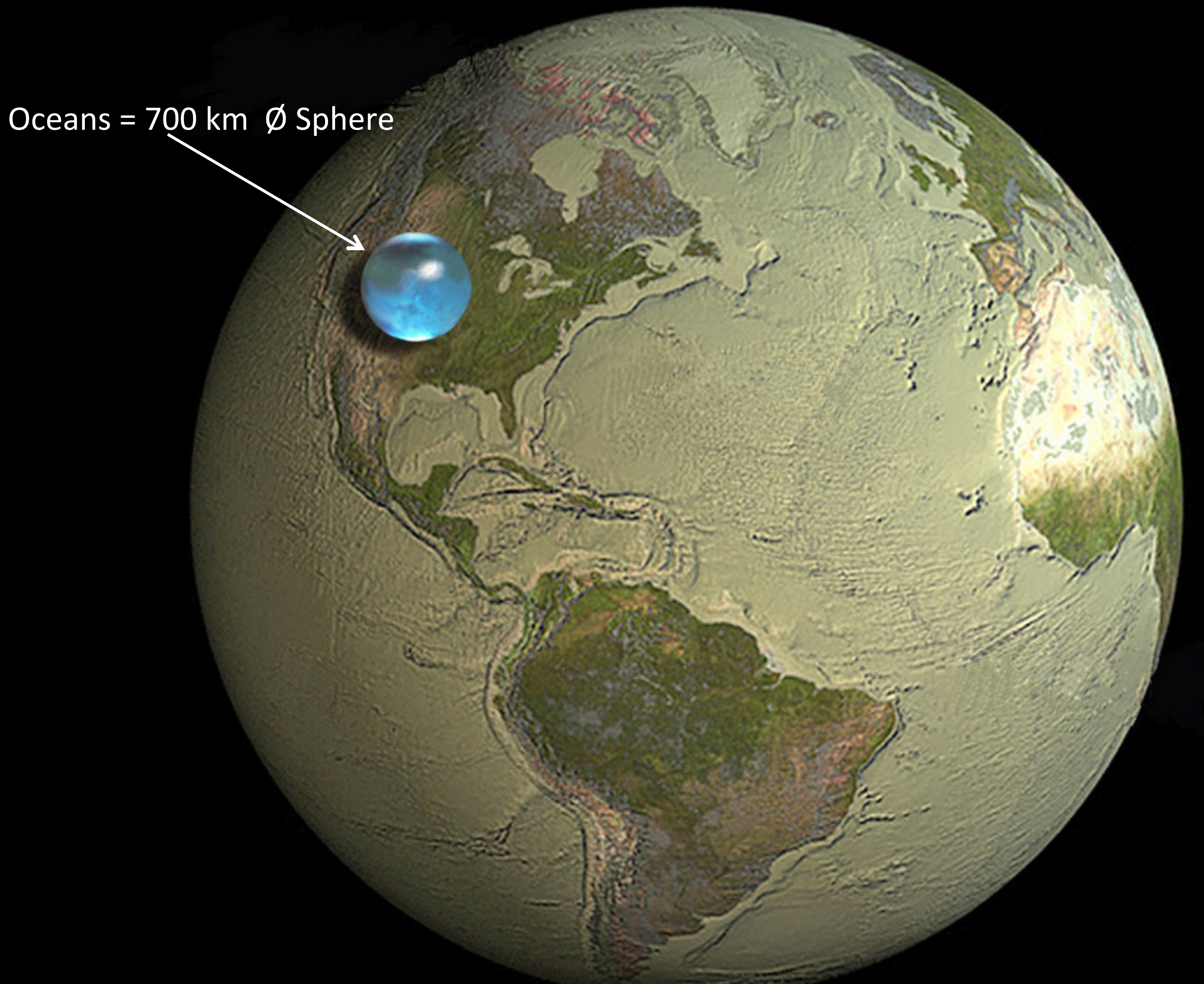


Illustration by Jack Cook, Woods Hole Oceanographic Institution

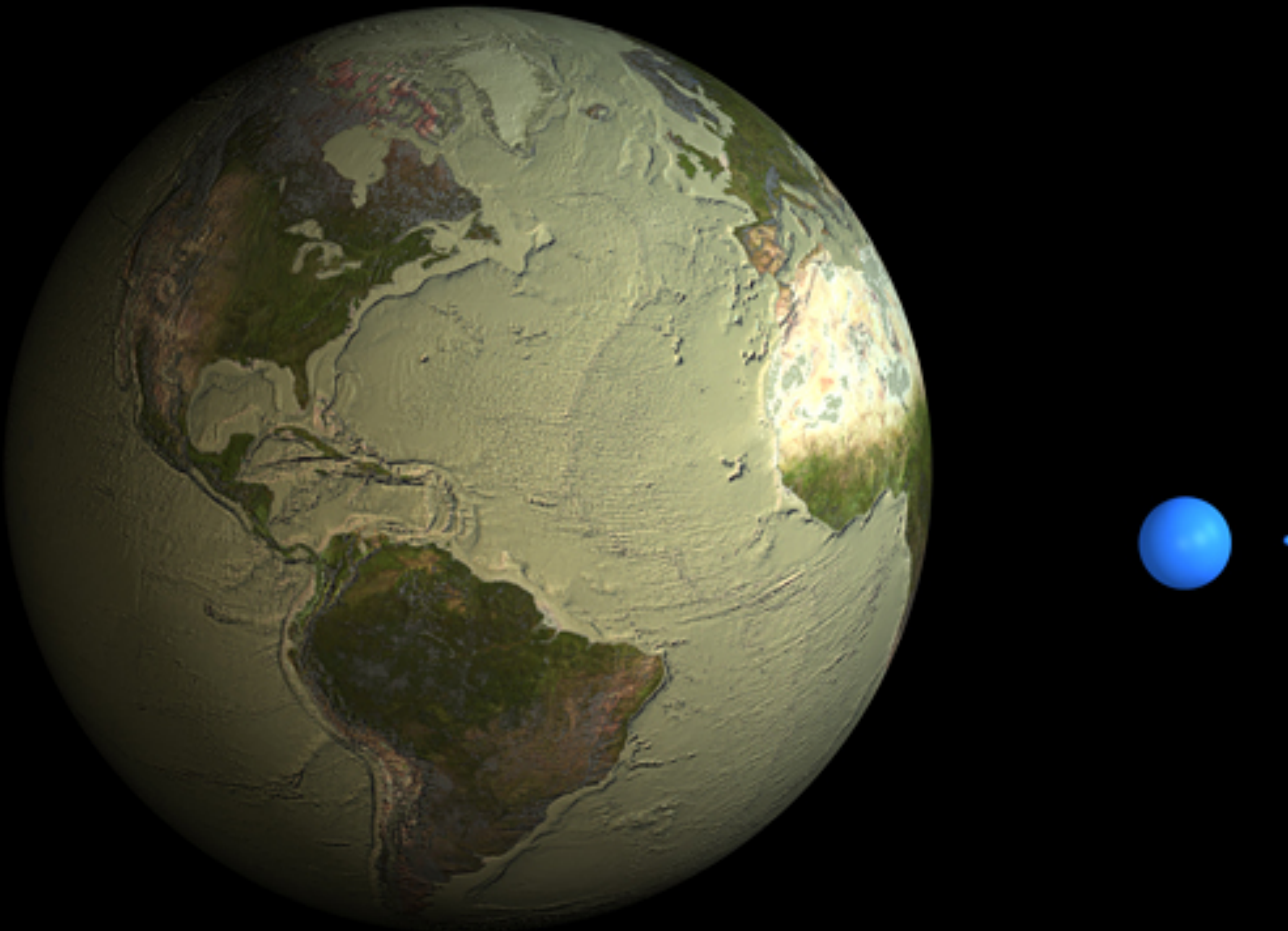
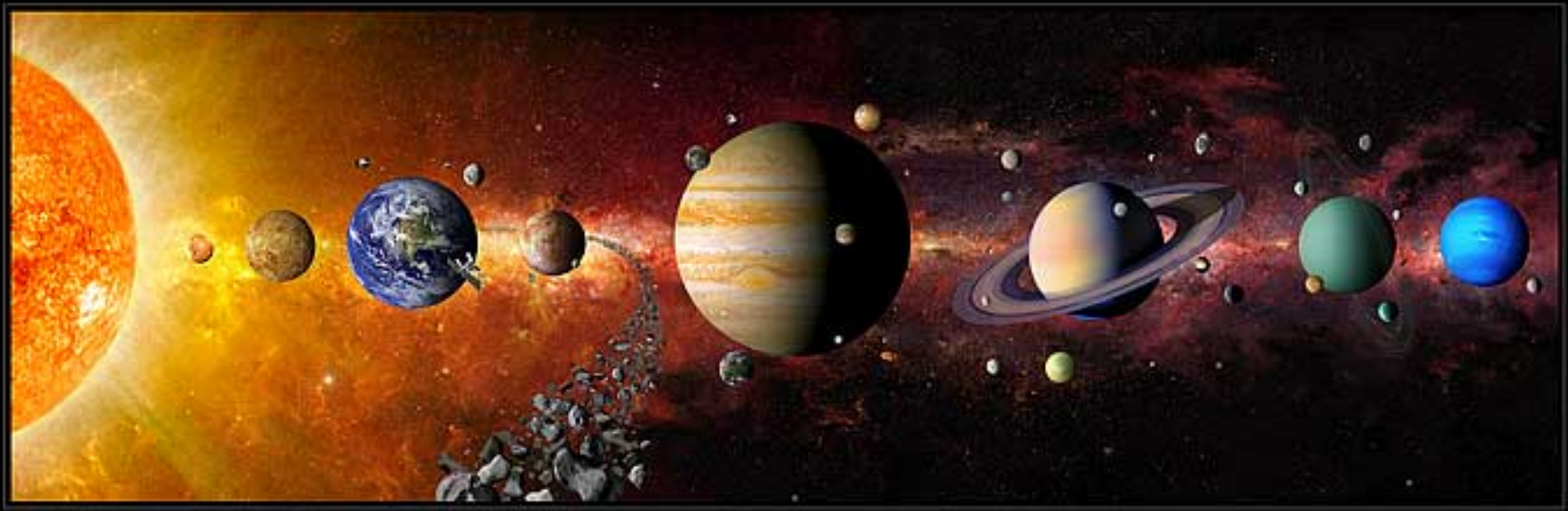
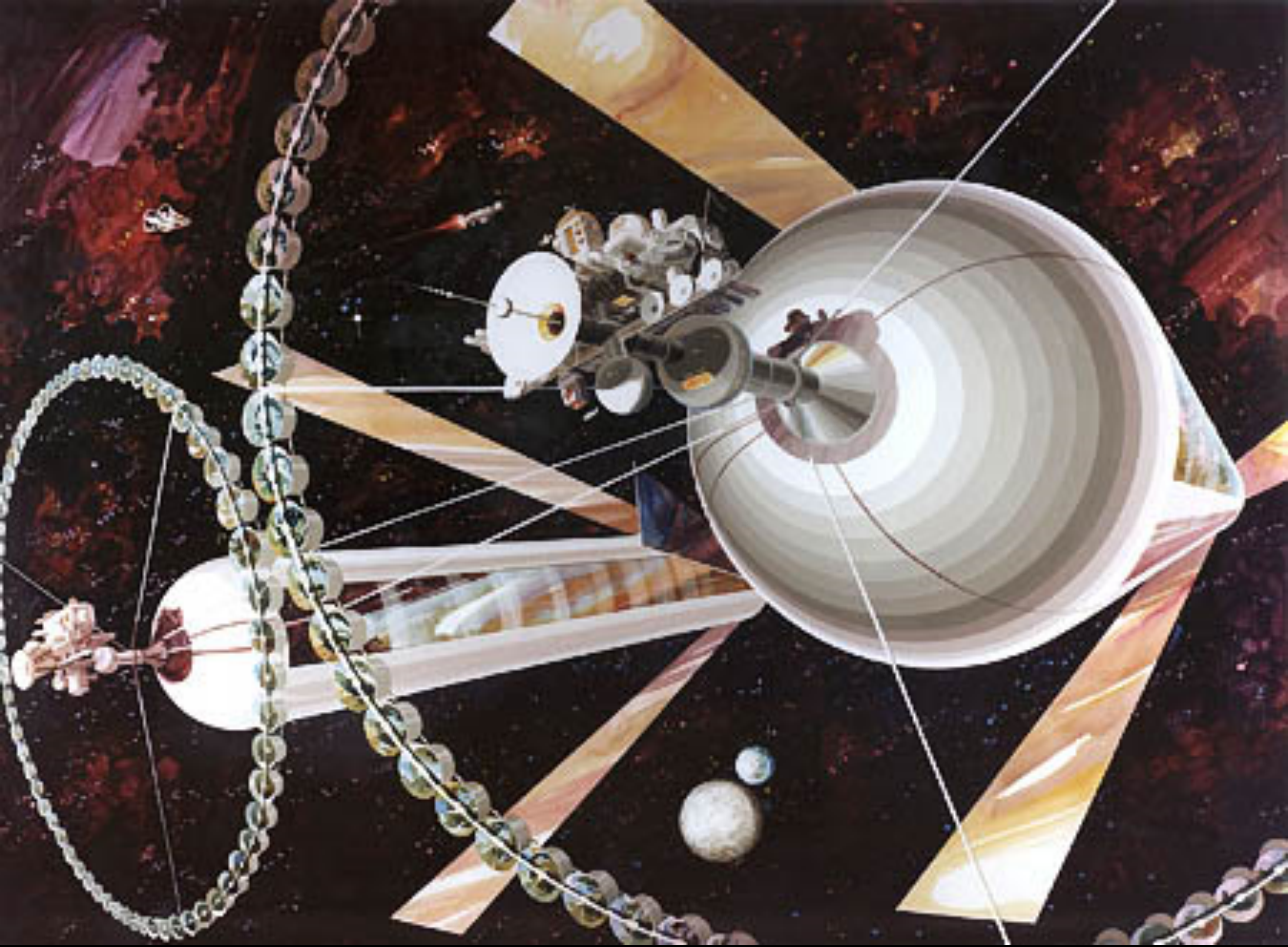


