

NASA Technical Memorandum 106271
AIAA-93-2278

1N-16

175557

P. 25

Space Transportation Alternatives for Large Space Programs: The International Space University Summer Session — 1992

Bryan A. Palaszewski
Lewis Research Center
Cleveland, Ohio

Prepared for the
29th Joint Propulsion Conference and Exhibit
cosponsored by the AIAA, SAE, ASME, and ASEE
Monterey, California, June 28-30, 1993

(NASA-TM-106271) SPACE
TRANSPORTATION ALTERNATIVES FOR
LARGE SPACE PROGRAMS: THE
INTERNATIONAL SPACE UNIVERSITY
SUMMER SESSION, 1992 (NASA) 25 p

N94-10811

Unclas

G3/16 0175557

NASA



Space Transportation Alternatives for Large Space Programs: The International Space University Summer Session - 1992

Bryan Palaszewski*
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, OH

Abstract

In 1992, the International Space University (ISU) held its Summer Session in Kitakyushu, Japan. This paper summarizes and expands upon some aspects of space solar power and space transportation that were considered during that session. The issues discussed in this paper are the result of a 10-week study by the Space Solar Power Program design project members and the Space Transportation Group to investigate new paradigms in space propulsion and how those paradigms might reduce the costs for large space programs. The program plan was to place a series of power satellites in Earth orbit. Several designs were studied where many kW, MW or GW of power would be transmitted to Earth or to other spacecraft in orbit. During the summer session, a space solar power system was also detailed and analyzed. A high-cost space transportation program is potentially the most crippling barrier to such a space power program. At ISU, the focus of the study was to foster and develop some of the new paradigms that may eliminate the barriers to low cost for space exploration and exploitation. Many international and technical aspects of a large multinational program were studied. Environmental safety, space construction and maintenance, legal and policy issues of frequency allocation, technology transfer and control and many other areas were addressed. Over 120 students from 29 countries participated in this summer session. The results discussed in this paper, therefore, represent the efforts of many nations.

Nomenclature

CAN	Canada
DOE	Department of Energy
CNES	Centre Nationale d'Etudes Spatiale
EOTV	Electric Orbital Transfer Vehicle
ESA	European Space Agency
ETO	Earth to Orbit
EVA	Extravehicular Activity
FRA	France
FY	Fiscal Year
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GW	Gigawatt
H	Atomic Hydrogen
HLLV	Heavy Lift Launch Vehicle
ISAS	The Institute of Space and Astronautical Science
ISU	International Space University
IUS	Inertial Upper Stage
I_{sp}	Specific Impulse
JETRO	Japan External Trade Organization
JPL	Jet Propulsion Laboratory
JPN	Japan
kW	Kilowatt
LSS	Large Space Structures
METS	Microwave Energy Transmission in Space
MILAX	Microwave Lifted Airplane Experiment
MINIX	Microwave Ionosphere Non-linear Interaction Experiment

* AIAA Member,

MITI	Ministry of International Trade and Industry
MPD	Magneto Plasma Dynamic
MSS	Master in Space Studies
MW	Megawatt
NASA	National Aeronautics and Space Administration
NLS	National Launch System
OTV	Orbital Transfer Vehicle
PLV	Personnel Launch Vehicle
POTV	Personnel Orbital Transfer Vehicle
SDI	Strategic Defense Initiative
SEE	Societe des Electriciens et des Electroniciens
SFU	Space Flyer Unit
SHARP	Stationary High Altitude Relay Platform
SPS	Solar Power Satellite
SSPP	Space Solar Power Program
SSTO	Single Stage to Orbit
STS	Space Transportation System
TSTO	Two Stage to Orbit
USA	United States of America

Introduction

Space power has been studied in the past as an alternative to terrestrial power systems (Refs. 1, 2, 3, 4, 5). Its attractiveness lies in the thought that because energy is produced in space, the thermal and material pollution of the Earth can be substantially reduced. Also, because these power stations are in space, there is the potential for continuous power. With no cloud cover, storms or other weather to obscure the solar radiation, power can theoretically be generated 24 hours a day and transmitted as it is made. This seductive concept becomes more attractive if the costs of all of the required technologies to assemble and maintain it are small compared to competing terrestrial power sources.

Many past studies of space power have made both realistic and optimistic assumptions of the costs of the power generation, of maintenance, and of transportation technologies. In the most realistic and near-term cases, space power can provide specific benefits for a restricted set of users in space and on the ground. In its most

optimistic incarnations, it can provide almost unlimited power for all of the world's industries. Finding where the truth lies will require more thoughtful consideration.

Space Solar Power: Background and History

During the early 1960's, several researchers considered the possibility of collecting energy from the Sun and transmitting it to the Earth. Peter Glaser (Ref. 6) was the first to propose and patent the idea of beaming solar energy from a satellite to Earth. Some of the first experiments with ground-based beamed energy were conducted with a small-scale helicopter (Ref. 7). JPL and NASA conducted other larger scale demonstrations of the technology for power beaming in the atmosphere. Amongst these are the world's highest power level transmitted by microwave beam through the atmosphere (Refs. 8 and 9). A total of 30.4-kW of beamed power was received at the NASA-JPL Deep Space Network Station in Goldstone, California. An array of lights were illuminated from a distance of 1540 meters.

The NASA-DOE study (Refs. 2, 4) investigated large scale 5-GW power level solar power satellites. Detailed conceptual designs of all of the components were developed over a period of 5 years from 1976-1980. Dozens of these satellites would be needed to power the USA or any other large industrial user nation. All of the satellites would operate in Geostationary Earth Orbit (GEO). A typical size for these rectangularly-shaped satellites is 5 by 10 km. This large surface is almost entirely covered with solar cells. As the energy is produced, it is transmitted to a ground station with a microwave beam. The transmitting antenna diameter is 1 km. The frequency of the microwave transmission would be 2.45 GHz. On the ground, a receiving antenna, or rectenna, would intercept the beam and ground processing stations would convert the energy into usable power for the main electricity grid.

While ambitious, this idea for generating power for Earth is expensive. The initial investment costs based on the NASA/DOE study estimated the investment costs over the first 30 years to be more than 2 trillion dollars (FY 1992 dollars, Ref. 1). The payback for the system began 20 to 40 years after the first operational power satellite launch. Even with an international program, it is unclear that Space Solar Power will be attractive in a large scale application. ISU therefore embarked on the task of finding a more cost-effective method or path to develop the technologies for SSPP.

As part of the 1992 10-week International Space University Summer Session, several alternative space solar power systems were studied. Space power systems for ground-based and space-based power usage were envisioned. During this study, many of the assumptions of past analyses were reviewed and critiqued. The large drivers in cost were reviewed and a series of demonstration projects were conceived to show the possible benefits of space power for ground-based use. The cost review helped focus the direction of our study groups and allowed us to list important directions for future studies. The demonstration projects showed that the costs of space systems are not low. Future systems must establish new paradigms in space flight to reduce these costs if space power is to become a viable energy alternative.

The cost of space access was one of the major cost factors in the development and operations of space power systems. Space transportation costs have historically been a major influence on space program costs (Refs. 1-5). Large space programs, especially, will use space transportation systems extensively and frequently. To reduce the cost of these systems, new methods and paradigms will be required to remake the face of space. Later in the paper, a number of space access methods will be discussed.

To fully assess the space transportation influences on costs and other aspects of the program, a broad systems perspective is needed. This view will uncover the effect of other parts of the system as well as the influence of the legal

and international agreements. This interdisciplinary perspective is where the International Space University (ISU) can play an important educational and technical role.

What Is the International Space University ?

The ISU is a major venue for students from all over the world to discuss and assess future space missions and applications. Not only does ISU provide a fertile ground for the review of space projects, but it allows persons from all over the world to meet and attempt to open the floodgates of international communication between space enthusiasts.

Each summer since 1988, ISU has sponsored a 10-week session in a different city around the world. Cambridge, Massachusetts (USA), Strasbourg (FRA), Toronto (CAN), Toulouse (FRA), and Kitakyushu (JPN) have been past ISU sites. These sessions are a very intense time of education and commitment to a design project. To complement the stresses of the academic workload, there are many cultural and social activities to promote a cooperative atmosphere amongst the students and the faculty. In Kitakyushu, the ISU community was even invited to perform traditional Japanese dances in a local festival.

