Space-Based Economy Valuation, Analysis, and Refinement

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A sequence is postulated, through which today's mission-dominated space enterprise may begin the transition into a self-sustaining space-based economy dominated by extraterrestrial resources and services. A set of 15 enterprises is considered, that define the basis for the expansion to another 15 larger enterprises. Examples of the first four enterprises are given. Interactions between these enterprises are projected to enable an order of magnitude reduction in the cost of access to geosynchronous orbit.

I. Introduction

In Ref. 1 we took an initial look at the issues involved in generating a flourishing space economy, postulating that opportunities developed at the interface between existing projects, to provide common resources and services. We postulated that by combining the business plans of two or more well-chosen "space commercialization" concepts, the market projections of both the concepts could be greatly improved, their costs and risks slashed, and hence their return on investment improved, sometimes by large enough factors to make them attractive. A 4-level evolution shown in Figure 1, and summarized in Table 1, from Ref. 2, was envisaged, starting with today's largely isolated major projects at Level One. Level One projects can be designed as *Missions*. Level Two involves *Interactive Services* such as the ISS, in-space attachment of re-boost packages, orbit transfer vehicles and common launchers. In Level 3, these in-space resources enable and create demand for enterprises that extract *Extra-Terrestrial Resources*, such as lunar mining and lunar oxygen. In Level 4, a host of smaller *Derivative Enterprises* caters to niches providing common services, leading to a full-scale space based economy.

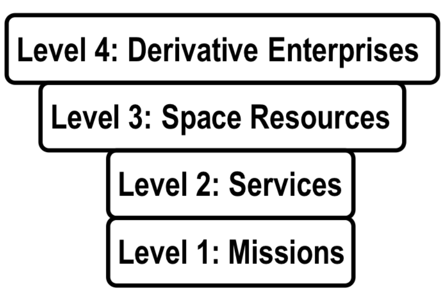

Figure 1: 4-level Evolution of Space Economy. Summarized from Ref. 2

This paper begins the process of laying out a sequence in which such a space based economy might grow, focusing on Level Two – Interactive Services. The process depends on two key assumptions which derive from previous work[1]. The first is that there is an acceptable level of certainty that all business elements in this process will start operation on a common timetable. The second is that competition and mutual interaction will bring keep reducing costs over time, while allowing windows of attractive profitability and market security. These assumptions enable synchronization and scheduling of market demand, price reductions, and technical feasibility. Implicit in these assumptions is the presence of a multinational / global entity[2] organized and empowered to enable and sustain this progression through planning, coordination, and some backing to obtain capital at sustainable costs. The paper lays out the sequence at a very simple and basic level, to explore the process by which a plan for the rapid growth of a Space-based Economy can be developed.

Forecasting business fortunes in space is no more accurate than forecasting the performance of individual stocks. It is even less so, because of the large differences, sometimes artificial, in the *known costs* of every element involved, and in technical options. Many steps that might be obvious in most other fields of venture are not "done" or feasible in the space enterprise, for complex reasons that may or may not disappear suddenly. Thus the problem formulation for this paper includes the following caveats:

- The numbers used are the best that we can find; however, we have preferred simplicity to precision and thus avoided, for instance, complex orbital and financial calculations that do not in our view, provide significant gains in accuracy of prediction.
- Of the myriad factors that influence the profitability of an enterprise, we have tried to select and focus on those, which are of first-order significance – rudimentary and special to the enterprise.
- No particular company is envisaged; rather, the economy is developed in terms of general business parameters facing any company in a general area such as in-space refueling or lunar metal extraction, within the framework of a space economy with some synergy and organization.
- The detailed exploration of opportunities and avenues within the framework is the province of entrepreneurs and specialists on the particular technologies.
- A framework, however, has been seen to be essential for all to move ahead, and this is what we try to present.
- To address the unreliability of the numbers, we posted the business cases as they develop, on an Internet site[3], so that comments from those who know better numbers, might improve the accuracy of the models. The problem being considered in this paper is how to quantify the viability of the first steps that are essential to the subsequent development, and then to show that these steps will lead to tangible benefits in the short term, as applied to the case of a well-known objective of the space enterprise – reducing the cost of access to Geostationary Earth Orbit (GEO).

