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How Moon Rocks can Save the Earth

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Topics

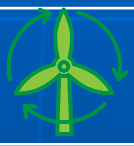
- Motivation
- The ultimate answer for baseload power
- Critical Component – Oxygen extraction
  - Supersonic Dust Roaster (patent pending)
- Critical Component – Silicon beneficiation
  - Isotope Separator (US 6,630,304 & 6,618,014)
- Critical Component – Solar Power Satellites
  - Invented in 1968 by Peter D. Glaser
- Summary

Motivation

- Humans use 447 Quads/year now
- We will need 702 by 2030
- In 26 years, need 8,500 GW extra
- Must build 328 GW per year!
  - Itaipu is largest at 15 GW (6 yrs, $19B)
  - Mega-nuclear at 5-8 GW (8 yrs, $25B)
- Humanity needs a HUGE, RENEWABLE, SCALABLE, CLEAN power source.

We MUST use the SUN

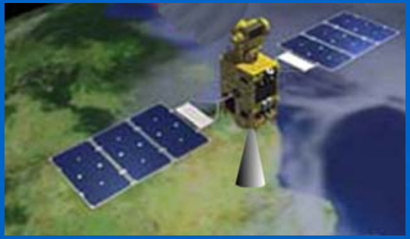
(need 8500 GW by ’30; 14,000 by ’50)

RENEWABLE		AVAILABLE GWs
Wind		4000
Biomass		7000
Tide/Ocean		2000
Hydroelectric		900
Terrestrial Solar		600,000
Orbital Solar		660,000

Terrestrial vs. Orbital Solar

GROUND-BASED	Solar Power Satellites
40% insolation	100% insolation 
880-1050 W/m^2	1357 W/m^2
Black-outs 12 hr/day	Black-outs 4 hrs/year
Low pollution	Very low pollution 
Regional solution	Global solution 

SSP from Lunar Materials

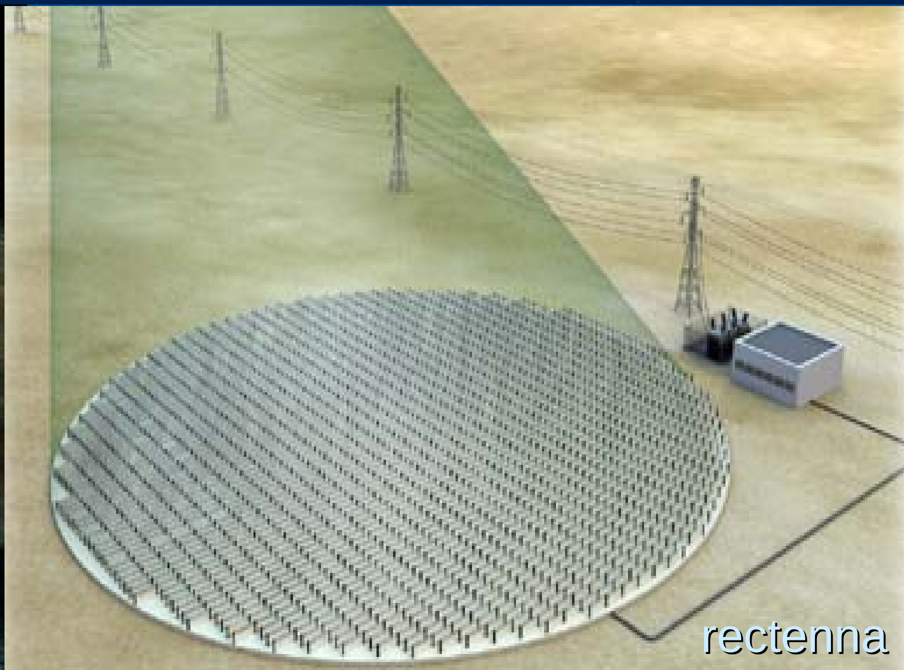


- The Moon is 21% silicon
  - 7% aluminum - for metal contacts
- Lunar escape velocity = 2.4 km/s
  - For Earth v_e=11.8 km/s
  - Remember that K.E. = $\frac{1}{2} mv^2$ *(24X)*
- Abundant solar power (70% at poles)
- Ultra-high vacuum (10^{-11} Torr)
- Luna has everything needed for SSP!