The summer sessions will ultimately be complemented with a permanent campus site where ISU will offer a Master in Space Studies (MSS) degree. This campus will be in Strasbourg, FRA. Additional affiliate campuses will also be chosen to further continue and promote ISU research and education in a large number of additional cities. These campuses will not offer academic degrees, but their work will foster students' international space cooperation.

Departments, Lectures and Workshops

Nine departments are part of the ISU lecture series during a summer session: Architecture, Business and Management, Engineering,

Life Sciences, Physical Sciences, Policy and Law, Resources and Manufacturing, Satellite Applications, and Humanities. Five weeks of core lectures allow each department to cover the basic space-related topics that are part of the design project. Other special lectures and seminars are also provided by various luminaries in the international space community. These lecturers include astronauts and cosmonauts, directors of various nations' space programs, artists, historians, entrepreneurs, and ISU alumni. Also, researchers from the local area are invited to perform joint experiments with the students as part of the departmental workshops. For example, the Shimizu Corporation provided a domed area where a Mars surface drill was simulated and used by engineers from The Institute of Space and Astronautical Science (ISAS), Nishimatsu Construction Company, and Nagoya University to investigate different boring techniques (Ref. 10). Various consistencies of simulated Martian soil and different drill techniques were evaluated over a period of one week using ISU student volunteers to conduct the experiments.

Design Projects

During the summer session, there are technical design projects that involve all of the students. After absorbing the core lecture materials, and having many hours of additional lectures on how to approach our design projects, students are organized into task groups. During the first phase of the design project, our groups were asked to identify important questions to be answered during the second phase of the project. Several groups were formed to address the issues of economics-business, demonstration-specific problems, political-social-legal, technical, and environmental-safety. As an example, Table I lists the major issues discussed by the environmental-safety group. Each group represented numerous disciplines which yielded new perspectives on many space issues. This interdisciplinary aspect is one of the major strengths of ISU.

In the SSPP design project, the ISU international perspective gave new insights into almost any space issue. Our space transportation group was

composed of students from 5 countries: France, Germany, Japan, Sweden, and USA. Though not direct members of the group, representatives from China and Russia also provided their perspectives on space launchers. All agreed that launch costs are a major stumbling block to success and cost-effectiveness in large programs.

Table I
Environmental/Safety Group Issues
for SSPP

Living Organisms

Human:

Effect of Microwaves
Political, Social Influence
Heating

Other:

Effects on Flora, Fauna
Protection Needs
Safety Demo

Atmosphere

Microwave-Atmosphere Interactions
Safety Demo
Global Warming

Rectenna

Local Environment Effects
Rectenna Placement
Hydrology, Geology, Aesthetics

Launch Systems

Environmental Damage (Atmosphere, Land)
Space Debris
Demo of Environmental Impacts

Why the ISU Space Solar Power Program?

One function of the SSPP was to develop a cost-effective incremental program for the demonstration of space power. This step-by-step approach was proposed by Peter Glaser (Ref. 11) and embraced by the ISU. Based on the initial solar power satellite cost

estimates, it is not clear that one nation could afford such a system. An incremental program might allow less costly demonstrations and generate sufficient confidence for international partners to become investors. By attacking the smallest, simplest pieces of the problem first, the succeeding steps would hopefully become much easier. Also, the visibility of the demonstrations would foster public acceptance of beamed space power.

Japan and other nations have embraced this phased approach (Ref. 12). Several design studies have been initiated (Ref. 12): SPS 2000, Space Flyer Unit (SFU) Energy Mission Study and Microwave Garden Project. Also, small-scale experiments have been conducted: the Microwave Lifted Airplane Experiment (MILAX), Microwave Ionosphere Nonlinear Interaction Experiment (MINIX), and Microwave Energy Transmission in Space (METS). The latter two projects were launched on suborbital sounding rockets. The sounding rocket experiments used high-density micro-electronics and have shown the potential for lightweight power generation and heat rejection. The Japanese METS experiment, launched in early 1993, transmitted 1 kW of electric power from a sounding rocket mother vehicle to a smaller daughter free flyer released from the mother rocket. This experiment was conducted in cooperation with the USA's Center for Space Power at Texas A&M University and the NASA Lewis Research Center.

Canada and Europe have also conducted or are planning experiments that show their increasing interest in beamed power (Ref. 13). The Stationary High Altitude Relay Platform (SHARP) was conducted by Canada to investigate long duration airplane surveillance and communications (Ref. 14). The European Space Agency (ESA) has held several international conferences on space power (Refs. 15, 16, 17).

The Design Project: A Phased Approach

Using the phased approach (Refs. 1, 11), the SSPP team attempted to identify the best

experiments to demonstrate the feasibility of differing aspects of power beaming and reception. Figure 1 shows the SSPP approach and development plan (Ref. 1). There are five major phases: space to space, terrestrial testing, space to Earth, large-scale precommercial satellites, and solar power satellites. In each of these phases, Earth-bound experiments with point-to-point transmission and other environmental impact studies and/or research would be conducted prior to any large space demonstrations.

Small Space Experiments

Small experiments or demonstrations were proposed as the vehicle for popularizing space power. One idea even suggested using a roll-out rectenna or "magic carpet" (Ref. 18) that would intercept a microwave beam from a passing satellite. This demonstration, though appearing somewhat whimsical, could allow power to be available in remote areas over longer periods of time. A follow-on program might provide more-continuous power to developing nations and remote exploration sites (in equatorial jungles, etc.).

Low-Cost Demonstrators

During the study, several demonstration projects were conceived to provide some data on power transmission and integration of the spacecraft, the solar power generation, and the microwave power-beaming technologies. A wide range of ideas were proposed, including a transportation experiment with electric propulsion.

Cost constraints were given for two of the demonstration missions: 80 and 800 million dollars (FY 1992). In the 80-million dollar mission, the Russian Mir space station and robotic Progress tanker vehicle combination was used. This experiment allowed a demonstration of space-to-space transmission and reception. Power was planned to be transmitted from the Mir to the Progress and the power level of the experiment was to be a maximum of 10 kW for multiple 1-hour durations. The use of existing Russian

spacecraft allowed a significant cost savings over a completely new vehicle design. For the 800-million-dollar experiment, a large spacecraft in sun-synchronous orbit with a 1000-km altitude was assumed for space-to-Earth power-beaming experiments. At 1000 km, the satellite would deliver 50 kW to a 1-km² rectenna. Though the ground station visibility time at this low altitude was only 5 percent of an orbital period, the experiment plan was to demonstrate that beaming to equatorial locations was preferable to the originally-selected Antarctic regions due to higher orbital visibility and the lower losses at the equator. The major losses at the polar areas are due to blowing snow and ice inadvertently covering the rectennas.

Two additional experiments were also designed: one for under 8 million and one for 2-3 billion dollars. In the 8-million-dollar experiment, a small satellite would intercept microwave transmissions from the 300-m diameter radiotelescope in Arecibo, Puerto Rico. The satellite would be launched aboard an Ariane rocket as a auxiliary payload and placed into a polar orbit. Weighing less than 150 kg, the satellite would use an inflatable rectenna and intercept a small fraction of the beamed energy from Arecibo. The more-costly multibillion dollar experiments beamed energy from space to Earth and required a minimum of two Russian Energia launches and several USA STS flights. These vehicles would have a 1-MW solar-array power level, operate at a final altitude of 20,000 to 36,000 km, and beam power to near-equatorial ground rectennas. A range of different satellites were analyzed to assess the assembly requirements and the costs for several high-power precursor power satellites. Though the cost of this system was several billion dollars, these satellites are relatively low-cost version of the high-power 5-GW power satellites proposed as part of a full-scale solar power satellite constellation.

The results of these design examples were long, extended exercises for the students in the difficulties and intricacies of planning space projects. All of the students learned an important lesson; they were impressed with how small the return was for the invested cost.

Other SSPP Issues

The specific issues that were studied also included many of the international and technical aspects of a large multinational program. Environmental safety, space construction and maintenance, legal and policy issues of frequency allocation, technology transfer and control, costs and many other areas were addressed. Tables II and III show the specific groups that were formed to address these issues and the major issues, respectively. Some of the important results are presented in the next sections.

