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LEGAL CONSTITUENCIES AND ECONOMIC EFFICIENCIES OF SPACE SOLAR POWER (SSP): A JOINT JAPANESE AND AMERICAN PERSPECTIVE

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ABSTRACT

Recent action in California in the U.S.A. vividly illustrates that lack of appreciation by civil actors of the economics of energy companies. This study seeks to act as future roadmap for legal actors to obtain clarity on economic issues affecting a potential future energy source, namely Space Solar Power (SSP). Currently envisioned systems SSP systems would deliver gigawatts of power to terrestrial power grids from space, lasting over 20 years and having orbital masses on the order of 40 International Space Stations. The interaction of legal challenges and economic justifications is examined for any group of public and private entities (fully domestic commercial ventures, international conglomerates, international civil organizations, etc) that seek to build and/or operate an SSP system. In April of 2000, the Ministry of Economics and Industry (MITI) of Japan and the National Aeronautics and Space Administration (NASA) of the United States started a joint feasibility study on Space Solar Power. Due to the current climate of limited public funding for such large-scale space projects, governments would prefer more industry involvement (technically and more important financially) in SSP. Conceptual case studies are developed of innovative future government and private sector partnerships for SSP. Sensitivities are performed on proposed legal and economic architectures.

ACRONYMS

CABAM	Cost and Business Assessment Module
DDT&E	Design, Development, Testing, and Evaluation
DSM	Design Structure Matrix
ETO	Earth-to-Orbit
GEO	Geostationary Earth Orbit
GW	Gigawatt
IGA	Inter-Governmental Agreements
IOC	Initial Operability Capability
ITU	International Telecommunications Union
MOU	Memorandum of Understanding
NPV	Net Present Value
PPP	Public-Private Partnership
RLV	Reusable Launch Vehicle
SPS	Solar Power Satellite
SSP	Space Solar Power
SSPATE	Space Solar Power Abbreviated Transportation Economics
SSTO	Single Stage to Orbit
TFU	Theoretical First Unit

INTRODUCTION

Space Solar Power (SSP) for terrestrial use is a concept to beam energy from space to terrestrial power grids that could be feasible in about twenty to forty years (see Figure 1). In theory, due to negligible atmospheric losses, power generation from solar cells in space are nine times as efficient as on the ground. SSP would harness these efficiencies through technologies such as microwave wireless power transmission (WPT) to large (several kilometers in diameter) terrestrial rectifying antennas (rectennas) for eventual dispersion into the power grids of the world.

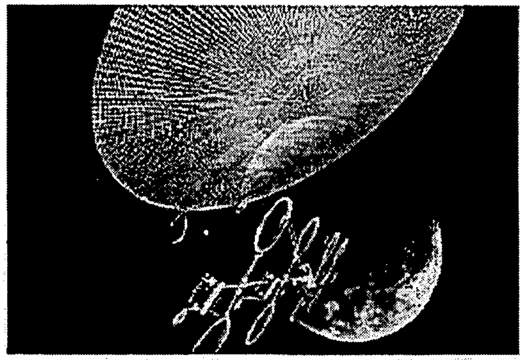

Figure 1. Space Solar Power Architectures in Orbit

A current sample SSP architecture incarnation, the Geostationary Earth Orbit (GEO) SunTower, would deliver about 1.2 GW of power to a terrestrial electrical grid, having a total system mass of over 20,000 MT (equivalent to more than 40 International Space Stations) and each lasting over 30 years in orbit (see Figure 2)[1,2,3].