A. Background

Every concept for a large advancement of a Space Economy brings the question of how contemporary national space programs will change direction and expand to enable the realization of such dreams. No short-term solutions have been found. Many excellent ideas remain unable to generate the credibility required to advance towards realization – thus validating the position that national space programs cannot expand to realize such dreams. National programs appear to have given up, and decided to focus on "reducing cost of access to Space" as the top priority, although there is neither the expansion of demand, nor any evident breakthrough in technology, to offer much hope in this regard. One way to break out of this cycle is to accept that we are not at a stage where we can turn the course of next year's budget. This frees us from the need to compete against other concepts, and instead try to lay out what a global space economy of the future would involve. Then we consider how to get there from here. The general line of thought pursued in this paper and its predecessors is to go out and envisage what might comprise a well-developed Space economy, and then work to build the framework that gets us to that level from today's level. We hope to show in this paper, that pursuing such an approach will in fact also cut the cost of access to Space by an order of magnitude in the short term.

Table 1: Evolution of a Space Economy. Modified from Ref. 2

Level 1: Missions	Launch Vehicles, Lunar exploration, Military reconnaissance, ISS & STS, Hubble Telescope, Crew Exploration Vehicle, Deep Space Science, Weather sensing, GEO Television, Telephone / internet, Remote Sensing, GPS, GLONASS, Galileo, LEO science missions, Sounding rockets, Suborbital tourism
Level 2: Interactive Services	Orbit Reboost Packages, Refueling, Repair, Orbit Transfer Vehicles, Orbit-on-demand common cargo vehicles, Tethers, new earth-based enterprises
Level 3: Extra-terrestrial Resource Exploitation	Lunar oxygen factory, Lunar / space solar power station, Lunar metal mining & extraction, Lunar metal parts fabrication, Lunar radiation shielding production, Lunar landing and launch facility, Lunar orbit transit station, Mars / Asteroidal Cyclers
Level 4: Derivative Enterprises	Long-term habitats, Food growth, Food supply, Water Supply, LEO fuel transfer depot, Facility repairs/ spares, Space junk removal, Tourist / hotel facilities, Lunar prospecting laboratories, NEO sampling labs, Space Training … (Hundreds more)

B. Previous Work

At the current time, the space related industry is valued at about 126 billion dollars per year. It is still true that all of this is spent on Earth, since all resources, services and markets are still on earth. In addition, much of the above figure consists of earth-based infrastructure and customer support, rather than the space portion of the enterprise. The overall size of the space related industry is relatively small compared with the total economic activity of the earth (about 30 trillion dollars of total GNP in 2000). If the space economy were a country, however, it would rank between 25 to 30th in the world. As extraterrestrial resources come into play, the value of the space economy can be several orders of magnitude larger. A required enabler for this evolution is large-scale in-space infrastructure. We argued in Ref. 1 that such infrastructure would not develop initially without global participation as investors, customers, developers and workers. We then considered that such global cooperation would face severe problems due to national security concerns. We suggested that this problem offered the impetus for its own solution – that the security concerns are in fact common to most national governments in the world, and are not solved by approaches based on nationality.

We considered organizational structures where nations could cooperate, and people could move freely across systems and technology developed by various nations, without compromising national security concerns. The airport and air traffic infrastructure was cited as an example of global cooperation. The current trend of multinational participation in large-scale aircraft manufacture and the new European "Galileo" global positioning system were seen as examples of global commercial synergy. We pointed to the European Space Agency as offering valuable lessons and case studies in developing such a structure, where international cooperation and ESA-owned projects co-exist in appropriate openness and compartmentalization, with the national space programs of several nations. We suggested a form of the ESA structure, modified to incorporate commercial entities, as a first model of a global space infrastructure developer, ISIC (International Space Infrastructure Consortium).