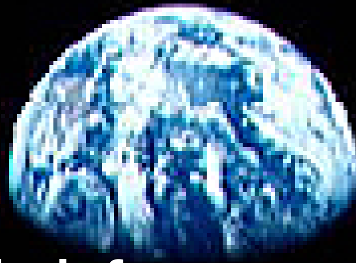

launch seen from ISS


“tower” SPS


railgun launcher

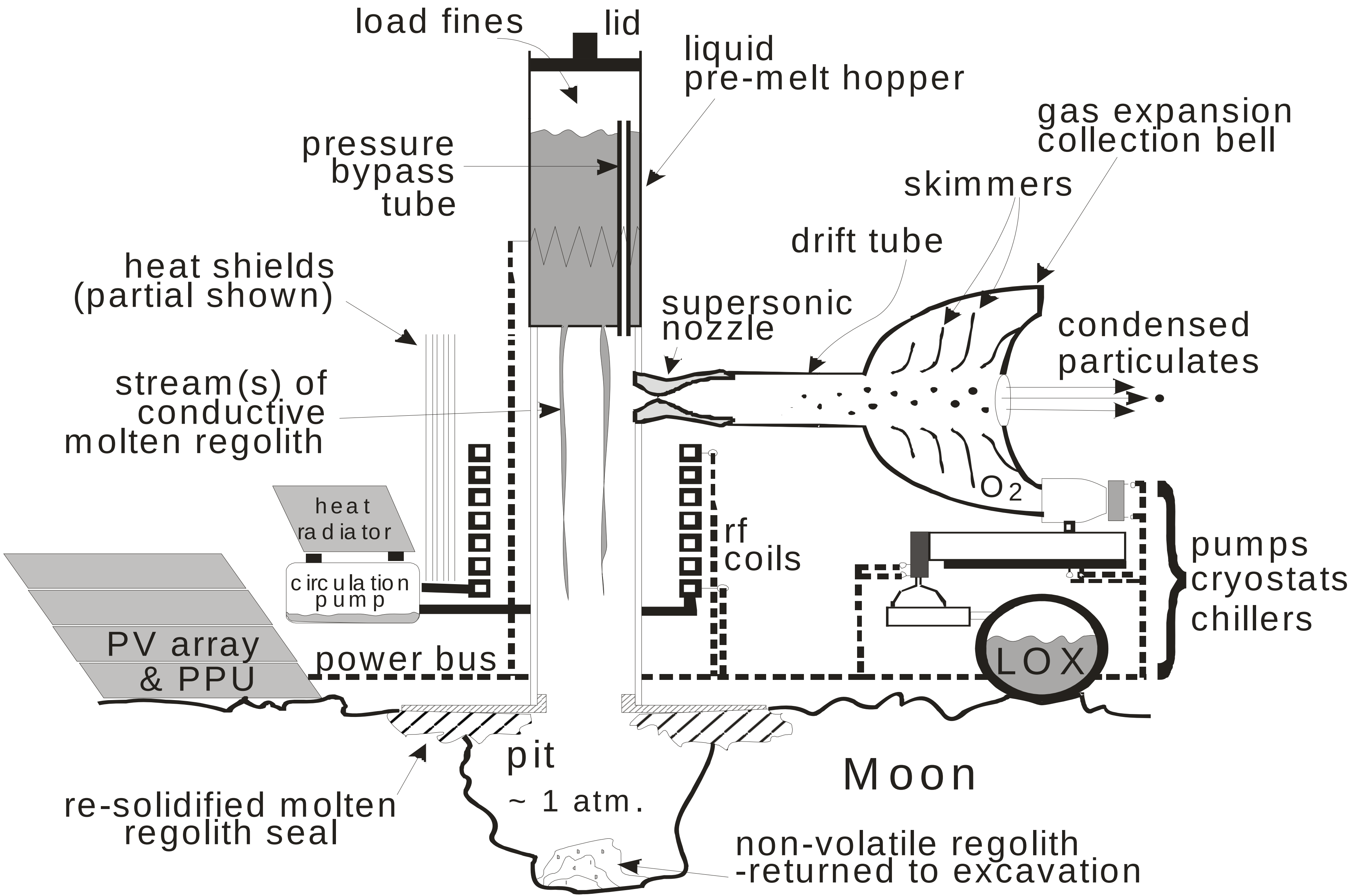

rectenna

Critical Component - Oxygen



- The Moon is 42% oxygen!!!
- Oxygen is essential for:
  - Life support
    - You need 0.84 kg/day
  - Propellant
    - 88% of mass for H_2+O_2 rockets
- On-site oxygen production enables:
  - Continuous human presence
  - Larger payloads delivered to the lunar surface