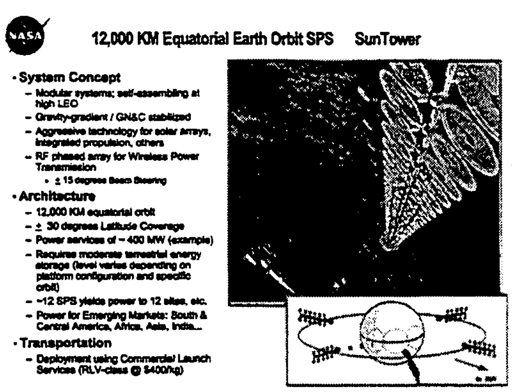

Figure 2. Notational SSP SunTower Architecture

Each Solar Power Satellite (SPS) would have its operational life be in GEO and be constructed from smaller pieces typically delivered from Low Earth Orbit (LEO). A dual phase transportation system emerges from this scenario, namely separate Earth-to-Orbit and in-space transportation modes. In this envisioned scenario, an RLV delivers a 20-40 MT piece of the SPS to LEO which is either sent directly with the in-space "tug" to the final orbit in GEO or aggregated with previously delivered RLV pieces into a "wagon train" in-space transportation system to GEO[4]. This delivery schedule would be kept in order to assemble one SPS in orbit for over 30 years.

Dr. Peter Glaser first proposed Solar Power Satellites (SPS) in 1968 with NASA and the Department of Energy (DOE) of the United States (U.S.) eventually conducting its own feasibility study[5]. Ever since the energy scarcity created by the oil shocks in 1970s, solar energy has been regarded as significant clean alternative energy source[6]. In 1978, the Sunset Energy Council was set up in the U.S., consisting of private entities and scientific institutes (including MIT, Arthur D. Little, Boeing, Martin Marietta, McDonnell Douglas, General Electric, RCA Grumman, Avco Corp, Westinghouse, Southern California Edison, and Aetna Life and Casualty Insurance Co.). This resulted in a bill to provide for a research, development, and demonstration program to determine the feasibility of collecting space solar energy to be transmitted to Earth and to generate electricity for domestic purposes (H.R.12505). In 1997, NASA concluded the "Fresh Look" Study resulting in various configurations including the SunTower[1]. This led to other SSP concept definition studies and eventually to an increased budget of $20 million for the SSP Exploratory Research and Technology (SERT) program in 1999; being conducted with representatives from Japan, European Union (EU) and Canada. Due to the current climate of limited public funding for such large-scale, non-defense oriented space projects; the governments of the world would prefer more industry involvement (technically and more important financially) in SSP.

MOTIVATION

The past decade has seen the idea of commercialization of space come to the forefront as the enabler of massive space access and infrastructure development. Many notions of how this commercialization would occur have been mistaken (i.e. LEO constellations focusing on mobile phone users). This emphasis on commercialization has also been felt in the past decade's analysis of Space Solar Power (SSP). The NASA "Fresh Look" study and subsequent follow-on studies have had an emphasis on feasibilities of future markets and economic scenarios for SSP[1,3]. Priority is now being placed on market forecasts, profit maximization, operational concerns, and legal frameworks[7,8]. At this point, the technical feasibility may not be as suspect as the financial and legal viability.

A general conclusion the authors make here is that many analyses show that a fully commercialized SSP system for terrestrial use will not be viable due to the incremental profit compared to massive up-front investment cost and project risk. For clarity, the "fully" commercial project as defined above would obtain minimal government assistance for program research and development (as well as system acquisition), not receive any government subsided loans, not receive any government tax breaks, not receive any government liability waivers, not receive any free spectrum for transmission purposes, or benefit from pollution taxes on competing sources of power.

Realizing large-scale Space Solar Power for terrestrial use is an obstinate task, from construction to operation, from earth to space construction, both legal and financial. Fanciful speculation abounds as to the promise of SSP concepts, yet the actual viability is almost always at suspect. The authors take the view that even given the pure financial loss of a fully commercial venture; Space Solar Power has other side benefits to society. These include (and are not limited to) infrastructure improvement in developing nations, enabling next generation reusable launch services (ETO and in-space), increasing efficiencies for terrestrial solar power, and less reliance of more polluting forms of energy. The goal is then to see how one can pragmatically, given the dual constraints in government funding and private financing, enable SSP for terrestrial use. The starting point for this examination is thus the previously mentioned idea; that a fully realized commercial entity could not afford to initiate an SSP project for terrestrial power use. The qualitative "objective function" is then summarized as follows: what is most commercialized form of SSP that can occur and what are the resultant financial packages and organizational / legal entities (domestic and international) that emerge.

