Business Scenarios for Space Development

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Abstract

Examining a scenario in which the initial objective is a business opportunity may help develop new approaches to space-based activity. The described scenario illustrates the inherent strategic advantages of creating a revenue-based mass driver, a low earth orbit facility design for a specific commercial application, and the desirability of backward integration leading to the construction of commercial space power facilities. The discussion is based on two common and inherently useful commercial applications - waste disposal and electric power generation. Each has the advantage of significant markets, long production cycles, and known revenue patterns. By following the simple expedient of looking for revenue potential first and then extending the operation into space, it is possible to explore each opportunity further. Both garbage disposal (particularly high-level waste) and electric power production develop some unique competitive advantages when these operations become space-based.

Introduction

Discontinuous change will occur to virtually every organization at some point in time. A significant part of a manager's challenge is to prepare for the unexpected. The creation of new markets, new competitors, new combinations of technology, new legislation, and new societal expectations all represent sources of potential unanticipated change. Frequently, what is a present crisis could have been viewed as an opportunity if the situation had been anticipated.

"*Scenario:* a description of the future competitive environment of a business, based on a selected combination of assumptions and forecasts about future events. Strategists develop scenarios in order to identify and anticipate emerging or potential competitive threats and *to stimulate thinking and discussions about strategy*."[1]

As has been frequently stated, access to space "means developing a service, not just *developing* hardware."[2] Space has long been viewed as an environment, a place , and/or a destination overflowing with opportunity; however, it has yet to become a place of widespread commercial activity. Satellite operations not withstanding, space-based business activity remains mostly potential rather than active development. Clearly, part of this is due to the constraints of transportation. Business-rated transportation systems do not yet exist.[3] This business scenario is to suggest how such a system might develop as part of an overall business project, where space activity is an essential component of the service provided. It is intended to foster discussion on many of the factors needed to create viable space-based enterprises.

Seeking Opportunities to Create New Businesses

The first step in the creation of a new business is to identify an opportunity. That opportunity is frequently expressed as a need currently unfilled in terms of a product or service. Alternatively, the opportunity can be described as a belief that a need currently being met via other mechanisms can be improved or replaced with another choice. Generally, this new choice is described as likely being preferred by the customer because of factors such as lower cost, better value, or other significant advantages viewed as important in the marketplace. However, not every advantage is of equal importance and each customer makes their own tradeoffs. Furthermore, each market has its own internal constraints including such things as: competitive issues, entry barriers, and levels of profitability.

Few businesses exist in such isolation that they are unaffected by a multitude of other factors which are constantly changing. These changes affect the nature of competition and the ability of a given firm to continue to compete successfully. The proposed scenario is not a panacea for space-based business activity. Nor is it free of the inherent limits imposed by the commercial requirements of competition and profitability. However, firms competing in an industry with high entry barriers, which would include space-based businesses, tend to enjoy higher-than-average returns.[4] Creating a space-based business system having the possibility of significant financial returns further improves the likelihood of developing the infrastructure to support other, more exciting, interesting or profitable projects.

The scenario, as presented, is based primarily on known technology or on technology in which the fundamental limitations are engineering issues rather than theoretical constraints. Theoretical constraints imply we do not yet know how to do something. While engineering constraints are more in the realm of we know we can do it but we are not yet certain of the costs. The *can we do it* distinction is important because if we can do something, the most critical limits are likely to relate to cost or competitive considerations. Virtually everything that is to be discussed within the context of the proposed scenario is either available in one form or another or could be built using known technology. But as in many scenarios, numerous important considerations require more extensive analysis and costs are frequently ranges based on limited and inherently *squishy* numbers. The essential point to keep in mind is that this assessment is about creating a service with revenue potential. As it happens, that service could also provide for the development of space infrastructures. It is not about creating a space transportation architecture and then figuring out what can be done with it.