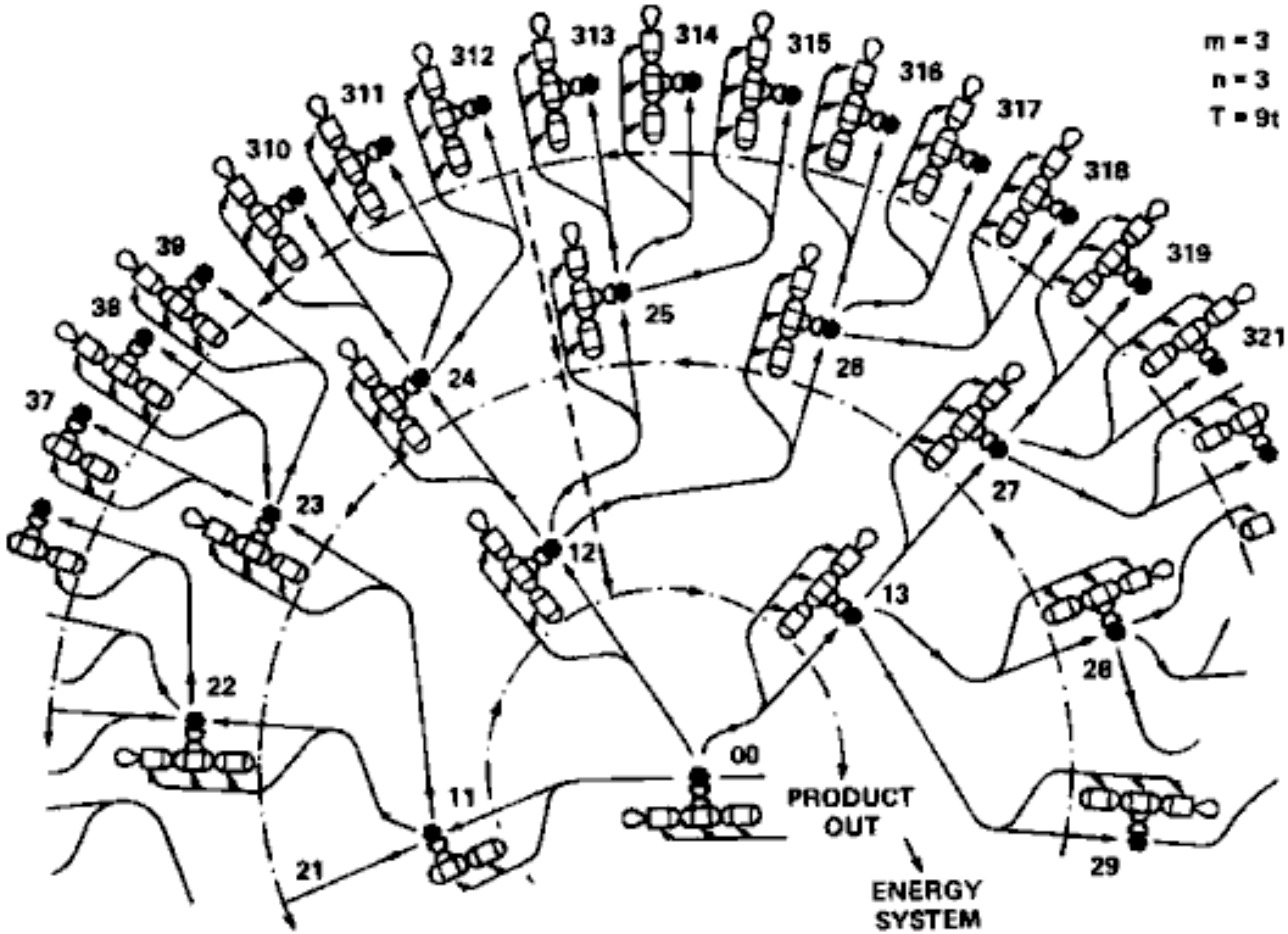
Illustration by Jack Cook, Woods Hole Oceanographic Institution

Astronomers estimate that if Ceres were composed of 25 percent water, it may have more water than all the fresh water on Earth. Ceres' water, unlike Earth's, is expected to be in the form of water ice located in its mantle.



