

# Habitat Size Optimization of the O'Neill – Glaser Economic Model for Space Solar Power Satellite Production

Peter A. Curreri<sup>1</sup> and Michael K. Detweiler<sup>2</sup>

<sup>1</sup> NASA, Marshall Space Flight Center, Mail Code EM30,  
Alabama 35812, USA

256-544-7763, [peter.a.curreri@nasa.gov](mailto:peter.a.curreri@nasa.gov)

<sup>2</sup> Junction Solutions, Englewood, CO, USA

540-521-4621, [mkdetweiler@gmail.com](mailto:mkdetweiler@gmail.com)

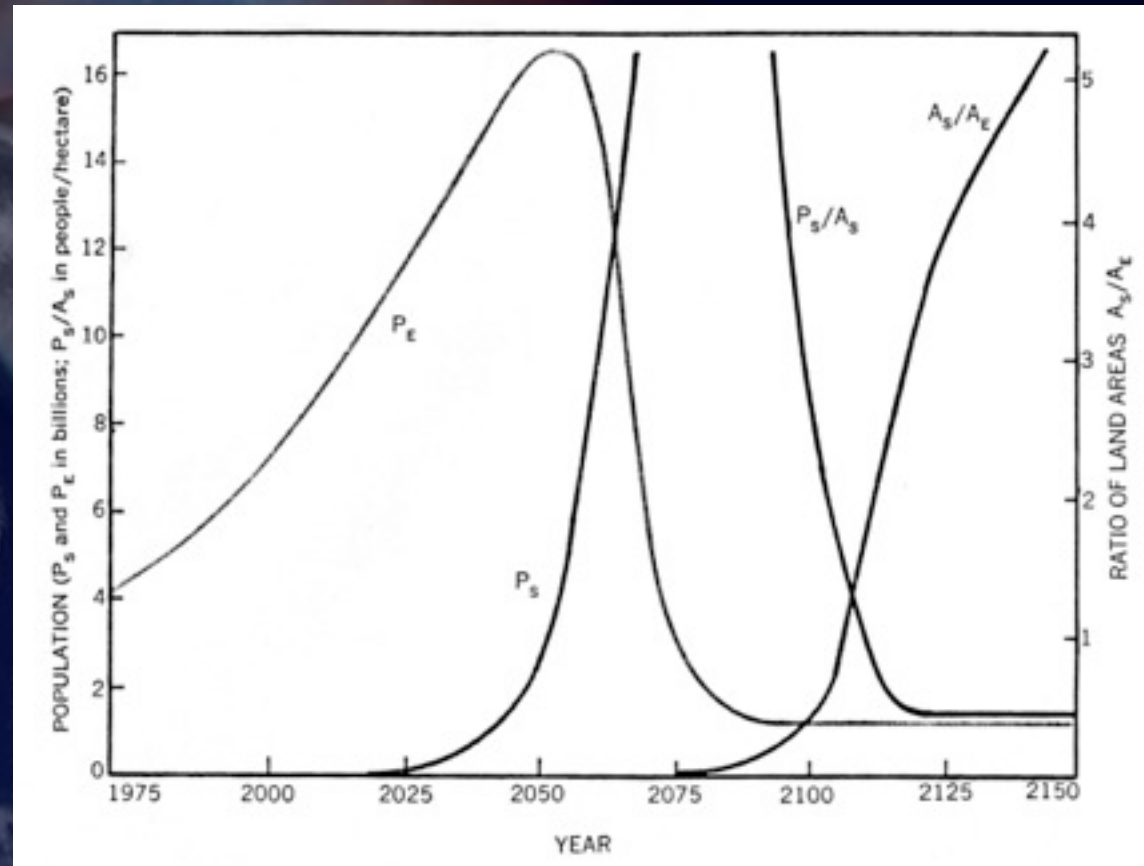
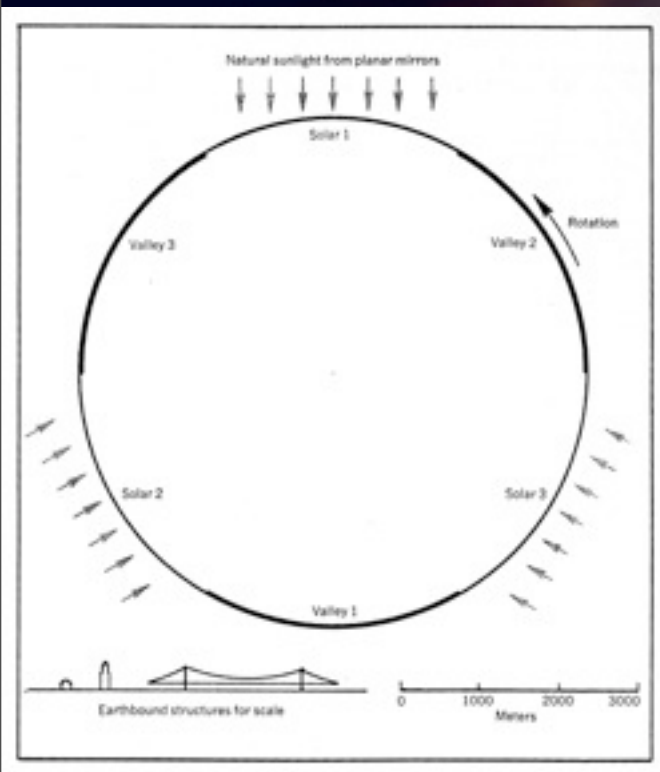
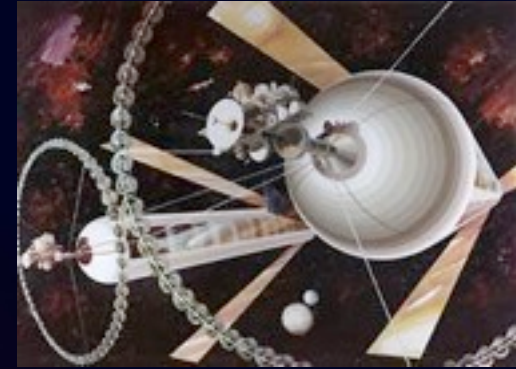
*Session 3, Closed Environment Life Support Systems,  
Saturday, October 30, 2-3:30 PM  
NASA Ames Conference Center*

*Space Manufacturing 14: Critical Technologies for Space Settlement  
NASA Ames Conference Center, CA, October 30 – 31, 2010*