Scenario Overview

The impetus for the concept is a simple one. The amount of high-value waste available for disposal represents a source of revenue sufficient to justify the development of a space-based disposal system. In addition, the hazardous nature of the high-value waste is such that permanent disposal is desirable. Furthermore, the nature of the waste suggests that final disposal by launching it into the sun solves the permanent disposal problem. However, the current launch infrastructure has little to commend itself to such a project. This view is based on two fundamental issues. The first is the need for as close to 100% reliability as possibility on launches of such material and virtually 100% safety in the event of a launch failure. Rocket systems do not presently provide such assurances. Second, the very public nature of such an operation requires a public and government confidence in the reliability of the overall system that is unlikely to be satisfied with rocket-based systems.[5] In fact, the issue of public acceptance is arguably the most important driver in the development of a commercial space disposal venture. Any economic benefit of space disposal is moot if regulation and protest prevent operations.[6] The effort that will be required in convincing people of the safety of this concept cannot be overstated. To provide the desired level of confidence with the acceptable level of safety in the event of failure, the scenario suggests the use of mass drivers for placing containers of material in a low earth orbit (LEO). These containers would then be collected by manned orbiting collection stations. Containers would be loaded onto an appropriate transit vehicle which would be designed for a sun intercept.

The number and placement of LEO stations and their design would be determined by the launch site and number of operating mass drivers. These stations, operating much as commercial diving or offshore drilling rigs do now, would be manned by crews for a minimum 30-90 day shift. In fact, adapting hard suit systems currently used by diving companies for their commercial projects could make space-tending operations less expensive to develop. For example, there are at least two commercial grade hard suits presently available. Each is capable of prolonged periods of operation while keeping their operators at one atmosphere.[7] The ability to keep development costs is a key component in moving this project or any similar project toward profitability. As the LEO facilities need ongoing support and supplies, the same launch system used for waste disposal can easily provide containers of water, food, and other necessities. Resupply of the orbiting collection points can be accomplished using containers sent up via the mass drivers. This could also reduce operating cost concerns. More problematic are crew changes. Ideally, crew changes would be accomplished using the next generation shuttle or comparable vehicle. Actual time in orbit is a question of access and relative cost. Longer periods between crew rotation are possible, but the tradeoffs include better quarters, more entertainment options and higher wages and/or salaries.

As the system developed, it is probable that additional cost and revenue considerations would be pursued. One of the major costs of operation is the electricity used by the mass drivers and supporting industrial facilities. Consequently, an additional opportunity in the form of building and using solar power satellites (hereafter referred to as SPS) can easily be envisioned as a follow-up to the waste disposal operation. Having created systems for its own use, the business could find the revenue-enhancing possibilities for additional SPS systems irresistible. Although beyond the scope of the present paper, the cost saving which might be obtained through the use of lunar raw materials for the construction of large numbers of SPS systems might provide an economic justification for the creation and operation of a companion commercial lunar facility. Backward integration is a common business practice in which manufacturers extend their operations back to the components or raw materials used in the construction of a specific product. Depending on the volume or size of a SPS construction operation, the availability of less costly lunar material could quickly necessitate a commercial lunar presence depending on the cost drivers. The scenario, as briefly described, provides an economic, self-supporting, rationale for creating an entire range of space facilities. Although, the initial customers are government institutions, part of the appeal is that there are numerous nations with similar problems, thereby reducing the dependence on a single customer. In strategic terms, the number of waste suppliers diminishes the power that any single customer might attempt to exercise over the business.

