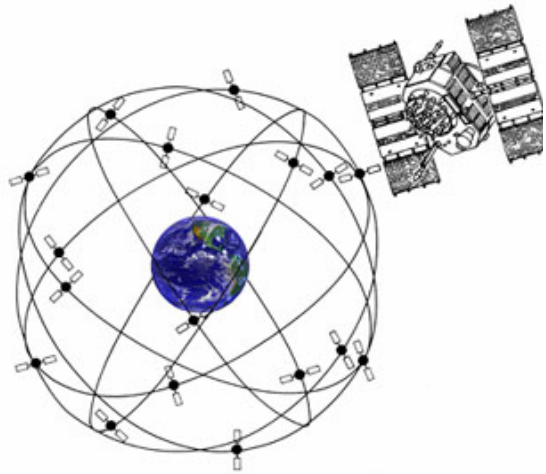
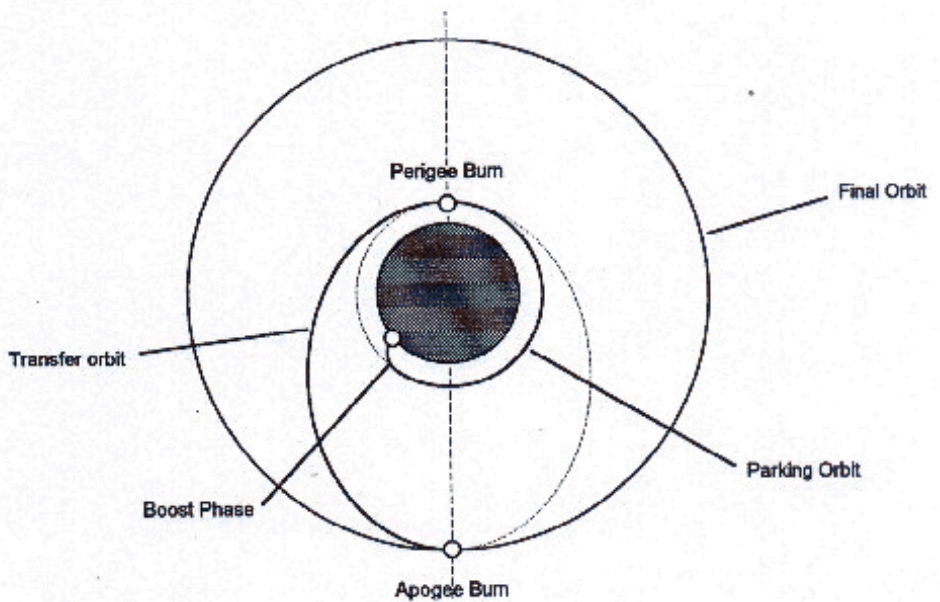




# High-orbit , multi plane invulnerability ??



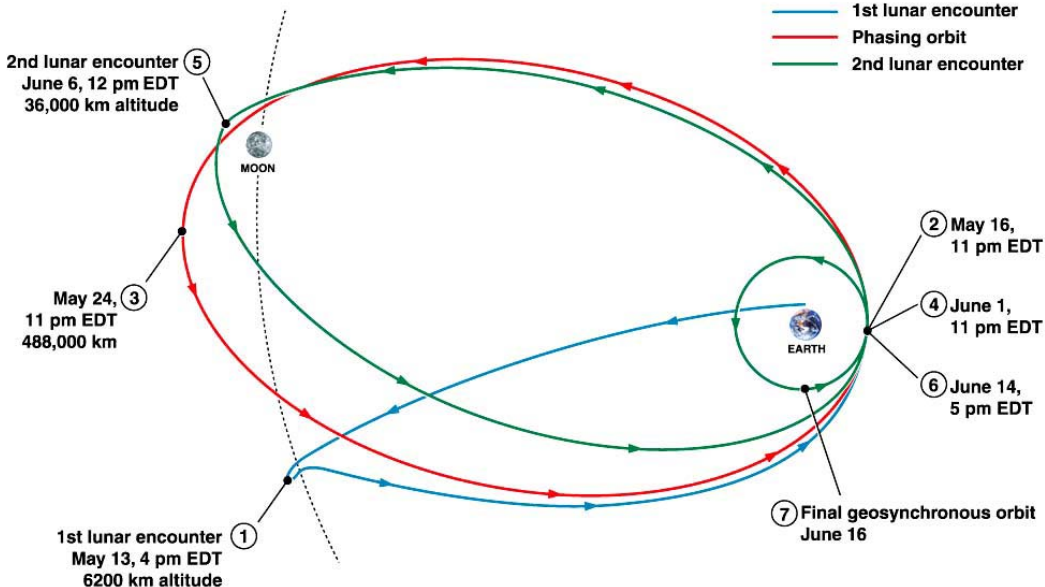
GPS Constellation



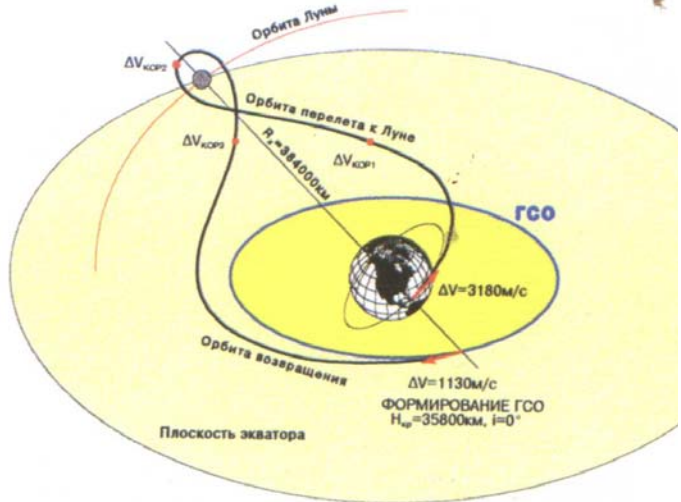
It's hard to get to these orbits -- and that hardness is seen as their best defense



# Finding the hidden path....



**HGS-1 2nd LUNAR FLYBY ORBITAL TRAJECTORIES**



.... and realizing where ELSE that kind of path can lead.  
LGA is the "Backdoor" to MEO/GEO

# *A Comm-Sat Encounters the Moon*





# Government and Commercial Satellite Comparison



With only 16% of revenues, commercial space companies generating 60% of the marketcap of their government space peers

Satellite entertainment companies achieve 3X higher Price to Sales than government space peers