# The “Classical” Model of Space Settlement – Extending Humans Beyond LEO



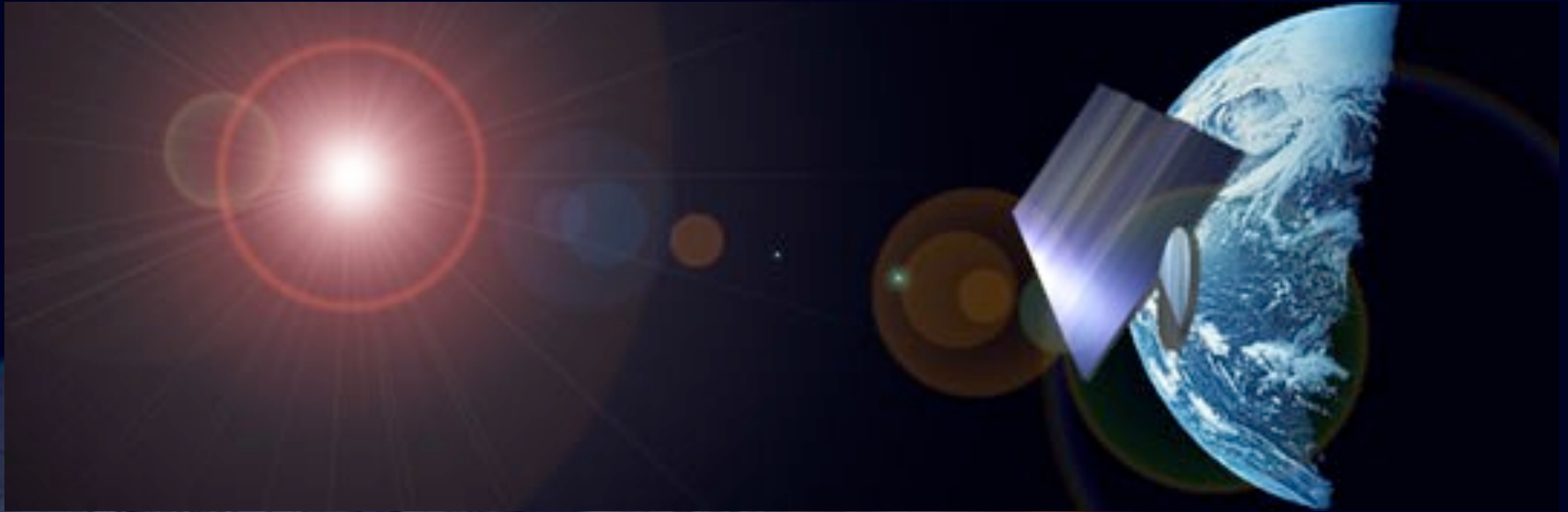
Rather than live on the planets and moons that nature provides, Space Age humans will eventually live in constructed homes, towns and cities in free space.



Gerard K. O'Neill, *Physics Today*, 27(9):32-40 (September, 1974)

Saturday, November 20, 2010

# Solar Power Satellite – “the killer app.”



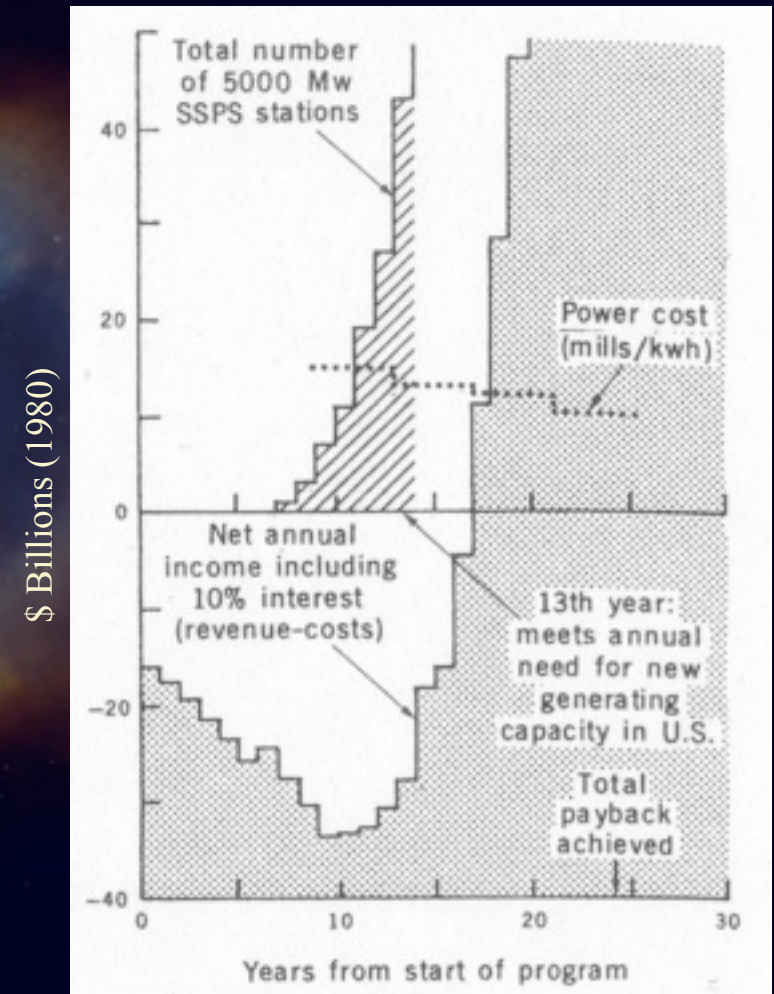
Space Solar Power Satellite suggested by Dr. Peter Glasser in 1968  
21 by 5 km Satellite would provide 10 GW to Earth by Microwave Beam

“No alternative at all was found to the manufacture of solar satellite  
Plants as the major commercial enterprise of the colony.”

Johnson, R. D. and Holbrow, C., eds., *Space Settlements, a Design Study*, SP-413, NASA, Washington, D.C. 1977, ch4.



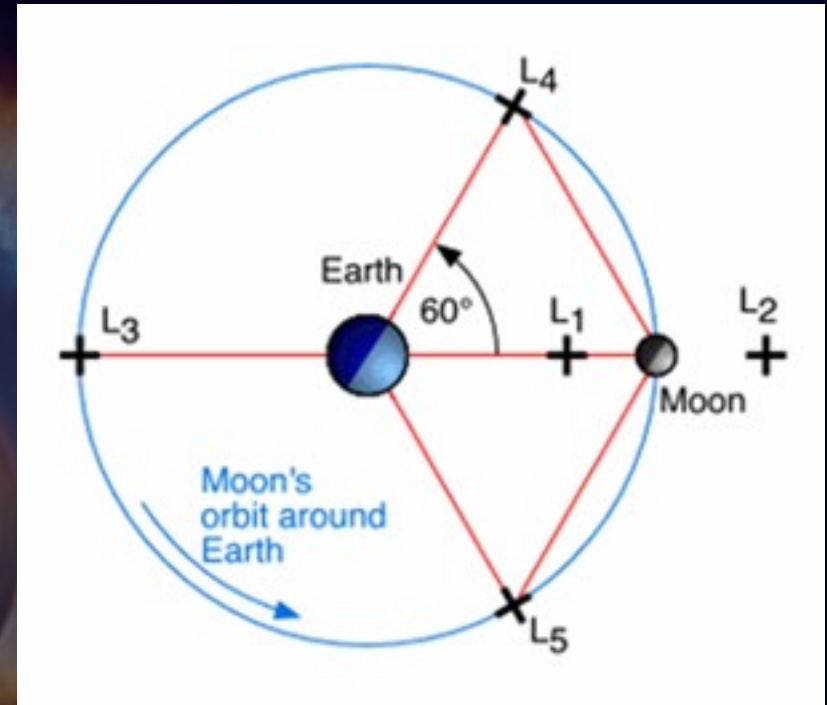
# Affordable Space Solar Power + Human Colonies in Free Space Built using Lunar and Asteroid Materials