The Supersonic Dust Roaster

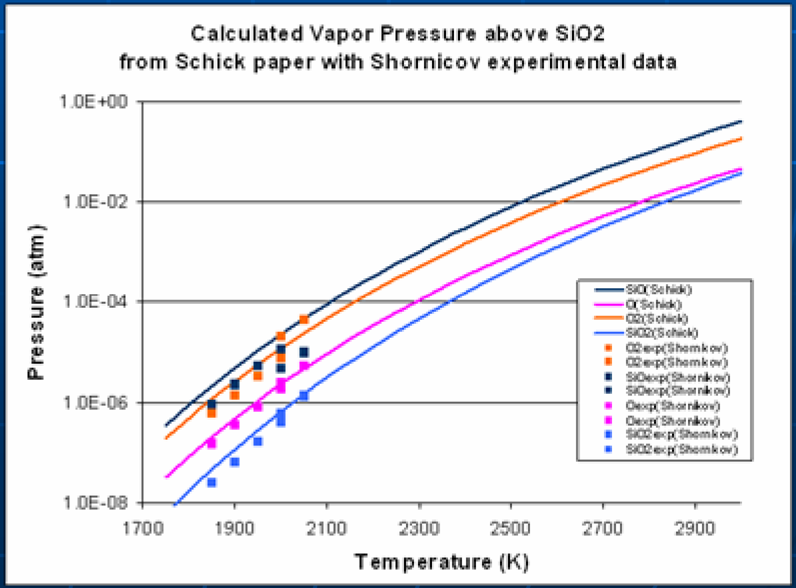


Risk: Ultra-high Temp

- 1 atmosphere P_o needs: **3010ºK**
- Radiative heat loss is BIG (αT^4)
- Monatomic oxygen O^- ablation

$$\frac{dP_\infty}{dT} = \frac{h_{fg}}{(V_v - V_l)T}$$

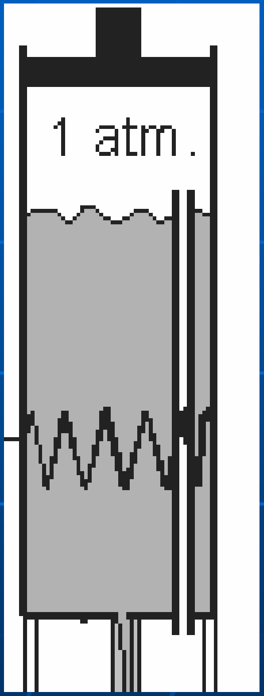
Clausius-Clapyron equation



Pre-Melt

- Sift fines to 1 mm
  - 92% will pass
- Liquify with resistance heaters
  - 1723 ºK, 5-7 Poise
- Gravity fall through apertures

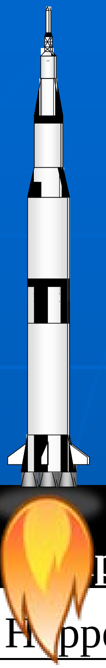
$$\dot{m} = \frac{\pi}{8 \cdot \eta} \left(\frac{\Delta P}{L}\right) R^4$$



- Pressure equilibrate
  - Bypass tube prevents vapor lock

Free-fall Heating

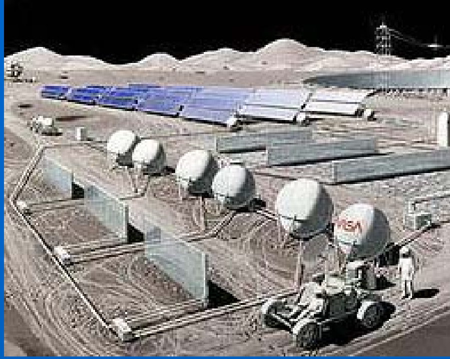
- Inductive heating of conductive magma
  - About 25 siemens-m at 1750 K
- Insulating chamber passes rf energy
- Avoids direct contact
- Wall temperature modulated by radiation shield efficiency



Performance

Component	Mass (kg)	Power (kw)	Key Assumptions
Hopper	257	49.8	50 stream apertures, 45 minute heat-up time
Free-fall shaft	143	19	Conditions based on temperature, length calculated by matching flow rate to evaporation
SS nozzle	44.8	0	Area relation to determine shape
Drift tube	9.69	0	1.8 m long, shares same area as the exit of the nozzle.
Expansion bell	1.28	0	Half sphere, tube area 5% of total exit area so we capture 95% flow.
Pumps and cryochillers	62	2.16	Mass of pumps is linearly related to the flow rate.
Passive cooling pipes	260	0	Length for radiative cooling from 1200 down to 200 K
Storage	100	0	Mass of large storage tank (buried)
Subtotal	876	**70.9**	12x12m solar panels
Grand Total	**1302**		Assumes 6 kg/kw, including power processing unit