In Ref. 2, a quantitative modeling technique was adopted, to construct the core of a Space economy model involving mutual interactions. The result of interactions in a space-based economy showed that the seemingly insurmountable barriers to entry and sustainability began to lessen as the number of separate enterprises increased. It was shown quantitatively that benefits arose from reduced insurance risk, greater markets for products, and vastly lowered cost of supplies in some cases. The idea of the global Consortium was further refined, and we showed that it would also provide a solution for one of the greatest problems of space business. This is the difficulty in obtaining low-cost financing for commercial ventures. Many business plans that look good when modeled with the 6% cost of money from long-term government-backed loans, become impractical when the cost of money reflects venture capital market rates. The Consortium offers a way to link government backing and commercial ventures in order to assure financing on better terms. Finally, we suggested that a Consortium might offer a way to break the impasse regarding property rights. The idea of using multinational global corporations for space resource utilization was mooted as a way to get both the risk-spreading and broad, long-term financial backing needed, and to alleviate concerns about single-nation monopolies over space resources. With such an arrangement, we suggested that new treaties would address "common heritage" concerns while permitting entrepreneurship in exploiting space resources.

Previous ideas for Space-based business are abundant. Blair [4] developed an economic forecasting model and applied it to the lunar-derived fuel industry. Blair et al[5] summarized prospects for many of these, and provides balance sheet projections for companies formed on some of them. His focus is on lunar-based enterprises, as well as contemporary enterprises such as Space Tourism using suborbital launches. Blair et al[6] emphasize the role of *in situ* resource utlization (ISRU) projects, as enablers for space commercialization. The ideas presented there are carefully considered in developing our sequencing scheme in this paper. Blair et al argued for efforts to promote investments in ISRU technologies. A roadmap[7] for ISRU capability development has been developed by NASA in 2005. Other data sources used here include the Space Access Society[8], Commercial Space Markets data[9], a U.S. Federal Aviation Administration report on the economic impact of Space Transportation on the U.S. economy[10] and a paper on economic analysis tools for mineral projects in space[11]. Cox[12] considers commercial activities that might develop in space, and agrees with the need for organized private-public ventures to enable both long-term infrastructure projects and short-term entrepreneurship. Maness and Hendrickson[13] give comparative cost figures for several types of power generation enterprises.

II. Objective and Scope

With the conceptual structure in place, we now turn back towards considering interactions between space business concepts. The objectives of this paper are:

1. To look more closely on the first steps that are needed to develop the Level Two enterprises, considering interactions.

2. To demonstrate that these steps will lead to a tangible short-term benefit – the reduction of the cost of access to GEO.
3. The long-term objective is to create a platform for future space-based businesses to validate and determine the feasibility of their respective operations.

In this paper, we lay out 30 business concepts selected from existing and projected ideas. The modeling continues to use Microsoft Excel spreadsheets to model the basic, nearer-term set of enterprises, and then the "STELLA" and "ITHINK" software to enable temporal evolution and graphical visualization of the model simulations for the more far-term enterprises, with greater complexity and randomness introduced.

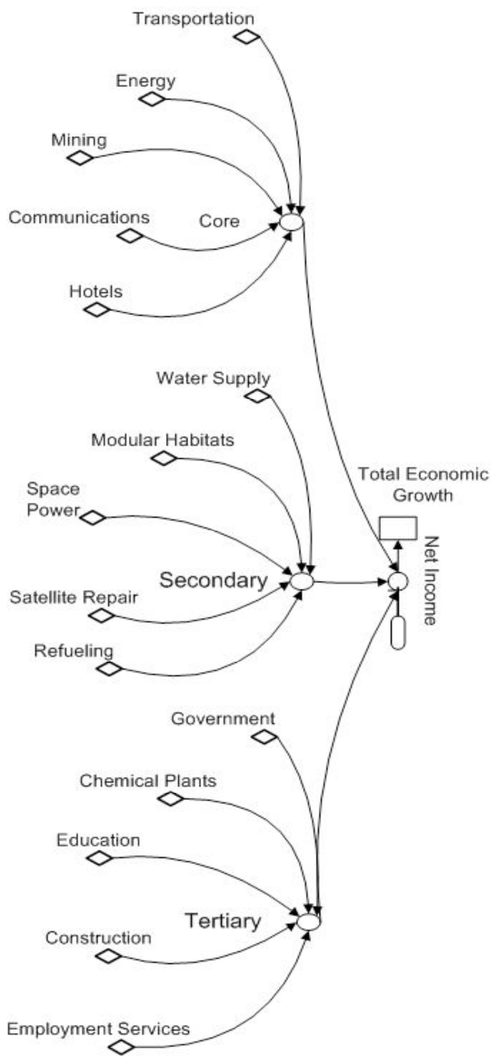

Figure 2. Conceptual form of the Space economy, where several enterprises interact. From Ref. 2

Figure 2, from Ref. 2, shows a conceptual form of the Space economy, where several enterprises interact.