Waste Disposal as a Space-based Service

"One of the first questions the investment community asks about any potential venture is what does the market look like and how is it expected to grow? Investors must have some idea of the size of the overall market in order to evaluate the potential cash flows relative to the investment capital that will be risked."[8] For example, a general analysis of hazardous waste disposal via a space-based system is contained in the Commercial Space Transportation Study[9] (CSTS) produced in 1994. While many of the components of CSTS approach are viewed as problematic, its underlying arguments as to the need for disposal are essentially the same here. First, the longevity of the nuclear waste hazard represents a current and ongoing problem. Second, the terrestrial solutions for long-term storage of nuclear waste are still open to question. Third, the amount of money allocated to deal with the problem suggests significant revenue potential if a lower cost and/or more effective solution could be created. Lastly, there appear to be few competitors poised to enter the high level waste market apart form government institutions.[10] Effectively, this translates into a market opportunity of considerable size, revenue positive, and of significant duration.

Market Potential

There is a tremendous stockpile of high-level nuclear waste in this country left over from 50 years of bomb-building and 35 years of nuclear power generation. With the ending of the Cold War, there is additional plutonium to dispose of in the safest way possible. In addition, the rest of the world, especially the nations which comprised the former Soviet Union, has an abundance of high-level waste. In spite of issues relating to paying for disposal operations, there is no dispute about the need for high-level disposal options within the nations which compose the former Soviet Union.[11] Some estimates based on nuclear power generation data put the total worldwide high-level waste exceeding 100,000 metric tons by the year 2000. Some of that waste is currently being processed (glassified) for aboveground storage (e.g., in France), but most will be sitting in temporary storage tanks in the year 2000. However, even the glassified waste material requires long term storage which is not considered permanent disposal in some parts of the world. In the United States alone, the amount of nuclear waste to be disposed of by the year 2000 is estimated to be 40,000 metric tons of spent nuclear fuel and another 10,000 metric tons of defense related wastes. The market for permanent disposal of high-level nuclear waste is therefore of sufficient size to justify further interest.

Cost of Current Disposal System - U.S. Example Only

Nuclear waste disposal is an expensive business. The Department of Energy (DOE) waste operations budget for 1990-1996 was $22.3 billion with an additional $2.2 billion for technology development. Much of the ongoing expense for the storage and treatment of nuclear waste within the U.S. is to be obtained from The Utility Waste Fund.[12] The value of the fund is now in excess of 12 billion dollars. By the year 2030, nuclear power is expected to expand to about 190-250 gigawatts, generating more than $1 billion per year for the waste fund. Government estimates put the cost of the first permanent repository in the vicinity of $28 billion and the second in the $17 billion range ($45 billion total). These estimates probably represent the lower end of the cost envelope as other estimates go as high as $53 billion.[13] However, using the estimated U.S. cost for repository disposal as a starting point estimate, each metric ton of waste (50,000 metric tons of U.S. waste only) translates to a cost structure of approximately $900,000 per metric ton.[14] This does not include things such as ongoing security, oversight or associated expenses. For instance, landlord activities for the sites in question could increase expenses an additional $13 billion for just the first third of the next century. Transportation to the sites is not included as transportation costs are subsumed in any waste disposal system.[15] It is also difficult to include such important issues as onsite preparation versus bulk transport as part of this comparison due to the wide range of options. Consequently, they have been excluded from this scenario, although representing a cost consideration of some importance. Regardless, the revenue potential from the safe and efficient handling of high-level waste should be sufficient to warrant investment in infrastructures, assuming an acceptable financial return.

Waste Disposal Service System

As indicated in the overview, there are essentially four components to the proposed disposal service. The first component is the ground to LEO delivery system – electromagnetic acceleration, i.e., mass driver, of waste containers to escape velocity. The second component is the handling facilities which operate in a low earth orbit. These manned outposts provide a central assembly point for transporting large numbers of containers for their ride into the sun. Concurrent with this operation are two additional basic components which include the equipment for actual assembly and handling of waste containers and the transit vehicle itself. A fifth component, consisting of SPS power systems, is not part of the initial operation but would likely be added once operations were stabilized.