Table II
Task Groups of the Space Solar Power Program

-
- Assumptions, Intentions, and External Relations
 - Scheduling
 - Legal and International Relations
 - Business Planning
 - Environment and Safety
 - Space Transportation
 - Manufacturing, Construction, and Operations
 - Spacecraft
 - Power Collection, Conversion, and Distribution
 - Technical Trade Identification
-

Energy Analysis. To justify the consideration of space power, and to quantify the need for future power systems, a preliminary energy analysis was conducted. The predicted energy needs of the world and the supplies of current energy resources were compared. Current terrestrial energy sources considered in this analysis are listed in Table IV. Several future energy consumption scenarios were considered: low, medium, and high growth. In all of these cases, the total demand for energy will increase, with the low model increasing by 150 percent (2.5 times the current rate) and the high model

Table III
Critical Issues for SSPP (Ref. 1)

Design Project Group	Issue
Space transportation	reduction of ETO launch costs
Spacecraft	attitude, orbit, and vibration control of LSS
	efficient radiators
Power collection, conversion, and distribution	more efficient power conversion systems
Environment, physical and life sciences	determine beam effects on biota and Earth's atmosphere
Social and political	create international management group for space solar power project
	ensure security of satellite and beam
Manufacturing and assembly	develop advanced assembly techniques in robotics and EVA
Business and other	achieve business feasibility for program
	search for long-term funding
	achieve scientific acceptance
	public awareness

having a 400-percent increase (5 times the current rate).

Alternative Energy Sources. A wide range of energy sources were considered as competitors with space power. The potential alternative energy sources are shown in Table IV. The current energy sources of coal, oil and gas

Table IV
Current, Potential and Speculative Power Sources

Current:

Fossil Fuels: Oil, Gas, Coal
Nuclear Fission

Potential:

Fusion
Geothermal
Biomass
Wind
Solar - Thermal and Photovoltaic
Ocean - Thermal, Tides, and Currents
Extraterrestrial Resources

Speculative:

Black Holes
Crystals
Human: Bicycles, Treadmills
Volcanos
Gravity Waves
Antimatter
Alternate Universes
Tachyons

provide 90 percent of the world's energy (Ref. 19). These sources are destined for depletion in the early part of the 22nd Century. The other 10 percent of the energy is produced by nuclear fission, hydroelectric and other technologies, such as solar and wind.

Alternative energy sources were also identified using a brainstorming method. Many alternative technologies are available for sustaining the Earth's needs. The time scale for the depletion of the natural resources may be a driver for the logical progression of space power from its current formative stages to its genesis as a major power supply. Some of the unusual and striking alternatives that were considered during the brainstorming sessions were black holes and crystals.

A preliminary comparison of the costs of power systems is presented in Figure 2 (Ref. 20). It is clear that the best-estimate cost of space-based power is very high: 2 to 6 times that of a current ground-based alternative. Though this analysis shows that space power may be unattractive in the near term, the analysis does not include the cost of environmental impact and the need for increasing energy demand with the depletion of currently-available fossil fuels. Once these costs are included, the picture may dramatically change. The final analysis will depend upon the urgency of the need for alternative power, the technology readiness of these alternatives, and the political will to invest in future power directions.

Markets. Another direction our study addressed was the market for power from space. This included not only the space applications but the terrestrial possibilities as well. Table V lists the market opportunities that were found for

Table V
Markets for Space Power:
Near, Mid and Far Term

Space -	
	GEO and LEO Satellites
	Space Stations
	Electric Propulsion
Earth -	
	Remote Sites:
	Power Relay
	Peak Power
	Primary Power

space power. The analysis looked into near-, mid-, and far-term options for space and Earth markets. Peak power and electric propulsion were the two areas where space power might make a large contribution. Peak power is needed at times during the day when industrial or other commercial power consumption are particularly demanding. Because the cost of peak power level is at least twice as costly relative to

base-load power, a low-cost space power system might provide benefits.

Electric propulsion systems have been investigated for orbital transfer missions and especially for deployment of space power satellites. Electric propulsion is already acknowledged as a powerful force in reducing the costs of space transportation (Refs. 2, 4, 21). Using beamed energy with electric propulsion, in the proper form and manner, might further reduce the cost of this transportation option and the overall SSPP. This concept involves bootstrapping the use of the power satellite: using it for a traditional power demand as well as powering the Electric Orbital Transfer Vehicles (EOTV) that are lifting their brethren into their final orbits. Though this may provide a savings for the overall transportation system, there is also the added complication of potentially beaming energy to multiple targets and handing off the EOTV to other satellites as they fall out of the line of sight with their orbital power stations.

SSPP Space Transportation Issues

After reviewing the existing literature on space power satellite designs, the costs of the differing systems were identified and assessed. Space transportation was found to dominate the cost of advanced power systems in space. In past studies of these solar power satellites, up to 40 percent of the program cost was directly related to space transportation; this is shown in Figure 3 (Ref. 1). The transportation system costs for solar power satellites were 40 to 45 percent of the total research, technology and development costs. These costs include the Heavy Lift Launch Vehicle (HLLV), the chemical Orbital Transfer Vehicles (OTV) and EOTVs. Thus, in the planning of future space programs, space transportation will play a critical role. This paper will address alternatives to reduce the cost of space flight and the options for various programs' transportation needs. Innovative technologies and new architectures are

available to potentially reduce these costs and make all of space flight more affordable.

The Space Transportation Group was formed to assess new ways of conducting space missions that would reduce launch and other transportation costs. Figure 4 shows the driving requirements that were identified in the overall development plan for space solar power. These planning activities identified the interactions between not only our different space system areas but also the international and political forces that are a critical part of this large space program. The interactions of the Space Transportation Group with the other groups in the space solar power program are also depicted in Figure 4. These interactions include the selection of the appropriate launch vehicles for demonstration missions, the identification of markets for space transportation related to space power, the discussion of the payload accommodation of the differing satellite payloads and the review of issues related to the most promising technologies that merit further analysis.

NASA/DOE Study: Transportation

In the studies conducted in the late 1970's, the elements of space transportation were divided into Earth to Orbit, orbital transfer and lunar transportation. Initially, the transportation included only an Earth-centered system. The primary elements were heavy lift launch vehicles with electric propulsion and chemical propulsion OTVs. A lunar transportation system was placed in the systems analysis after realizing that Earth transportation costs were too high to make space power economical. Lunar materials were processed into propellants and building materials to construct the solar power satellites. Production factories would be transported to the Moon and the initial cost for emplacing them would have to be paid. After these factories paid for themselves and lunar materials were used in lieu of those strictly from Earth, the cost of the satellite systems dropped dramatically. A number of transportation vehicles had to be added to the overall system. These included a mass driver, mass catcher, lunar base, oxygen and construction material production plants on the lunar surface and/or in space, and the

traditional lunar transfer vehicles and landers for personnel and equipment transport. Though the apparent complexity of the system increases, producing materials on the moon significantly reduced the Earth-launched mass. Less mass is needed because the energy to transport the materials from the lunar gravity well to GEO was less than that from Earth to GEO. However, even with the use of lunar materials, the payoff for the space power systems is typically many decades in the future (Refs. 1, 22). Combining and using innovative propulsion concepts might further reduce the time for SSPP to pay for itself. We therefore embarked to identify new ways to make space transportation cheaper and therefore make SSPP more attractive.

New Paradigms

A paradigm is a model of how things should be done. New paradigms for space transportation include a number of technologies and vehicle concepts that when taken together, may reduce the costs of space access. The technologies and vehicle types that appeared most promising for cost reductions were cataloged. A method of selecting the technologies and vehicle concepts for the various mission types was also developed.

Transportation Costs

The costs of space transportation included not only the monetary value of the vehicles, but also the "costs" of reliability, accessibility, launch environment, operability and vehicle resiliency. These costs may severely limit the viability of a space solar power system if not addressed early in the program. The technologies and vehicle concepts we reviewed were assessed based on their ability to allow reduction in all of the cost of space flight, not just reductions in its dollar value. We also prepared a white paper which discusses these other important costs for space transportation (Ref. 1).

