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ARCHITECTURE FOR A RADIATION SHIELDED, ORBITING HABITAT IN THE EARTH-MOON SYSTEM

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ABSTRACT

This paper considers the process for jump-starting a space-based economy. The centerpiece is a project to build the massive radiation shield for the first large-scale human habitat at one of the Lagrangian points of the Earth-Moon system. A process of synergistic development is outlined, where the markets, resources and risk reduction implications of a large economy are facilitated. Provision of clear knowledge and methods to reduce risks and calculate business models, is seen to be key to igniting sufficient public interest for this process.

INTRODUCTION

In the 1970s, O'Neill[1] and Johnson et al[2] considered the problem of building large orbital habitats in some depth. Three basic points emerged:

1.Large habitats for a distributed economy were ideally situated in orbit, not on or below planetary surfaces.

2.Long-term human residence in Space required artificial gravity, spin rates below 1 rpm, and most of all, radiation shielding which would stop all ionizing radiation.

3.Human labor for construction would be prohibitive in both hazards and cost.

Given these constraints, there was no practical solution. The mass needed for full radiation shielding was immense, and techniques for assembly of the outer shell and shield of any such habitat demanded millions of human work-hours in unshielded Space.

In Ref. 3 we considered how such a radiation shield might be constructed with at most telepresence needed from Earth to control robotic machines. The idea was to use electromagnetic forces to launch metal containers of regolith towards a spinning wire cage at Earth-Moon L-2, and position the containers on the grid using an electromagnetic construction grid. This paper begins by outlining the technologies and steps that make up this project plan, and then layout the construction process. It then goes on to look at the economics of such a project within the paradigm of a Space Based Economy (SBE) that has been proposed by our group in earlier papers. We postulated[3] that with a concerted effort, a Space-based development plan supported by a majority of humanity can be outlined. We have built on this by outlining more detailed risk reduction and costing and a more specific roadmap for the Space based Economy.

PART 1- TECHNOLOGY:

The first issue is the technology for building what was considered impossible a few decades ago - a massive radiation shield, large and strong enough to form the foundation for the first large human habitat in orbit. Enmeshed into this issue is the larger question - how to set up an environment where such a project becomes economically feasible and makes sense as a public and corporate investment. At the outset, we point out that our interest is more in laying out a path to build massive habitats using automatic, low-recurring-cost techniques, than to get into the "Moon vs. Mars" debate, and hence our choices are not necessarily optimal – it is enough for our purposes to show what it takes to make them feasible. Features of the O'Neill habitat[1] concepts are summarized below and contrasted with modern realities:

Economic Opportunities As Motivator. The precise industries foreseen as the leaders of this enterprise may not today be the prime movers, but the basic concept that economics - rather than exploration or national / military motivations - would drive the construction of the habitat, remains valid.

Moon As The First Source For Extraterrestrial Resources. The choice of the Moon as the ***first*** site for the extraction of resources such as oxygen and metals, remains valid today, since there is far more quantitative knowledge about the Moon than there is about any other heavenly body. O'Neill pointed out that much of the material processing might actually be done in the habitat itself, where varying amounts of artificial gravity would be available.

L5 As The Logical Location For The Settlement. The argument for a habitat in Space, rather than on the Moon, was based on access to "employment" locations such as GEO, to service other satellites and Space Stations, and to provide access to Mars and beyond. In this scenario, levels of automation for facilities on the lunar surface and elsewhere would be comparable, and need for human presence on the lunar surface would be comparable to that at other orbital destinations.

This choice triggers debate. Concepts for radiation-sheltered sub-surface habitats[4] offer attractive options for habitats with controlled atmospheres. A sub-surface habitat offers easier radiation shielding. With our concept, the facilities developed to build the shield in orbit will remain as permanent facilities for lunar transportation and manufacturing, and reduce the marginal cost for shield construction by several orders of magnitude. The advantages of variable-gravity facilities for manufacturing are strong additional arguments for a Space habitat.