III. Postulated Sequence of Development

Initial Enterprise Ideas

Table 2 shows one possible sequence of development. In this section, several of the initial businesses will be discussed. Their interactions will be discussed in a following section, and the overall economy development will then be considered.

1. Reboost Packages

Reboost packages[14] have been proposed, to extend the lifetime of geosynchronous satellites. Since present-day GEO satellites are not designed to handle refueling, the reboost package is an autonomous system including fuel, an engine, controls and communications, as well as the capacity to rendezvous and attach to a satellite. Reboost packages are extremely significant, because they substantially extend the lifetime of a satellite. The military interest in this stems from the possibility to execute several plane-change maneuvers, which are expensive in fuel consumption, to respond to international crises. Initial customers outside the military are expected to be GEO satellite operators whose satellites are nearing their successful design life. These satellites have paid off, and are generating revenue at little cost. Additional life would be gravy. The ability to do orbit reboost vastly reduces the risk of GEO launches, and thus reduces insurance costs.

The idea of reboost has been discussed in conference presentations and DARPA solicitations. In the US, the reboost package is modeled as an enterprise developed under DoD sponsorship, aimed at enabling DoD satellites to perform plane changes, and extend their lifetimes. Thus it is expected that the development cost is already borne by DoD, and the enterprise is ready for commercialization. It is expected that this will be restricted to US-flag GEO communications satellites until ITAR concerns are addressed. The reboost business was modeled, with an assumed number of GEO satellites as the market. It is argued that ITAR exemption may be possible for this application, as long as it is limited to civilian/ commercial satellites, and the launch is done from the US, so that the equipment is never out of US hands until it reaches Space, when it is beyond anyone's reach. An example of a public-domain reference to a reboost-capable system developed by China, with commercial potential is cited here[15].

For our purposes, DoD funding is assumed to have paid for the development of the US technology when it goes commercial in the US, so that it has an easier time reaching breakeven. As Figure 3 shows, reboost appears to be a viable business. Parameters are given in Table 3. Reboost is clearly a limited-window business opportunity, as future satellites designed for on-orbit refueling will render the engine, controls, power systems and fuel tanks of the reboost package superfluous. Accordingly, Figure 3 shows the NPV crossing zero quickly, and rising to a good level, but then peaking and dropping thereafter.

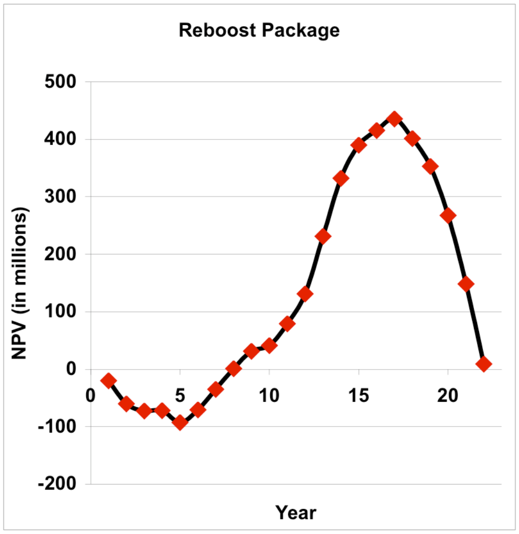

Figure 3. The NPV of the reboost enterprise becomes positive in 8 years, and peaks in 17.

2. Refueling

Once the rendezvous technology of reboost becomes routine, satellites will be designed for refueling. So the next business is assumed to be one where small craft rendezvous with expendable launchers or external fuel tanks, fill up with the reserve fuel contained there, and service other satellites in LEO with fuel. Thus, reboost packages may be refueled in LEO, and lift boost themselves to GEO, or be refueled in GEO. The viability of this business is tied to the Δv needed for LEO-GEO, the cost of fuel as obtained from the expendables (there is finite risk of collision creating a debris problem for the launcher's owners), and the cost of fuel delivered directly from Earth. Thus this business is surprisingly difficult to justify on the basis of return on investment. Its development, however, is crucial to following events, and to the justification of lunar and NEO-based fuel extraction enterprises which are postulated to be precursors to a true breakout from Earth orbit. In view of this, viability of the fuel enterprise may require intervention from the Consortium or national agencies.