Table VI
Propulsion Technology and Vehicle Link
To SSPP Applications

Earth to Orbit:	Metallized Propellants High Energy Density Propellants High Energy Chemical (O ₂ /H ₂ , etc.) Slush Hydrogen Gun Propulsion Mass Driver Laser Propulsion • Vehicles - TSTO SSTO HLLV Pressure-Fed Booster
Lunar:	In-Situ Propellants Mass Drivers / Mass Catchers Gun Propulsion High Energy Chemical (O ₂ /H ₂ , etc.) Aerobraking/Aerocapture • Vehicles - Lunar Transfer Vehicle Lunar Excursion Vehicle
Orbital Transfer:	Solar and Nuclear Electric Propulsion Beamed Energy Electric Propulsion Nuclear Thermal Propulsion High Energy Chemical (O ₂ /H ₂ , etc.) Aerobraking • Vehicles - Light Weight Upper Stage
Propulsion-Related Technologies	Light Weight Structures High-Temperature Materials • Vehicles - All of the Options Above

Technologies

The Space Transportation Group compiled a list of future technologies that could potentially reduce the cost of access to orbit. Table VI is a compilation of the technologies considered for

space transportation and their link to different vehicle concepts. Many of the technologies have been considered over the last fifty years and have greatly varying degrees of technology readiness. Several of the technologies were considered most attractive for cost reductions and these will be discussed later in the paper.

Selection Criteria. In the planning for space solar power, there are three power level ranges that were considered and they can be thought of as directly linked to the level of advancement in the space transportation system. Table VII summarizes the power level influences. For

Table VII
SSPP Power Influence On Transportation
Technology

Power Level Range	Advancement Needed
kW	• New Vehicle Technologies
MW	• New Systems or Architectures
GW	• New Paradigms: Lunar transportation, Extraterrestrial resources

example, if only several kW of power were planned to be delivered, then relatively small improvements in technology would be required. However, if large satellites of the GW power level were developed, it seems clear based on past assessments (Ref. 5) that a new model of space transportation, a new paradigm, would be needed. This new paradigm might entail lunar transportation - using in-situ resources to construct propulsion systems, and the satellites

themselves, using minimal Earth-derived resources. This new system might include mass drivers and have a minimal dependence on traditional rocket propulsion systems for ascent from the Moon's surface (Ref. 5).

In-situ resources, however, do not necessarily solve all of the transportation problems. To place all of the elements of the lunar transportation system in place, they must initially be launched from Earth. There is therefore a payback time over which the mass of the lunar base and its transportation systems are amortized. This payback may take a decade or more. Also, all of the materials of the solar power satellite may not be easily fabricable from lunar resources. The quality of solar cell production from lunar materials has been both supported and questioned (Refs. 23, 24, 25). This and other competing paradigms should therefore be examined before any transportation system design is finalized.

The decades-long payback period also led us to believe that government support will be needed to sustain such a long program. Commercial investment may be solicited after the full-scale space power system has been proven and put into practical use. Other smaller-scale programs, such as the remote site power relay or the peak power application might attract earlier commercial investors, but it is unlikely that investors alone will absorb the initial start-up cost for space solar power.

Two vehicle paradigms, the Big Dumb Boosters (Ref. 26, 27, 28, 29) and Two Stage to Orbit (TSTO, Refs. 30, 31, 32, 33) are technologies that can potentially reduce SSPP costs. These vehicle technologies reduce the number of components and potentially simplify the operations for the overall launch system. Higher density and higher I_{sp} propellant technologies were amongst the other technologies considered (Ref. 34, 35). Increased density and I_{sp} can be important for smaller, lighter, more-compact rockets because the lower dry mass of the rocket, the easier it is to achieve orbit. This aspect can be critical for TSTO and especially for SSTO vehicles. The technologies that our Space Transportation Group deemed most likely to reduce costs were discussed in the most detail.

The important results of this transportation technology survey are discussed in the next sections.

Big Dumb Booster. This launch technology was considered in the early 1960's as a method of placing large payloads into orbit. Several different types of engine technologies were considered but one that was most attractive was the pressure-fed booster. Because this rocket used no high-pressure turbomachinery, it is perceived as a very simple vehicle. With the pressure-fed booster, propellants are fed to the engines with only the pressure from the propellant tanks. The tankage pressures for this booster are typically very high: 300-500 psia. This is in contrast to the low-pressure, 50-psia, thin-walled tankage designs that are typical of flight systems like the Space Shuttle or Ariane. Versions of the pressure-fed booster have been proposed in its most ambitious form in the Sea Dragon (Refs. 27, 28) and most recently in the SEA Launch And Recovery (SEALAR) concept (Ref. 29).

The Sea Dragon (Ref. 27) was the first large pressure-fed booster to be studied for space missions. It was a two-stage rocket with a payload to LEO of 1.1 million lb_m. Its name was derived from its large size and the fact that it was sea launched. The Sea Dragon was over 540 feet long, 75 feet in diameter, had a GLOW of 40-million lb_m and a liftoff thrust of 80-million lb_f. Each stage used only a single engine to deliver its total thrust level. Its impressive dimensions would perhaps be unwieldy in a land-based launch pad but using the ocean obviates the massive infrastructure of a fixed launch site. Other support facilities, such as a dock for construction and refurbishment are required, but the relative cost of the ocean-based dock to the land-based launch pad favors the ocean system (Ref. 27). Also, with the ocean-based system, nearly any size rocket can be launched without creating a new launch facility. The first stage was to be recovered at sea and towed to the launch vehicle shipyard where it would be refurbished.

The vehicle also was designed to use tankage made in shipyards rather than in the clean-room environment of a typical aerospace factory. Shipyards were considered because the size of the tankage was extremely large and its walls were very thick. With the 1.1 million pounds of payload design, the Sea Dragon fuel tank wall thickness was several inches, a marked contrast to the delicate paper-thin tankage of our current launch vehicles. The launch vehicle stages were designed for rugged use, including sea recovery with minimal aerodynamic braking, and therefore aerospace-standard tolerances and clean rooms were not required. The cost of using shipyard-quality fabrication techniques was substantially below the costs in the more-typical aerospace plant which further reduced the estimated cost of the launch system.

The more-recent SEALAR program was a reusable, sea-launched rocket that can place 10,000- to 140,000-lb_m payloads into LEO (Ref. 29). With a SEALAR rocket, many payloads could be launched at a high rate, which was very attractive for potential Strategic Defense Initiative (SDI) applications. Subscale water immersion tests of the rocket components and shipboard rocket engine firings were conducted in the SEALAR program. However, due to budget reductions, SEALAR was never fully demonstrated. Its inspiration, Sea Dragon, was perceived as somewhat radical and impractical by NASA in the 1960's due to its immature design and the potential low reliability of a single engine system. Their potential to lift large payloads at reduced cost, however, make these large sea- or ground-based pressure-fed boosters strong candidates for reducing launch costs.

Two Stage to Orbit. This launch vehicle uses an airbreathing first stage and accelerates a second stage to a speed of approximately Mach 6 to 10 (Ref. 30-33). The first stage is a winged airplane. A rocket-powered second stage then proceeds to orbit. The airbreathing stage flies back to an airport-like landing area for refurbishment. The second stage may be either a payload canister or a reusable flying vehicle. The operations of this vehicle can potentially be very simple compared to traditional rockets. It is also

a potential interim step prior to developing a Single Stage to Orbit (SSTO) vehicle. Turbojets and scramjets on the TSTO will produce much lower velocities than that for an all-airbreathing SSTO. Therefore the airbreathing technology is much more near term than the Mach 25 scramjets needed to go to orbit.

The TSTO appeared attractive because of the aircraft-like operations afforded by winged stages. Though the current Space Shuttle is a winged vehicle, it does not have any of the airplane-like operational characteristics of the TSTO. The first stage, with the large air-breathing engines, can be maintained with many of the well-developed techniques employed by the military for high-speed aircraft. The Space Shuttle requires a large army of technicians to assess its safety after each flight. Hopefully, that large contingent of personnel could be pruned with the new TSTO approach.

Single Stage to Orbit. The advent of high performance rocket engines and lighter weight structures may someday make the concept of Single Stage to Orbit vehicles a reality (Ref. 31). Because the vehicle only needs to be reloaded with propellants and serviced, the cost of operations is theoretically reduced. Current rocket and material technologies, however, make SSTO impractical. The current technology levels for propulsion I_{sp} and lightweight materials can only deliver a marginally-small payload to Low Earth Orbit. Development of these technologies may be driven by the needs of an SSPP-type endeavor. As discussed in the TSTO section, airbreathing SSTO is also an option, but the technology required is in the development stage. The TSTO therefore seems to be a more near-term SSPP option for reduced launch costs.