"Bernal Sphere" + Toroidal Agriculture Stations On Either Side, With Near-1-G At The Equator. O'Neill believed an angular velocity of less than 1 revolution per minute could be tolerated long-term by 97% of the population, but a gravity level near 1-G had to be maintained for a population which would continue to be able to visit Earth. These constraints suggest a habitat diameter of about 2 km and rotation speed of 1RPM as design criteria. Various shapes of habitat were considered in A NASA-ASEE study in 1975-77 [2] selected a toroidal habitat shape with an inner rotating toroid enclosed in an outer toroidal radiation shield tube. Examination of their logic shows that a cylindrical shape would have been better, but was far more spacious than needed to support 10,000 inhabitants. Thus the toroid chosen can be viewed as a minimum-length cylinder with only the rim shielded.

Shell Of Aluminum And Glass (To Admit Sunlight); Support Structure Made Of Aluminum Ribs And/Or Steel Cable. This was based on then-prevalent construction techniques for lightweight, mobile structures. Human labor was assumed, in order to not make assumptions about the availability of robotic machines. The aluminum and glass were assumed to be shipped from the Moon initially, and from orbital manufacturing facilities for subsequent construction projects. We avoid the need for such detailed construction for the other shell, and present a system amenable to automatic construction.

Projected Earth-Leo Launch Costs Of $110/Lb. Even with that cost assumption, Earth-launch is unrealistic for any recurring-cost or mass-manufactured items that can conceivably be manufactured on the Moon or in orbit. It is still necessary to Earth-launch such items as control equipment, the spacecraft needed to shepherd loads to the construction site, hydrogen, nitrogen, and the robotic arms for manufacturing on the Moon and at the habitat site.

Lunar-Based Mass Driver. The bulk of the material for the radiation shield, which was to be built of lunar regolith, was to be launched as baseball-sized lumps of regolith, accelerated at 30G over a 10km track, and at a rate of about 10 per second. The launcher was to be a gas-powered gun. A "catcher" system positioned near L-2 would receive these ballistic payloads and "take" them to the construction site. We depart from this launcher, which was optimized for the single project of building a habitat, and instead argue for a versatile launcher system which will form the nucleus of the future translunar surface transport system. Our basic payload unit is a 160,000 kg "boxcar" filled with regolith, launched by a carriage which keeps the electromagnetic components of the launcher on the Moon for re-use.

Radiation Shielding Dominated The Mass Of The Settlement. Ref.[2] envisaged a stationary radiation shield around a revolving toroid, with some means for maintaining a suitable gap between the shield and the moving structure. This was seen to greatly reduce the strength demands on the spokes and other structure of the habitat. In our concept, we use metal cables to provide the initial scaffolding, followed by a robotically-welded-box rib and longtitudinal beams for the shell strength. The boxcars which carry the regolith become structural elements.

PRESENT MODEL OF A HABITAT

We adopted a strategy whereby the habitat project would itself serve to bootstrap an entire Space-based economy. Rather than optimize everything for the most efficient construction of the habitat, we looked at how to set up the many other industries in a synergistic economy. Our approach also assumes that human presence at the construction site is not necessary until the radiation shield is complete. Recurring costs are minimized, and thus the project can be spread out over a longer period. Since the construction is automatic (with at most telepresence supervision and control from Earth) we can afford to consider building a cylinder 2km long, with the entire radiation shield gradually accelerated to 1 RPM by the time the shield is complete. Major differences with the 1975 approach are summarized in Table 1.

Table 1: Primary Differences Between 1975 and Present Models

#	1975 models	Present model
1	$110/ lb Earth- LEO	$1,300 to $14,000 per lb to LEO
2	Human labor	Robots with telepresence supervision
3	Toroid with non-rotating shield.	Cylinder with flat or hemispherical end-caps for radiation shielding.
4	Build at L-5	Build shell at L-2 followed by slow move to L-5
5	H_2-powered 30g, 10km mass driver. Baseball-size loads.	Lunar-equatorial Solar-power fields, 6 e-mag launchers; round-the clock launches. Railcar-sized loads. 8-g, 40km track.
6	Inner toroid pressurized.	Pressurized 30m-membrane to provide micro-climates.

