SPS : Solar Power Satellite

July 2021

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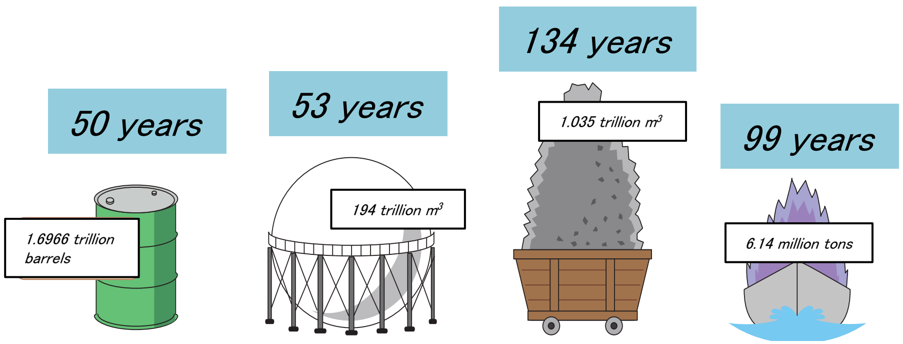
1. Global energy problems and environmental problems

Energy problems and global environmental problems

Limited Energy Resources

Proven Reserves



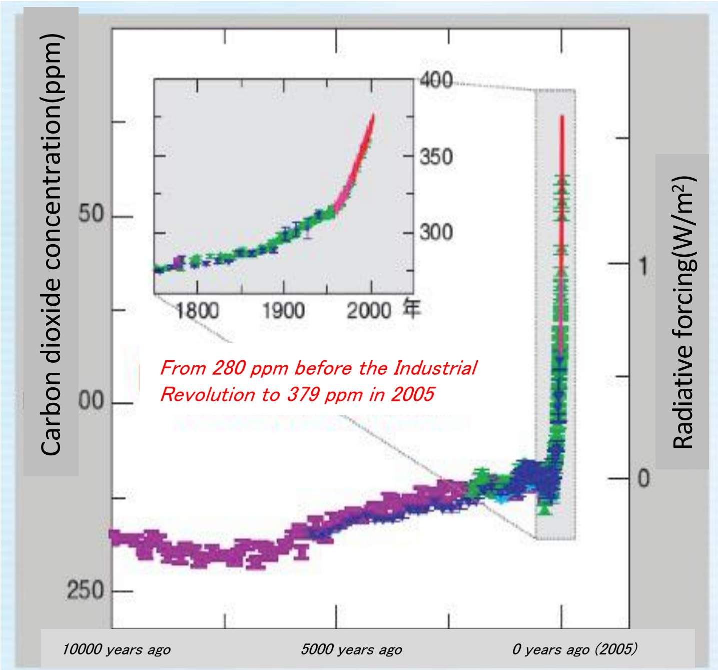
Oil | Natural gas | Coal | Uranium

Reference :Japan Atomic Energy Relations Organization

Consumption of fossil fuel

The earth accumulated solar energy in the form of fossil fuel over hundreds of millions of years. Mankind is using it up in just 100–150 years.

Energy acquisition by burning oil, coal, natural gas, etc. brings about deterioration of the global environment.



Changes in CO_2 concentration

(IPCC, 2007)

▶ *We need a new clean energy system.*

Is human being a virus for the Earth?

Glacial melting

Desertification

Erath

Other Planet

▶ To avoid this situation, …

It is difficult to solve global problems within the closed system of the earth. We have to look for a solution outside the earth, i.e., in space.

- *In space, unlike on earth, there is a vast field and plenty of solar energy that is not affected by weather.*
- *The concept of Solar Power Satellite (SPS) is to use space, the frontier of humanity, as a place for human to obtain energy. SPS has great potential as a clean and large-scale energy system.*
- *If the energy that supports modern society can be obtained in sufficient quantities by an environmentally friendly system, the serious problems that confront modern society will be solved and mankind will be able to take a new step toward further development.*
- *At this stage, SPS has not been shown as the best option for the future energy system, but it is a viable option as the technical principles for SPS have been already verified.*
- *SPS that collects natural solar energy on a large scale has an intrinsic advantage in terms of safety in case of accidents compared to the power systems that artificially generate large amounts of energy in a spatially limited area.*
- *Basic research for the realization of SPS has been progressing rapidly in recent years, and the level of technologies has already reached a level where full-scale experiments of SPS can be started to verify its feasibility as an energy system.*