A New Level of Civilization



m = 3
n = 3
T = 9t
00
11
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27
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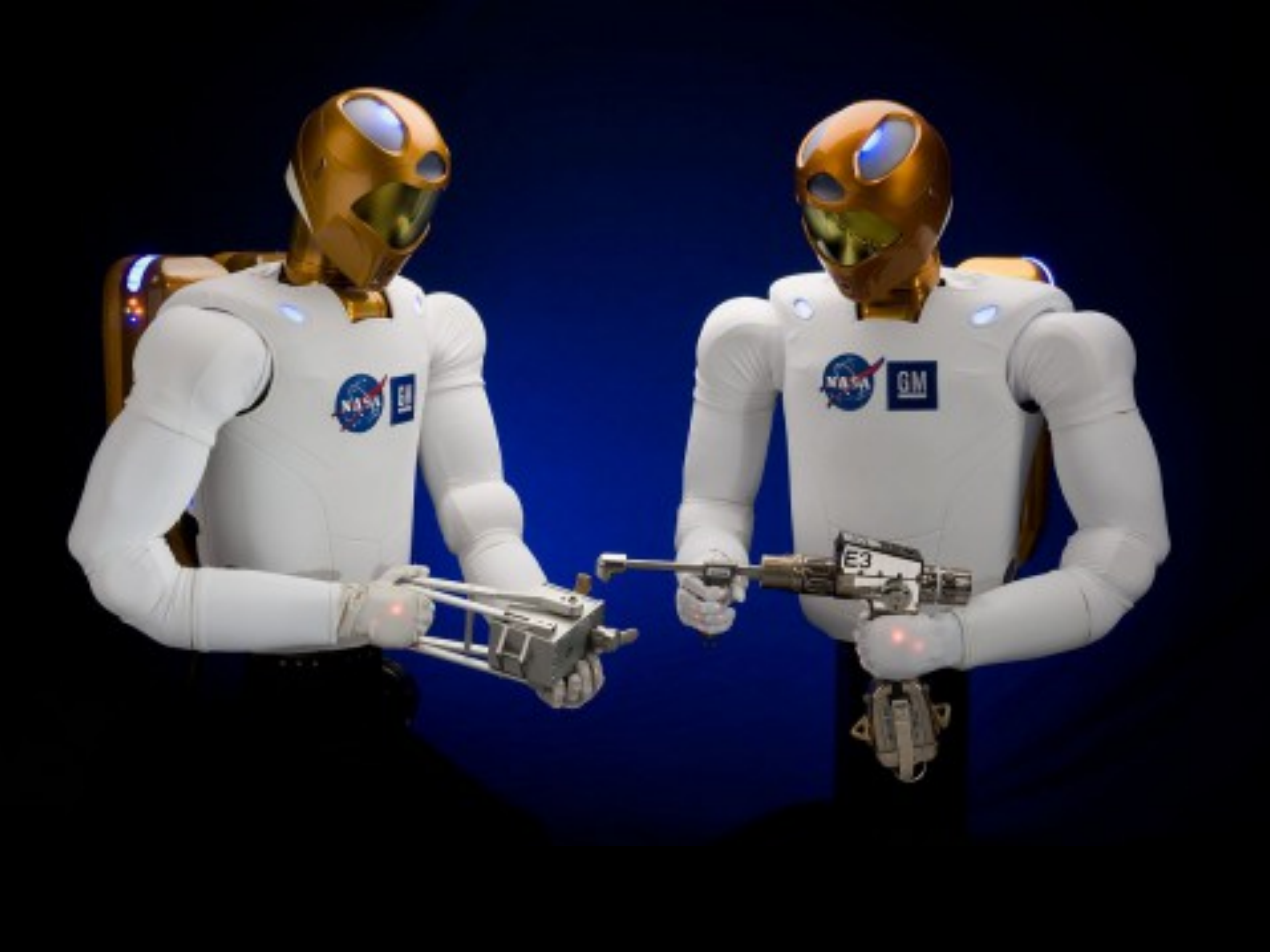
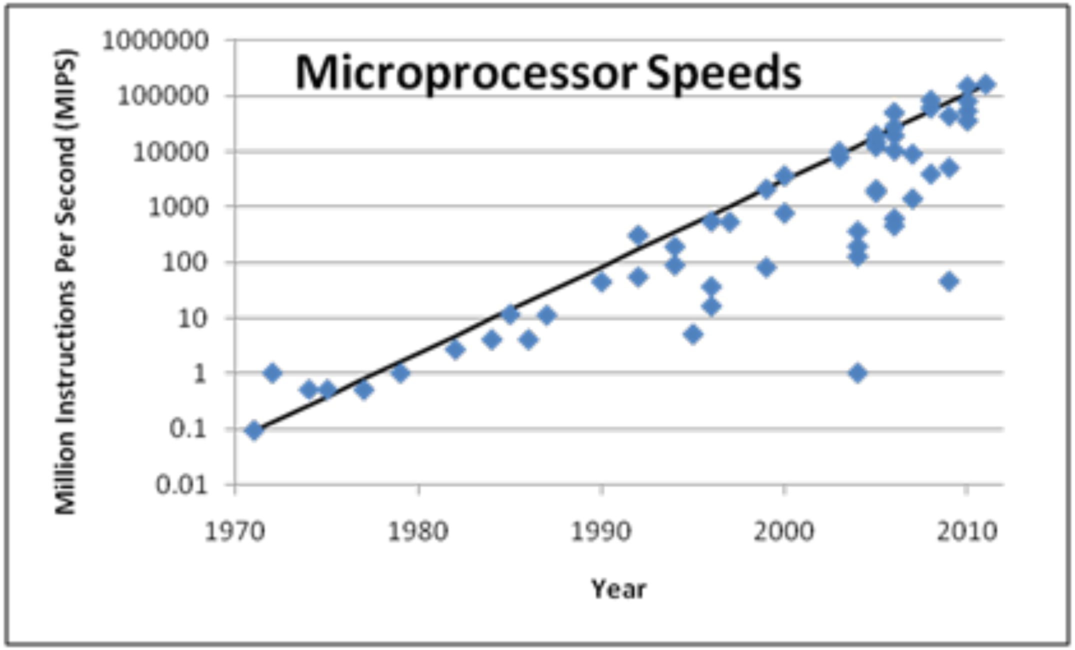
37
38
39
310
311
312
313
314
315
316
317
318
319
321
PRODUCT OUT
ENERGY SYSTEM

Assembly
Parts fabrication
Chemical processing
Solar canopy
Chemical processing
Parts fabrication
Assembly