Guns. Gun propulsion is a way to provide orbital velocities while leaving the main "propulsion" system on the ground. Using a high muzzle velocity gun or cannon to launch payloads is potentially attractive if the payload is insensitive to shock and

vibration (Ref. 36). The payload must also have a system to allow maneuvering after the launch to circularize the orbit. A high mass fraction for propellant tanks and other structures may not be possible with such high launch velocities and accelerations. Also, a remote site will have to be selected for the launch of the projectiles. The noise generated by the firing during launch will be very high. An estimate of the distance to minimize the sound level to 70 dB is 2 km (Ref. 36). A similar safety distance is typical for a rocket launch. Many of the past studies have discussed the mass of the projectile and ignored the added mass to withstand the high accelerations during launch. Current studies have included these factors and have shown promising results. An SSPP using this technology would have to acquire and use many small masses and assemble them into the final vehicle. Typically, the proposed gun launchers have payloads of 1,000 kg. Assembling these many small masses into a large operational vehicle may be a significant challenge.

Electric Propulsion. The technology of electric propulsion will potentially allow great reductions in the cost of space transportation. It enables this through the reduction of the mass launched into orbit, the reduction of the mass of the propulsion system, and the reduction of the payload capacity needed of the launch vehicle to place a payload into orbit. All of these factors can reduce overall program costs.

Electric propulsion differs fundamentally from chemical propulsion in several ways: electrical power supply, low acceleration, large flexible structures and low-thrust attitude control. A large electrical power system is carried on board the vehicle to provide energy to electric thrusters. This electrical energy is used to ionize and accelerate a propellant to very high speeds. This acceleration produces a very high I_{sp} . Because of the high I_{sp} , the total mass of the vehicle can be significantly reduced over chemical propulsion. This is especially true for the very high energy missions. The performance of an electric OTV is strongly dependent upon the power technology, power level and the I_{sp} of the thrusters. For each mission type, a series of

trade studies and an optimization of power level and thruster performance is therefore needed.

With electric propulsion, a vehicle thrust to weight of 10^{-4} to 10^{-6} is typical. The low acceleration requires long thrusting times in Earth orbit or in Earth-lunar space. An attitude control system is needed that will autonomously maintain the correct thrust angle and attitude of the entire vehicle during the long orbital transfer. Also, large light weight flexible structures are typically used for the solar arrays and other power system structures, taking advantage of the low acceleration of the vehicle.

There are several thruster technologies that are appropriate for OTVs. They are ion, arcjet and Magneto-Plasma-Dynamic (MPD) thrusters. Each system can use varying propellants and the performance is dependent upon the propellant selection. Ion propulsion will typically use inert gas propellants, such as xenon, krypton or argon. Arcjet thrusters may use hydrazine, ammonia or hydrogen. For MPD thrusters the propellants may be deuterium, hydrogen or even lithium for very high efficiency engines.

By using electric propulsion, the I_{sp} of the upper stage propulsion system is increased very significantly: up to 5000 $\text{lb}_f\text{-s/lb}_m$ versus the typical values of 300 to 450 $\text{lb}_f\text{-s/lb}_m$ for chemical propulsion. An example of reducing the launch vehicle size is the use of solar electric ion propulsion for the deployment of Global Positioning Satellites (GPS, Ref. 21). Over the life of the GPS system, the total cost savings will be many billions of dollars. Similarly, for space solar power, electric propulsion offers the most efficient method of emplacing and maintaining the satellites.

Program Plan

In addition to assessing the propulsion technologies and vehicle options, we also created a timeline for the development of the

flight systems needed for a solar power satellite program. Figure 5 shows a simplified schedule and flowchart of the SSPP. Four demonstration missions, which were discussed earlier in the paper, are planned, each using existing boosters with some small modifications and near-term technology upgrades.

One critical problem with space transportation development for SSPP is the time scale that is considered. Over the period from 1992 to 2037, many improvements in technology are possible. Therefore, two iterations on the design of the vehicles and the technologies are included in the plan. Though technology infusion has moved slowly in the past twenty years, the impetus of the SSPP may provide the incentive to advance transportation technology at a higher rate than has been seen previously. International investments, not only from space programs but from energy-based investments, may provide the funding to leap-frog to the next generation in technology rather than following the typical, ponderous evolutionary path.

After the initial identification of the vehicle sizes required for the power satellites, the vehicle selection will be made. Depending on the satellite technology to be demonstrated, the launch system will have to be designed or current vehicles and systems will be pressed into service. For example, if the demonstration were only for a small-scale power beaming demonstration, there would be no need for new technology.

Prior to 2006, the technologies that were perceived as important in the 1992 time frame will be developed. In 2006, the reevaluation of the STS concepts would begin. New technical developments would hopefully allow lower cost implementations of SSPP.

Because the time scale for SSPP development is up to 50 years in the future, it is difficult to point to a specific technology as the one of choice for a specific application. Innovative solutions to many of the technical challenges of space solar power are possible and it is nearly impossible to predict the potential of space propulsion over a five decade span. Though the scale and direction for SSPP is hard to predict, the need for

advanced propulsion technology is clear only if very high power levels are desired. In our planning, the low-cost demonstration missions occur in 1992, 1996, 2005 and 2012 (see Figure 5). The first advanced space transportation system is available in 2006. Therefore, no new launch system is available for the first three demonstrations. Existing boosters such as Ariane, Space Shuttle and Energia will be used.

For the fourth demonstration and the remainder of the SSPP, the first iteration of the new transportation system will be available. It is planned to have yet another generation of launch vehicles completed prior to the final full-scale deployment of SSPP. In the 30 years from 2006 to 2037, there is sufficient time in the schedule to accommodate this new vehicle's development and operational testing. The new transportation paradigms, if any, would be born from this phase of the program plan. Sufficient time would be devoted to systems analysis and technology development to assure that the new paradigms would reduce costs and make the system "better, faster, cheaper."

Concluding Remarks

Only by reducing the costs of space transportation can solar power from space become feasible. With many past studies of solar power satellites, the transportation system cost has been 25 to 40 percent of the total program cost. Even with current space projects, the cost of space launch services is terribly high. Without active measures to bring down the costs of space access, the viability of any large space program is questionable. It should also be clear that these "costs" include not only dollar value of the booster, but also the transportation system reliability, accessibility, launch environment and the vehicle resiliency. All of these factors can increase cost and defeat our purposes in space. Only through the application of innovative technologies and streamlined space launch operations will

humankind attain the height of perfection and low "cost" in space flight.

There are many options for launching payload for a space power system. In the near term, there are numerous capabilities to deliver large and small payloads to LEO and beyond. Over the next ten years, there will be little change in the capacity to move satellites since there are few developments in the planning stages other than incremental vehicle payload improvements. Beyond the ten year horizon, new launch vehicle designs, propulsion and materials technologies have the potential to make exciting leaps in payload delivery efficiency. Vehicles using Two Stage to Orbit and Single Stage to Orbit have the potential to reduce operational costs of payload launches. Simplifying these operations is a major stumbling block to making our access to orbit affordable.

Many technologies are available for space transportation systems of the future. The final selection of which technologies are used is very dependent on the time frame of the solar power system development. Based upon this report's development plan, the first launch vehicle developments for any large scale power satellites would be in the 2005-2010 time frame. The first satellite would be launched in 2035-2040. Because of the long time until the first vehicle flight, it would be unwise to select a specific technology or set of technologies for the transportation system. Also, the specific architecture of the space solar power system will determine the relative importance of the transportation technologies. If a large scale power system is required, the need for lunar resources may become crucial. On the other hand, a smaller satellite constellation would most likely not use extraterrestrial-based resources. The propulsion technologies that would be used would be advances reflecting the potential of Single Stage to Orbit and other improvements in propulsion technology to increase the energy density of propellants (such as metallized propellants and high energy density propellants). Light weight or high temperature materials will also play a vital role in reducing the cost of space operations and space access. Only time will tell how ambitious and exciting our global

technological future will be in space transportation.