System Metrics



- Oxygen production rate = 8.3 kg/hr
- For 71 kW, efficiency = 8.6 kWh/kg
- Extraction efficiency = 20%
- Specific mass = 9 kg-O_2/kg-regolith
- System mass = 1.3 MT
- Yearly output = 61 MT (70% sunlight)
- Ratio to launch mass = 47
  - This is 3X better than any other method!

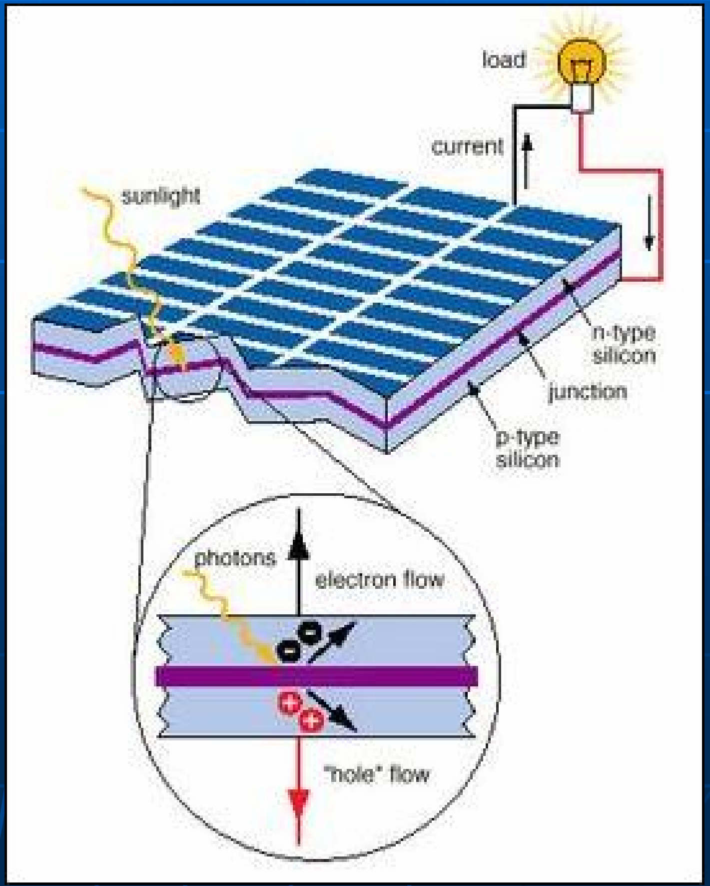
Critical Components - Metals

- Aluminum has many uses:
  - Metallization on solar cells
  - Electrical buses, wires, and cables
  - Structural material
  - Solid propellant

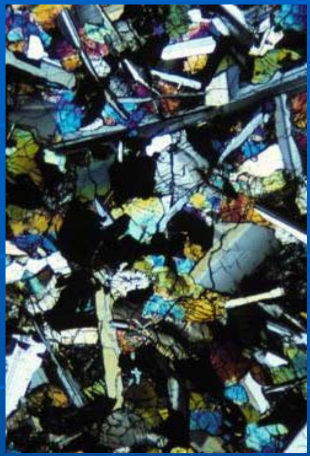
- Iron (12%)won't rust, and is used for:
  - Structural material
  - Canisters for railgun payloads
  - Rails for circumpolar railroad
    - Perpetual sunlight enables agriculture!

Critical Component - Silicon

- Photons on P-N junction make power
- Make as thin as possible
- Collection efficiencies:
  - Single-crystal: 17%
  - Polycrystalline: 8%
- Orientation: cosine law

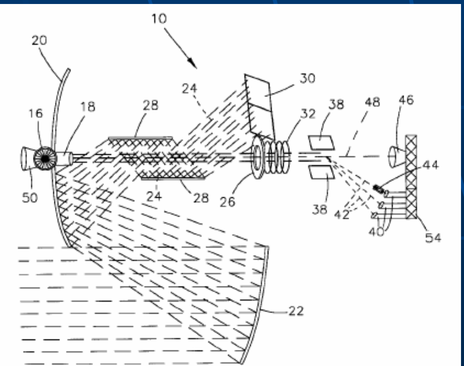


Metals Extraction (Si, Al, Fe)