In various discussions about SSP, historical and modern analogues are often used to define how any actual SSP system would operate. Many times those analogues are limited by just examining a single discipline of SSP. For example, legal analogues will be made but will miss the implications for the financial community. This study seeks to make some recommendations to both the financial and legal community studying SSP. This is examined specifically in terms of the international organizational structure of SSP and the sensitivity of the economics to that structure.

The authors do not make a high fidelity case by fully defining the parameters that maximize the above objective, but wish to initiate the next phase of the Space Solar Power debate. A transition has to take place from the "idea" of SSP to the "deed" of SSP. Examination of the actual legal entities that would run an SSP system and the resultant economics would be beneficial in providing current strategic decision makers with hindsight as to the optimum trajectory for SSP development. This knowledge can help effectuate logical government funding profiles and regulatory regimes for future SSP development, even if not leading to a full-scale system.

PROCEDURE

This examination proceeds in three broad categories. It is hoped that to the reader, each category builds upon the subsequent one. The final part of this examination attempts to couple both legal and financial aspects to obtain some clarity for conclusive recommendations for both legal scholars and economics modelers.

The first part of the examination deals with the various types of organizations that could initiate a SSP project. Example organizations are given and legal problems identified as related to SSP. The second part of this study relates key economic drivers that are influenced by the organizational structure of the SSP project. Economic model sensitivities are given for a sample SSP program.

LEGAL CONSTITUENCIES

One of the most critical aspects of any actual, large scale SSP program will be the organizational structure of the entity running the program. The viability of such a program will be impacted by the different characteristics inherent to each structure. A reasonable starting locale for the examination of organizational structures would be to define the terminology. For this examination, the organizational structure generally refers to the legal and financial framework that governs an organization and its relationship with other actors in the environment around it. The organizational structure defines both which other entities are affected and by how much.

Theories about international organizations define three main organizational types[9]:

- International governmental organization (IGOs)
- International non-governmental organizations (NGOs)]
- Multinational enterprises

Many times these systematic conventions fail to reveal the true differences between types. Thus other alternative classification schemes have been developed. These include defining the type of organization by the manner in which it is created (initial meetings), the membership or subscribership, and exclusive information or data networks.

The above three formulations are taken as the starting point for this study. Examination of the current international aerospace field reveals sundry organizational types. The scope of this examination is contained by only looking organizations that have some component of international presence. Thus any type of international organization would be included as well as companies having transnational businesses. Companies that are specific to a single country would not be included. It is important to note that this exclusion can leave out national utility or energy companies which may wield substantial political and economic clout (even when compared with their transnational counterparts).

Each of the basic three organizational types has many offshoots, including types that are domestic or transnational. Several example structures that arise out of the basic three types include:

- Civil government consortium: International Space Station (ISS) agreements with each country having jurisdiction over own portion of station within international regulatory agreement
- Commercial consortium: International Launch Services (ILS) organization of multiple companies from multiple nations with various marketing, production, and operational locations
- Commercial organizations: Boeing having national and international contracts with both other international companies (GE) and other countries (defense sales)
- Public/private organization: Arianespace's public funding of various developments but also pursuing commercial customers for its products and transitioning from government funding to more commercial financing

Each of the above-mentioned, distinct entities can be semi-autonomous from their nation or company of origin and can deal with the like.

The current international framework for SSP can be rotationally described as a multi-national structure with no formal international organization. Scholarly exchanges occur between professionals and academics but besides domestic-ordained and oriented organizations a world-unified body does not currently exist.

One can envision a SSP system developed by an IGO as a consortium with a formal organization and procedures. Governments own pieces of the architecture (as in the ISS) or separate ownership along functional lines (as for joint European-Russian civil interplanetary missions with the Russians providing launch services). Issues need to be resolved as far the legal abilities of this organization to compete with individual state monopoly powers as far as energy transmission and distribution. In addition, matters arise to what constitutes a member of such an organization. States within nations could legally join such an organization and thus the jurisdiction of federal law (in addition to state) to the IGO would have to be determined. In addition, IGOs themselves (such as energy consortiums) could join an SSP IGO. However, SSP IGOs stand to benefit more than any other type of SSP organizational structure when dealing with other IGOs (like the WTO). This is due to the natural networks that are established generally between governments regardless of the IGO.