Choice Of Construction Location

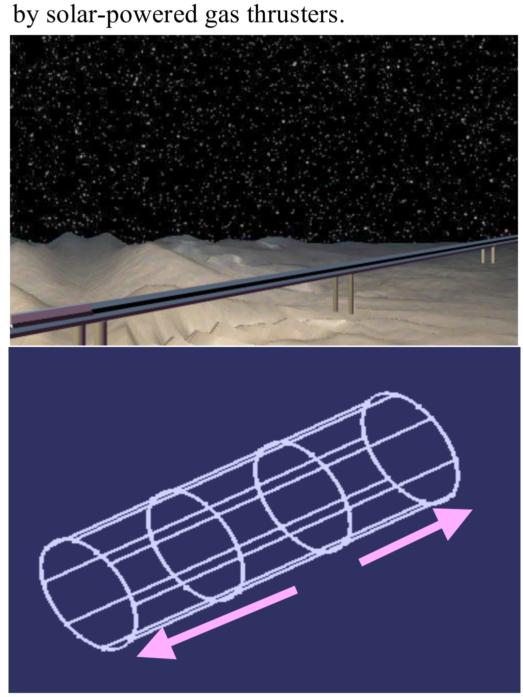
The Earth-Moon L-2 is chosen over L-5 as the construction location to minimize the lunar launch energy, followed by a low-thrust orbit transfer to L-5. The choice between Earth-Moon L2 and L1 is somewhat arbitrary, and is based on the convenience of direct observation on the near side of the Moon as the first power generation & beaming, metal extraction and launcher construction proceed. Heppenheimer and co-workers[5-7] evaluated over 48,000 test trajectories to obtain all achromatic trajectories from the moon to any of the earth-moon libration points L1 - L5, as candidate sites for a mass-catcher to receive material launched from the moon. They detailed ten such achromatics a photographic atlas of their launch sites. The best transport mode found was to launch from Mare Tranquillitatis to L2. A critical launch longitude was shown along the lunar equator (33.1 deg E) for a certain class of trajectories to L2. In the O'Neill system, the manufacturing facility was located within a DV of 10 to 30 m/s from L-2.

Optimal launchers for the O'Neill system were powered by gas or nuclear energy, either option requiring large earth-shipped mass. Their model imagined most of the regolith processing to occur inside the "manufacturing facility" part of the habitat – so there was little incentive to develop other infrastructure on the moon. These considerations drove their optimum solution to be one where a stream of mass, sized to approximate baseballs, would be accelerated at 30gs by a 10km accelerator track[7]. A complex "mass-catcher" would transport the mass to the "manufacturing facility".

In our model, we synergize other people's aspirations to build infrastructure on the moon, to enable all such projects. Thus, there can be multiple launchers, distributed around the moon's equator, and accordingly, multiple solar-power fields, power plants, mines and metal processing sites. Thus our launchers are part of a permanent lunar export infrastructure, with dual-use as the nucleus of a lunar surface transport system. Metal extraction and moderately sophisticated fabrication can already be done robotically on Earth hence these industries will be jump-started on the Moon. With the lower frequency of regolith launches in our model, it makes sense to have a few "Shepherd" spacecraft performing the triple functions of (a) mass-catcher, (b) transporter to the construction site, and (c) maneuvering the loads into position as the assembly of the structure. Interlocking appendages on the regolith containers enable much of the structural loads to be carried before the boxes are welded together by robot arms.

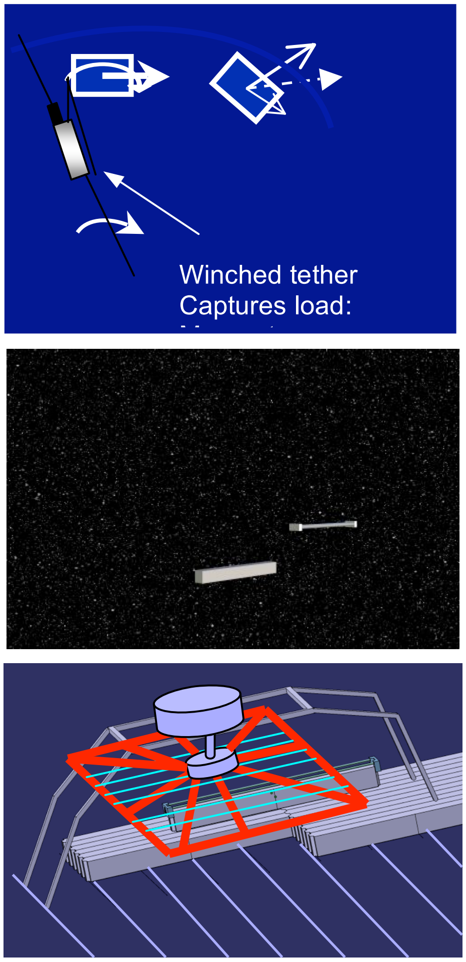
Construction Sequence

Figure 1 shows the launch of the boxcars from the moon and its rendezvous with the "Shepherd" craft. The first 4 boxcars carry the initial wire cage. A hub structure and a "construction spider" with an autonomous power supply, an electromagnetic wire grid, four robot legs with grapplers, and a robot welding arm, will be brought from Earth and positioned by the "shepherd" craft. The four cable rings, 1km in radius, spaced 4 meters apart, will be connected by longitudinal cables. The cage will be started in rotation by solar-powered gas thrusters.