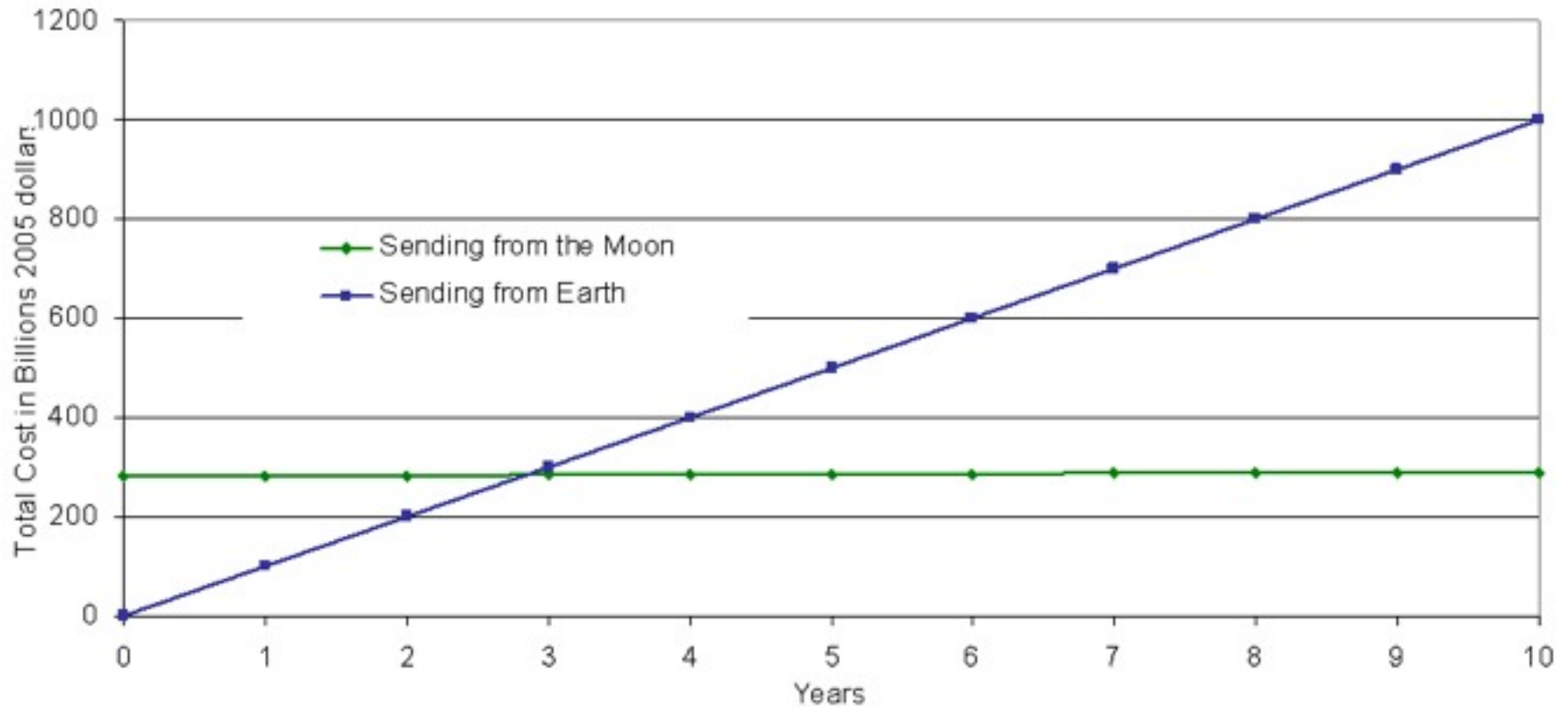
Senate Committee on Aero and Spa. Sci. Dr. O'Neill, 1976

Sun pumps out  $4 \times 10^{26}$  watts (40 million times the needs of even a projected Solar System Society). 4

# ECONOMICS OF EARTH SUPPLIED VS. LUNAR SUPPLIED INDUSTRY FOR SPACE SOLAR POWER CONSTRUCTION

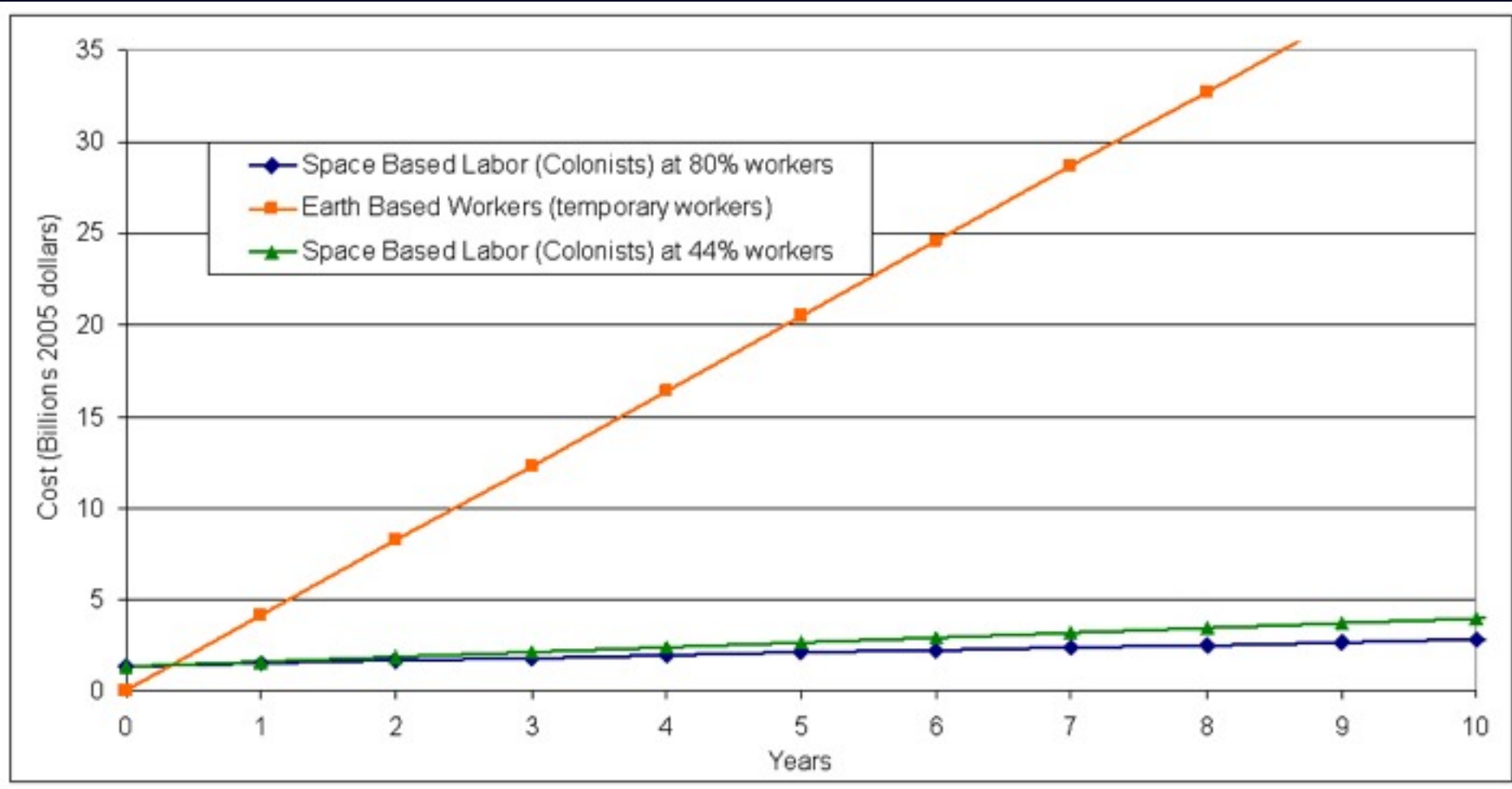


# Economics of Using Lunar Resources versus launch from Earth For Construction of Space Habitats and Solar Power Satellites



The economics of using space resources relative to Earth launch is compared by showing the cumulative cost for sending 50 kT/yr of material from the Earth or from the Moon. The cost from the Moon includes the \$283 billion required to build a lunar base and other necessary infrastructure.