The Mass Driver Approach

Mass drivers have been discussed as launch systems for some time as the pioneering efforts of the Space Studies Institute attest. The technology is relatively straightforward. Design studies have gradually grown to include working examples constructed both by private institutions and the military. The fundamental issue is whether or not such a system can be scaled up to the size required to provide an efficient means of placing waste containers in a low earth orbit. The technical limitations do not appear to be as daunting as site selection and public concern. Increasing the size of such a system to encompass the scale necessary for the described scenario would ideally result in a capability of placing, at least, metric ton containers in orbit.[16] Although waste disposal is a volume-based business, the sheer number of launches required to produce the desired revenue stream should not be viewed as excessive. At the same time, the point of using such a system is to provide a capability of launches twenty-four hours per day with many launches per hour. This must occur day-in and day-out, without much regard for weather or other interruptions. With time set aside for maintenance, operational issues, and catch up etc., perhaps the target more reasonably becomes a sixteen-hour launch day in conjunction with a three shift twenty-four hour LEO handling day. Both operations work 5-6 days a week with all the normal personnel scheduling variations suitable for a business with little tolerance for failure. Without stretching credibility, a significant amount of material can be handled in a relatively short time period.

Table I. Material to LEO for a typical work week

Days of Operation	**# of 8 Hr/Shifts**	**# of Launches Hour**	**LEO Delivered Tons**
5 - minimum schedule	2 shifts = 16 work hrs	3	240/week
7 - max schedule	3 shifts = 24 work hrs	3	504/week

Table II. Material to LEO for a typical year

Weeks of Operation	**Launches Per Week**	**LEO Delivered Tons**
44 (allow delays, off time etc.	240	10560/year
48 (minimum down time)	504	24192/year

These numbers assume only one launch system. From a business perspective, placing all of your reliance on a single system would be considered imprudent. The more likely course of action would involve several mass drivers. The configuration is less important than the realization that redundancy for reducing business risk is not much different from redundancy to reduce technological risks. Regardless, additional launch capability increases the tonnage to LEO by whatever factor would make best economic sense. Scaled up mass driver costs can be compared to the creation of a new aircraft only less costly. Development costs for new planes can easily approach eight billion dollars or more. Optimistic projections for mass driver development have ranged from several hundred million dollars to more than two billion dollars. Investment thresholds at even the higher estimates could be met if waste disposal volume is increased or if the economies of scale provided by the system reduce the cost of each ton to orbit. Construction costs are more difficult to estimate because a significant part of the cost would be determined by the site selected for operations.

Presuming the desirability of a near-equatorial location with a relatively high terminal elevation, mass driver costs should approximate those of any other large scale projects in which most of the components can be prefabricated. Depending on its design, this system could have more in common with the Alaskan pipeline project than with more traditional space projects. For example, it may be possible and highly desirable to create mass driver sections using extruded concrete pipe technology. Current equipment is capable of producing finished pipe sections up to 54 inches in diameter with cutouts or other features needed to attach liners and many of the features a large mass driver might require. If located in very difficult terrain such a system could price out at over a $5000 per foot. It could easily remain cost effective, if it was capable of sustaining several hundred launches without major interruption.[17]

The problem is that different design approaches have tradeoffs. Interior contact versus no interior contact translates to increased wear and more frequent replacement. Rapid acceleration might allow a shorter runup to speed, while a longer take off could provide reduced stress on the system. Both approaches have cost and operational tradeoffs that would have to be determined and evaluated in the context of available funding. These are just a couple of the types of decisions that would have to be made to get the best operating system for the lowest possible cost. Regardless, if the market for waste disposal is viable, then a development and construction cost between three and twelve billion dollars could be classified as a real bargain for such a system.