1(a)

1(b)



1(c)

1(d)

1(e)

Figure 1(a) Deployment of initial cable loops. (b)Boxcar launched off the lunar surface in an orbit with apogee at L-2. (c)Boxcar enroute to rendezvous with "Shepherd" craft.(d)capture at the wire grid. (e) positioning using construction "spider".

Lunar regolith 2 m. deep is brought up in iron/steel railroad boxcars. Each boxcar is met by a "Shepherd" craft (Fig.1c). Each boxcar is brought by a hybrid gas/ e-mag "shepherd" craft, and guided towards the grid, where it is captured by a winched tether attached to the rotating grid. Axial momentum is transferred to radial and tangential, bringing the load to the periphery at 1kmph, into the space between the outer grid and an active, powered electromagnetic "Spider" construction grid (Fig.1e). Electromagnetic interaction between the loads, the construction grid, and the shepherds, moves the loads into position against the outer grid. The shepherds leave. Robots attached to the construction grid weld the boxcars to each other.

The ends of the cylinder are covered in any of various ways – inflatable water bags being one option. However, in our costing, we assumed that the same regolith/ boxcar system was used to seal up the entire side faces, with radial cables for initial support. To create atmospheres where needed for humans or agriculture, inflatable structures suffice. Fig. 2 is an artist's conception of the completed habitat, with pointable solar arrays shown attached.

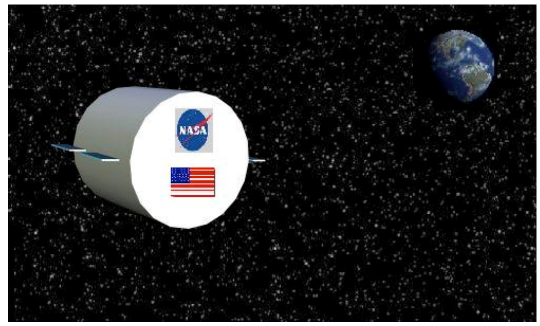


Figure 2: Completed cylindrical habitat

Summary Of Construction Sequence

•Lunar Solar-Power Fields made by robotic rovers around the equator

•Lunar metal extraction; cable manufacture using robotic plants.

•Lunar launcher construction.

•First cable-set deployment and spin-up.

•First ring of loads forms framework for subsequent cables and loads.

•Solar collectors, thrusters; hub with tethers and "Construction Spiders".

•Gas extraction from regolith for thrusters.

•Cylinder completion; endcaps sealed with regolith and water bags;

O2/N2 bubbles for habitation near rim; micro-g axial facilities.

•Human habitation commences.

Summary Of Construction Parameters

Table 2 highlights the Construction Parameters of the 1km radius cylinder radiation shield.

Table 2: Construction Parameters of 1km cylinder radiation shield:

1km radius, 2km long; 0.945 rpm; 1G. 2m shield depth. Grid current ~ 35 amps;12.5mm cable. Solar panels for grid power: 350m^2	Boxcar dimensions: 2mx2mx 20m Regolith: 160 Mg / load 10 launchers operational at any time (20 total around lunar equator) Time to build: 10 yrs.

Issues In The Technology

Shepherd craft - propulsion
Current concepts for Orbit Transfer Vehicles visualize solar-heated gas-powered vehicles which will perform LEO-GEO transfer missions. To eliminate large solar collectors, focused sunlight beamed from the Moon or the cylinder constitutes one option. The gas supply must be replenished, likely from a containers carried with some of the boxcar loads. One option is to use the robot arms on the Spider to refill these cylinders from ISRU units, and attach them to the thrusters needed to add angular momentum to the cylinder.