	<b>Trailing 12 month Sales (\$B)</b>	<b>Market Cap \$B)</b>	<b>Price to Sales</b>
<b>Boeing (NYSE: BA)</b>	<b>52.4</b>	<b>42.2</b>	<b>0.8</b>
<b>Lockheed Martin (NYSE: LMT)</b>	<b>34.5</b>	<b>24.2</b>	<b>0.7</b>
<b>Orbital Sciences (NYSE: ORB)</b>	<b>0.7</b>	<b>0.5</b>	<b>0.8</b>
<b>General Dynamics (NYSE: GD)</b>	<b>19.0</b>	<b>20.2</b>	<b>1.1</b>
<b>Government Summary</b>	<b>106.6</b>	<b>87.1</b>	<b>0.8</b>
<b> DirecTV (NYSE: DTV)</b>	<b>10.5</b>	<b>23.3</b>	<b>2.2</b>
<b>Echostar (NASDAQ: DISH)</b>	<b>6.7</b>	<b>15.2</b>	<b>2.3</b>
<b>Sirius Satellite (Nasdaq: SIRI)</b>	<b>0.0</b>	<b>8.3</b>	<b>177.5</b>
<b>XM Satellite Radio (NASDAQ: XMSR)</b>	<b>0.2</b>	<b>6.8</b>	<b>34.7</b>
<b>Commercial Summary</b>	<b>17.5</b>	<b>53.5</b>	<b>3.1</b>