Giving Waste a Home

The entire point of this exercise is to provide a permanent, yet economically-viable, approach for high-level waste disposal. Part of that approach is a desire for safe and reliable handling of the waste material. Such caution suggests that it is unwise to use rockets to place this material in a low earth orbit. In much the same vein, once in a low earth orbit it seems reasonable to have individuals on the site to handle the waste and deal with any potential problems. This phase of the operation is effectively a collection and assembly point for sending bundles of waste containers into the sun. Some argument can be made for telepresence in the handling of containers. However, complete confidence in technology is almost always misplaced. In very simple terms, everyone knows that "stuff" happens. Human beings have the ability to be flexible in situations in which things do not work as intended. A trained individual, with the right tools and equipment, has saved many an expensive venture. From the Hubble telescope to possibly your last commercial airline flight, examples abound as to the value of the well-trained person on the spot.

The LEO Facility

The literature on constructing LEO facilities is both extensive and confusing. Plans exist for the construction of orbiting habitats from external shuttle tanks, specially designed components shipped up from earth, expandable modules, inflatable bubbles and many many other approaches. The choice in this case is one of safety, of utility and, ultimately, of cost. It need not be fancy, but the station (or stations) placed at collection points must be relatively self-contained and cost efficient.[18] This precludes many of the approaches utilized to date within the aerospace industry. That is not to say one should exclude the technology, just how the technology has been incorporated in most orbiting facility proposals. What is required at this junction is a radical innovation.[19] Current approaches to space station design are simply too expensive to consider even with billions of dollars in potential revenue. The best approach for station construction might be to get non traditional sources for its design. Part of that effort should include techniques that would make assembly easier, faster, and less expensive.

The operation of a LEO collection site capable of handling several hundred tons a day is not terribly complicated. The station is a basic cargo terminal. The cargo arrives. The cargo is picked up. The cargo is inspected. The cargo is attached or loaded on the transit vehicle. This vehicle is most probably an open frame with appropriate guidance, engine and related hardware. Each transit vehicle might hold several weeks' worth of canisters. When full, the vehicle is sent on its way. With the right equipment, the loading operation could consist of two loaders per shift, a loading inspector or supervisor, and an appropriate number of support personnel. A crew for a station could consist of some 15-25 people per rotation. The overall effectiveness of the operation could be improved by increasing the scale as the amount of waste to be handled increased.

Backward Integration or SPS Development

Assuming that a space-based waste disposal system becomes operational, it would be a relatively short time before efforts would be made to improve the rate of return and/or reduce operating costs. Investor expectations and/or concerns about operating efficiency would focus attention on improving the business within a short period. One clear avenue of inquiry would be to reduce the constant cost associated with electric power utilization for the mass drivers. A second would be to create peripheral business opportunities from the now available space infrastructure. Both areas could be addressed with the development and construction of solar power satellites.[20] An SPS system creates the opportunity to provide electric power at a constant cost and reduces dependence on outside suppliers. Conceivably, it could also out price the cost of electricity from other sources.[21] These factors readily convert to competitive advantages in the face of competition from other disposal systems. It could also increase the the entry barriers to competing launch systems.

In addition, the construction of an SPS power grid for internal use clearly creates the expertise to deploy such systems elsewhere. The demand for clean sources of electric power is likely to grow in the twenty-first century.[22] Electricity is and will continue to be the fastest growing component of energy demand. It is estimated that between 1995 and 2020, total world electricity demand is expected to rise from 12 trillion kilowatt-hours to 23 trillion kilowatt-hours. See: Table III. While growth will be the slowest in the industrialized countries, absolute and per capita consumption levels are expected to rise in response to new uses for electricity. However, it is among developing nations where SPS systems may have the greatest potential. Electricity demand is projected to grow at more than twice the rate of growth in the industrialized countries. Aggregate consumption is anticipated to more than triple within developing nations between 1995 and 2020. Of particular interest is that the greatest demands are expected in parts of Asia and in Central and South America..[23]