Shepherd craft – electromagnetic force.
A set of 3 electromagnets arranged in a "delta" on each end of the shepherd can provide enough maneuvering forces and moments during interaction with the field due to the grid held by the Spider. Superconducting magnets may be an option, with developments in the technology. Power could come from batteries charged during travel through the cylinder.

Optimal orbits and launch sequences.
Optimal trajectories and launcher locations have to be adapted to an architecture, which considers solar-power fields and metal mining/extraction sites on the Moon. Other issues related to this architecture are discussed in the next section where the project cost is considered.

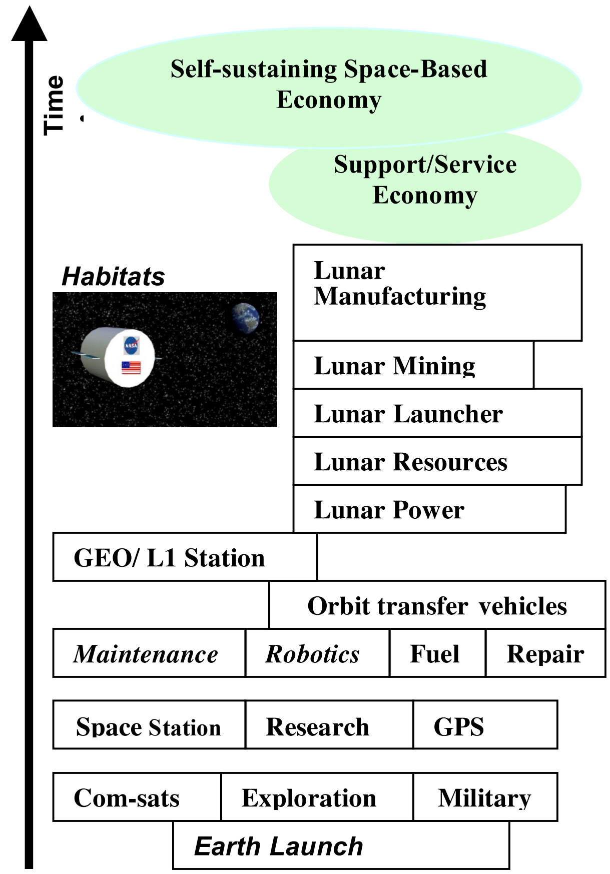


Figure 13: Evolution of the Space-Based Economy

PART 2- COST AND ARCHITECTURE MODELS FOR A SPACE-BASED ECONOMY

Introduction to the Space-Based Economy Concept

Figure 3 considers the evolution of space-related economic enterprise. Starting with the 1950s focus on launchers, Space enterprise has evolved through exploration and research, military and civilian remote sensing, com-sat businesses, the GPS, and Space Stations in LEO. Refueling and repair capabilities are expected soon, followed by orbit-transfer vehicles and then a large Station at earth-moon L1. With these will come a larger Space economy, in turn creating markets for lunar resources – especially oxygen and power. The growing industrial presence on the Moon and in GEO will, in time, create demand for orbital habitats, and then for resource extraction from the Near-Earth Objects.

As these enterprises develop, the primary markets, and the primary suppliers, of Space-related business will be located away from Earth – a true Space-based economy. Given that resources accessible on Earth are only a very small fraction of Solar System resources, the Space-based economy will surpass Earth's within a relatively short time beyond this stage, and has boundless potential for growth Below, we examine the costs of accelerating much of this development sequence using a synergistic plan to develop the first large habitat.

Arguments for a Space-Based Economy Approach to Building Habitats
The cost of building a habitat is dominated by that of the radiation shield and outer shell. With our proposed automatic technique, the cost of actually building the shell is made negligible in comparison with that of delivering the huge amount of material to L-2. The cost for this delivery (little recurring fuel cost except for orbit corrections of the Shepherds) is dominated by that of amortizing the electromagnetic launcher. The key to making such an immense project affordable is to ensure the congruence of various needs for such launchers on the Moon. Prior work on Space Manufacturing looks at manufacturing in space using non-Earth based resources and energy[8-11]. The Report of the National Commission on Space, 1986,[12,13] emphasizes an economical, phased approach for space exploitation,

which will be technically reasonable, and will support private enterprise. It focuses on the benefits that can accrue to humanity and the nation in particular. The report, however, stops short of outlining a clear vision of the concept that will integrate Science, Technology and Economics. That concept is the Space based Economy.