For an NGO, the matter of SSP initiation becomes more complex. An NGO does not have the "insider" perspective or extra-governmental (government-to-government) relationships of an IGO. However, an NGO may not be bound to the affiliation constraints of an IGO. Yet the problem remains of defining a realistic objective for the organization besides financial profit.

A commercial organization running the SSP program enjoys the same freedom of association as the NGO. However, governments (foreign and domestic) will probably look upon this organizational type with the most regulation and oversight. In addition, international commercial consortium will have to deal with multiple jurisdictions even if a newly incorporated entity is used to maintain the commercial relationship (as the case in SeaLaunch).

Examination of these organizations indicates a transient nature inherent to most. Jus as the initial mandates of the United Nations (U.N.) did not specially include peacekeeping and eventually peace-making, individuals at the U.N. extended existing frameworks when the time was seemed opportune. Eventually, perceptions of the organization mutated, until today where peacekeeping is seen as one of the standard roles of the U.N. Similarly analogues can be seen in the transformation of Arianespace, INTELSAT, and perhaps even the International Space Station (ISS) into more pure commercial ventures. The last three examples are situations in which government(s) paid for massive up-front research and development and when appropriate starting transition to private industry. It seems to have been relatively successful for the former two with the latter yet to be determined. Starting off these large-scale development projects, as pure commercial models, does not seem to have been the way of the past. Evidence then suggests that faith in pure commercial ventures to widen the space frontier may be the politically palatable decision but perhaps not the most pragmatic one.

Current Legal Statues of SSP

One of the main foundations of SSP's claim to any actual legality originates from the Moon Agreement of 1979[10]. It applies to "other celestial bodies within the solar system" including the Sun as stipulated in Article I (1). Solar energy has been regarded as a natural resource and common heritage of mankind as indicated by Article XI (1)[11]. Since states have equipped solar panels onto artificial satellites or on the ISS without any objection from other states, the utilization of space solar energy is internationally and customarily legal[12].

Legal Regime for International Governmental Organization (IGOs)

There are other relevant conventions and treaties that cover SSP in various forms including:

- 1967 Outer Space Treaty (Art. II {non-appropriation in space), Art. III (subject to international law and UN Charter), Art. VI (international responsibility/authorization and continuous supervision), Art. VIII (jurisdiction and control/ownership)
- 1972 Liability Convention
- 1975 Registration Convention and the Convention on International Telecommunication Union[13,14]

In addition, bilateral or multilateral governmental guidelines are also possible legal instruments that can be used to implement the SSP project like the various Inter-Governmental Agreements (IGA) or Memorandum of Understanding (MoU) used for the ISS. Another major issues will be to deal with one of the international regulatory bodies for spectrum, the International Telecommunications Union (ITU). The orbits (LEO and GEO) of both the SPS and in-space transportation systems (if they are reusable) will entail reexamination of both orbital location ownership and frequency allocation.

Another aspect will be the impact of the space transportation component upon SSP's legality. Reusable Launch Vehicles (RLVs) will be required to fly many times a day to establish and maintain the envisioned SSP operational schedule. Currently, the United States has to inform the state of Russia 24 hours before a launch according to previously signed missile treaties. However, launch frequencies for SSP will be on the order to every few hours and new mechanisms have to be established to offer simultaneous or no launch information to other relevant states of concern.

SSP will have to negotiate the still being debated global environmental pacts collectively known as the Kyoto Protocol to the United Nations Framework Convention on Climate Change (FCCC) accomplished in December 11, 1997 with legally biding reductions in emissions of six "greenhouse gases".