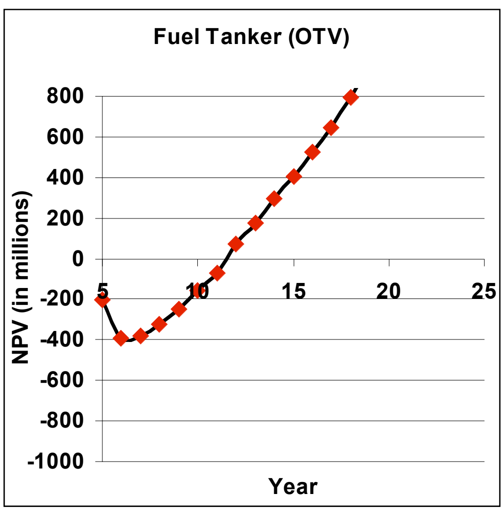

Figure 4: The fuel tanker orbital vehicle enterprise

Here, the vehicle is modeled on existing cargo suppliers such as the Progress cargo/fuel vehicle, but with a low liftoff mass comparable to that of the 3rd stage engine of a GEO satellite, since its primary function is to be a fuel tank and a rendezvous vehicle. Hence the development cost is quite low. The challenging part of the operation is to rendezvous with expendable boosters and draw out their remaining fuel before they drop out of orbit, and then detach and transfer the fuel to customer craft. The advantage is that the fuel is obtained at a low cost, delivered in LEO, while it can be sold to craft bound for GEO or elsewhere.

Market Size for services is based on how many satellites require refueling. The average lifetime for a satellite is 13 years. As of 1995, there were 238 operational GEO satellites[16] (both commercial and military). We started at a low amount saying that out of the satellites in orbit, at least 10 of them are near the end of their lifetime and could be refueled. Considering that each year, 12 satellites are put into orbit[17], if refueling is an option, at least 10 could be refueled and used instead of launching another satellite. With 10 as a maximum for number of services, the market size was randomly varied to reflect highs and lows of the business. Figure 4 shows that the enterprise breaks even in 13 years, and thereafter has a window of high profitability. The possibility of accidents and setbacks is not taken into account in this simple model.

3. Reusable Upper Stage Orbit Transfer Vehicle

The next major step is the Orbit Transfer Vehicle or Space Tug, to ferry satellites from LEO to GEO. In-space refueling enables OTVs to carry out many missions. OTVs render the expensive cryogenic third-stage of many GEO launchers, superfluous. A much smaller orbit correction engine and a supply of fuel is all that is needed, with the OTV performing the LEO-GEO delivery. In the short term, this would hurt the manufacture of third-stage engines, but in the longer term, the demand for OTVs should more than replace the lost business. Here the emphasis is on the engine rather than the fuel. The idea is to provide high-thrust upper-stage engines that will take satellites from LEO to GEO, and then leave them there with only low-thrust, high Isp orbit correction engines for the rest of their lifetime (with the possibility of reboost/refuel). The engine then comes down and is reused. The number of engine firings is limited by material degradation. The impact on customer cost is the drastic reduction in launch cost per unit payload delivered to LEO, since the mass of the upper stage engine, the boost fuel, and the risk associated with first-time operation of a new cryogenic engine, are all avoided. The fuel is delivered in LEO, at the cost negotiated between the RUS and the tanker OTV, and may range from the low costs expected if the fuel comes from expendable boosters, to the higher costs of earth-delivered fuel, which comes in packages sent up on low-cost, high-risk launches rather than the expensive satellite launch vehicle. Figure 5 projects the NPV of the enterprise.