Differences in Proposed Approach

It is appropriate to ask: *"What can be done differently to improve the rate of progress of the human development of extraterrestrial resources?"* The literature on Space Commerce has focused on transportation, communication, remote sensing, and, to some extent, manufacturing. "Infrastructure" has usually been taken to mean Earth-based infrastructure[14-16]. Table 3 summarizes the differences in concept between today's Space economy, and a true Space-Based Economy (SBE). The SBE provides a vision which unifies proponents of robotic exploration, human exploration, lunar resource utilization, and asteroidal resource utilization – who today compete, often destructively, for a diminishing pool of public support and funding. The SBE vision follows a 'policy resilient approach', which builds up infrastructure to support multiple uses and goals.

Table 3: Differences Between Today's Space Enterprise and a Space-Based Economy

Current models of Space Enterprise	Space-Based Economy
-Earth as the only possible market. -Drive towards miniaturization. -3-to-5 year Return on Investment (ROI) expectation. -Terrestrial launch cost is key limiter. -No infrastructure for repair or resupply – high investment risk. -Support constituency: NASA Centers, launch companies, scientists. -Limited and decreasing interest and funding. - adversarial competition in support constituency.	-Most materials and products originate beyond Earth -Large Space infrastructure -Extra-terrestrial materials extraction & processing; large scale manufacturing. -Exchange of products and services between space-based enterprises. -Support constituency: diverse businesses & professions – broad cross-section of taxpayers. -Critical mass of funding and long-term investment.

Educating the Public

The business plan of a single industry that may appear risky and unsubstantiated when viewed by itself, can become realistic when patched into the network of a Space based Economy. From discussions with various graduate classes on Strategic Marketing over three years, we conclude that the key to attracting public interest is the provision of clear knowledge and methods to reduce risks and calculate business models. A detailed form of Fig. 4 can be used to develop every step needed for the SBE project. Technical risk can be reduced, and calculated, by developing alternative markets/ uses for all the technologies, which require large investment in the process.

At Georgia Tech's Center for a Space-Based Economy, we are developing and organizing public access to knowledge on what has been tried before, and on all the studies which have been performed. The steps in articulating such a comprehensive plan is given in Table 4.

Table 4: Steps in Articulating a Space-Based Economy

Setting up a space based Economy:	Key Requirements
-Articulate vision of the markets in space. -Work with authorities and visionaries on Space Resource Utilization, tourism, construction, aerospace, towards goal of a space-based economy. -Outline key requirements. -Give examples of potential space business ventures -Educate about gains in living standards. -Inform lawmakers of improved tax base, and national benefits.	-Clear vision of a Space-based economy, showing how most people and industries are stakeholders -Belief that such a space-based economy will develop -A credible plan to base this belief -Concrete examples of ventures in space, and predicted returns. -Project planning, cost estimation and risk-reduction strategies to articulate definite steps . -Communication of mutual interests between NASA, business, industry and lawmakers.

Summary of Industry & Infrastructure Bootstrapped by Habitat Project

The following extraterrestrial industries and infrastructure will be enabled in a synergistic Habitat project through the architecture, which is described above. Each is provided with an assured market, both from the habitat project, and from the other projects enabled.

- Power plants.
- Metal mining.

- Flexible manufacturing facilities for cables, metal panels, boxcars, rails.
- LEO – GEO – Lunar Orbit shipping industry
- Tether system for delivery to the Moon.
- Electromagnetic rail launchers – nucleus of circumlunar ground transport system.
- Oxygen extraction plants.
- Solar panel production
- Repair, exploration and prospecting facilities on the Moon.
- Habitat sized for eventual population of 10,000 people in orbit.
- Means to ship construction materials anywhere in the vicinity of Earth

The total markets for lunar resources, enabled by the Habitat project, are summarized below.

•Steel 2.8 million tons over 11 years
•Or Ti: 1.5 million tons over 11 years
•Regolith: 75 billion tons over 11 years
•Power: 66,200 GWh just for launch services; plus power for manufacturing.
•Manufacturing: 470,000+ boxcars; 960 km of e-mag rails.

Power Requirements

We assume an installed capacity of the Ignatiev Power plant of 1,000 MW, distributed around the lunar equator. The cost is assumed to be $ 0.40 per kW-h. .Professors Ignatiev and Criswell now estimate that beyond an installed capacity of 1GW, their solar-powered lunar power plants could generate electricity at a marginal cost below $0.01 per kW-h. We have not included this drop in our cost estimation. From the launch requirements, we find that the rated power capacity of the power plant is capable of supporting 6 launches an hour, with an excess of 18% for other uses, which amounts to 188,000 kW-h every hour.