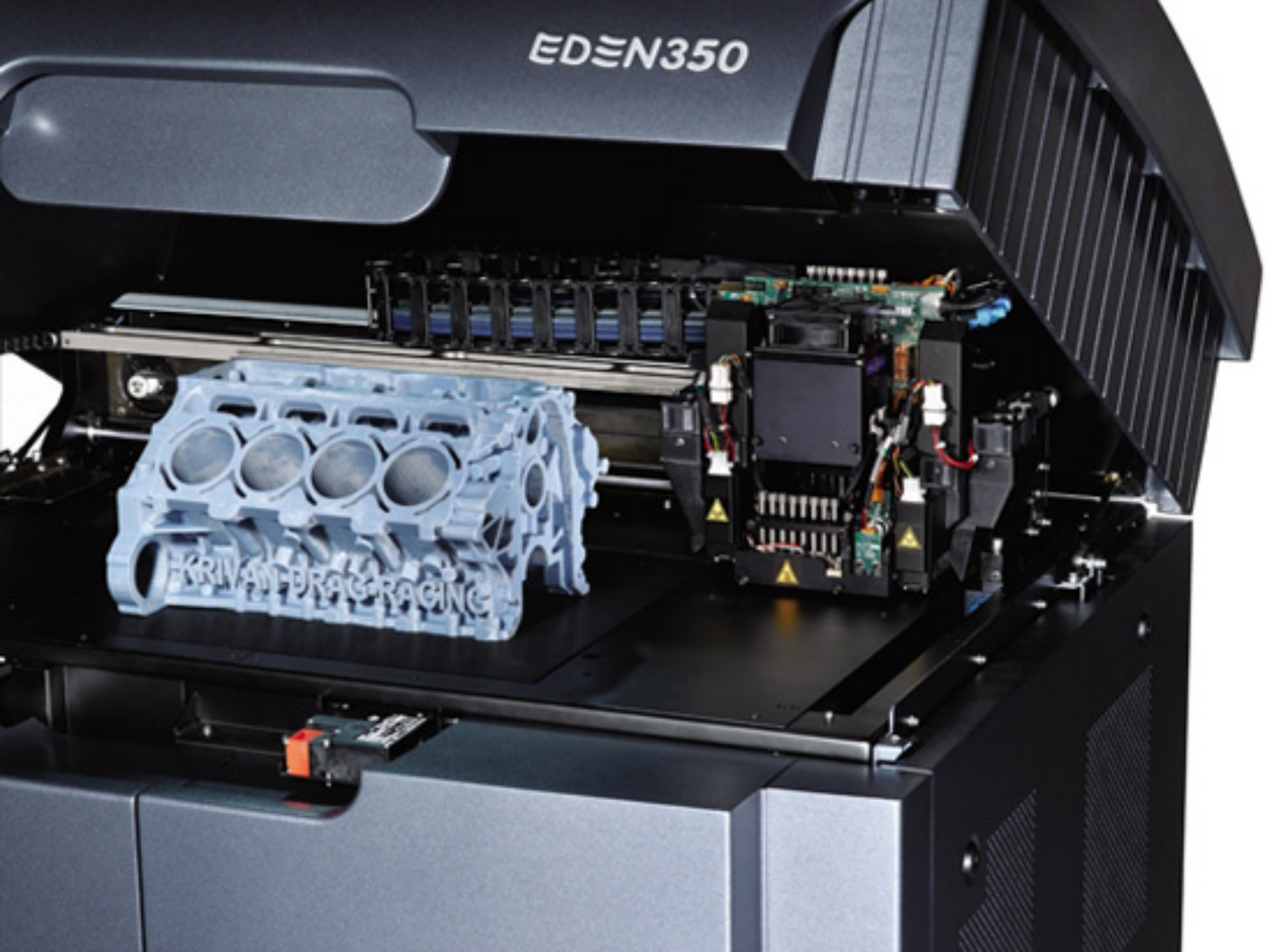
But it hasn’t happened……..yet

GAME CHANGERS

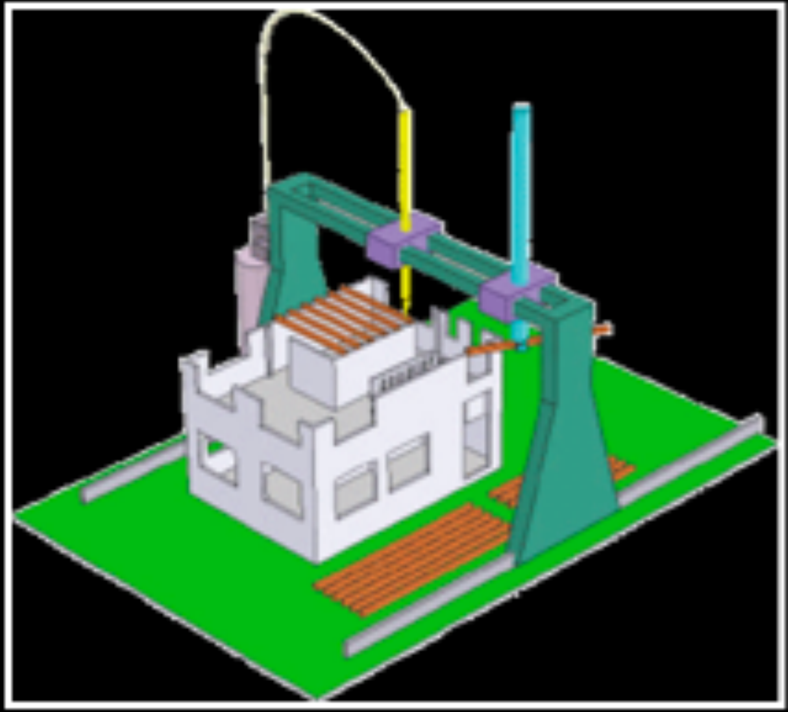

NASA
GM
NASA
GM
E3

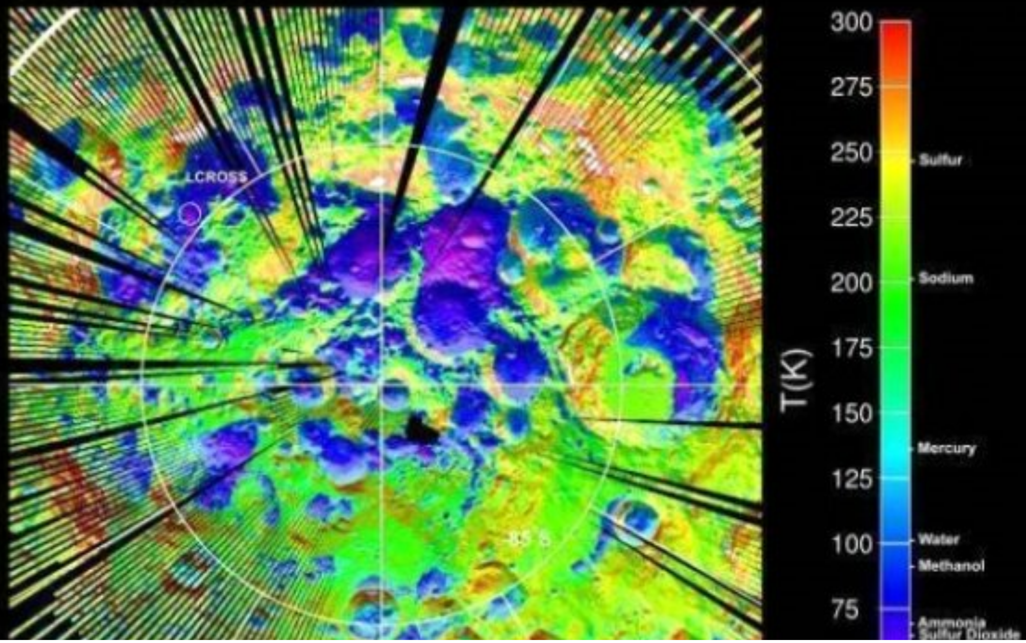


Progress in Microprocessor Instruction Processing Speeds by Year

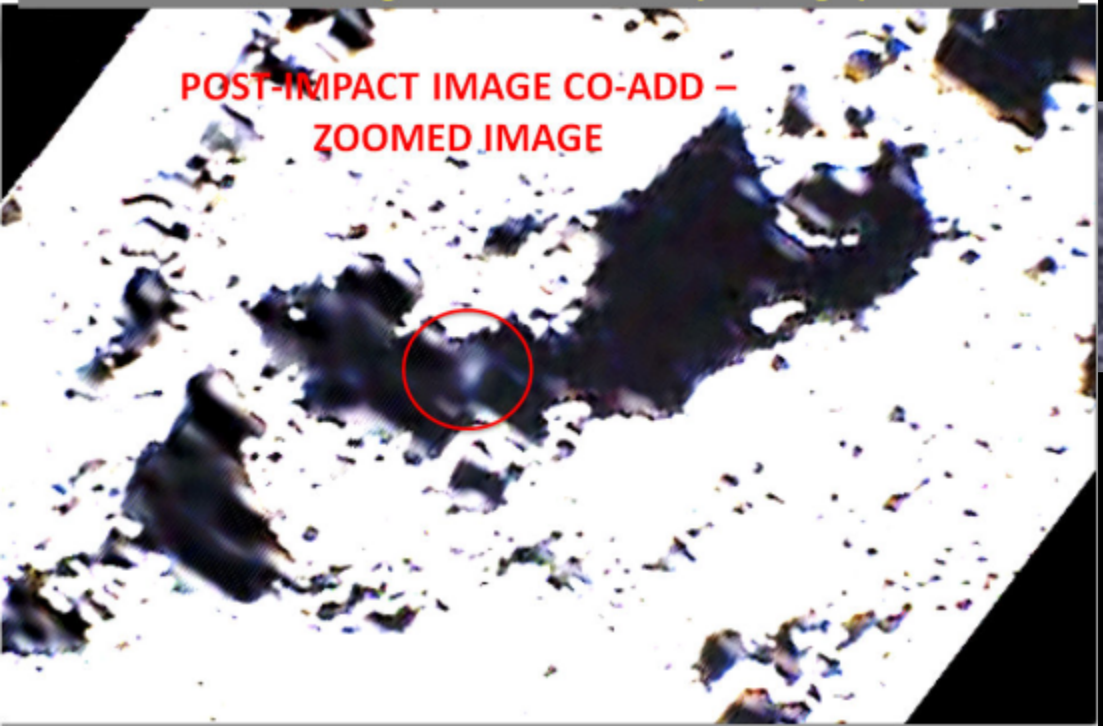

EDEN350
KRIVAN DRAG RACING

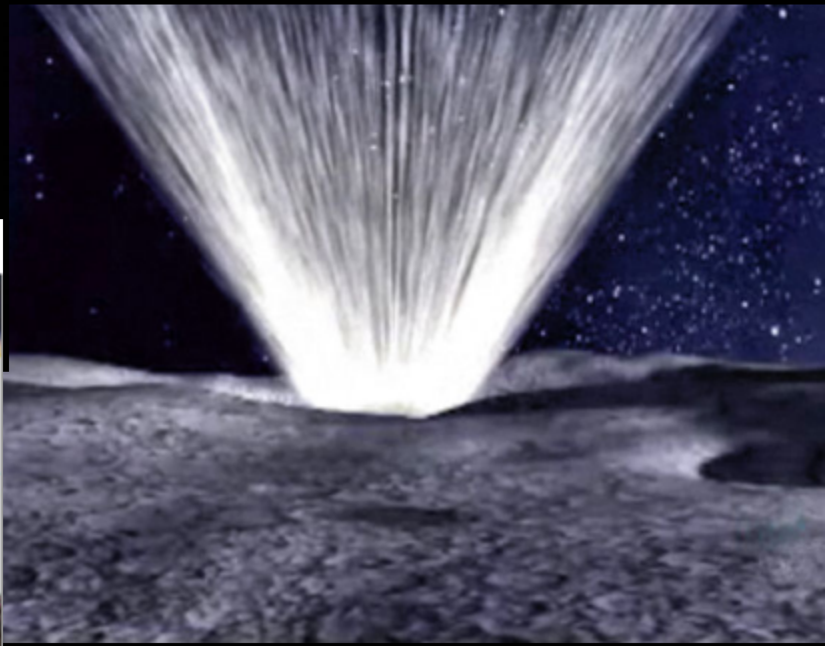

Direct Metal Laser Sintering (DMLS)