# Energy/Destination Comparison



1000 Kw-hours per ton

18

16

14

12

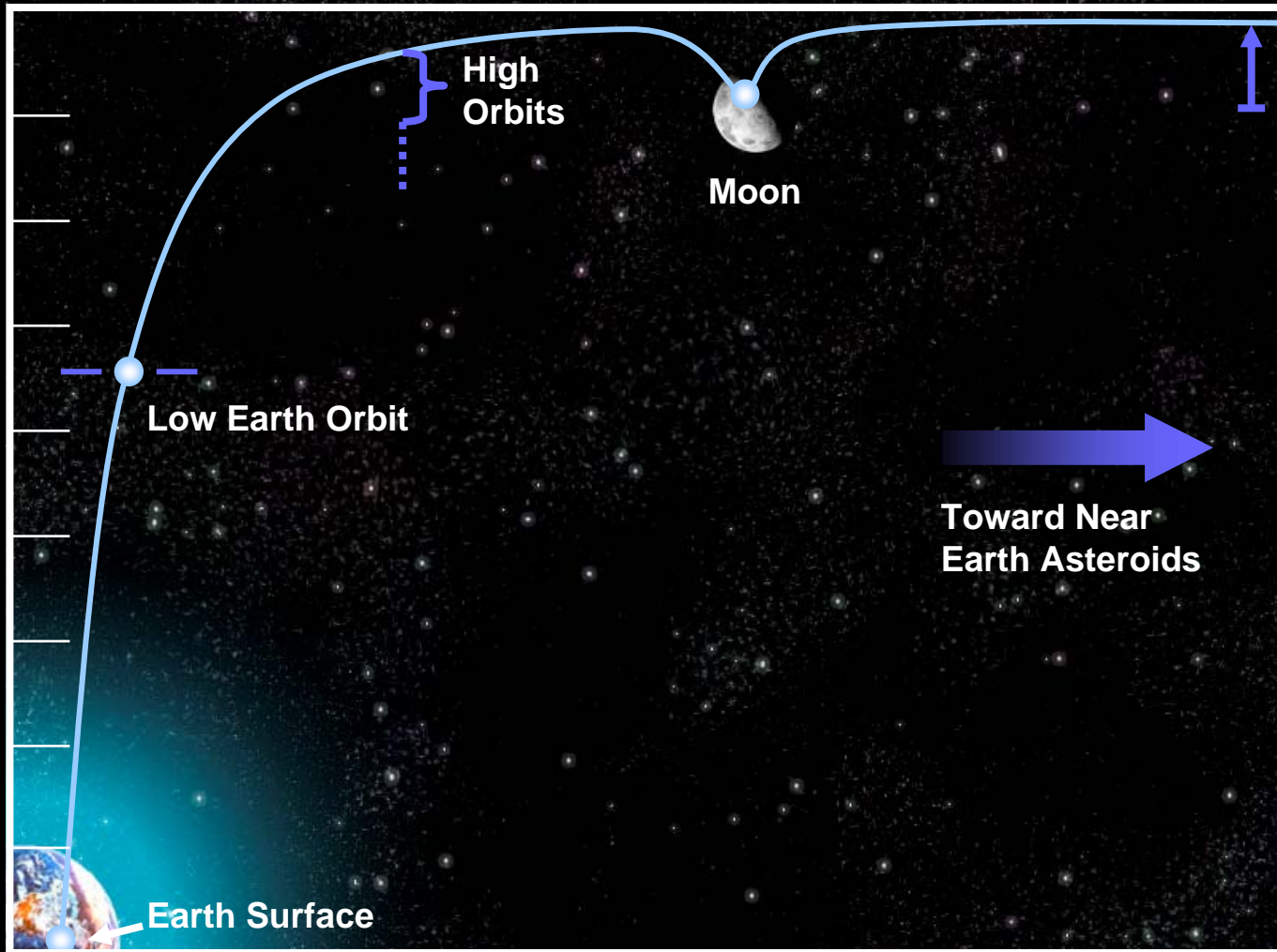
10

8

6

4

2



800

0

Low Earth Orbit

High Orbits

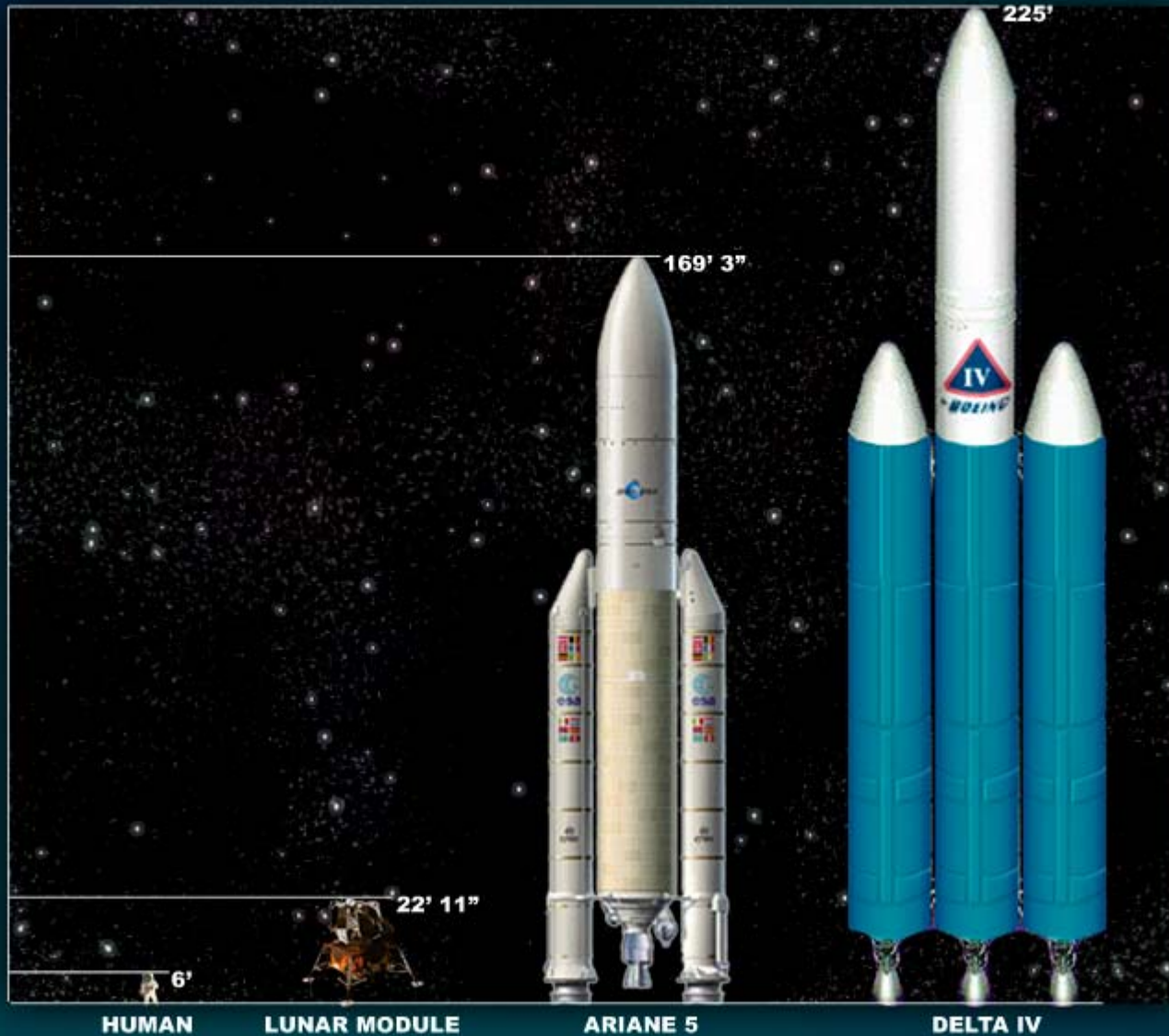
Moon

Toward Near Earth Asteroids

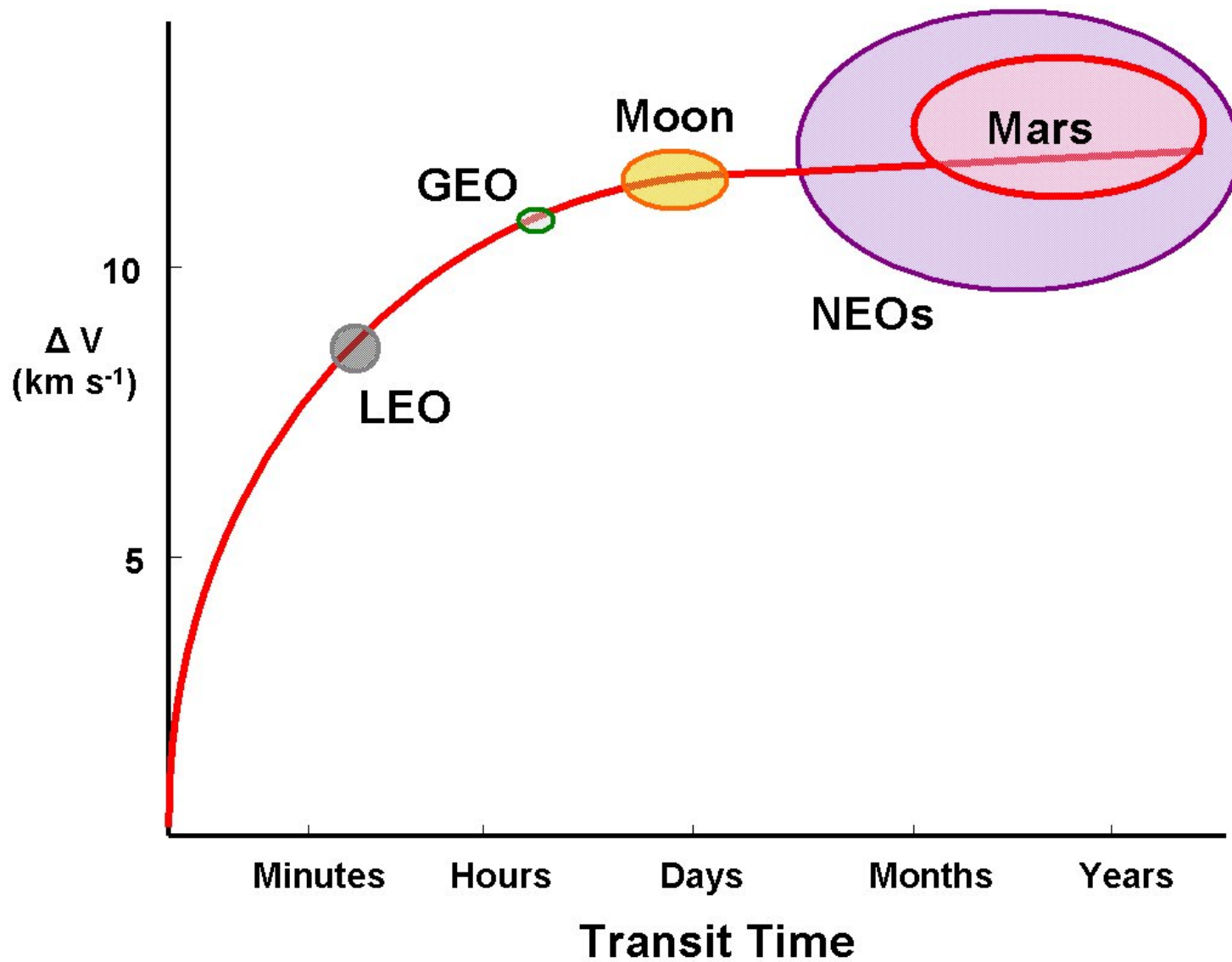
Earth Surface

DISTANCE FROM EARTH (not to scale)