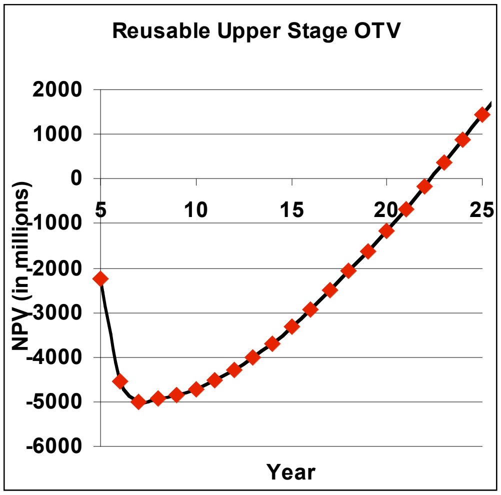

Figure 5: Reusable Upper Stage enterprise

4. External Tank Fuel Depot

The idea of boosting the external tank of the Space Shuttle to a stable low earth orbit has been considered for many years. A business plan for an operating Tank Farm was presented by Taylor[18]. Many of the ideas there are adopted here, but the plan is set within the context of the staged development of Space infrastructure. The Refueling business provides the motivation for a fuel collection depot, to be assembled from STS main tanks, or large ESA / Russian rocket parts. This is the precursor to the long-discussed External Tank (ET) Space Station. Again, this business poses considerable hazards and business risk. At its initial stage, it appears advisable to separate the fuel depot function from the manufacturing / habitat functions, in view of the risk. In the shorter term, the limited lifetime of fuel tanker vehicles, the high cost of extracting fuel from expendable launchers, and the construction cost of the tank farm, make a difficult business. In the long term, as launcher designs are modified to take advantage of this business, these costs come down. Figure 7 shows the prospects.

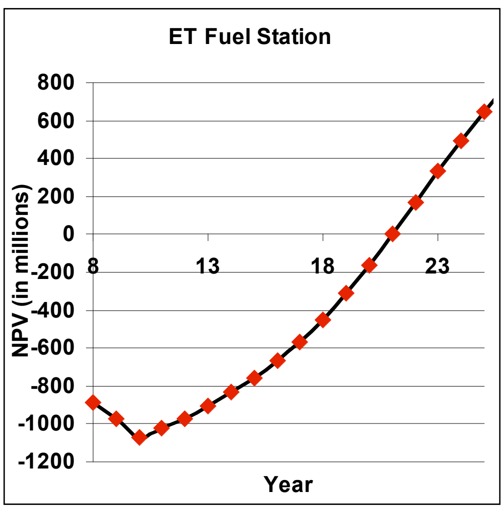

Figure 7: External-Tank Orbiting Fuel Station

5. Orbit-on-Demand Common Cargo Vehicle

This is included as a step in the economy evolution, is a minor departure from today's Progress series of Russian cargo launchers. Given the extensive experience with the Progress vehicle, it will be difficult for competitors to match the costs of this system; however, reusable launchers with airbreathing stages may become viable at some point. For now, we base calculations on the Progress series. The large market for these launchers comes from the next item on the list – which in turn offers the potential for an entirely different type of orbit-on-demand systems.

6. Orbital Tethers

Much work has been done on the application of tethers in Space. The best-known is the grand idea for a "Space elevator" – a very long and very strong tether system in geosynchronous orbit, tied to a point on earth (usually a launch platform in the Pacific off Central America, where lightning strikes are said to be virtually unknown). However, less ambitious tether ideas abound, among them, systems that orbit Earth, use the electrodynamic forces of the earth's magnetic field for propulsion, and serve to move orbiting objects from one orbit to another.

Orbiting tethers provide a possible solution to the "space junk removal" problem, by swinging dead spacecraft, or large pieces thereof, from their present orbits and into atmospheric reentry trajectories. Going further, orbiting tethers could conceivable swing small payloads from a suborbital flight, into an actual orbit, while allowing the delivery vehicle to return to Earth. This would be a breakthrough for renewable launchers, in that most of the launch vehicle can return to earth, never exceeding high supersonic speeds, while the payload itself is given the energy to reach orbit.

7. Junk Removal
Tethers and reboost packages offer the technology to remove dangerous orbiting objects. The market for this enterprise has been considered by Blair[4]. Other ideas have been suggested for melting external tanks and other expendable components in orbit using solar energy and forming them into useful shapes.

8. Tourist flights to orbit
While suborbital tourist flights are a crucial precursor to a breakthrough, we do not include that industry here as it is already very real, and as it does not actually reach orbit as yet. However, the orbital tourist industry has started with a handful of astronauts already, and once the other enterprises above reduce risk and cost, orbital tourism will indeed become a player. This enterprise too has been studied extensively.