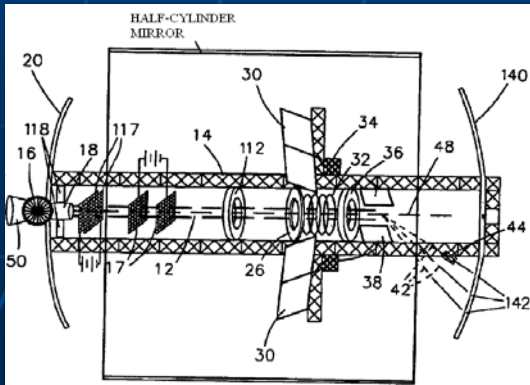
- Isotope Separator downstream of Supersonic Dust Roaster:
  - Ballista are ionized
  - Expanding plasma gated by slits
  - Transverse electric field separates by the charge/mass ratio of isotopes
  - Collect species
  - Accrete slag

$$a = \left(\frac{q}{m}\right) \cdot E$$



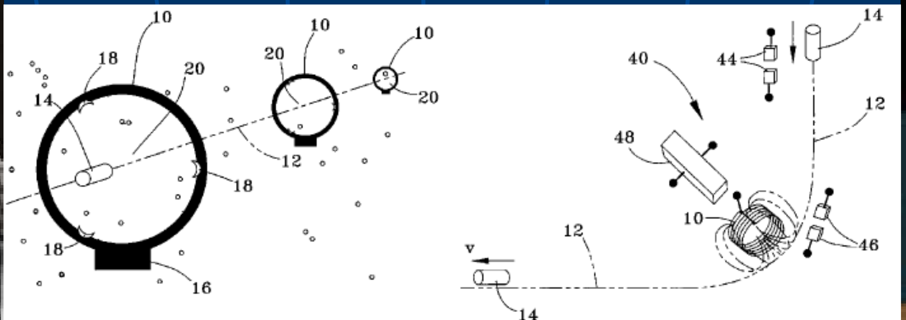
US 6,618,014
for zero gravity

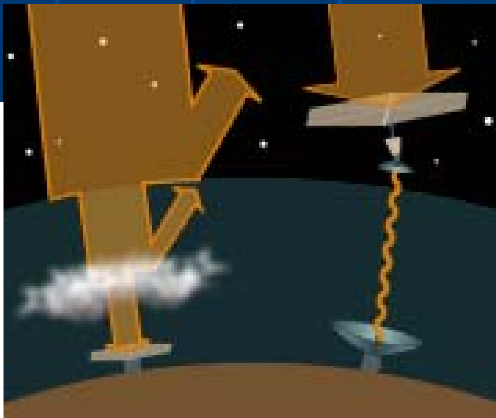
US 6,630,304
lunar gravity



Critical Component - SSP

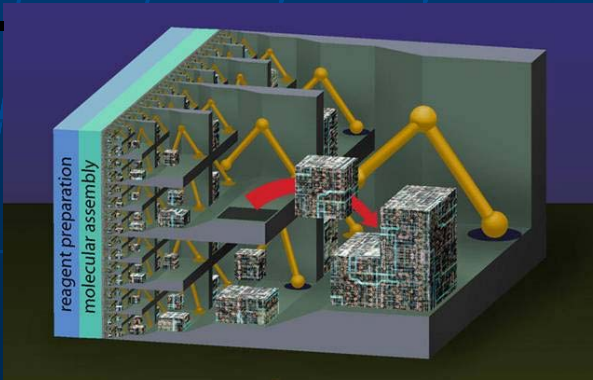
- Cis-lunar architecture & infrastructure
  - Fabricate solar panels on Luna
  - Railgun launch panels in iron canisters
  - Receive canisters electromagnetically
    - US Patent 7,118,075, AIAA 43rd Prop. Cincy 07
  - Build solar arrays, link to transmitter
  - Beam low-density microwaves to earth
  - Receiving antenna directs power to grid