# Impact of Energy on Launch Vehicle Scale



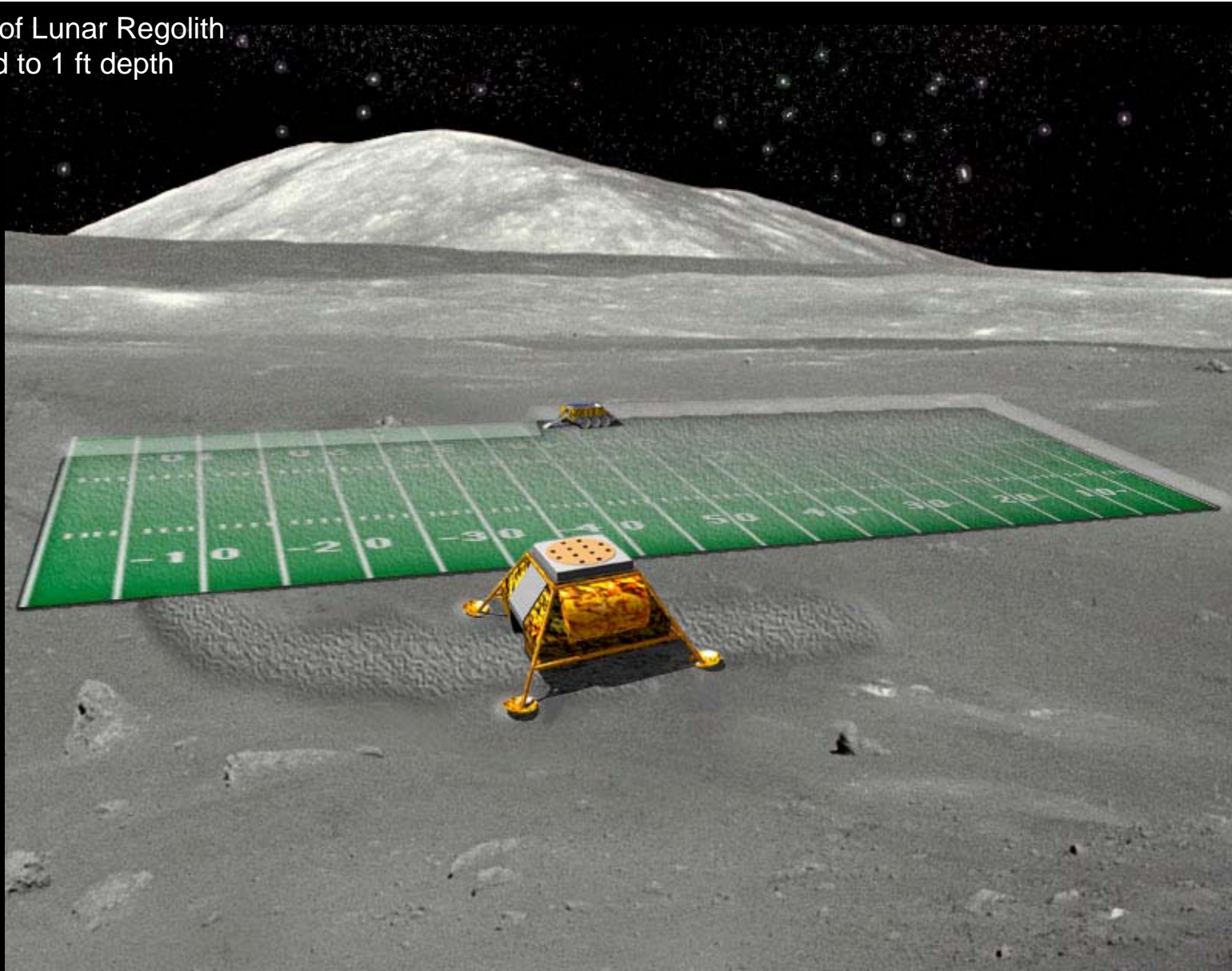
# The Moon is Close!



# *Earth Launch Mass vs Lunar Mining Mass/Volume*



20 Saturn Vs= Mass of Lunar Regolith  
of 1 Football Field to 1 ft depth



# Potential Applications of Lunar and Near-Earth Asteroid Resources



Resources \ Applications	Moon and Asteroids	Sunlight	Unprocessed Materials	Bricks	Metals	Ceramics	Oxygen	Silicon	Volatiles	Slag
Shielding			x	x	x <sub>1</sub>					x
Reaction Mass, Propellants, and other consumables					x		x	x <sub>2</sub>	x	
Structures				x	x	?				
Projectiles				x	x	?				
Targets and Decoys	x	x	x	x	x	x	x	x	x	x
Stabilizing Inertia			x <sub>1</sub>	x						x
Heat sinks					x				x	
Energy Storage					x	x	x	x	x	
Energy Productions and Distribution	x <sub>4</sub>	x						x		
Strategic Materials		x <sub>6</sub>								
Lunar/Base Platform	x	x <sub>6</sub>			x <sub>5</sub>					
Space Manufacturing	x	x	x	x	x	x	x	x	x	x

## KEY

X – potential match of resource to applications deserving study. Potential application; utility depends on engineering details of specific requirements

- most likely drivers

- 1 – These two applications are most likely (in terms of total tonnages needed) to drive NTMs for space application.
- 2 – Reaction mass could be dust; propellants could be liquid oxygen/hydrocarbon/hydrogen; more advanced propulsion systems (e.g., Electric Propulsion using Ammonia).
- 3 – Lunar Water returned to GEO may provide an early high-leverage return from NTMs.
- 4 – Solar arrays constructed on the lunar surface may provide a viable power source for high power systems in cis-lunar space.
- 5 – Independent source of these materials may be sufficiently important that standard cost/benefit considerations may not apply.
- 6- Solar Energy may be collected on lunar surface for transmission



## ***“Big Idea”***

- **Its not just Lunar Manufacturing (LM) or ISRU**
- **It’s the practical implementation of the Von Neumann Self Replicating Automata**
- **LM Systems are designed to be manufactured with a % of their parts from lunar materials which they manufacture**
- **Replicating geometric system**
- **Harness “The Most Powerful Force in Universe: Compound Interest” (Einstein)**
- **Brings in many disciplines**
- **Revolutionizes space logistics as we know it**
- **Requires real leadership to bring industry along**
  - **New Industrial Approach not traditional “Aerospace”**
  - **Boeing does not mine the Aluminum it uses in a 777**



$$M_o = M_f * \exp(\Delta V / (I_{sp} * g))$$

- Imprisoned by the tyranny of the rocket equation, an unfavorable exponential...
- There is an antidote...