# Economics of Using Lunar Resources versus launch from Earth For Construction of Space Habitats and Solar Power Satellites



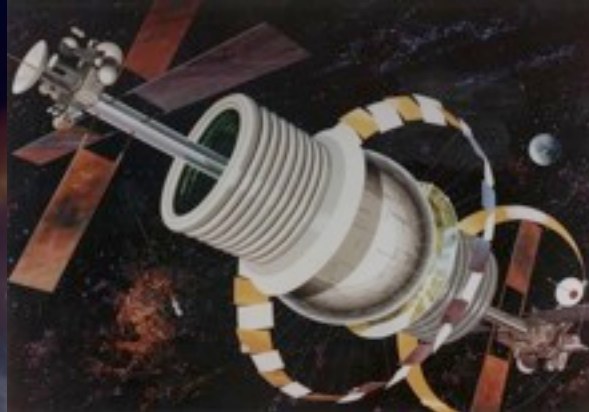
**Cost for 614 Earth based (orange) versus space based labor (blue).**



# Artists Renditions of NASA Studied Space Habitats



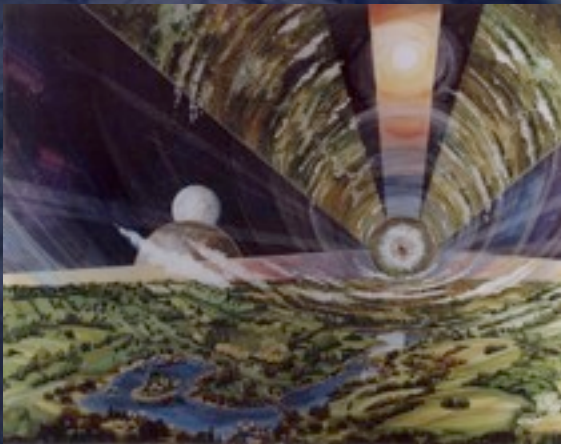
(a)



(b)



(c)



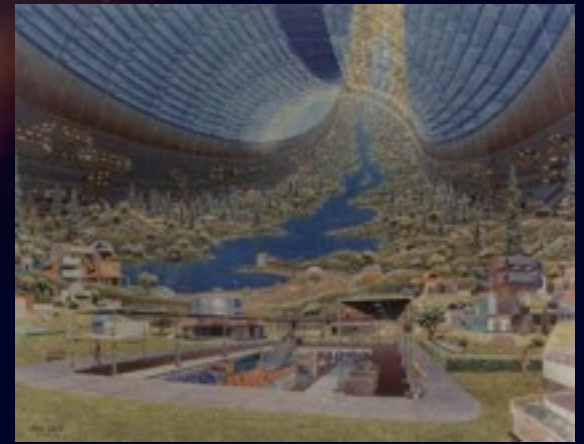
(d)

Cylinders



(e)

Sphere



(f)

Torus



# “MODEL ZERO” – SPACE HOMESTEAD



Table 1. Possible Stages in the Development of Space Communities					
Model	Length	Radius	Period	Population <sup>▲</sup>	Earliest Estimated Date
	(km)	(m)	(sec)		
1	1	100	21	10,000	1988
2	3.2	320	36	100-200 × 10 <sup>3</sup>	1996
3	10	1000	63	0.2-2 × 10 <sup>6</sup>	2002
4	32	3200	114	0.2-20 × 10 <sup>6</sup>	2008

\* Population figures are for double unit; higher figures are the approximate ecological limits, for conventional agriculture.

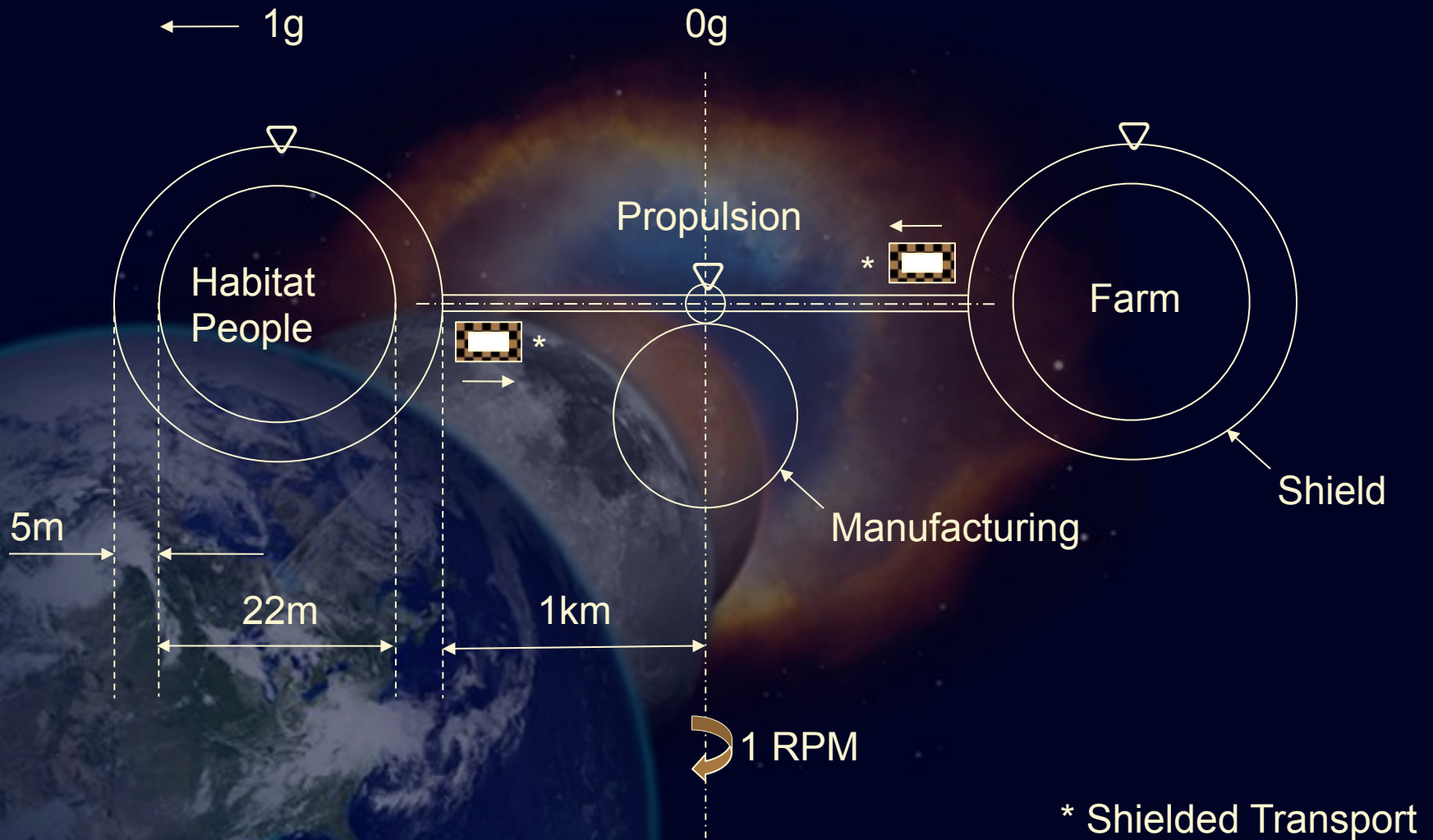
Gerard K. O'Neill, *Physics Today*, 27(9):32-40 (September, 1974)

Library of Congress, Farm Security Administration

## CRITICAL MINIMUM SET OF TECHNOLOGIES:

- SPACE HABITAT THAT SUPPORTS ONE HUMAN FAMILY
- SELF REPRODUCIBLE IN LESS THAN ONE GENERATION
- USES LOCAL ENERGY AND MATERIALS RESOURCES
- ECONOMICALLY VIABLE, SUBSISTANCE FARM
- INDIVIDUALLY INDEPENDENT
- CAN GROW INTO TOWNS, CITIES AND NATIONS

# SPACE HOMESTEAD CONCEPTAL DESIGN



Humans in the Loop Self-Reproducible Self-Sufficient Habitat in Free Space.