Of the many technologies that have exciting potential for cost reduction, electric propulsion has a special and important added feature. It can not only reduce the transportation cost but there is also a potential market for beamed power. Orbital Transfer Vehicles using electric propulsion potentially can be more effective using beamed power. Using a remote power source reduces the mass of the transfer vehicle and improves its acceleration. This acceleration shortens the trip time and makes electric transfer not only more mass efficient than other competing propulsion technologies but also reduces the vehicle trip time over traditional electric vehicles. The benefit of electric propulsion for space transportation and the potential market it may create in other transportation systems makes it especially attractive. Therefore, using electric propulsion is one of the high leverage issues that should be considered in any future large space transportation system.

We recognize the importance that propulsion technologies have for the success of space solar power and any large space program. A lunar base or a Mars mission all need very capable propulsion-intensive vehicles. Reducing the "costs" of space transportation may make these ambitious projects a reality. This is a crucial consideration for the future of many space programs. The synergism of the transportation technologies of a space solar power program with other large scale projects can ultimately reduce the cost of access to space for all nations. Major reductions in the "costs" of space access will also make space truly useful and desirable for commercial ventures. A large low cost space transportation program, such as the one for space solar power, could be the rising tide that carries all spaceships.

Acknowledgements

I would like to acknowledge NASA for its support of the International Space University. Also, I'd like to thank the ISU Faculty, the SSPP Design Team and the other members of the Space Transportation Group of the Space Solar Power Program for their significant contributions to the Summer Session Final Report. They are listed below:

Chistophe Bardet	FRANCE
Phillippe Berthe	FRANCE
Frederic Ferot	FRANCE
Stefan Foeckersperger	GERMANY
Toshiya Hanada	JAPAN
Mario Hucteau	FRANCE
Yoshitsugu Kanno	JAPAN
Thierry Le Fur	FRANCE
Alain Louis	FRANCE
Ulf Palmnas	SWEDEN
Michael Reichert	GERMANY
Masaharu Uchiumi	JAPAN
Richard Wills	USA

References

- 1) Arif, H. , et al. , "Space Solar Power Program," Final Report of the Summer Session of the International Space University - Kitakyushu, Japan, Available from the International Space University, Boston, MA, August 1992.
- 2) "Space Solar Power Satellite System Definition Study Phase III, Final Report," Boeing Aerospace Company, Volume 3, 1980.
- 3) "America At The Threshold: America's Space Exploration Initiative," Stafford Synthesis Group Report, NASA, U. S. Government Printing Office, May 1991.
- 4) "SPS Concept Definition Study - Systems Subsystems Analyses, Final Report," Rockwell International, Volume II, 1980.
- 5) O'Neill, G. , The High Frontier: Human Colonies in Space, Space Studies Institute Press, Princeton, NJ, 1989.
- 6) Glaser, P. , "Power From the Sun: It's Future," Science, Volume 162, Number 3856, 1968, pp. 857-861.
- 7) Brown, W. , et al. , "An Experimental Microwave Powered Helicopter," IEEE International Convention Records, Volume 13, Part 5, 1965, pp. 225-235.
- 8) Dickinson, R. , "Evaluation of a Microwave High-Power Reception-Conversion Array for Wireless Power Transmission," NASA CR-145625, JPL TM-33-741, September 1, 1975.
- 9) Dickinson, R. , and Brown, W. , "Radiated Microwave Power Transmission System Efficiency Measurements," NASA CR-142986, JPL TM-33-727, May 15, 1975.
- 10) Kawashima, N. , et al. , "Development of Drilling Machine on Board Mars Rover and Drilling Test of Simulated Martian Soil," in Proceedings of the International Conference on Missions, Technologies, and Design of Planetary Mobile Vehicles, published by Centre Nationale d'Etudes Spatiale (CNES), 1992, pp. 337-343.
- 11) Glaser, P., "The Economic and Commercial Development of Space," Journal of Social Political and Economic Studies, Volume 9, Issue Number 2, Summer 1984, pp. 211-229.
- 12) Anon. , "New Technology Japan: Special Issue - Solar Power Satellite R&D in Japan," Japan External Trade Organization (JETRO), Three 'T' Publications, Ltd. , Japan, 1991.
- 13) Deschamps, L. , Pignolet, G. , and Toussaint, M. , "A European View Regarding Power Transmission in Space," 1st Annual Wireless Power Transmission Conference, Feb. 1993.

- 14) Schlesak, J., Alden, A., and Ohno, T., "SHARP (Stationary High Altitude Relay Platform) - Rectenna and Low-Altitude Tests," in GLOBECOM 85 - Conference Record - Volume 2, 1985, pp. 960-964.
- 15) "SPS 86 - Solar Power Satellites," Societe des Electriciens et des Electroniciens (SEE) Proceedings, June 1986.
- 16) "SPS 91 - Power from Space," Societe des Electriciens et des Electroniciens (SEE) Proceedings, August 1991.
- 17) "SPS Rio 92 - Space Power Systems and the Environment in the 21st Century," Societe des Electriciens et des Electroniciens (SEE) Proceedings, June 1992.
- 18) Collins, Patrick, Foreign Research Fellow, The Institute of Space and Astronautical Science (ISAS), Kanagawa, Japan, Personal Communication at ISU '92, July 1992.
- 19) Energy for Planet Earth, Scientific American, Special Issue, September 1990.
- 20) Hopkins, M., "The Satellite Power Station and the Non-Cost Uncertainty Aspects of Risk," in Final Proceedings of the Solar Power Satellite Program Review, U.S. Department of Energy, Conf-800491, Contract Number FG05-79ER10116, July 1980.
- 21) Rosen, S. and Sloan, J., "Electric Orbit Transfer Vehicle: A Military Perspective," AIAA 89-2496, July 1989.
- 22) "Solar Power From Satellites," Hearings before the Subcommittee on Aerospace Technology and National Needs, Committee on Aeronautical and Space Sciences, U.S. Senate, 94th Congress, U.S. Government Printing Office, 1976.
- 23) Landis, G. and Perino, M., "Lunar Production of Solar Cells - A Near Term Product for a Lunar Industrial Facility," in Space Manufacturing 7: Space Resources to Improve Life On Earth, Proceedings of the Ninth Princeton/AIAA/SSI Conference, 1989, pp. 144-151.
- 24) Criswell, D. and Waldron, R., "Lunar System to Supply Solar Electric Power to Earth," in Proceedings of 25th Intersociety Energy Conversion Engineering Conference (IECEC), 1990, pp. 61-71.
- 25) Brandhorst, H., NASA Lewis Research Center, Chief, Power Technology Division, Personal Communication, August 1992.
- 25) Anon. , "Big Dumb Booster - Assessment of the Pressure Fed Booster," United States Office of Technology Assessment Report, U. S. Government Printing Office, No Number, February 1989.
- 27) "Sea Dragon Concept, Volume 1: Summary," Aerojet-General Corporation, NASA CR-52817, January 1963.
- 28) Truax, R. , "The Pressure-Fed Booster: Dark Horse of the Space Race," IAF Paper SD-2, October 1968.
- 29) Frey, T. , "Sea Launch and Recovery (SEALAR): Responsive and Affordable Access To Space," AIAA Paper 92-1361, March 1992.
- 30) Weldon, V. , and Fink, L. , "Near Term Two Stage to Orbit Fully Reusable, Horizontal Takeoff/Landing Launch Vehicle," IAF Paper 91-194, October 1991.
- 31) Nadell, S. , et al. , "Mission and Sizing Analysis for the Beta II Two-Stage-To-Orbit Vehicle," AIAA 92-1264, February 1992.
- 32) Stanley, D. , Wilhite, A. , Englund, W. , and Laube, J. , "Comparison of Single-Stage and Two-Stage Airbreathing Launch Vehicles," Journal of Spacecraft

and Rockets, Volume 29, Number 5,
September-October 1992.

- 33) Plencner, R. , "Overview of the Beta II Two Stage to Orbit Vehicle Design," AIAA Paper 91-3175, September 1991.
- 34) Palaszewski, B. , "Launch Vehicle Performance Using Metallized Propellants," AIAA Paper 91-2050, June 1991.
- 35) Palaszewski, B. , "Atomic Hydrogen As A Launch Vehicle Propellant," AIAA Paper 90-0715, January 1990.
- 36) Hunter, J. , and Hyde, R. , "A Light Gas Gun System for Launching Building Material Into Low Earth Orbit," AIAA Paper 89-2439, July 1989.