# ***Compound Interest!***

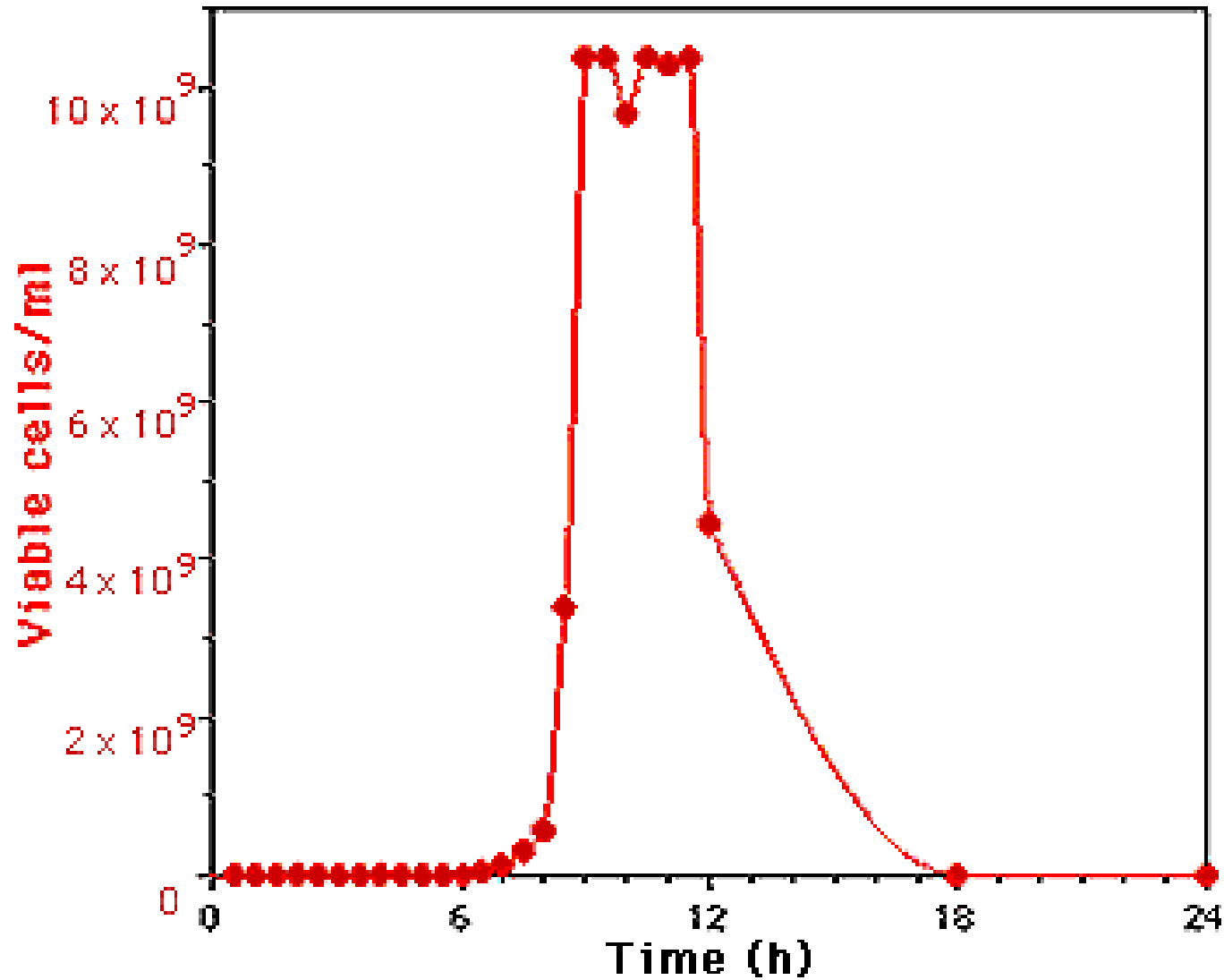


- $P = C \exp( rt )$
- **Here the exponential is working in our favor instead of against us**
- **Biological systems exploit this**