Financing of Electric Power Expansion - An SPS Opportunity

Electricity is a capital-intensive industry, perhaps the most capital-intensive of all industries. To meet the global demand for electrical power with currently available technology will require an estimated expenditure of more than $2.3 trillion between now and 2010. Roughly two thirds of that investment will be needed in developing countries.[24] Particularly in the developing world, vast infusions of foreign capital will be required to sustain growth in electricity supply. Many developing countries are already coping with power shortages. The future power needs of such populous countries as Brazil, China, India, Indonesia, and Pakistan are immense, presenting investment demands beyond the financial means of their domestic capital markets or government resources. As a result, attracting foreign investment is critical to the successful expansion of the electric power sectors in these nations. Opportunities to use relatively less expensive, non polluting sources, such as SPS systems, could be very attractive. In part, they could become financially attractive investments because of the availability of a supporting space-based infrastructure.

Table III. World Net Electricity Consumption by Region, 1990-2020
(Billion Kilowatt-hours)

Region	History		<		Projections		>	
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**Average Annual Percent Change, 1995-2020**
Industrialized Countries	**6,299**	**7,113**	**7,968**	**8,804**	**9,663**	**10,497**	**11,349**	**1.9**
United States	2,713	3,163	3,318	3,601	3,877	4,115	4,308	**1.2**
EE/FSU	**1,908**	**1,552**	**1,509**	**1,685**	**1,881**	**2,056**	**2,248**	**1.5**
Developing Countries	**2,224**	**3,102**	**3,886**	**5,007**	**6,220**	**7,684**	**9,548**	**4.6**
Developing Asia	1,268	1,912	2,489	3,283	4,160	5,255	6,665	**5.1**
China	551	881	1,076	1,476	1,975	2,657	3,574	**5.8**
Other Developing Asia	717	1,030	1,413	1,807	2,185	2,598	3,091	**4.5**
Total World	**10,431**	**11,767**	**13,363**	**15,495**	**17,764**	**20,237**	**23,145**	**2.7**

Note: EE/FSU = Eastern Europe and the former Soviet Union.
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 1996*, DOE/EIA-0219(96) (Washington, DC, February 1998). **Projections:** EIA, World Energy Projection System (1998).

Conclusion and Observations

It is a great irony that wisdom for many firms that derive current good fortune from radical innovations of the past lies in erecting barriers to these same types of innovations today. Indeed, for some, the development projects that made them wealthy would be rejected if presented to current corporate staffers. 'Too risky,' they would say. "The projected stream of cash flows is too small to meet our internal rate-of-return hurdle.' 'The market is too small.' Taken by itself, the decision not to abandon well-worn products in a timely manner is transitory. It leaves much greater risks for the business down the line and increases chances of failure. Doing only incremental innovation leaves the firm closer to the inevitable end of its business, but with no preparation for the future.[25]

The focus of this scenario has been that there are sources of revenue that could create an opportunity to develop and construct a space-based infrastructure. The businesses involved are not exactly exciting - garbage disposal and to a lesser degree production of electricity. These are basic utility operations common to all parts of the planet. The fact that they are common is part of their attractiveness for creating mainline business opportunities. Some parts of the approach are somewhat radical; however, the essential components represent mainstream technology and fall within current industrial capabilities. They are extensions of what we know combined with questions for which there are means of obtaining explicit answers. Not every question raised in this paper was answered to the degree desired for a good business analysis. Some questions require a definitive proposal with limited parameters while others require a serious expenditure of time and funds. Neither was appropriate for this paper. Yet, in either case, the essential concept of a business driven model for creating space activity still works. Is it possible to actually build the described infrastructure? The technical problems are of the "what will it cost variety." The political issues are mostly of the "if we can't do it here - there are other choices" contingent.

In essence, given the will, vision, investors, willing customers, and the essential knowhow, it could be done. If nothing else, this scenario might help people to look for other opportunities upon which to build their space systems. As early ship-borne travelers noted, the ship took no notice of whether the voyage was one of high adventure to explore unknown lands or a cargo of trade goods bound for sale on the home market. The point is that whether the ship was intended for exploration or commerce it provided the same service - transportation. The same situation applies to the disposal of high-level waste. The relative appeal of space is lost on many people. What matters is that the garbage is taken away and that the lights come on when the switch is flipped. It just so happens that there may be more interesting approaches, with unique benefits, for accomplishing these relatively mundane tasks.