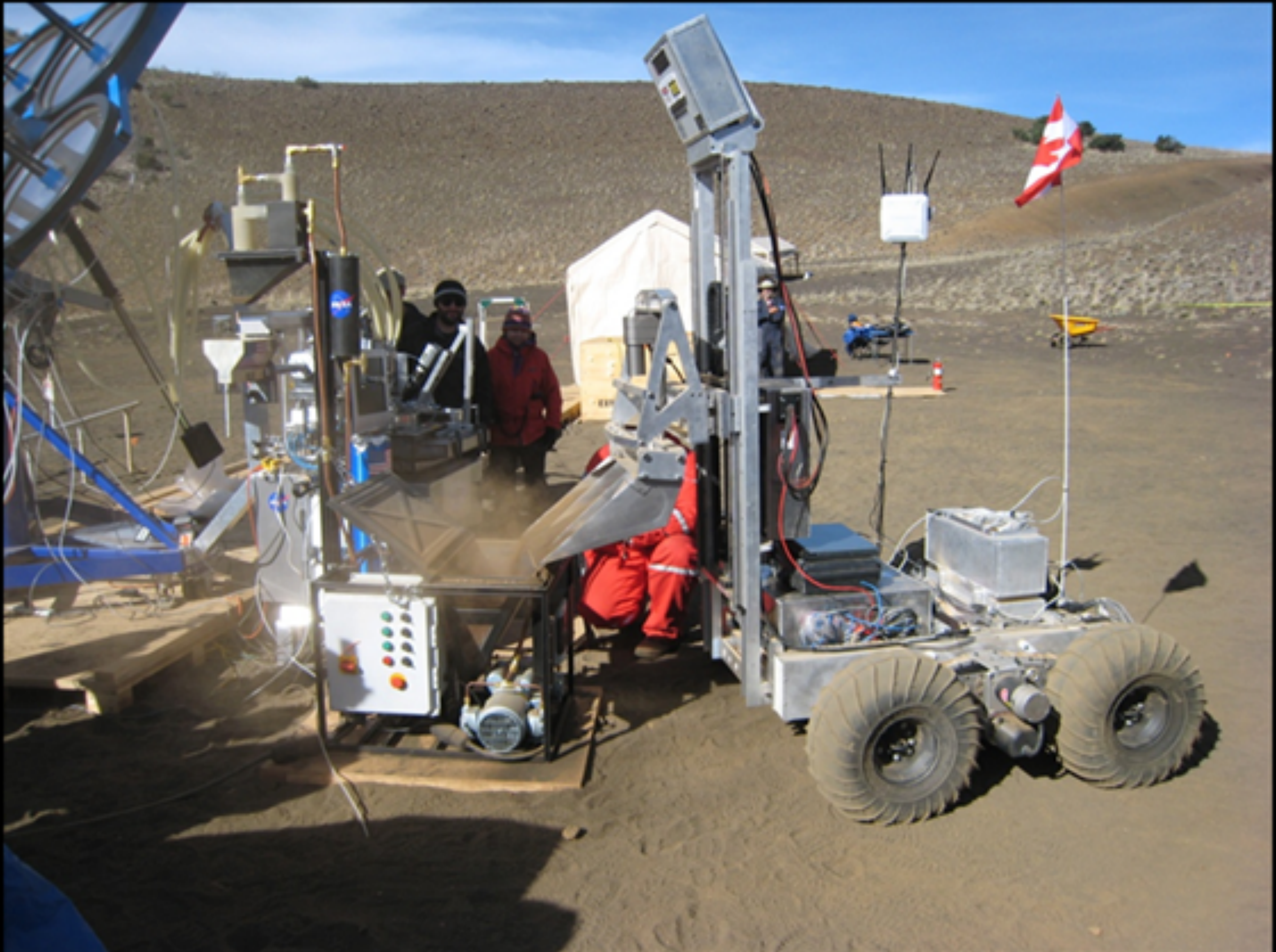




VisibleCamera Images from LCROSS Shepherding Spacecraft







PROPOSED NEW APPROACH

Key Ideas

- Don’t launch it; evolve it
- Not a simplistic “self-replicator”
  - The biosphere and industry are not self-replicators
- Use “Appropriate Technology” at each step
  - It doesn’t need to be low mass or high tech
  - It needs to be easy to make in space
- The technologies are already being developed
  - Simply “spin them in”
- The technologies are advancing exponentially

Example of Appropriate Technology

Europe, 1620

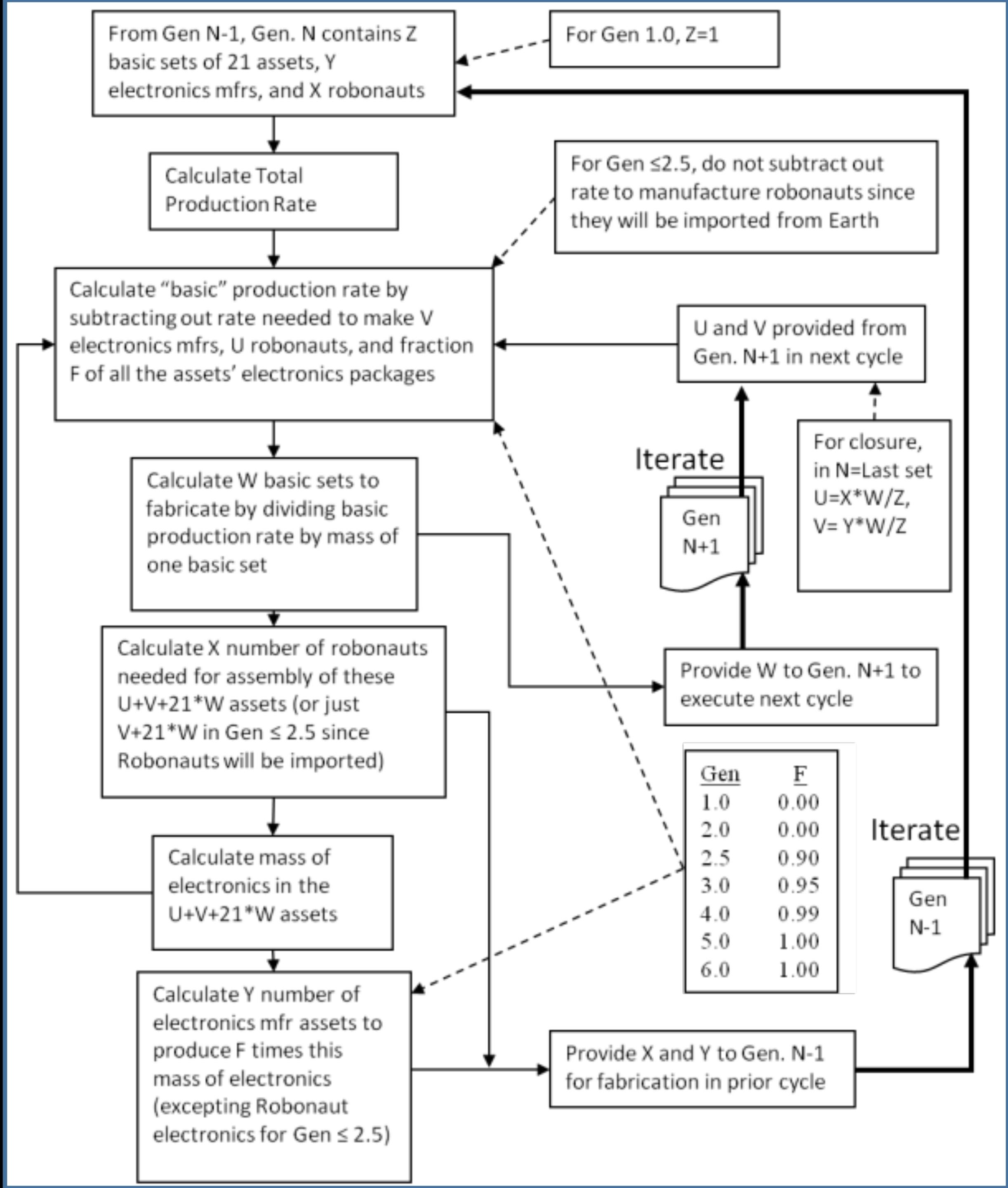
America, 1620

Appropriate Technology Water Pumps

Generations of Space Industry (Notional)

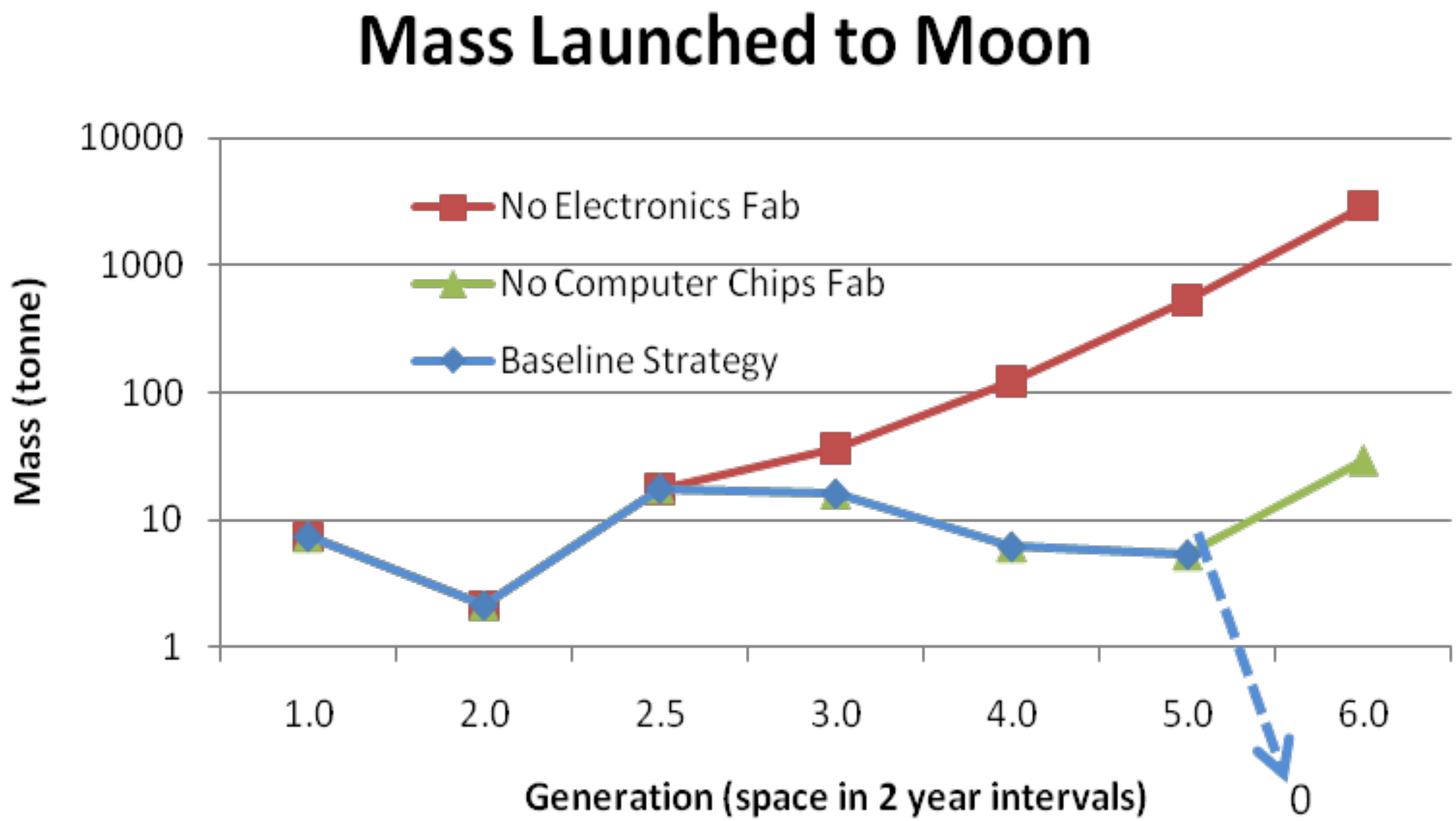
Gen	Human/Robotic Interaction	Artificial Intelligence	Scale of Industry	Materials Manufactured	Source of Electronics
1	Teleoperated and/or locally-operated by a human outpost	Insect-like	Imported, small-scale, limited diversity	Gases, water, crude alloys, ceramics, solar cells	Import fully integrated machines
2	Teleoperated	Lizard-like	Crude fabrication, inefficient, but greater throughput than 1.0	(Same)	Import electronics boxes
2.5	Teleoperated	Lizard-like	Diversifying processes, especially volatiles and metals	Plastics, rubbers, some chemicals	Fabricate crude components plus import electronics boxes
3	Teleoperated with experiments in autonomy	Lizard-like	Larger, more complex processing plants	Diversify chemicals, Simple fabrics, eventually polymers.	Locally build PC cards, chassis and simple components, but import the chips
4	Closely supervised autonomy with some teleoperation	Mouse-like	Large plants for chemicals, fabrics, metals	Sandwiched and other advanced material processes	Building large assets such as lithography machines
5	Loosely supervised autonomy	Mouse-like	Labs and factories for electronics and robotics. Shipyards to support main belt	Large scale production	Make chips locally. Make bots in situ for export to asteroid belt
6	Nearly full autonomy	Monkey-like	Large-scale, self-supporting industry, exporting industry to asteroid main belt	Makes all necessary materials, increasing sophistication	Makes everything locally, increasing sophistication
X.0	Autonomous robotics pervasive throughout solar system enabling human presence	Human-like	Robust exports/imports through zones of solar system	Material factories specialized by zone of the solar system	Electronics factories in various locations