Habitat Geometry	Number of People/unit	Planned US Launch capability	Testable on the Moon
O'Neill Cylinders	2,000,000	Beyond	No
Bernal sphere	20,000	Beyond	No
Stanford Torus	10,000	Beyond	No
Bolo (1975)	200	Difficult	Difficult
Homestead Bolo	10	Yes	Yes



# Some Details of the Economic Model for Space Solar Power

**TABLE 1.** Costs and Mass Transfer Capacity of In Space Transfer Machines

Machine Name	Transfer Capacity (kt/yr)	Cost Per Unit (in Millions, 2005 Dollars)	Transportation Costs (in Millions, 2005 Dollars. At \$1840 per kilogram)
Interlibrational Transfer Vehicle	500	11.5	9.2
Mass Catcher	313	2.3	1.84
Mass Driver	625	172.81	228.7

$$D = 1,875 \cdot 1.024^{y-2004} \cdot \left(0.024 + \frac{0.024}{4.32}\right) \cdot p$$

$$b = p_s \cdot 10^7 \cdot 0.95 \cdot 24 \cdot 365 \cdot 0.0712 \times 10^{-9}$$

$$w = a \cdot u^{\ln(c)/\ln(2)}$$

$c$  = the learning curve

$D$  = demand in GW

$p$  = market penetration for that year in fraction form

$b$  = the economic benefit in billions of dollars

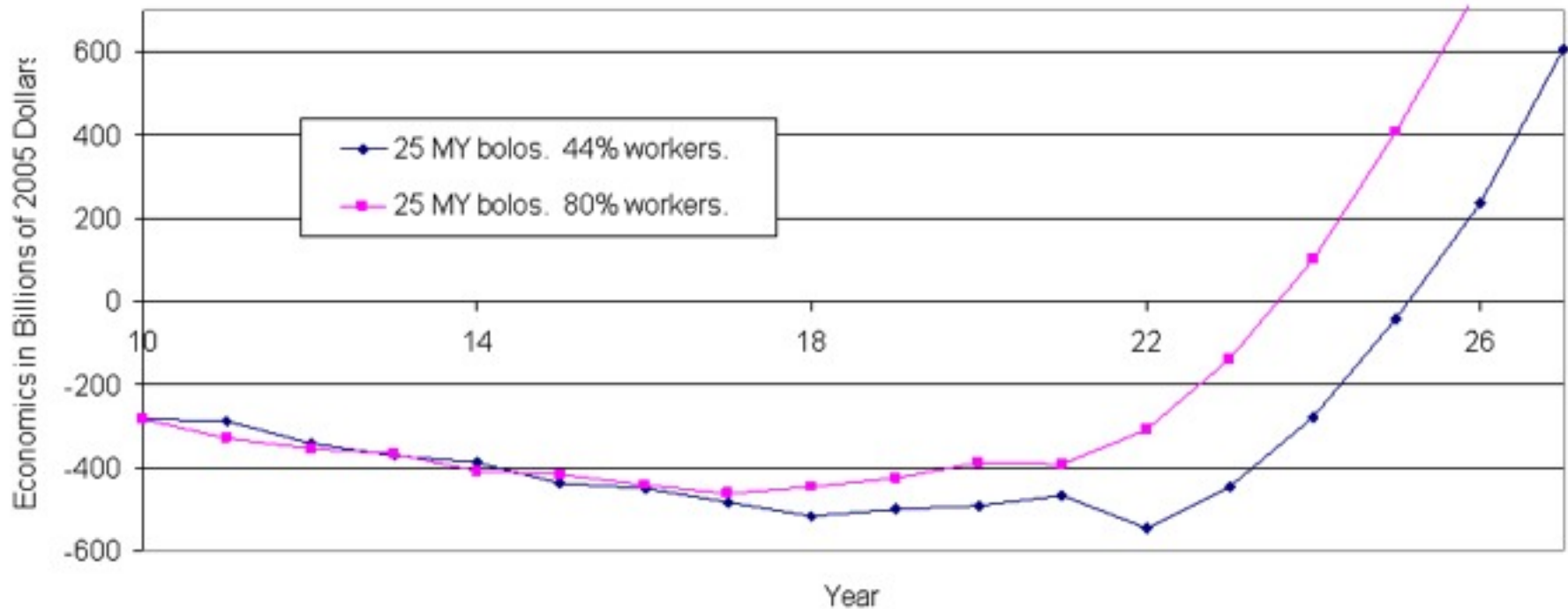
$p_s$  = total population of SSPS

$u$  = the amount of units created previously

$w$  = work done per unit

$y$  = the year

# The Economic Effects of Space Worker Productivity



Estimate of the economic benefits from productivity increases since 1975 (2005 energy demand and water shielding).