Endnotes

1. Catherine Hayden, The Handbook of Strategic Expertise (New York: The Free Press, 1986) p. 294.

2. Elizabeth Corcoran and Tim Beardsley, "The New Space Race," Scientific American (July 1990) Volume 263 Number 1, p. 74.

3. Business people really do not wish to hear about the assorted problems of launching material and people into orbit. The questions they want answered are when, how much, and will it work? Alternatively, think in terms of the typical questions firms ask when using a ship or an air freight system. Only when a launch system either alone or in conjunction with some other activity can provide answers to these simple questions will business people be satisfied. See: Mike H. Ryan, "Space Business Basics - Part 1: Business Rated Launch Vehicles," Space Business Notes Vol 1, No. 1 (1995) Features Section, part 4 or Mike H. Ryan, "Space as a Commercial Frontier: A Commentary," Space Commerce Vol. 1, No. 3 (1992) pp. 205-207.

4. Six common and formidable barriers to entry are economies of scale, product differentiation, high capital requirements, switching costs, lack of access to distribution channels, and other cost disadvantages independent of scale such as proprietary technology. New entrants frequently build their strategy for establishing a strong competitive position using one of the previous six approaches such as: reducing product costs; cutting price to build market share; offering a superior product; serving a new market niche; using an innovative marking approach or capitalizing on existing distribution systems.

5. See: Michael Maharik and Baruch Fischhoff, "Public views of using nuclear energy sources in space missions," Space Policy, Vol. 9 No. 2 (May 1993) pp. 99-108.

6. US policies governing the permanent disposal of HLW are defined by the Nuclear Waste Policy Act of 1982 (NWPA), the Nuclear Waste Policy Amendments Act (NWPAA) of 1987, and the Energy Policy Act of 1992. These acts specify that HLW will be disposed of underground, in a deep geologic repository. If U.S. sourced waste is to be part of the plan enabling legislation would, by necessity, be required.

7. Oceaneering International Inc., Houston, Texas produces the WASP one atmosphere diving system capable of manned operations to depth of 2,500 fsw. Newtsuit is the newest version in a long line of single atmosphere diving systems capable of operating at depths of 1000 feet for up to six hours designed and developed by the Ceanic Corporation of Vancouver, Canada.

8. U.S. Department of Commerce, Commercial Space Ventures: A Financial Perspective, U.S. Department of Commerce, Washington, D.C., 1990 p. 7.

9. NASA, Commercial Space Transportation Study, (Washington, D.C., NASA, 1994).

10. Although most of the arguments are based on waste generated and stored within the United States, the better case might be made for the disposal of non U.S. high level waste. There may be a stronger rationale for the creation of a non-U.S. based operation due to fewer regulatory hurdles, potential launch site selection issues, and ability to target a broader range of both private and institutional investors.

11. For example, more submarines are being taken out of service, so more and more spent fuel is waiting to be removed and safely managed. Over 150 reactors are already waiting to be defueiled and dismantled. Unfortunately, the Russian facilities for handling this fuel and associated radioactive waste

on such a scale are either not available or inadequate. The capacities for treating it are severely limited and those for storing it in the region are virtually non-existent and the possibilities of transporting it both within and to places outside the region are already restricted and are becoming even more so.

12. The waste fund is paid from a $0.001 kW/h nuclear waste disposal tax on nuclear power plants. At a power production level of approximately 100 gigawatts, the tax would provide about $500 million a year for disposal costs.

13. Department of Energy, "Executive Summary - 1996 Baseline Environmental Management Report," (Washington, D.C., Department of Energy, 1996) p. 22.