Legal Regime for International Non-governmental Organizations (NGOs)

Article VI of the 1967 Outer Space Treaty stipulates that state parties (governments) are internationally responsible for the national activities by non-governmental entities. According to Art. II of the Registration Convention, only one state (government) may register a space object to obtain the jurisdiction and control of SSP. However, analogous to ISS, member organizations for SSP can arrange the jurisdiction among themselves.

Legal Regime for Multinational Enterprises

If the nationality of multinational enterprise is fixed within US, national space laws would be applicable to conduct launching and operating SSP, to the extent that they are not against international law. The US Commercial Space Launch Act is applicable for launching, and if the US government contracts for the manufacturer of SSP, the negligence of construction would be the matter of governmental immunity, in other words, the US Federal Torts Claim Act would not be applicable[18].

However, as long as SSP is an international project such as one between Japan and the U.S., nation states would conduct IGAs and MoUs first to implement their responsibility, and then their private entities would conduct agreements with continued supervision by the appropriate state party pursuant to Article VI of the 1967 Outer Space Treaty.

Relevant Organization: Public or Private?

Previous proposals have looked to other agencies from which to derive a workable model of SSP organization. These include analogues to the International Atomic Energy Agency (IAEA) or Intelsat[15,16,17]. These analogues considered IAEA as a possible model since its purpose includes the production of electrical energy and peaceful purposes related to energy. Other examples have looked to manner in which INTELSAT has established a successful international commercial enterprise as NEW SKY Corp. by using telecommunication satellites. The legal articles in regards to this type of international machinery include conventions from the ITU such as:

- Article I (1) [international cooperation / promotion of technical assistance /efficient operation and telecommunication service/harmonization of Member States]
- Article I (2) [effect allocation]. NASA and Ministry of Economics and Industry of Japan

ECONOMICS EFFICIENCIES

Public-Private Partnership

Large-scale projects such as SSP do not have many genuine, applicable real world analogues in the same stage of concept development. However, the current European Union (EU) global navigation satellite system called Galileo can be used as a Rosetta stone for any eventual SSP system[19]. Similar to SSP, Galileo will offer both public and private services and requires initial multi-national cooperation pertaining to both legal and financial issues. Currently, the Galileo system is being operated as a Public-Private Partnership (PPP). This is a legal arrangement wherein a loose confederation of public and private entities work together with initial inflows of private capital being coupled to government budgets for the program. Thus there are initial private funding milestones that are required to be complete before the project can be approved by governmental entities. However, the commitment of private capital to be exposed for such projects requires evidence to be presented by governments to convince companies of public funding stability. These and other financing strategies being used for the Galileo proposal from the EU can be used to build a framework for SSP financing packages, current EU proposals include:

> A PPP for Galileo could provide complementary finance, improve project design and ensure overall value for money. Crucially, it would confirm private sector commitment to the project. In particular, the need to encourage take-up of the service in order to generate income and reach profitability would provide a powerful mechanism for ensuring user's needs are given central importance, while a PPP structure will help keep costs under control

since much of the risk of construction cost over-run would normally fall on the private sector.

However, not all aspects of the Galileo system are applicable to SSP. Even though the Galileo architecture is large relative to modern space programs, it is still on a smaller scale than any of the envisioned SSP architectures. Similarities also become less apparent with the more unified European government (EU) approach to Galileo versus the more trans-national aspects of any international organization pursuing SSP.

Financial Modeling

A previously derived model named the Space Solar Power Abbreviated Economics (SSPATE) model was used to attempt a unified view of the economics of the SSP problem: from infrastructure to ETO and in-space transportation (see Figure 3). The relationships between these companies (SSP Inc., ETO Inc., and In-Space Inc.) were modeled using three company specific MS Excel spreadsheets aggregated together in the SSPATE model. The model requires mass and cost inputs for each company's product (whether they be vehicles or SSP infrastructure).

The SSPATE model is based upon two transportation models derived at the Space Systems Design Lab (SSDL). This includes the Cost and Business Analysis Module (CABAM) used for ETO RLV economic analysis. The other model used was the In-Space Incorporated Model (INSINCM) used for in-space transportation economic assessments. Both models were either originally developed or enhanced by the authors[20,21]. A general-purpose economics model for the actual SSP infrastructure company was developed exclusively for this analysis. All three company models in the SSPATE model are not meant as representations of the full design process for each system, but "abbreviated" versions with limitations on market elasticities for power demand, financing schemes, acquisition schedules, etc.