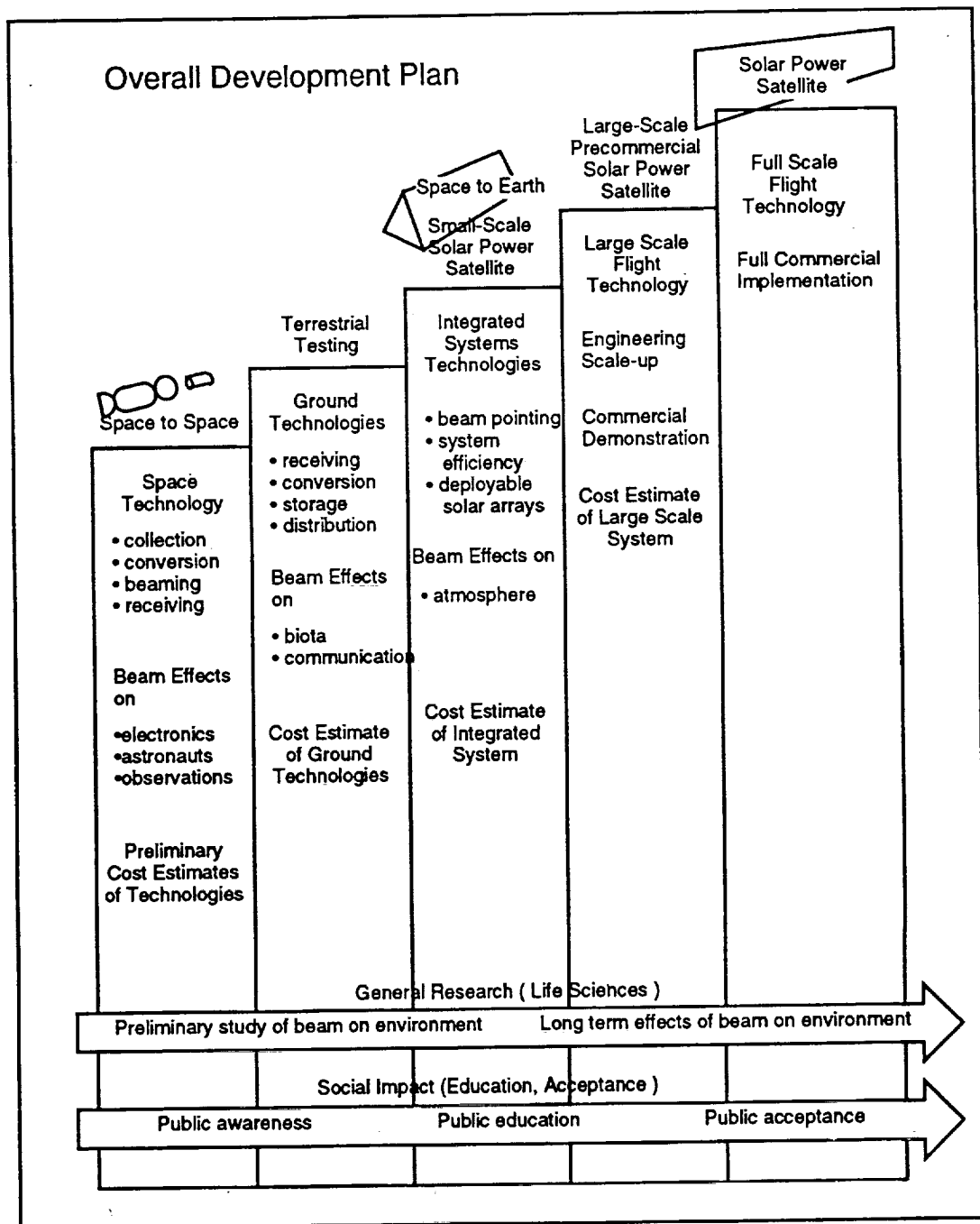
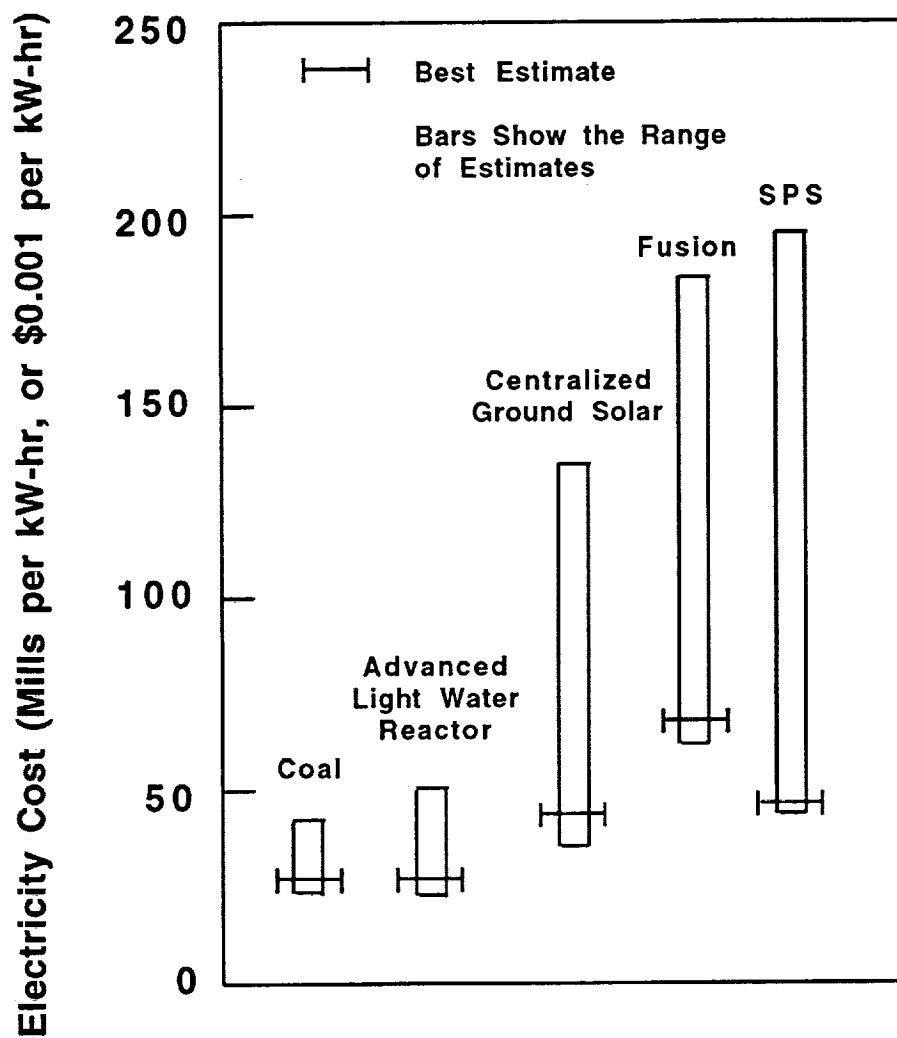


Figure 1. Phased Approach for Space Power Development



Projected Prices of Alternative Energy Sources for the Year 2000
(1978 Dollars, Ref. 20)