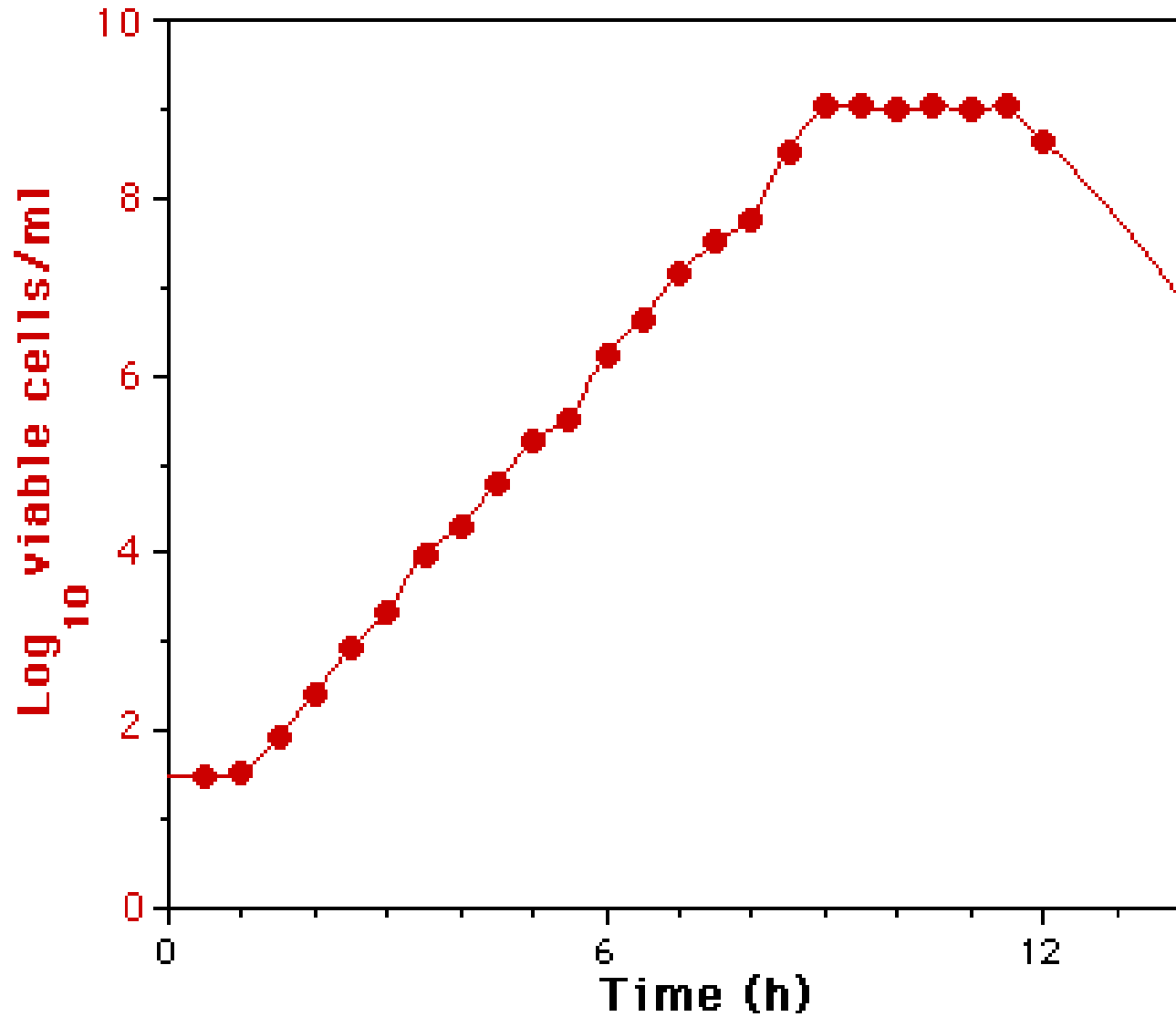
# *Biological Growth*



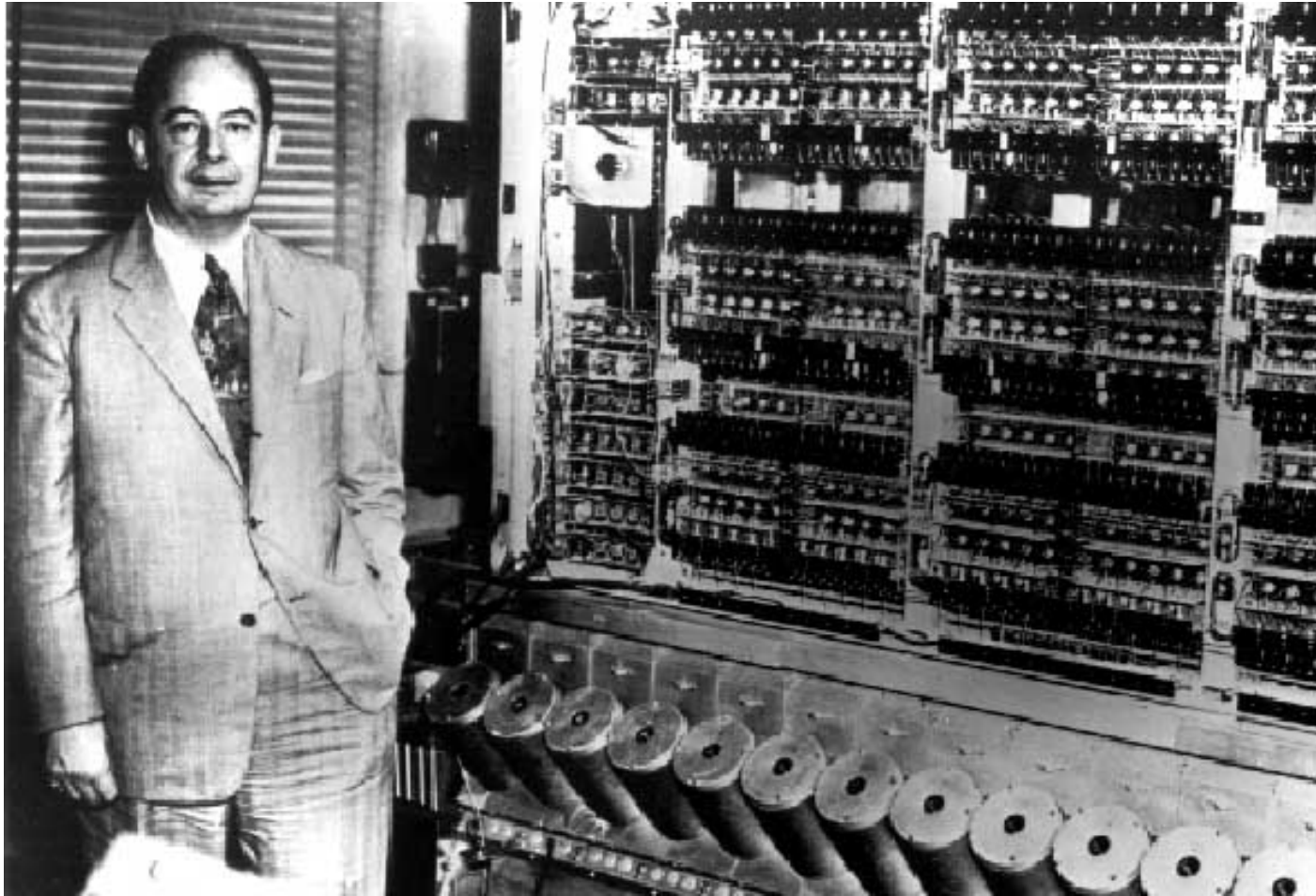
# Biological Growth Plot



# Biological Growth – Log Plot



# *Von Neumann with the first Institute computer*

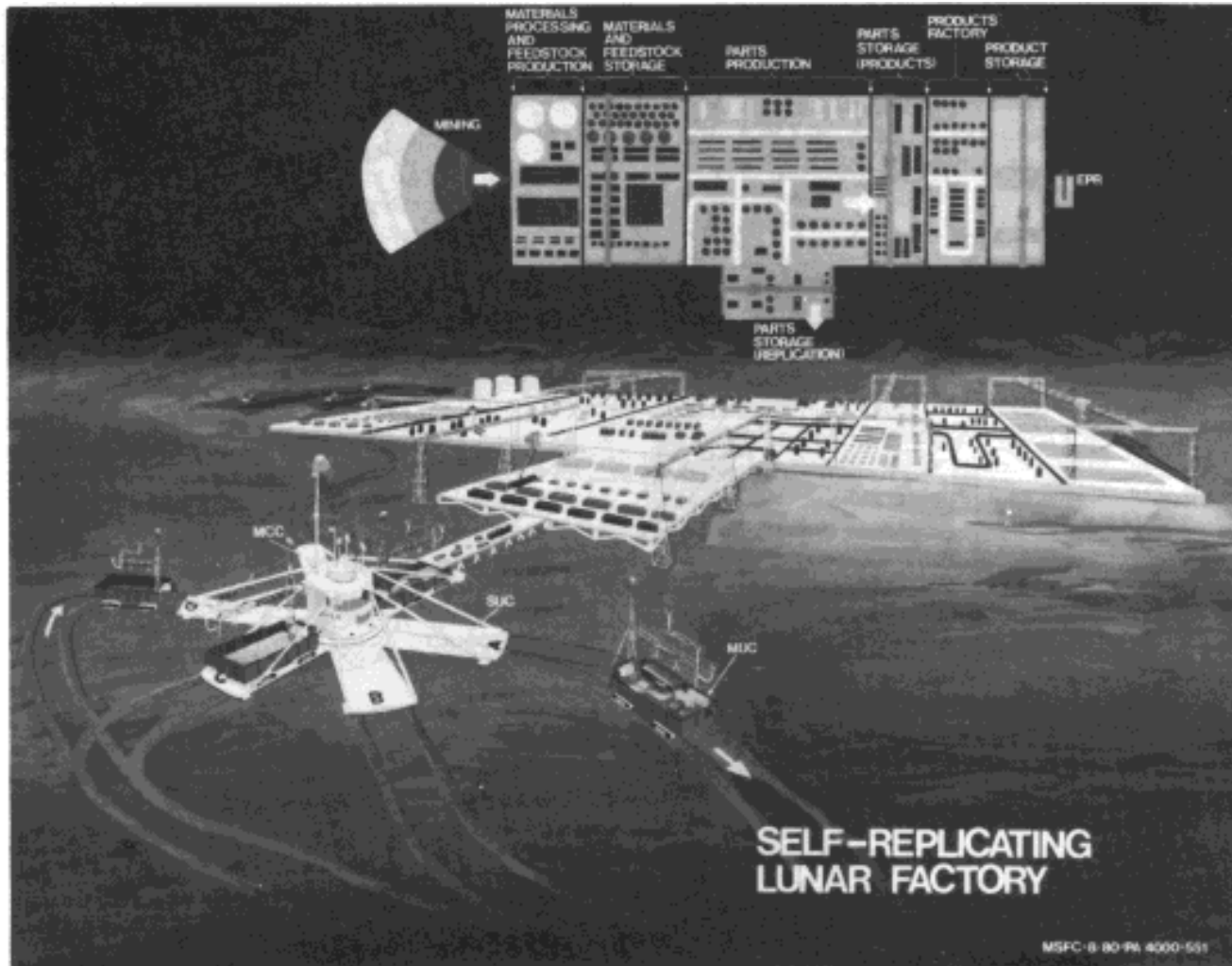


Photograph by Alan Richards, courtesy of the Archives of the Institute for Advanced Study

[http://www-groups.dcs.st-andrews.ac.uk/~history/PictDisplay/Von\\_Neumann.html](http://www-groups.dcs.st-andrews.ac.uk/~history/PictDisplay/Von_Neumann.html)



# Self Replicating Factory



Robert A. Freitas, Jr. and William P. Gilbreath

Proceedings of the 1980 NASA/ASEE Summer Study NASA Conference Publication 2255

-19-  
[-http://www.islandone.org/MMSG/aasm/chapter5.htm](http://www.islandone.org/MMSG/aasm/chapter5.htm)