An SSP representative concept was developed from a 20,000 MT GEO SunTower delivering 1.2 GW of power to the ground. As detailed in Table 2, system costs were broken out into four categories (space segment, ground segment, space launch, and in-space launch) into four cost grouping each (DDT&E, TFU, facilities, and operations). These costs came from review of literature and assumptions about technology development. The power delivered by each SSP SunTower was 1.2 GW. Both additional efficiency losses to customers and losses due to duty cycle for each SPS were taken into account (both set at 80%). It was assumed that each year 5% of the total SPS mass would need to be refurbished.

Uncertainty distributions were placed upon the pricing scheme of SSP Inc., ETO Inc., and In-Space Inc. portions of the SSPATE model respectively. Distributions were placed generally upon three categories of items: prices, system costs, and system masses[22].

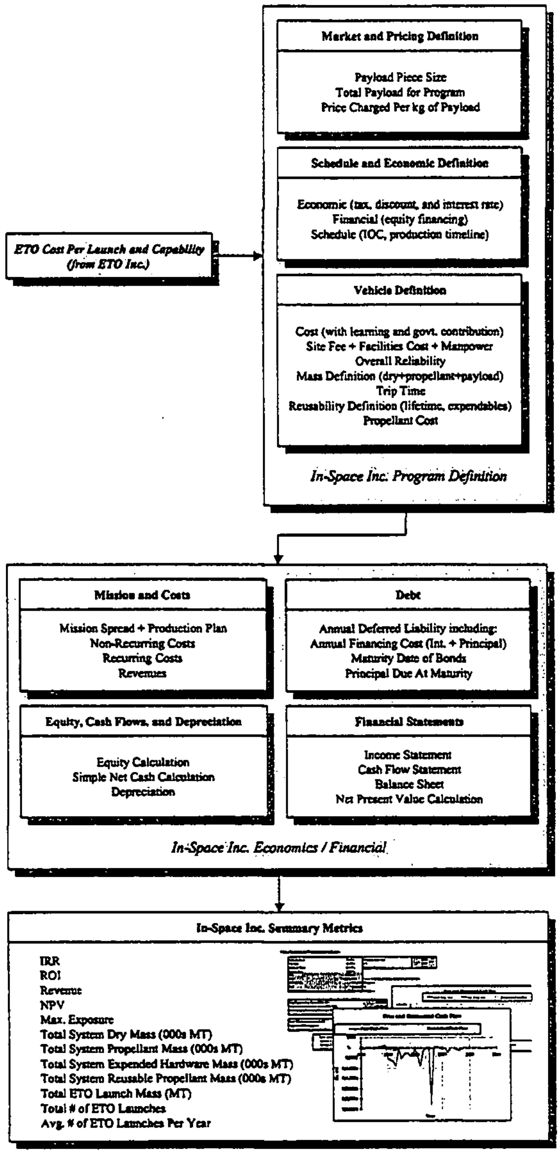

Figure 3. SSPATE Model Schematic

Three comparison cases were performed to examine the organizational impact upon government funding levels. The model characterizes the SSP program as a pure commercial program with inputs for government contribution assumptions. Three sets of government contribution assumptions were developed for the previously mentioned organizational types: one for an IGO, NGO, and commercial entity. The first entity has all DDT&E (space segment, ground segment, ground launch, in-space launch) and facilities costs for the SSP organization paid for the governments (with recurring costs being paid for the entity running the program after the government contribution), the second has half of the DDT&E and facilities cost paid for, and the last entity has none of those costs offset by governments. These extreme cases were used to point out the impact of organizational structure and its subsequent impact upon government funding to the metrics important to an SSP system. Monte Carlo simulations were performed on this model 1000 times to yield non-dimensioned Net-Present-Value (NPV) metrics (at a 90% confidence level, 90% of the NPV values are greater than or equal to this value) for each type of SSP company (see Figures 4 through 7). The NPV is a financial metric indicative of the value of a commercial project given discounted cash flow (DCF) analysis using a discount rate that is reflective of the risk of the project. A higher NPV is a sign of a much more financially worthwhile project.