14. By comparison, options for conventional waste can include incineration, chemical treatment, or land fill disposal for as little as $300/ton. For some municipalities the cost of general waste disposal has risen as high as $2000/ton due to the lack of land fill sites or the willingness of smaller communities to continue as the dumping grounds for their larger brethren. If the cost for handling a ton of waste continues to increase and the cost of handling a ton of material via the space disposal system were to drop sufficiently; it is conceivable that a secondary waste market might develop on the basis of very high volume and low cost for a variety of other waste categories.

15. It is also difficult to include such important issues as on site preparation versus bulk transport as part of this comparison due to the wide range of options. Consequently, they have been excluded for the moment.

16. The actual size of the payload is not nearly as critical as the ability to launch with great frequency. With smaller payloads, the need to launch more containers per hour as an offset becomes necessary. This in turn increases the handling capability needed at the LEO facilities etc. Larger payloads carry similar considerations as they might place greater stress on the launch facility and further reduce launch frequency. The sheer volume of the tonnage to be shipped to low earth orbit suggests that very high frequency launch capability is an essential characteristic for business success. Metric ton containers seemed a reasonable tradeoff both for launch purposes and for terrestrial transportation issues.

17. A working system, depending on the electromagnetic technology employed, roughly 1.5 miles long would cost in the vicinity of 40 million dollars at $5000/foot. It could easily increase in price depending on the technology and construction methods employed. This would not include any associated expenditures needed for protection from earthquakes, weather or other local conditions.

18. A three billion dollar example can be found in Randolph H. Ware and Philip E. Culbertson, "STS-Lab: A Low Cost Shuttle-Derived Space Station," The Journal of Practical Applications in Space, Vol. 3 No. 2 (Winter 1992) pp. 17-23.

19. The construction of the Troll offshore drilling platform is an example of how looking at a problem from a different angle can lead to new solutions. For approximately $4 billion, the largest offshore platform was built and put into place. Apart from transportation, it is increasingly difficult to imagine that orbital construction can not be constructed less expensively with ample margins for safety.

20. No attempt will be made to assess the best approach to SPS design. The essential point is that at a given level of electricity consumption it may make sense to create your own power sources. Whether a terrestrial or orbital system is more efficient depends on many other factors such as power requirements, desire for alternative business opportunities and even public willingness to accept the concept. Examples of technical information on SPS design include: Seth D. Potter, Low Mass Solar Power Satellites Built from Lunar or Terrestrial Materials: Final Report, (Princeton, New Jersey: Space Studies Institute and Seth D. Potter (joint copyright), April 7, 1994.)

21. With the current cost for constructing conventional power plants ranging from $431,374,000 to $523,517,000 for fossil-fueled steam-electric and gas turbine plants priced from $36,318,000 to $185,883,000 it would certainly make sense to examine all your options. This is particularly true if the most significant cost for constructing SPS systems is in the transportation of components and your firm has the cost of transportation fairly well fixed.

22. See: Department of Energy, International Energy Outlook 1998 [Washington, D.C.: U.S. Government Printing Office, DOE Report # DOE/EIA-0484(98) pp. 1-20.

23. This has some very interesting possibilities due to the possible location of mass driver facilities. South America, for example, has many attributes that suggest its use as the primary mass driver site.

24. The environment for developing interest in SPS investment is enhanced by actions taken in South America. Central and South America have led the developing world in the privatization of electricity and the implementation of electricity reform. In 1997, Brazil followed the path, broken first by Chile and later by Argentina, in aggressively selling off state-owned electricity assets to the public. Central and South American energy needs have given rise to regional, cross-border investment, development, and trade in natural gas and electricity. This could be encouraged to also include SPS as unique opportunity.

25. James M. Utterback, Mastering the Dynamics of Innovation (Boston, Massachusetts: Harvard Business School Press, 1994) p. 224.