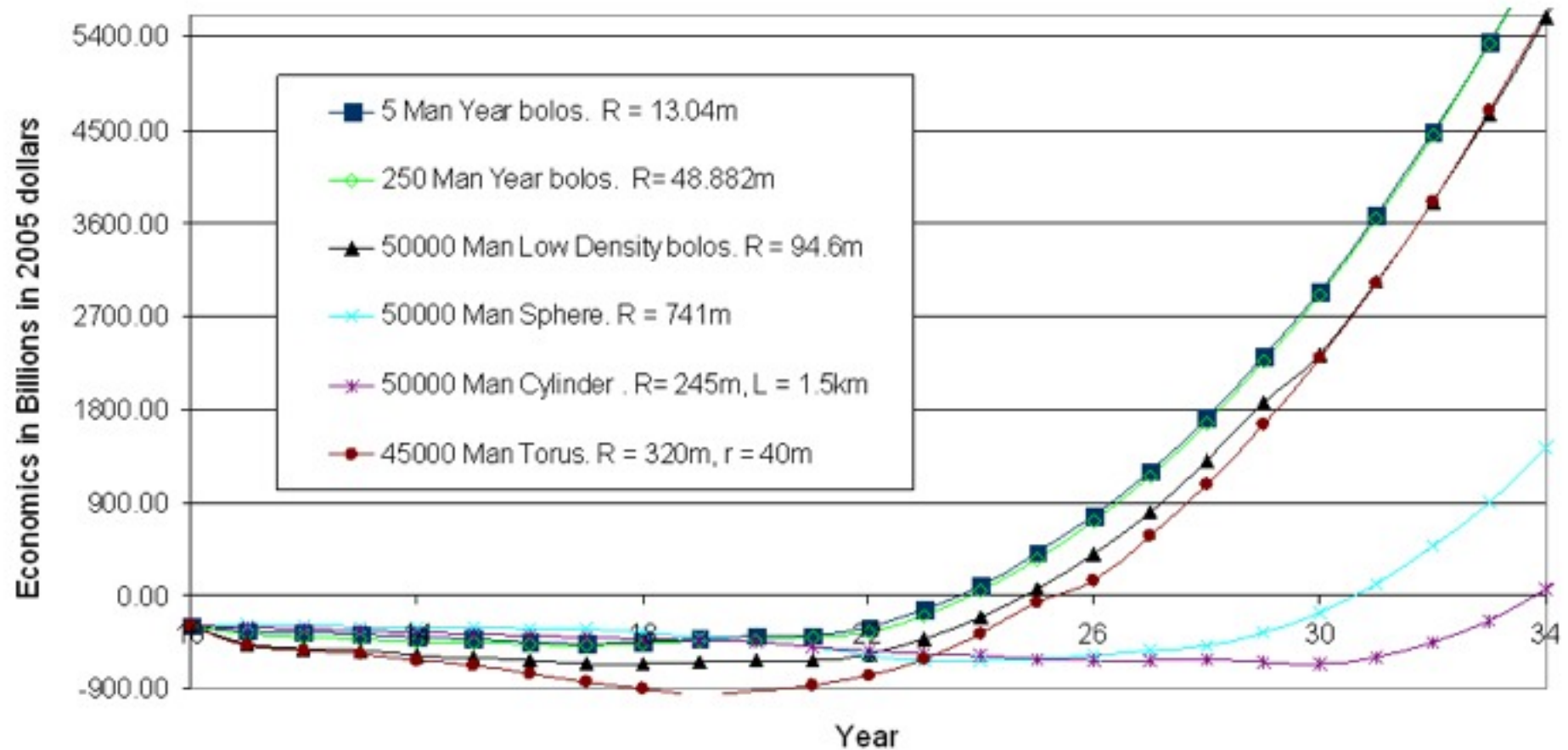
# Selection of Habitat Geometry and Initial Space Worker Population

**TABLE 2.** Characteristics of Habitats of Various Geometries and Population Densities

Habitat	Population	Construction Time (MY)	Structural Weight (kt)	Shield Weight (kt)	Dimensions (m)	Rotation Rate (RPM)
Cylinder	50,000	44,260	531.2	8,620	R = 245, L = 1,500	2
Sphere	50,000	167,583	2011	12,892	Radius = 741	1.15
Torus	45,000	1,825	21.9	14,404	Radius 1 = 320, Radius 2 = 40	1.75
HD Bolo	384	5	.06	13	Radius = 17.08, Tether = 422	2
HD Bolo	1,922	25	.3	35.57	Radius = 29.2, Tether = 373	2
HD Bolo	3,846	50	.6	55.32	Radius = 36.8, Tether = 343	2
LD Bolo	48,700	850	10.2	348.3	Radius = 94.6, Tether = 874	1.25