9. On-orbit repair
This enterprise is enabled by the capabilities of the reboost and refueling enterprises, but assumes a greater level of robotics confidence, and telepresence operation. It may start with specific high-value spacecraft rescue/repair missions, but evolve to a more routine space-based maintenance/servicing enterprise, based at the Fuel Depots.

10. Beamed Power to Space
At present each spacecraft has to carry its own solar arrays, whose deployment has been a problem area on several launches. Arrays degrade over time. Thus, space-based assets can afford to pay premium prices for beamed electric power. We project that this is a fertile area for starting an enterprise where power generated off-peak from renewable-energy plants (and from baseload nuclear plants) can be beamed to space-based assets. In this application, beamed power is made viable despite its 50%-60% peak efficiency by the large savings in satellite solar array costs.

The above suite of ten enterprises comprises the technical core of a major new infrastructure in space: refueling, reboosting, repair, tethers, junk removal, and power beaming, with resupply and tourism to provide a growing market for space launch. The next set of enterprises is more ambitions, and builds on this infrastructure.

11. The Space Power Grid
Building off the beamed-power enterprise, we have proposed that a low-earth orbit constellation of 36 to 64 satellites will enable virtually real-time beamed power transactions between points on earth, thereby enabling rapid growth in renewable-energy plants on earth which are currently handicapped by having to compete against the established earth power grid. The major technical challenges in this enterprise are solved when power beaming to satellites is established, with the exception of the problem of satellite heating.

12. Lunar Oxygen
The fuel industry infrastructure set up in the first ten enterprises, becomes the expansion market for a lunar-based oxygen extraction business. Initial customers for lunar oxygen will of course be on the moon, associated with planned bases. This business is also tied into the lunar water and lunar steel industries.

13. Lunar Shuttle
As lunar oxygen extraction gets underway, the market for delivery of hydrogen and equipment to the moon, and fuel and steel from the moon, justify establishment of lunar launch/lander services, connecting perhaps to orbiting stations in lunar orbit, or rendezvous with OTVs for transit to GEO or earth-moon L2, L4 or L5. Initially, the demand is for delivery of many tons of equipment, supplies, and hydrogen to the lunar surface, with high-value cargo for return being such things as crystallized lunar rocks and perhaps geology samples.

14. Lunar Water
Hydrogen from the fuel depots, delivered to the moon will be used in extracting steel and other metals, also generating water for use on the moon. This requires several flights to the lunar surface.

15. Lunar Steel
The moon is an abundant source to generate steel, aluminum and titanium. The lunar steel enterprise was discussed in Ref. 2, where we argued that the potential for this industry is unlimited, once lunar transportation is established, hydrogen is brought in (or power becomes cheap) and a market exists for the byproducts of metal production.

The other 15 enterprises that we have listed are more long-term, but define the progression to a large and expanding space-based economy.

Table 3: Parameters Used for Example Enterprises

Reboost	Tanker	Reusable Upper Stage	External Tank Fuel Station
Mass-500 kg Revenue per package – $60M Cost per package: Material - $20M Maintenance - $10M	Mass-2000 kg Revenue per service – $15 million Cost per tanker: Material - $7 million Maintenance - $10M Operation - $10M/refueling	Mass-10000 kg Isp of 460s[19]. Revenue per boost – $25M Development Cost - $100M Cost per 3rd stage[20]: $20M Maintenance - $10M Operation - $10M per boost + $5M/yr for flight control services. Lifetime: 50 burns.	2500 kg of fuel per ET Mass-10000 kg Revenue: $8000/kg of fuel – Development Cost $800M Cost: Maintenance - $10M Operation - $10M/ service Transportation (to retrieve fuel from ET) - $6000 per kg
Fixed (insurance) – 15% of material plus operation cost[21]. Launch costs: $26000 /kg to GEO (source: Futron[22], $13000/kg to LEO. Revenue starts decreasing by 5% per year, Y years after company begins			
Y=13	Y=20	Y=20	Y=13