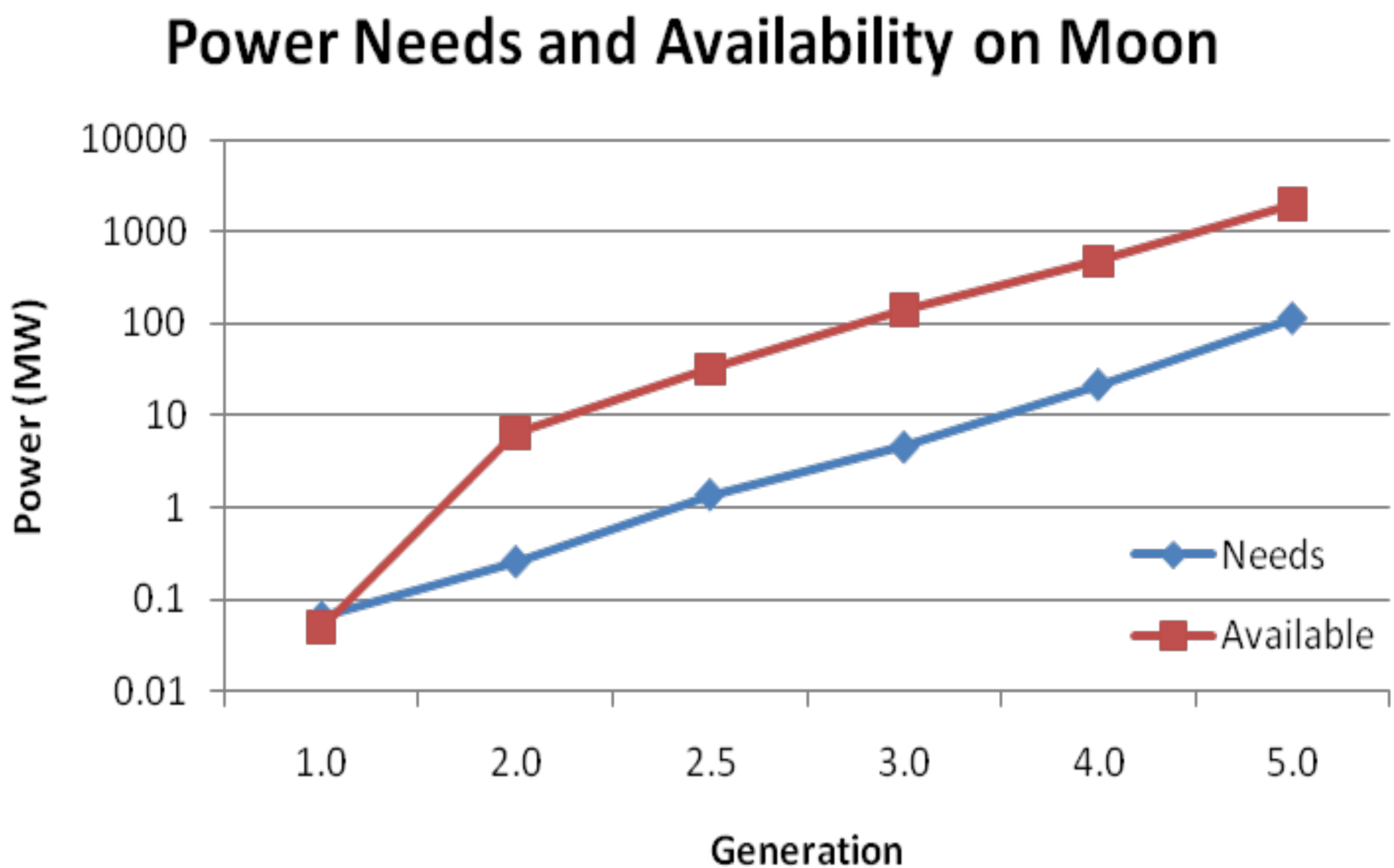
- **Simplistic Modeling**
- Not intended to be definitive
- Explores some of the key parameters
- Attempt to demonstrate basic feasibility
- Intends to generate interest and further investigation
- Needs a much larger study with a much larger group of contributors