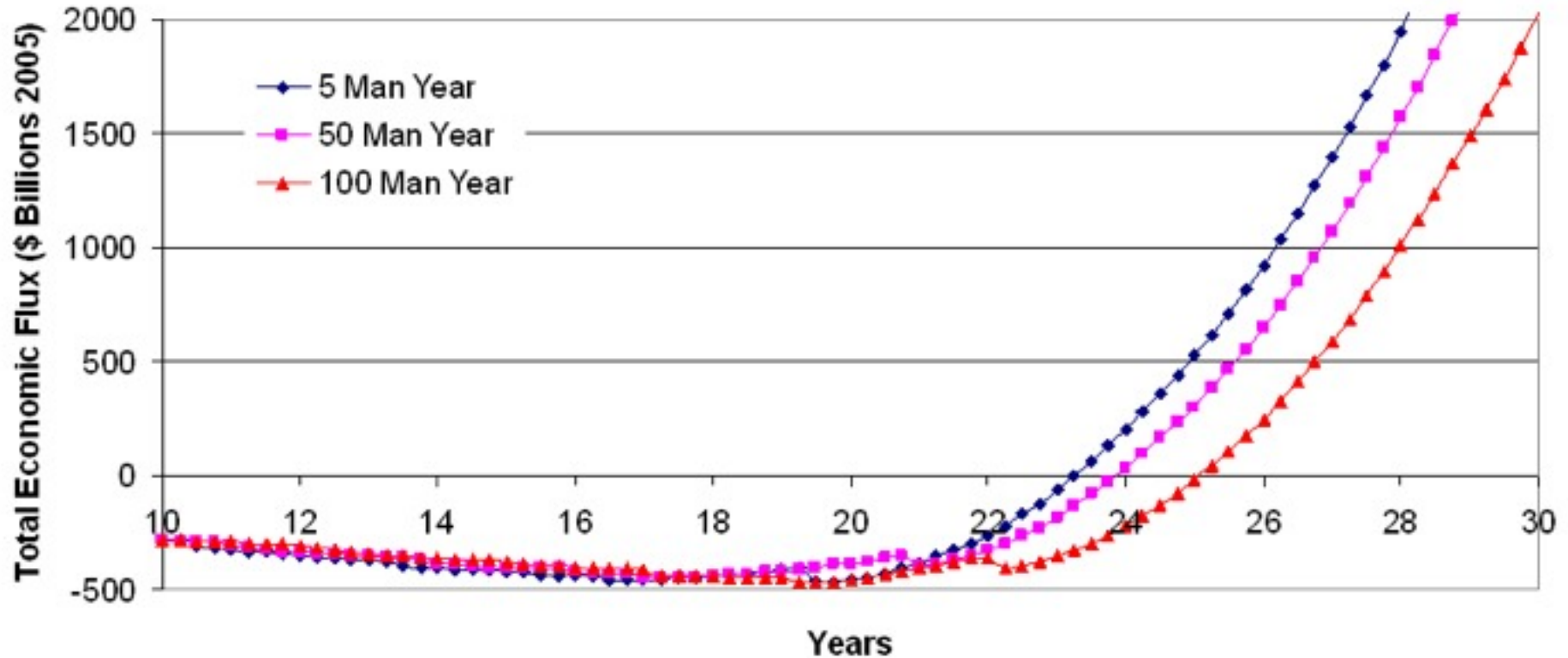


# Selection of Habitat Geometry and Initial Space Worker Population



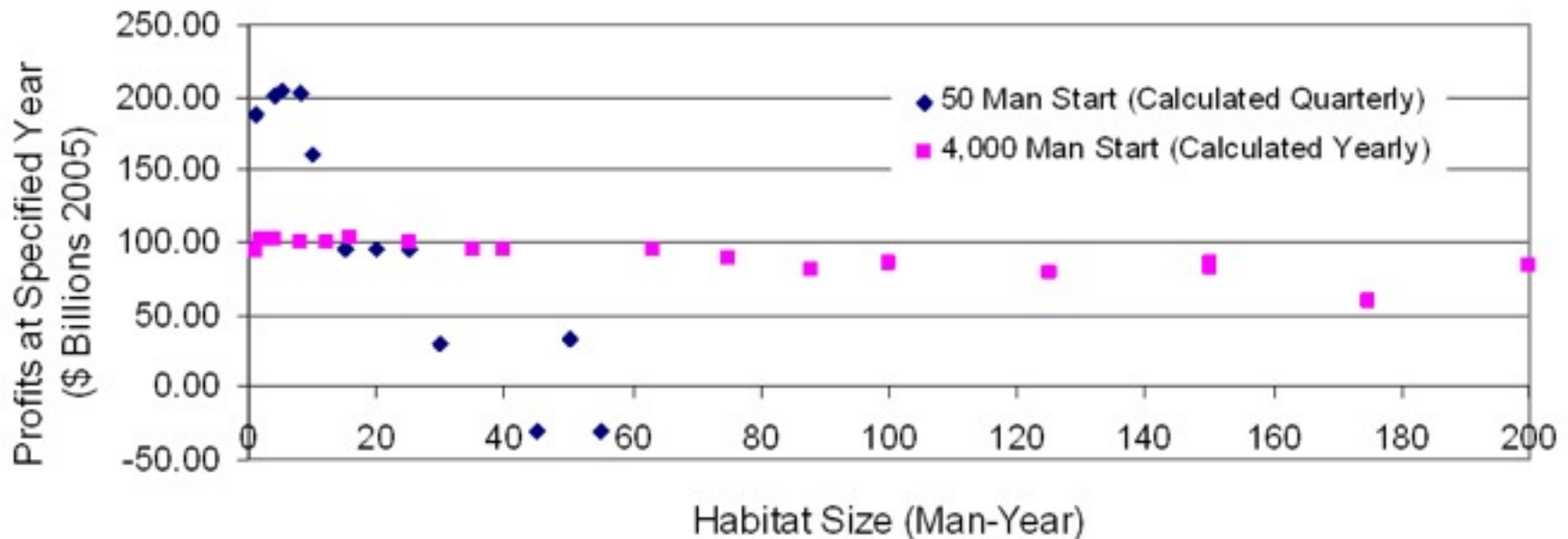
**Habitat geometry comparison (4000 person start) using the 2005 baseline power demand and assumptions shows that the bolos are the most profitable.**

# Optimizing Habitat Size



The economics of bolo habitats as a function of size with an optimum at 5 Man Years (384 person habitat). (50 MY = 3846 P, 100 MY ~ 8k P)

# Selection of Habitat Size and Initial Space Worker Population

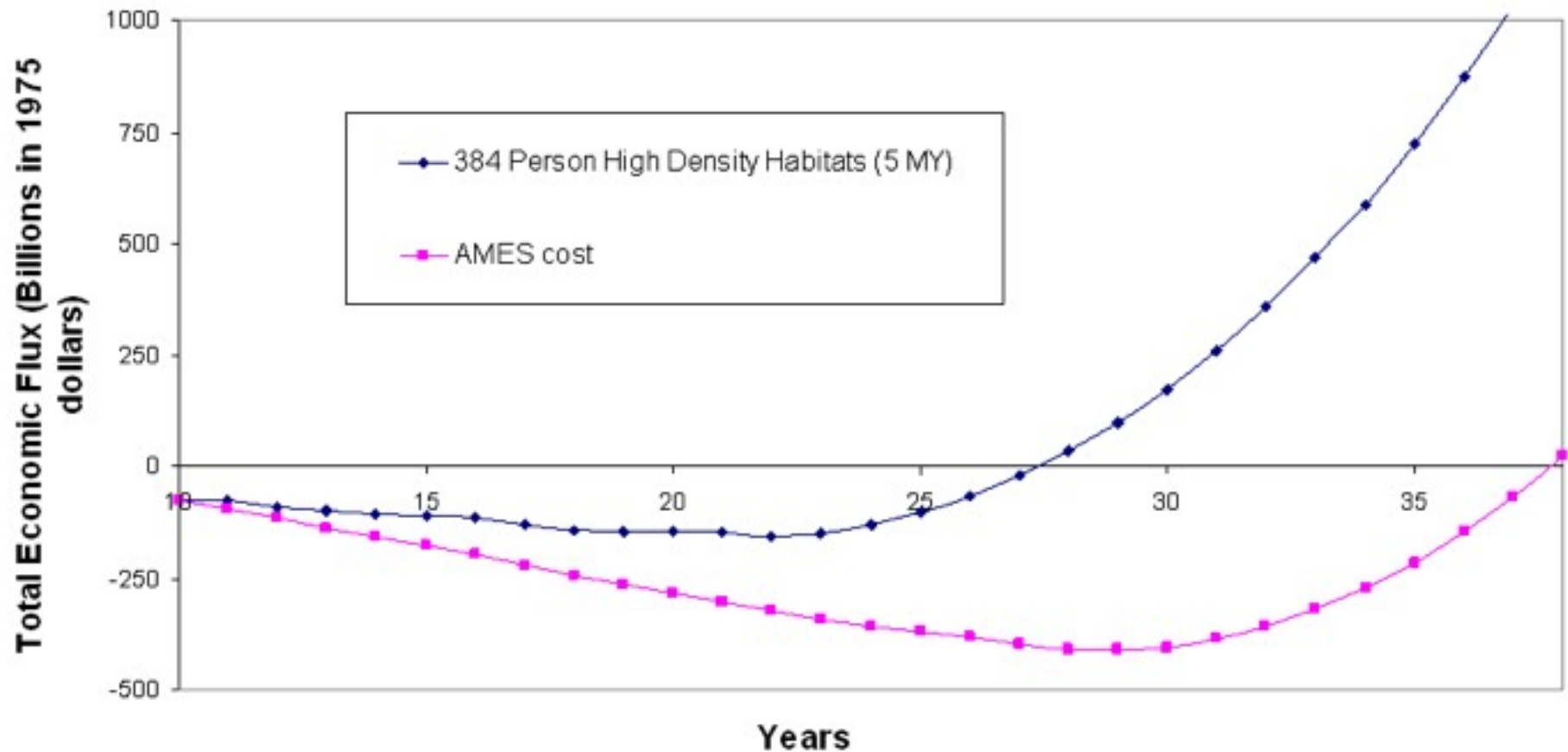


Beginning habitat construction with, for example, 25 man year ((1,922 person) Bolo habitats, enables the first two permanent habitats to be constructed in the first year with an Earth based work force of only 50 people. Subsequent space based labor would then be exclusively provided by more economical space based labor.

Note: Starting construction with only 50 workers a year, a 50,000 man cylinder would take about 200 years to complete!



# The Economic Advantage of Beginning with Small Permanent Space Habitats



A Comparison of small bolos to the 1975 NASA Ames project using an almost identical model (1975 economics). This shows the economic benefit of early spaced based labor achieved through smaller permanent habitats.

# GROWTH INTO TOWNS AND CITIES



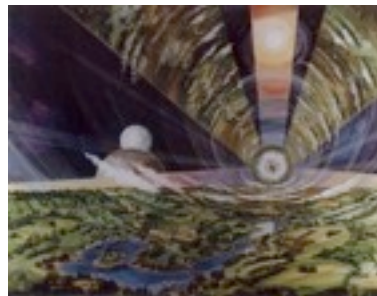
(a) Cylinder, Outside View.



(b) Sphere, Outside View.



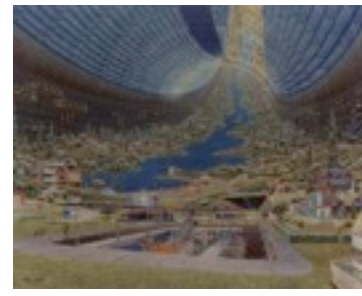
(c) Toris, Outside View.