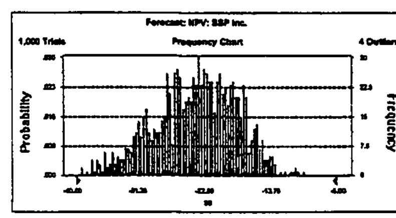

Figure 4. Output Probability Distribution for IGO Organizational Type

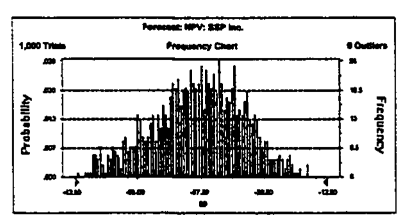

Figure 5. Output Probability Distribution for NGO Organizational Type

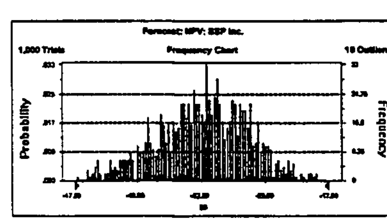

Figure 6. Output Probability Distribution for Commercial Entity Organizational Type

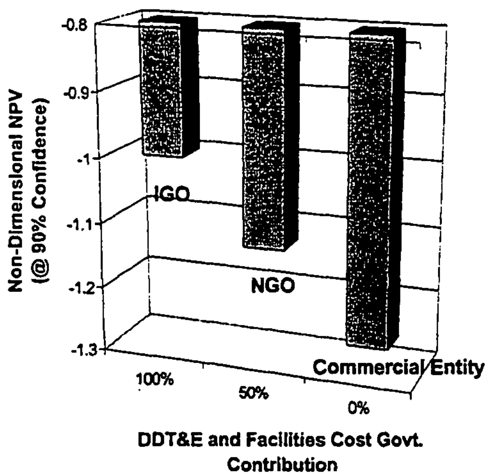

Figure 7. Non-Dimensioned NPV For Various SSP Organizational Types

The results for all three types show a negative NPV. This is indicative of the difficulty in making the general SSP business case close. For this examination the trends are the most important part of the analyses. Figure 7 details the comparison of all three NPV and reveals that the NGO organizational type is approximately 13% worse than the IGO type and the commercial entity is about 26% worse than the IGO type. This linear relationship is in keeping with the manner of how the government contribution assumptions were developed.

An overarching thesis behind this analysis is the coupling of legal examinations with economic modeling to produce a complete life cycle picture of the organizational impact of SSP on its economic viability. The above described regime of legal frameworks and subsequent economic modeling is a guide to the manner of analysis that is needed for clarity on the manner of any actual SSP development. The results and process are in no way conclusive but can act as a starting point for subsequent analyses.

CONCLUSIONS

Public/private partnerships for Space Solar Power can spread technical, economic, and legal risks for both entities. For public actors, joint relationships with private industry provide an advanced degree of budget stability to an otherwise chaotic annual appropriations process as well as both technical and political justification for expanded Human Exploration and Development (HEDS) of space. For a commercial entity, this partnership eases negotiation of environmental and frequency allocation issues, as well as assisting with the large capital requirements required at the beginning of any SSP program. The combination of the two entities may enable SSP to be both amenable to receipt of modern public treasuries and commercially feasible versus other energy sources.

REFERENCES

1. Harvey, et al. Space Solar Power: A Fresh Look at the Feasibility of Generating Solar Power in Space for Use on Earth, Science Applications International Corporation, April 4, 1997, Schaumburg, Illinois, SAIC-97/1005.

2. Feingold, Harvey, et al. Space Solar Power: 1998 Concept Definition Study, Science Applications International Corporation, February 1999, SAIC-99/1016.