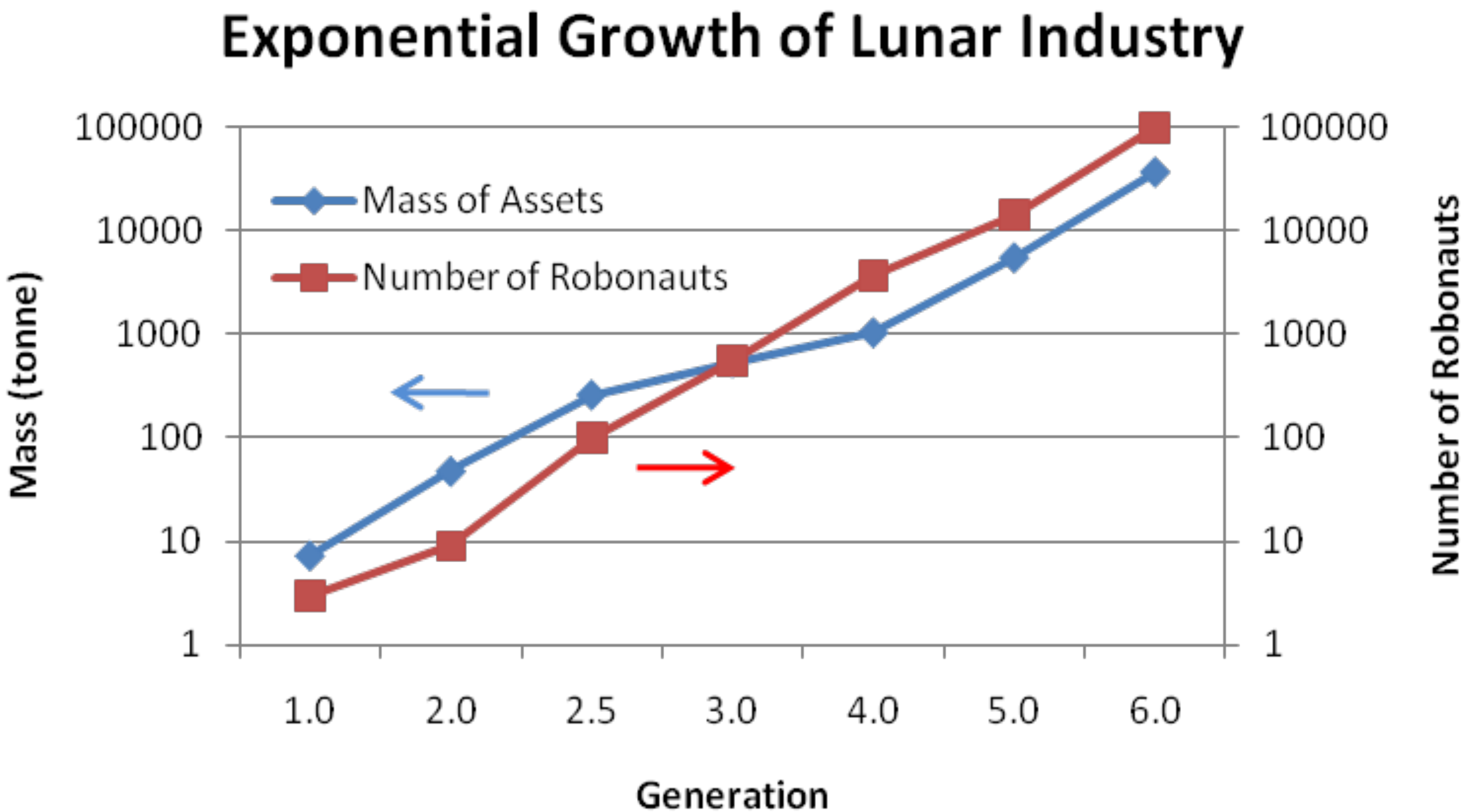


Additional Production

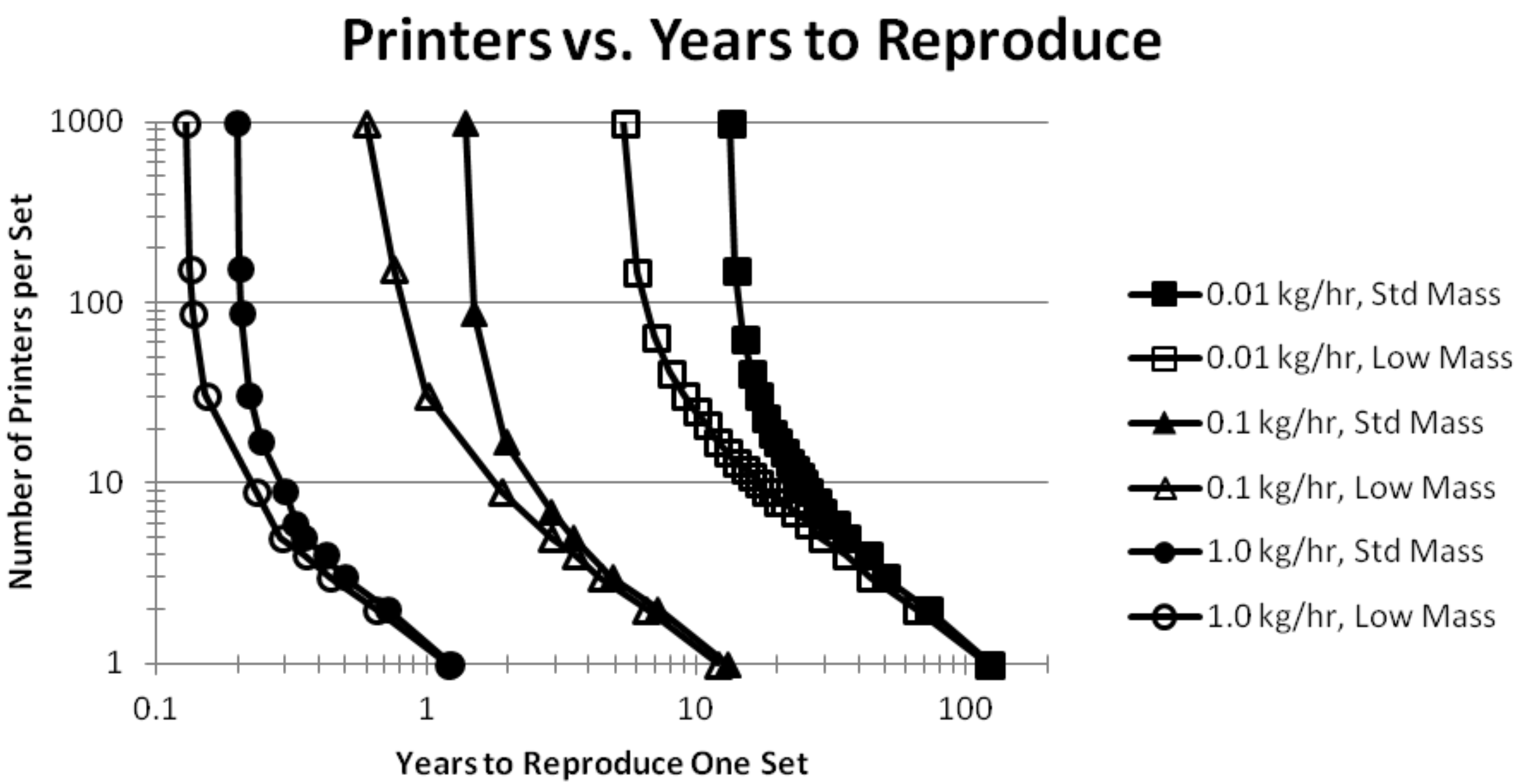
- Gen 3.0
  - 80 MT construction equipment
- Gen 4.0
  - Dust Free Laboratory Facilities
- Gen 5.0
  - 120 MT materials stockpiled to send industry to asteroid main belt
- Gen 6.0
  - Fleet of 6 spacecraft (20 MT plus 12 MT payload, each plus propellants)
  - Takes industry to Main Belt

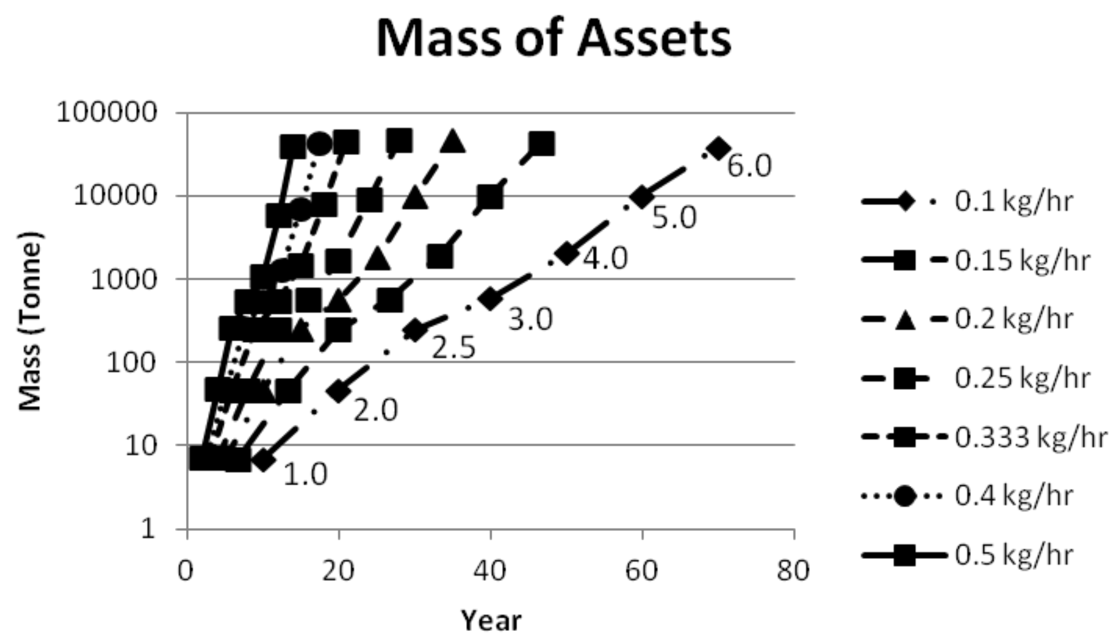

Mass Launched to Moon
No Electronics Fab
No Computer Chips Fab
Baseline Strategy
Mass (tonne)
10000
1000
100
10
1
1.0
2.0
2.5
3.0
4.0
5.0
6.0
Generation (space in 2 year intervals)
0

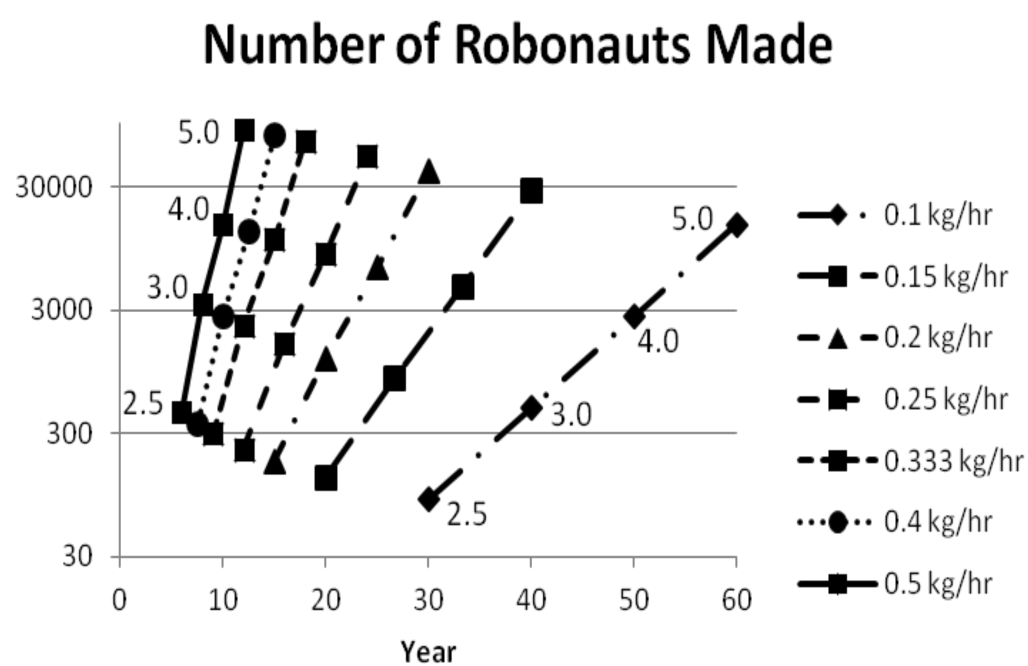

Power Needs and Availability on Moon
10000
1000
100
10
1
0.1
0.01
Power (MW)
1.0
2.0
2.5
3.0
4.0
5.0
Generation
Needs
Available



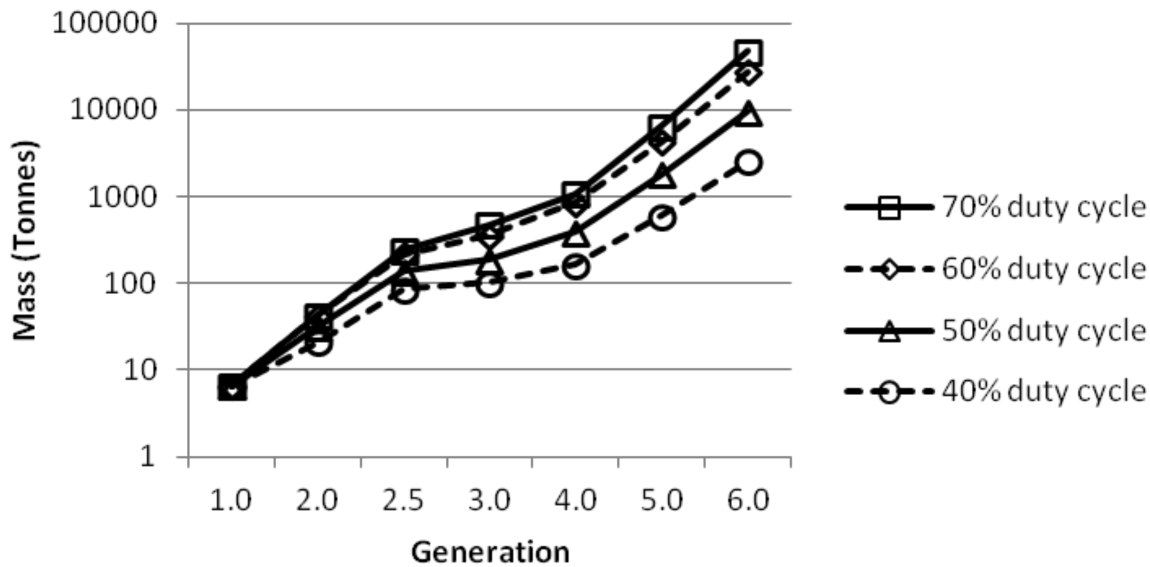
Exponential Growth of Lunar Industry
Mass of Assets
Number of Robonauts
100000
10000
1000
100
10
1
Mass (tonne)
Number of Robonauts
1.0
2.0
2.5
3.0
4.0
5.0
6.0
Generation