Table 4: Postulated Sequence of Deployment

No.	Enterprise	Year Deployed
1	Reboost packages	1
2	Refueling	5
3	Reusable Upper Stage	5
4	Fueling station (ET)	8
5	Orbit-on-demand common cargo vehicle	5
6	Orbital tethers	10
7	Junk removal	10
8	Tourist flights to orbit	10
9	On-orbit repair	12
10	Beamed Power to Spacecraft	15
11	Space Power Grid	20
12	Lunar oxygen	15
13	Lunar Shuttle	15
14	Lunar Water	15
15	Lunar steel	15
16	Orbital hotel	16
17	In-space production	17
18	Lunar power	16
19	Lunar port	16
20	Lunar metal parts	16
21	Lunar habitats	17
22	Lunar prospecting	17
23	Lunar materials	17
24	Lunar radiation shielding	17
25	Asteroid mass return	14
26	TFF – small parts	17
27	TFF – large construction	18
28	Mars Cycler	20
29	Orbiting Solar Power	25
30	Orbital food	20
31	Orbital habitat	22

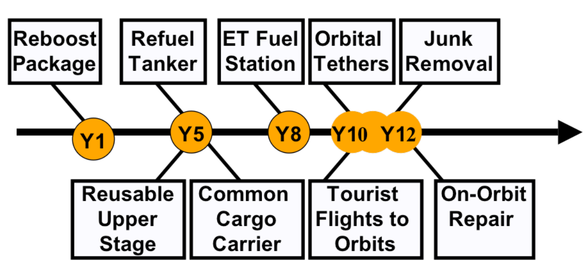

Figure 8: Sequencing of the first enterprises

IV. Interactions and Their Effects

Effect on GEO launches cost

The cost of satellite launch to GEO is used as an example of how costs come down as the space economy proceeds. The mass breakdown of a typical 4000kg GEO satellite is given by EADS[23] as 1250kg payload, 750kg Bus, 2000 kg chemical propulsion (including propellant). They give a cost of 20,000 Euros per kg for transfer from earth to GEO. The hardware cost of an upper stage motor is typically $4M to $8M for a payload of 2000 to 4000 Kg. The mass penalty of carrying the upper stage and its fuel, from earth to LEO is substantial. The risk is also high, as the upper-stage cryogenic stage engine is designed for short burn lifetime. The effects of interactions with the other enterprises named before are:

- No upper stage or upper stage fuel need be carried from earth to LEO. This implies that payload fraction from earth doubles. The cost of the expendable upper stage hardware is balanced against the cost of hiring an OTV instead. While the fuel used is assumed to be at least partially satisfied by the excess fuel farmed by the fuel tankers, the only fuel cost saving projected is a small saving due to the ability to send fuel in lower-quality expendable launch vehicles, versus the high-cost GEO satellite launcher.
- The presence of the reboost package reduces reserve fuel needs, contributing a 10% payload gain.
- Insurance premium comes down by a projected 80% because of the presence of the reboost package, refueling, and because the repair industry. This works out to 12% of the original mission cost.
- The availability of repair services cuts the need for redundancy of on-board systems – systems can be replaced. Also, a much greater saving comes from the fact that off-the-shelf components can be used, instead of long-life, high cost components. These contribute to a mass reduction of 30% of the bus, payload and controls, as well as a cost reduction by 60% of these components. Thus the payload fraction goes up by a further 10%, and the same payload mass now performs 2.5 times the functionality of the previous designs. The effective reduction in launch cost is now on the order of 82%, and the functionality gained is on the order of 200 to 250% with the same mass. Thus we have come close to reducing the initial space-based cost of a GEO satellite enterprise by an order of magnitude. Another factor of 10 reduction is needed, to achieve the levels projected by Collins et al for GEO power systems, so we maintain that even this level of interaction will not justify that enterprise.

V. Discussion

The data above show that a staged sequence of enterprises can each generate a positive NPV, very substantial in some cases, and yet cut the costs of access to GEO. The resulting infrastructure also sets the stage for the next set of enterprises, which are in fact the ones most discussed in modern concept studies. They also set the stage for the development of extraterrestrial resource exploitation, opening up the space economy. The precise pricing levels for interaction between the different enterprises is a matter of negotiation between entrepreneurs.

VI. Conclusions

1. A sequence of techno-business developments is postulated, leading towards a full-fledged Space economy. The Net Present Value of several of these developments is projected and examined.
2. The initial enterprises considered can provide a major change to space-based capabilities in the near term.
3. As an example, it is seen that the interaction with the projected sequence can slash the initial cost of Geosynchronous Earth Orbit communication satellites by nearly an order of magnitude.

VII. Acknowledgements

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VIII. References

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