3. Howell, Joe. Early, Preliminary, Partial Report: Space Solar Power Concept Definition Study. Huntsville, Alabama: Marshall Space Flight Center, 1998.

4. Olds, J., Way, D., Charania, A., Budianto, I., Marcus, L., "In-Space Deployment Options for Large Space Solar Power Satellites," IAA-00-R.2.02, 51st International Astronautical Congress, Rio de Janeiro, Brazil, October 2-6, 2000.

5. Glaser, P., "Power from the Sun: In future, in Sciences," Repport No. 162 du 22 novembre 1968, p. 857.

6. NASA, The Final Proceedings of the Solar Satellite Program Review, DoE/NASA Conference 800491, 1980, p. 107-8.

7. Christensen, Carissa Bryce, Comstock, D. A., Makins, J., "The Economics of Space Solar Power," Presented Space 1996 Conference, 1996.

8. Greenberg, Joel S., "Space Solar Power: The Economics Realities," in Aerospace America, Reston, VA: AIAA, May 2000.

9. Judge, Anthony, "International Institutions: Diversity, Borderline Cases, Functional Substitutes and Possible Alternatives" in "International Organizations; A Conceptual Approach," ed. Taylor, Paul and Groom, A.J.M., New York: Nichols Publishing Company, 1978.

10. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, adopted on 5 Dec. 1979, opened for signature on Dec. 18, 1979, entered into force on 11 July 1984. See, UN GA Res. 34/68; 1363 UNTS 3; 18 ILM (1979) 1434.

11. Rosenfeld, Stanley B., "Solar Energy and the Common Heritage of Mankind", Proceeding of the 21st Colloquium of the IISL, at 58-64: Ch. Chukuwuma Okolie, "Solar Energy Bank for Mankind in Contemporary International Space Law", Proceeding of the 22nd Colloquium of the IISL, p. 14.

12. Nordlund, F., "Legal Aspects of the Use of SPS", Proceedings of the Second International Symposium on SPS, held in Paris from 27 to 30 August, 1991, p. 143.

13. Convention on International Liability for Damage Caused by Space Objects, adopted on 29 Nov. 1971, opened for signature on 29 Mar. 1972, entered into force on 1 Sept. 1972. See,UN GA resolution 2777 (XXVI) annex; 961 UNTS 187; UKTS No. 16 (1974), Comnd. 5551; 24 UST 2389; TIAS 9962.

14. Convention on Registration of Objects Launched into Outer Space, adopted on 20 Nov. 1971, opened for signature on 29 Mar. 1972, entered into force on 1 Sept. 1972. See, UN GA resolution 3235 (XXIX) annex; 1023 UNTS 15; UKTS No. 70 (1978), Cmnd. 7271; 28 UST 695; TIAS 8480.

15. Cocca, A.A., "Consequences of Transmission of Solar Energy from Outer Space", Proceedings of the 25th Colloquium of the IISL, p.353.

16. Statute of the International Atomic Energy Agency, 1956, 8 UST 1093.

17. Agreement Relating to the International Telecommunications Satellite Organization, 23 UST 3813.

18. Commercial Space Launch Act, 49 USC 70101, et seq.

19. European Commission, Galileo, Involving Europe in a New Generation of Satellite Navigation Services, 9 February 1999.

20. Whitfield, J. A. and Olds, J. R., "Economic Uncertainty of Weight and Market Parameters for Advanced Space Launch Vehicles," AIAA 98-5179, 1998 Defense and Civil Space Programs Conference and Exhibit, Huntsville, AL, October 28-30, 1998.

21. Lee, H. and Olds, J. R., "Integration of Cost and Business Simulation into Conceptual Launch Vehicle Design," AIAA 97-3911, 1997 Defense and Space Programs Conference and Exhibit, Huntsville, AL, September 1997.

22. Charania, A., Olds, J., "A Unified Economic, View Of Space Solar Power (SSP)," IAF-00-R.1.06, 51st International Astronautical Congress, Rio de Janeiro, Brazil, October 2-6, 2000.