Excess Launch Capabilities:

The exact requirement of the number of launchers for construction period of 10 years is 5.6 launchers. Since 6 launchers will be built, this gives a considerable excess launch capacity, which can be used for other applications.

TECHNOLOGY OPTIONS FOR RISK REDUCTION

In this section, we lay out the conceptual process for reducing the risk and cost of the cylindrical habitat architecture. For each aspect, there are different competing technologies, of which one is taken as the preferred option, with alternatives, which might become the preferred option if political or other technical developments so dictate. Options for power, metal mining and extraction, and launchers are given in Tables 5 – 7.

Table 5: Options for Power Generation

Preferred Option:	Alternatives:
--Lunar Solar-Power Fields made by robotic rovers. 20 power plants around the equator.	--Nuclear Power Plant on the Moon --Beamed Power from Space Solar Power Plant

Table 6: Options for Metal Mining & Extraction

Preferred Option:	Alternatives:
--Lunar open-pit iron mines (est: 4 – 15% of soil is Fe, in oxides). --Solar-heated metal extraction – vapor separation more viable than chemical reduction? --Robotic fabrication plant shipped to the Moon for box-cars, launcher rails, structural cables, conductors and magnets for launcher	--Pre-fab delivery from Earth using tethers. --Steel production on Mars or a Mars moon. --Earth-delivered boxcars for initial structure; Ship Fabrication plant to cylinder site; ship steel rods from Mars; land boxcars on Moon and re-use; -NEO resources.

Table 7: Launchers from the Moon

Preferred Option:	Alternatives:
-E-mag launcher sized for boxcars at 8G. - local power plants. -6 launchers around lunar Equator. 80-90% of power capacity used by Cylinder project for 10 years; -Rest used for export of oxygen & tether counter-masses -Tethers and launchers form transport system for industrial development	-Tethers . -Nuclear rockets (need propellant gas)

Cost Estimation Approaches

An upper bound on cost is obtained by the 'Delivered Cost Approach' [3]. Here the cost of materials delivered at a given point in Space would be limited (a) from above by the cost of getting similar materials delivered from Earth and (b) from below by the supplier demanding the most that the market will bear. This approach will result in few projects being feasible. Secondly, one could estimate the capital cost of the government constructing the entire Space-Based Economy. A third approach is to bring in all players at the outset, and figure the costs and risks to each, given the presence of the rest. Ignatiev[17] for example, estimates a robotic 10,000 MW solar power plant on the Moon at $ 62B in year-2000 dollars. This will have a multi-customer base, including mining, fuel extraction, manufacturing and launch services. The cost for strip mining on the Moon is estimated as $3 B in year 1979 dollars[18], extrapolated using Consumer Price Index Inflation to $8B in 2000$. For the Lunar Launcher System, the cost adjusted for inflation, gives a Present Value estimate of $8B. The assumed cost figures, and the final cost estimate, are given in Tables 8 and 9 respectively.

Table 8: Cost-Drivers for the Cylindrical Habitat Project

Item	Sub-item	Cost, US$ (2002)/kg
Material Costs	Steel on Earth	5
	Aluminum on Earth	3
	Iron on Earth	1
	Steel on Moon	12.5
	Aluminum on Moon	12.5
	Iron on Moon	12.5
	Concrete on Moon	5
	Shepherd fuel on Moon	10
	Regolith on Moon	0.06
Launch Costs	Launch from Earth to L2, $/kg	4000
	Launch from Earth to Moon	5000
Power Costs	Power on Moon ($ /kwH)	0.4
	Solar panels at L2, $/m^2	50000

As more businesses are enabled by the "assured market" of the Radiation Shield project, the required public funding drops. The requirement drops from $200B if the Shield is the only end product, to $130B if it buys power from the lunar power plant while assuring the power-producers of demand during the initial decades of their production. With power and materials available, the launcher cost comes down again with an assured and diversified market to reduce risks in its development. The reduction of risk through the synergy of several technologies and customers, is illustrated in Table 10.