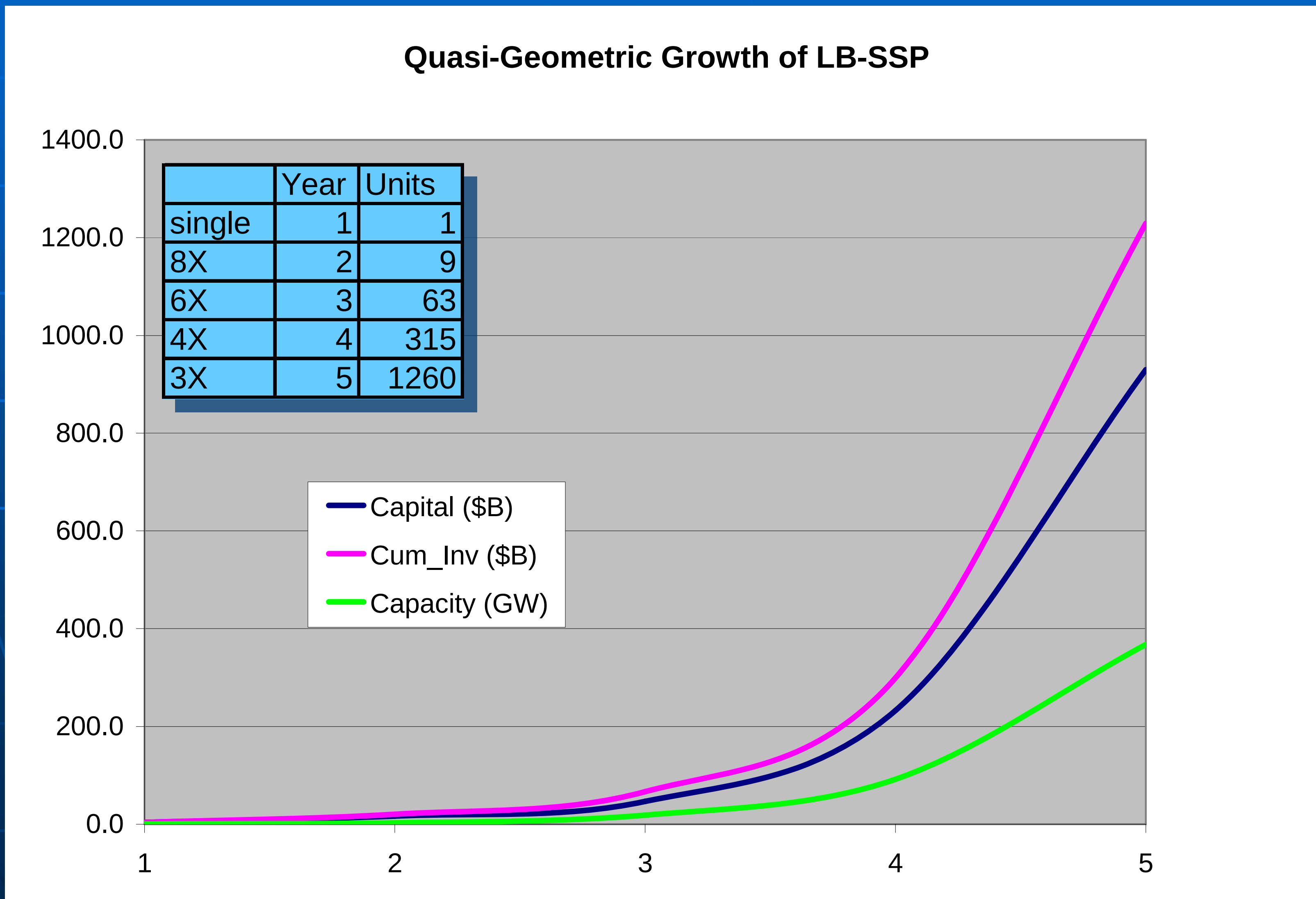


Geometric Manufacturing

- No known power source can meet projected energy needs in time!
- New power sources must scale GEOMETRICALLY.
- Lunar factories which are partly self-replicating may be the only viable long-term energy solution.



Scale-up of Lunar-based SSP



	Year	Units
single	1	1
8X	2	9
6X	3	63
4X	4	315
3X	5	1260

Assumptions – prev. chart

- $100M/yr operating expenses per unit
- No additional labor costs
  - Until tele-operated robotics take over, assume labor supplied by a government.
- Fe & Al have no monetary value
- Silicon yield is 60%
- Sunlight is 75% available (pole)
- Launch costs at NASA rates

Apollo 11 moon rocks 2.4mm

SUMMARY

- Space Solar Power from Lunar-based materials may be the technology which saves the Earth.
- Work at Packer is advancing several component technologies
- Additional R&D at Packer addresses the entirety of human energy needs.

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LUNA the 8th CONTINENT

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