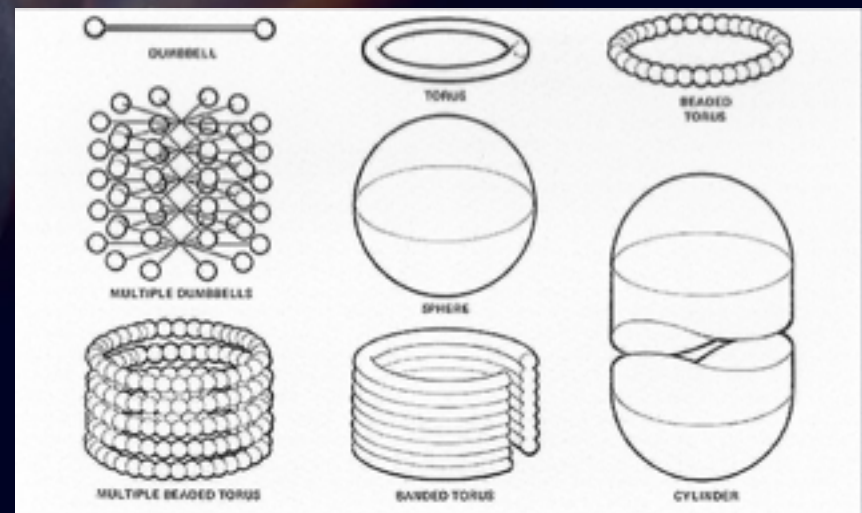
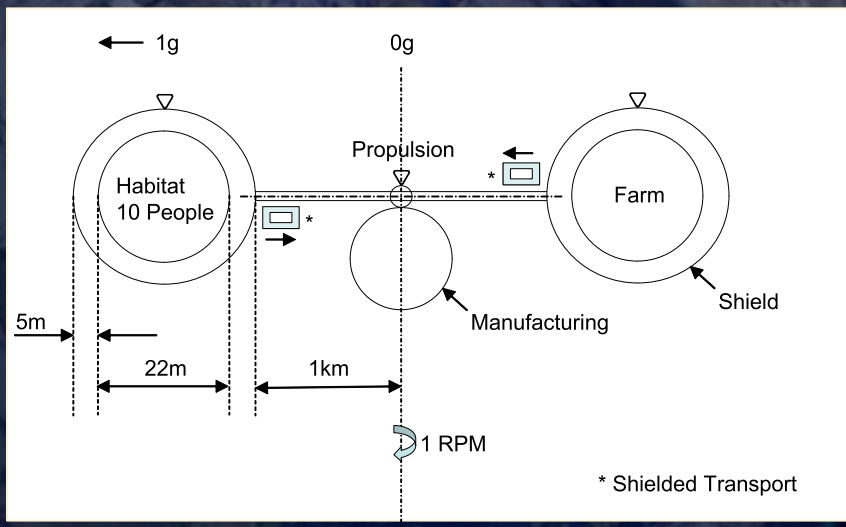
(d) Cylinder, Inside View.



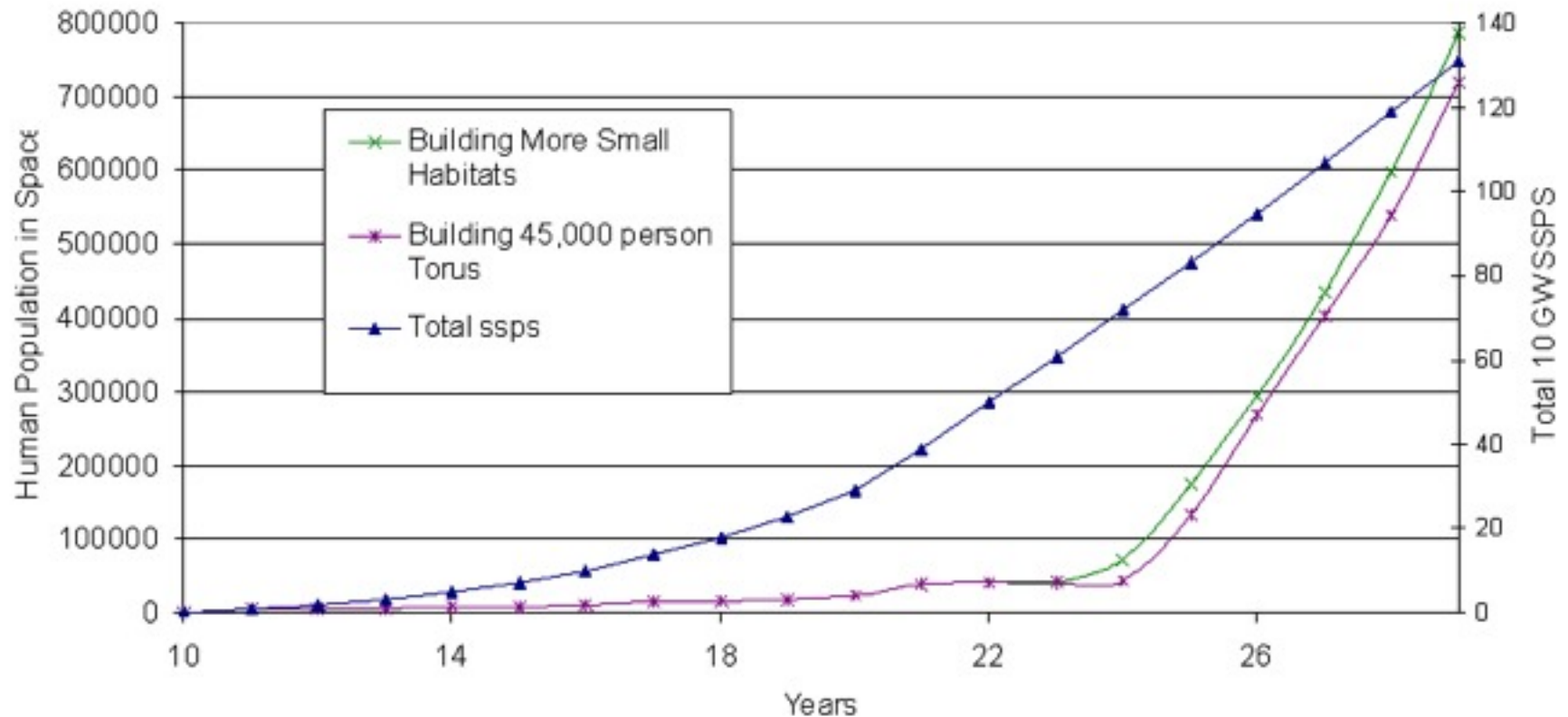
(e) Sphere, Inside View.



(f) Toris, Inside View.



# Moving from a Space Power Intensive to a Space Real Estate Intensive Economy



**Population living in space if the SSPS profits are invested in space real estate.**



# CONCLUSIONS

Creating large space habitats by launching all materials from Earth is prohibitively expensive.

Using space resources and space based labor to build space solar power satellites can yield extraordinary profits after a few decades.

The economic viability of this program depends on the use of space resources and space labor.

To maximize the return on the investment, the early use of high density bolo habitats is required. Other shapes do not allow for the small initial scale required for a quick population increase in space.

This study found that 5 Man Year, or 384 person bolo high density habitats will be the most economically feasible for a program started at year 2010 and will cause a profit by year 24 of the program, put over 45,000 people into space, and create a large system of space infrastructure for the further exploration and development of space.

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