CONCLUDING REMARKS

This paper takes a look at the requirements for setting up a Space-Based Economy. The technical issues in building the massive radiation shield for a human settlement are reviewed in the light of today's capabilities for robotics and communication. By including the visions of several concepts such as lunar-based power, mass drivers and resource extraction, it is shown that the overall cost and risk of such a major project can be brought down to imaginable levels. As more business visions are enabled by the assurance of a massive market provided by the infrastructure project, the level of public funding needed for the infrastructure comes down, even before tax revenues begin. The process for gathering public support for such an Economy is considered. Unlike today's exploration-focused government Space program, and isolated business plans for private ventures, the SBE can unite the public in supporting the Space enterprise. This approach outlines a roadmap that will help in triggering a self-sustaining economy in space. Construction of the large habitat forms the hub of the strategy of reaching a critical mass level in space exploration.

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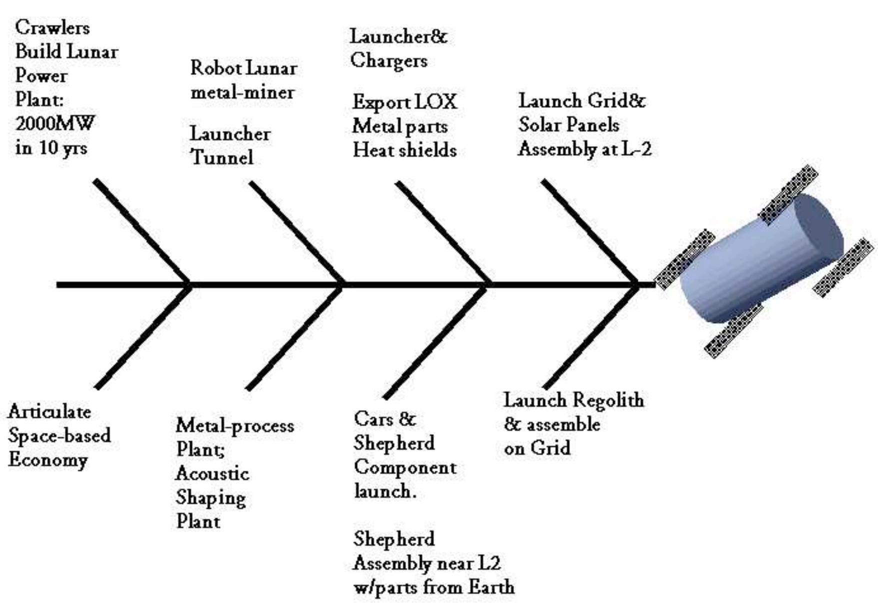

Figure 4: Architecture for the construction of the radiation shield of a 2km diameter cylindrical habitat

Table9: Final Cost Analysis for the Cylindrical Habitat Project

		in US BN $ (2002)					
Year	**Process**	**Material Cost**	**Earth Launch cost**	**Launch Power Cost**	**Power-L2 cost**	**Fuel cost**	**Total**
1 & 2	**Mass Driver Construction**	6.5	0.0	0.0	0.0	0.0	**6.5**
	Winch	0.0	0.0	0.0	0.0	0.0	**0.0**
	Shepherds	0.0	0.0	1.0	0.0	31.8	**32.8**
	Crawlers	0.0	0.0	0.0	0.0	0.0	**0.0**
3	**Wire Grid**	0.0	0.0	0.0	0.0	0.0	**0.0**
4 to 13	**Boxcars**	66.0	0.0	25.5	0.0	0.0	**91.5**
	Spin-up city	0.0	0.0	0.0	0.0	0.0	**0.0**
	Total	**72.5**	**0.1**	**26.5**	**0.0**	**31.8**	**130.8**

Table 10: Examples of Risk Reduction via Strategic Networking of Space Businesses

Investment	**Applications**	**Users**	**Alternative uses for facilities**
Lunar Power Station	Beam Power	Deep Space Probes, Space City, Satellites, Earth, Space Manufacturing,	Semi-conductors, Repair panels, Scientific microwave telescopes, Convert Rovers for mining
	Supply Power	E-mag launcher, Mining Operation, Advertising: laser billboards, Military	
Lunar mining	Materials	Space probes, Space stations, Fuel satellites, Radiation shielding, Repair material, Communication antennae-interplanetary communication hub	Construction, Digging tunnel habitations, Green house construction, Exotic materials for Earth based use