# SELF-GROWING LUNAR FACTORY

ASSEMBLY

PARTS FABRICATION

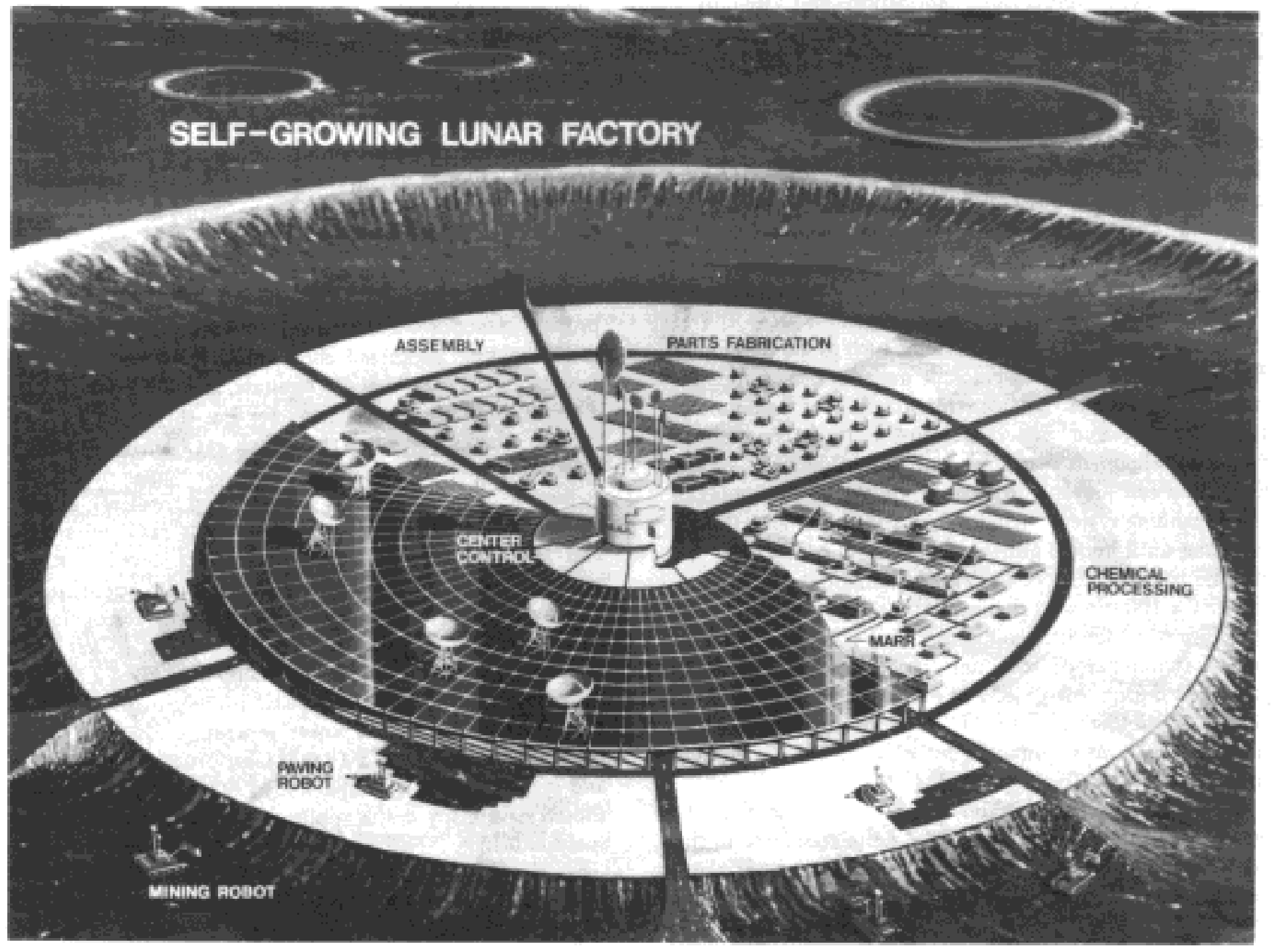
CENTER CONTROL

CHEMICAL PROCESSING

MARR

FLYING ROBOT

MINING ROBOT





# ***Ingredients for Self Replication***

- **Energy (In situ solar systems)**
- **Raw Material (Regolith and minerals)**
- **“Information” (Telepresence/Autonomy)**
- **Enough machinery to get started**
- **Critical “nutrients” (Resupply from earth)**

# Lunar Resource Extraction Energy Requirements



Operation	Specific Energy
Excavation of <u>regolith</u>	.01 kWh/kg regolith (elec)
Extraction of <u>water</u> from icy regolith <sup>1</sup>	2.8 kWh/kg H <sub>2</sub> O (thermal)
Reduction of <u>SiO<sub>2</sub></u> to Si + O <sub>2</sub>	5.2 kWh/kg SiO <sub>2</sub> (elec)
Electrolysis of water	4.5 kWh/kg H <sub>2</sub> O (elec)
Extraction of <u>hydrogen</u> from typical regolith <sup>2</sup>	2250 kWh/kg H <sub>2</sub> (thermal) (~250 kWh/kg H <sub>2</sub> O)

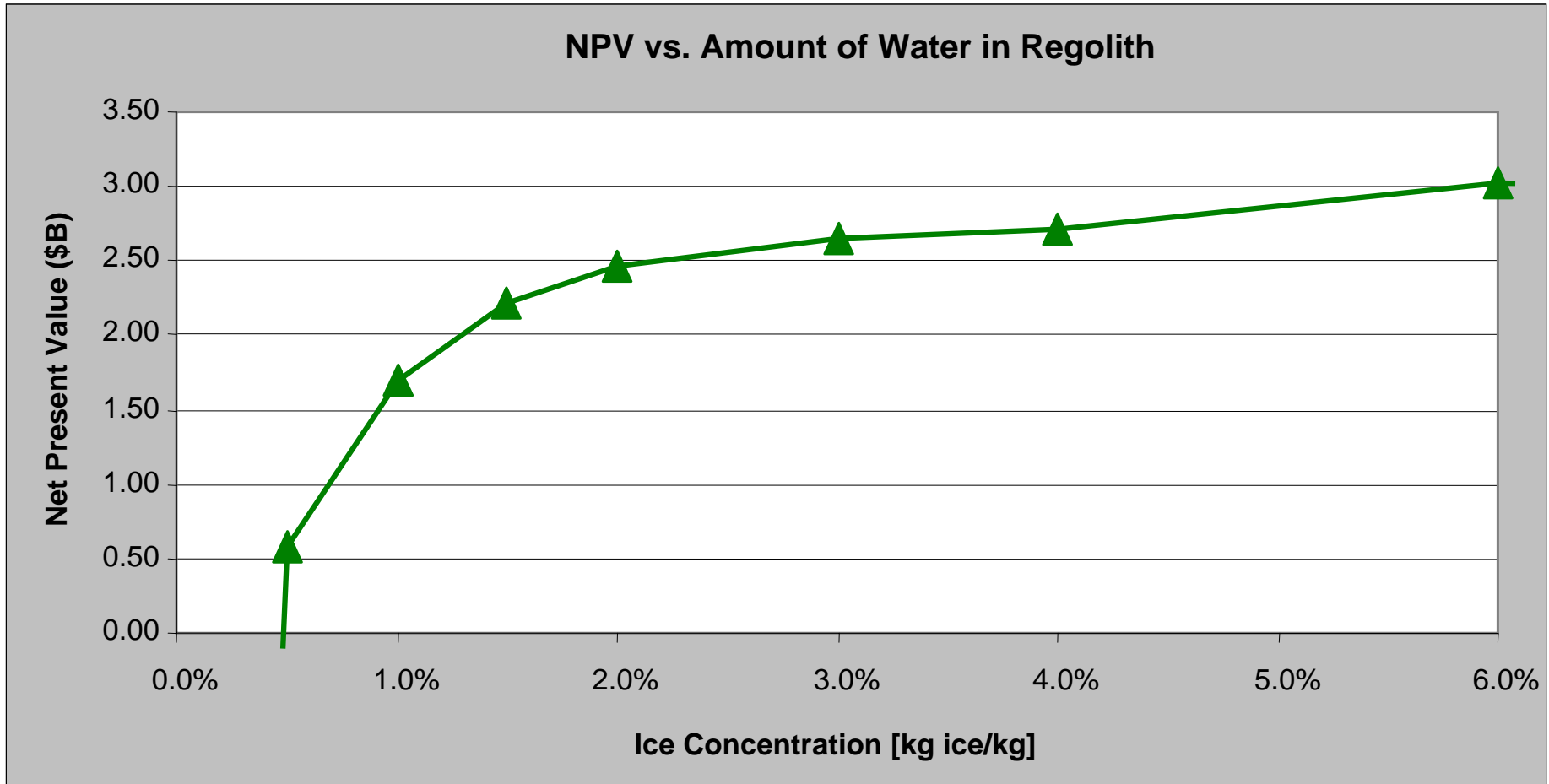
<sup>1</sup> Assumes 1% ice, heated 100° above ambient