Figure 2. Cost Comparison of Power Systems

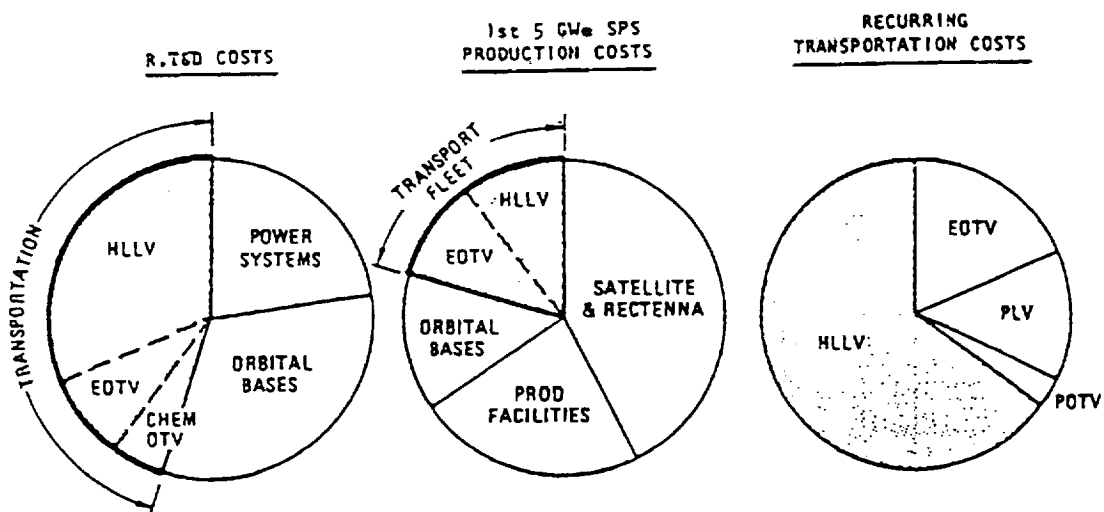


Figure 3. Space Transportation Costs for Solar Power Satellites

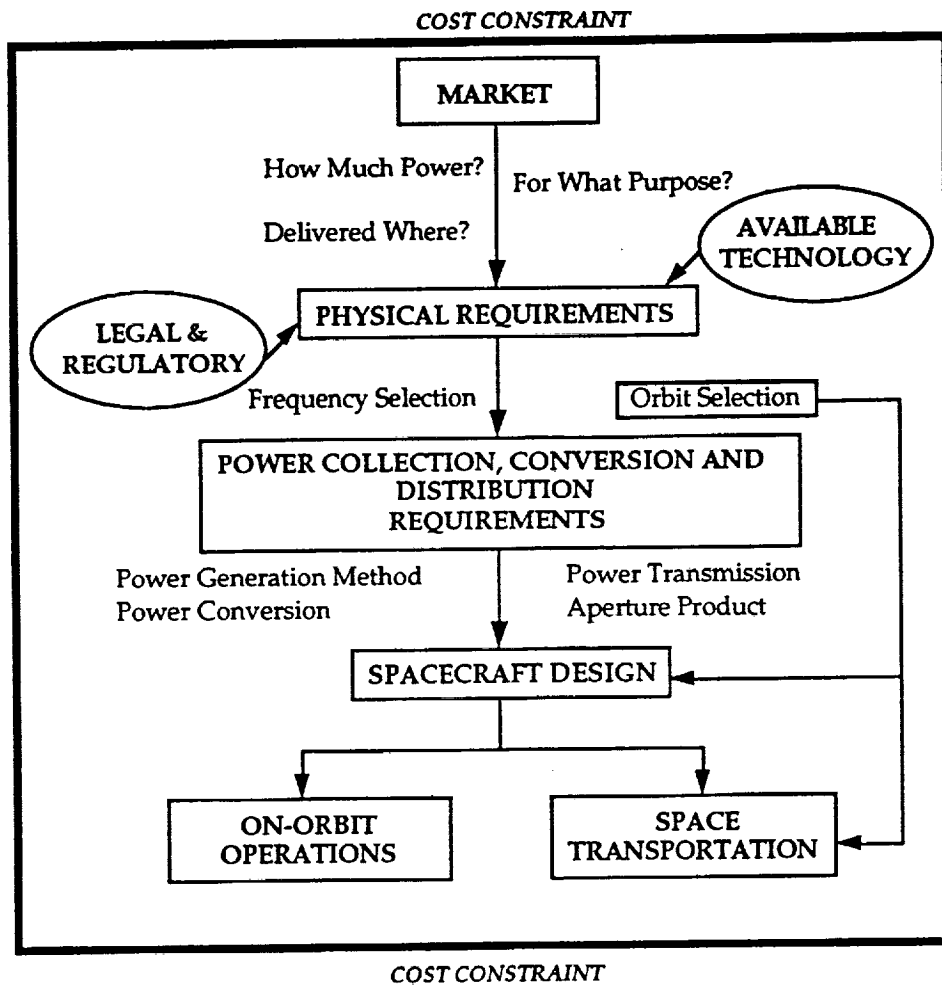


Figure 4. Group Interactions and Driving Requirements For SSPP Design Project

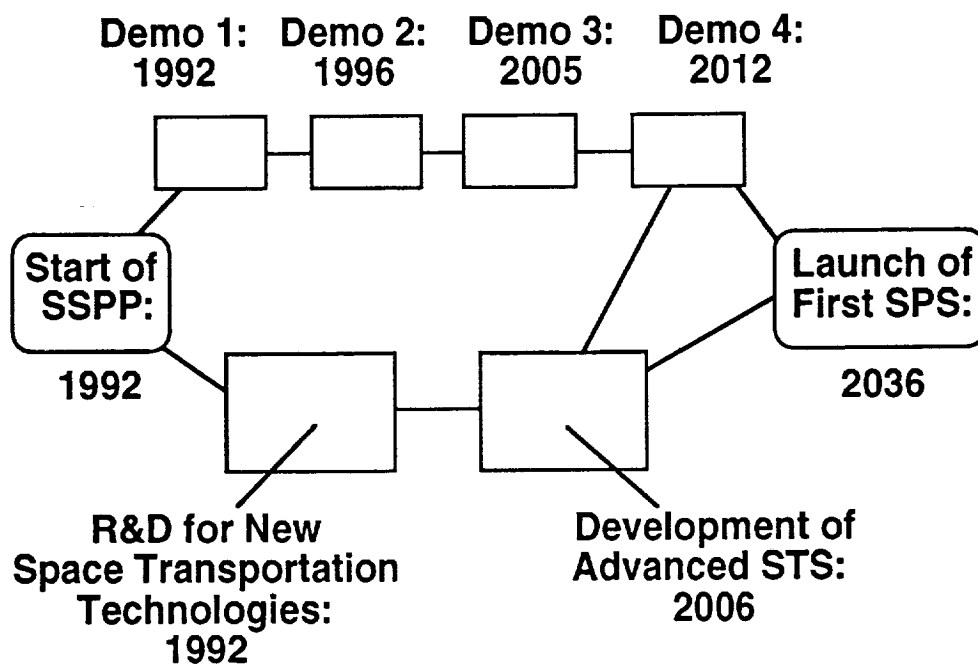


Figure 5. Overall Development Schedule

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1993	3. REPORT TYPE AND DATES COVERED Technical Memorandum		
4. TITLE AND SUBTITLE Space Transportation Alternatives for Large Space Programs: The International Space University Summer Session - 1992		5. FUNDING NUMBERS WU-506-42-72		
6. AUTHOR(S) Bryan A. Palaszewski				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		8. PERFORMING ORGANIZATION REPORT NUMBER E-7999		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, D.C. 20546-0001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-106271 AIAA-93-2278		
11. SUPPLEMENTARY NOTES Prepared for the 29th Joint Propulsion Conference and Exhibit cosponsored by the AIAA, SAE, ASME, and ASEE, Monterey, California, June 28-30, 1993. Responsible person, Bryan A. Palaszewski, (216) 977-7493.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Categories 16 and 20			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) In 1992, the International Space University (ISU) held its Summer Session in Kitakyushu, Japan. This paper summarizes and expands upon some aspects of space solar power and space transportation that were considered during that session. The issues discussed in this paper are the result of a 10-week study by the Space Solar Power Program design project members and the Space Transportation Group to investigate new paradigms in space propulsion and how those paradigms might reduce the costs for large space programs. The program plan was to place a series of power satellites in Earth orbit. Several designs were studied where many kW, MW or GW of power would be transmitted to Earth or to other spacecraft in orbit. During the summer session, a space solar power system was also detailed and analyzed. A high-cost space transportation program is potentially the most crippling barrier to such a space power program. At ISU, the focus of the study was to foster and develop some of the new paradigms that may eliminate the barriers to low cost for space exploration and exploitation. Many international and technical aspects of a large multinational program were studied. Environmental safety, space construction and maintenance, legal and policy issues of frequency allocation, technology transfer and control and many other areas were addressed. Over 120 students from 29 countries participated in this summer session. The results discussed in this paper, therefore, represent the efforts of many nations.				
14. SUBJECT TERMS Space transportation; Rocket propulsion; Launch vehicles; Metal propellants			15. NUMBER OF PAGES 24	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	