Printers vs. Years to Reproduce
Number of Printers per Set
1000
100
10
1
0.1
1
10
100
Years to Reproduce One Set
0.01 kg/hr, Std Mass
0.01 kg/hr, Low Mass
0.1 kg/hr, Std Mass
0.1 kg/hr, Low Mass
1.0 kg/hr, Std Mass
1.0 kg/hr, Low Mass

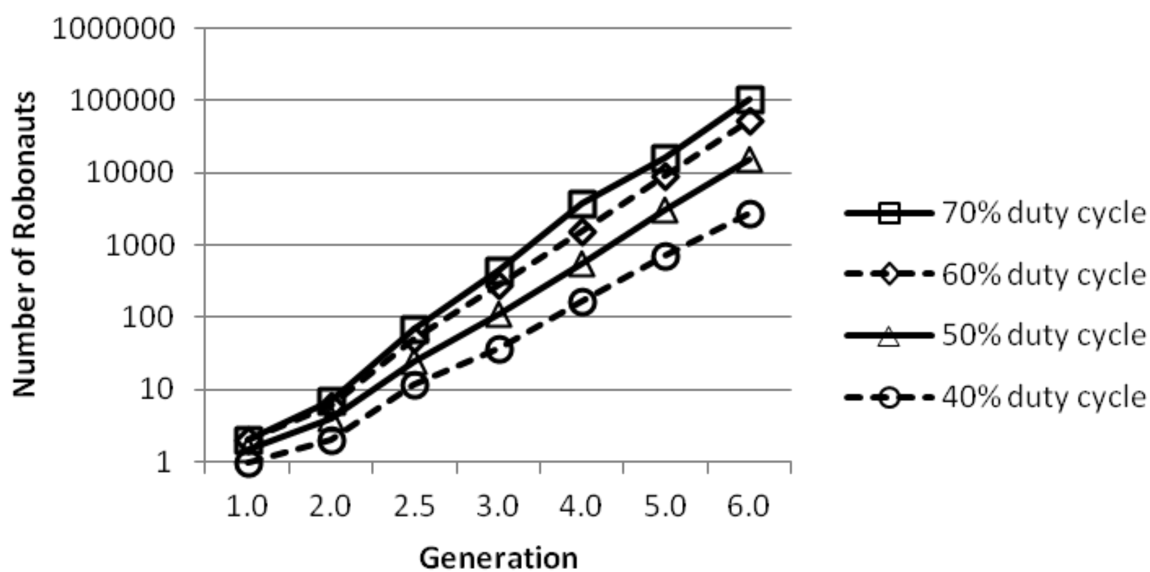

Mass of Assets
Mass (Tonne)
100000
10000
1000
100
10
1
0
20
40
60
80
Year
6.0
5.0
4.0
3.0
2.5
2.0
1.0
0.1 kg/hr
0.15 kg/hr
0.2 kg/hr
0.25 kg/hr
0.333 kg/hr
0.4 kg/hr
0.5 kg/hr


Number of Robonauts Made
30000
3000
300
30
0
10
20
30
40
50
60
Year
5.0
4.0
3.0
2.5
5.0
4.0
3.0
2.5
0.1 kg/hr
0.15 kg/hr
0.2 kg/hr
0.25 kg/hr
0.333 kg/hr
0.4 kg/hr
0.5 kg/hr

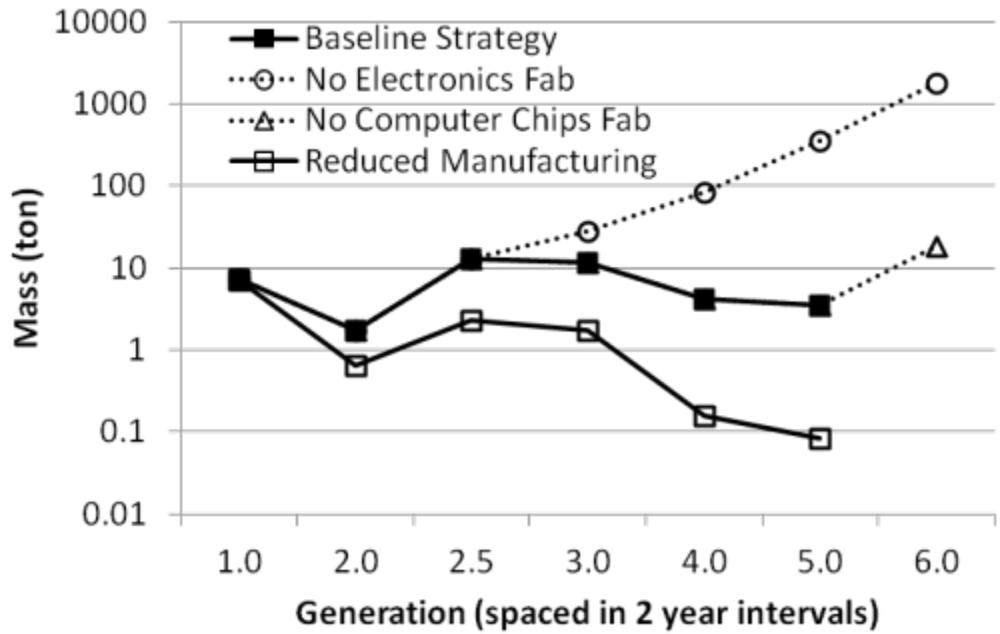
Mass of Assets on Moon

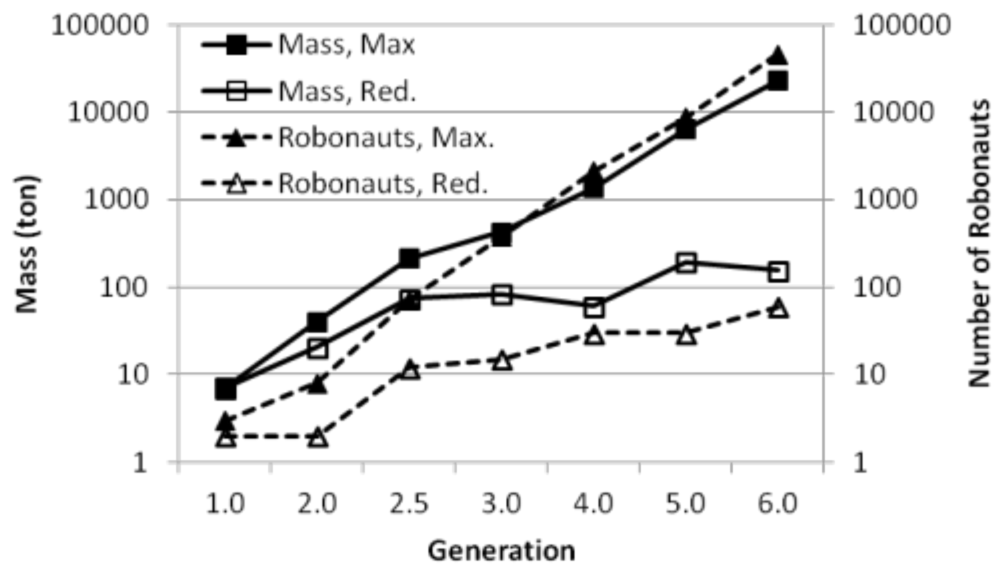


Robonauts on Moon



Minimizing Launch Mass





Benefit Scenarios – Why do you need Solar System Industry?

- Global Relief Effort – Export back to Earth
- The Great Migration – Emigrants to Space
- The Foundation – Asimov Kernel for Civilization
- The Space Endowment – Free Society University
- Anti Virus – Pro Active Measures against Mis-use
- National Defense – First in is always ahead

The Robosphere

- Like an Ecosphere – supports human existence
- Like a living cell – grows organically
- Beautifies the solar system – not resource limited
- Allows us to live at the top of a food chain
- Enables us to do great things:
  - Terraforming, colonies
  - Science, arts
  - Interstellar travel

Cost/Benefit

- Cost:
  - Develop and launch 12 to 60 tons to Moon and operate it for 20 years (1 to 4 Altair Class Lunar Landers)
  - Launch costs will be negligible using newer capabilities
  - Comparing to cost and mass of ISS, this will be less expensive than ISS (391 tons in LEO and over $100 B)
    - Most mass will be redundant hardware, not unique items
- Benefit
  - Move from being a Type-1 to a Type-2 civilization
    - Solve world economic problems
    - Make our existence safe in the solar system
    - Brilliant possibilities for the future
  - Move toward a Type-3 civilization
    - Extend human presence through the Milky Way

Conclusion

Rough modeling shows that solar system industry bootstrapping could be feasible and affordable

Critical Technologies needed are:

- Robotics /Autonomy
- Metals and Materials Processing
- Space Resource Prospecting
- Additive Manufacturing : 3D Printing Speed of 0.5 - 1 kg/hour
- Efficient Space Transportation

Exponential growth gap indicates that a competitive advantage is permanent for the first successful adopter of this model

Full details are available in the ISRU Special Edition of the Journal of Aerospace Engineering (JAE), ASCE Aerospace Division