<sup>2</sup> Assumes 100 ppm H<sub>2</sub>, heated 800°C above ambient

# ***SRD Model Sensitivity to % Ice***

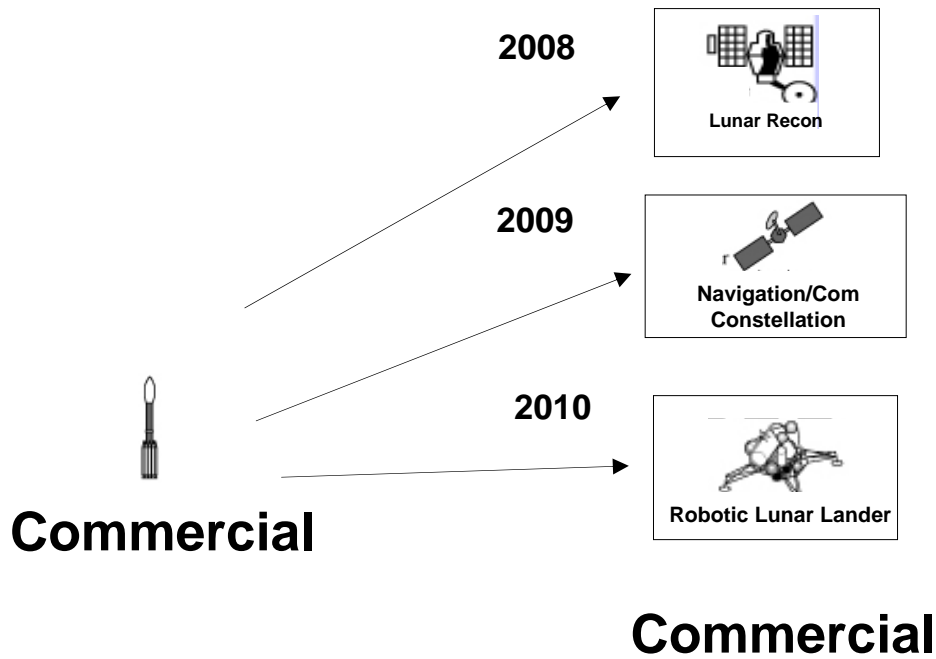


- Sensitivity of NPV to ice concentration (Arch 2, Version 4)





# Lunar Robotic Trailblazer



- Outpost site is selected and verified
- Communication/ navigation infrastructure



# Lunar Robotic Landing Site Test Bed

2-year

2010

2010

Mooncat      Lander Tanks      Solar Power Supply

2010

2010

ISRU Plant      Lander Tanks      Cryo Mobile Tanker      Maintenance      Cold Crater Explorer

2011

2011

Solar Power Supply      Solar Power Supply



2011

2011

Airlock/Node      Shelter Module

2012

2012

Material Production Facility      Construction

2013

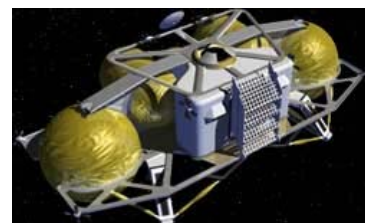
2013

Solar Cell Production      AI Production

2013 - 2020

2013 - 2020

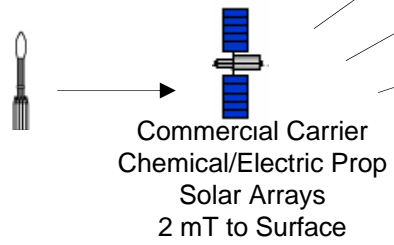
**Re Supply**



**Lunar ISRU**

Nuclear Energy Technology?

**Goal**



**Commercial**

- Demonstration of ISRU technology
- Pre-preparation of lunar site
- Energy generation and storage

**Commercial/Entrepreneurial**



## **Some GEO Metrics**

- **200 GEO SpaceCraft = 4 Mwe Installed = 1000 MT**
- **Grown from 1 Ton and 100 w 1965 (Early Bird) to 2005**
- **Average 20 Kwe/SC (BOL)**
- **200-400 Kw Installed/yr (10-20 Launches)**
- **\$3-6 B/yr (\$300 M/launch average), \$90 B/15yrs**
- **GEO=LLO, LLO to Lunar Surface = Factor of 2**
- **Say 10 Kwe on Lunar Surface = \$300 M**
- **10 Kwe =10 MT H<sub>2</sub> + O<sub>2</sub>/yr on Lunar Surface=4-5 EELV's/yr=\$1B/yr**
- **100 w @ GEO=\$1m/yr=36 Mhz =100 Mbs=10k voice channels=10 HBO**
- **GEO = \$40 B/yr=\$600 B/15 yr cycle say 2005-2020, Factor of 7 ROI**
- **Can Lunar Base/ISRU Technology take Current GEO 4 Mwe to 40 Mwe @ \$1m/100 w?**
- **1000 MT/yr Lunar ISRU = 1-4 Mwe Installed**
- **Factor of 10 increase Mass/Power in GEO worth \$6 T (Trillion)over 15 yr, 10,000 MT, 40 Mwe Installed Power**
- **10,000 MT@GEO =\$900 B from Earth, From Moon? \$100 B Emplacement (NASA) + 100 B/15 yrs operations, Total =\$200 B, ROI = 30(?), Private Sector takes over from NASA**
- **New Products and Services HBO =HD HBO Mobile= Tv's Receivers, Content etc**