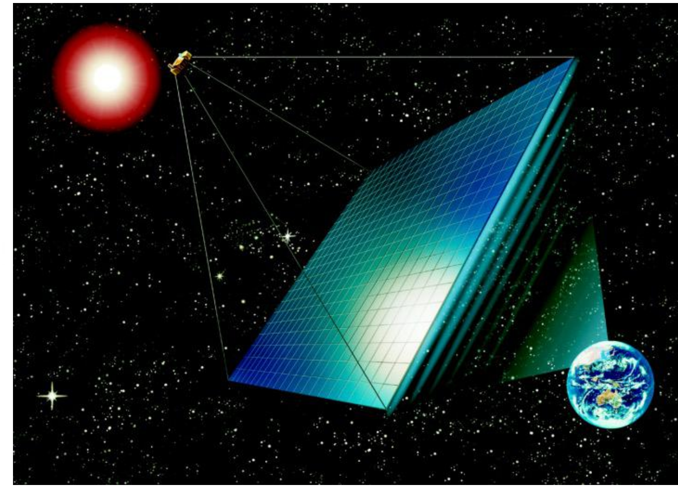
▶ *We are at the stage where we should start full-scale space demonstration experiments to show that SPS can truly be the savior of human society.*

2. Concepts and features

What is the concept of SPS？

Transportation of the parts to space using reusable vehicles

SPS construction by assembling the parts



Solar power plant on the ground

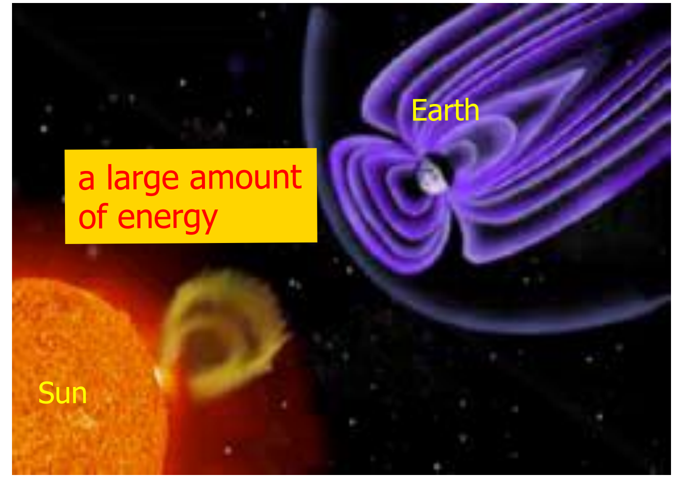
- ▶ *Simple and clear concept*
- ・*Transport the solar panels and microwave transmitters to space*
- ・*Assemble the solar power plant and microwave transmission system in space*
- ・*Transmit the generated power to the ground by microwave*

Why do we think of Solar Power Satellite?

Why the Sun?

Power from the sun to the earth is 1.77×10^{17} Watt, that is 10,000 times more than global power consumption.

▶ Solar energy has great potential as an energy source for humankind.

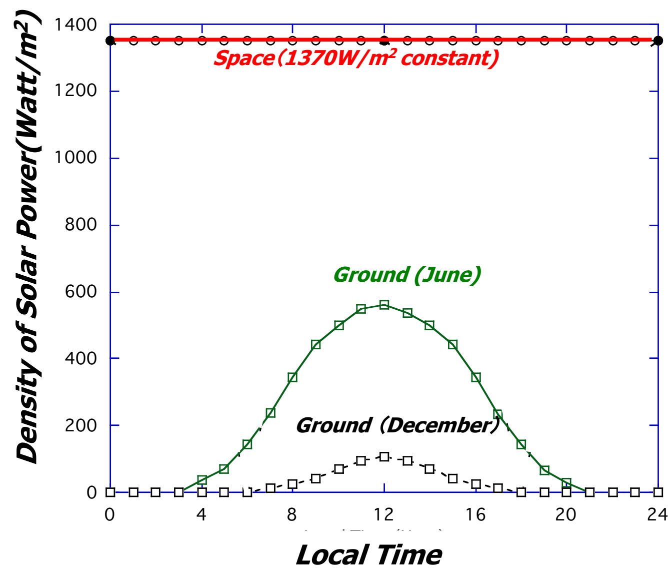


600 million tons of hydrogen burns per second (nuclear fusion) in the sun.

Why outer space?

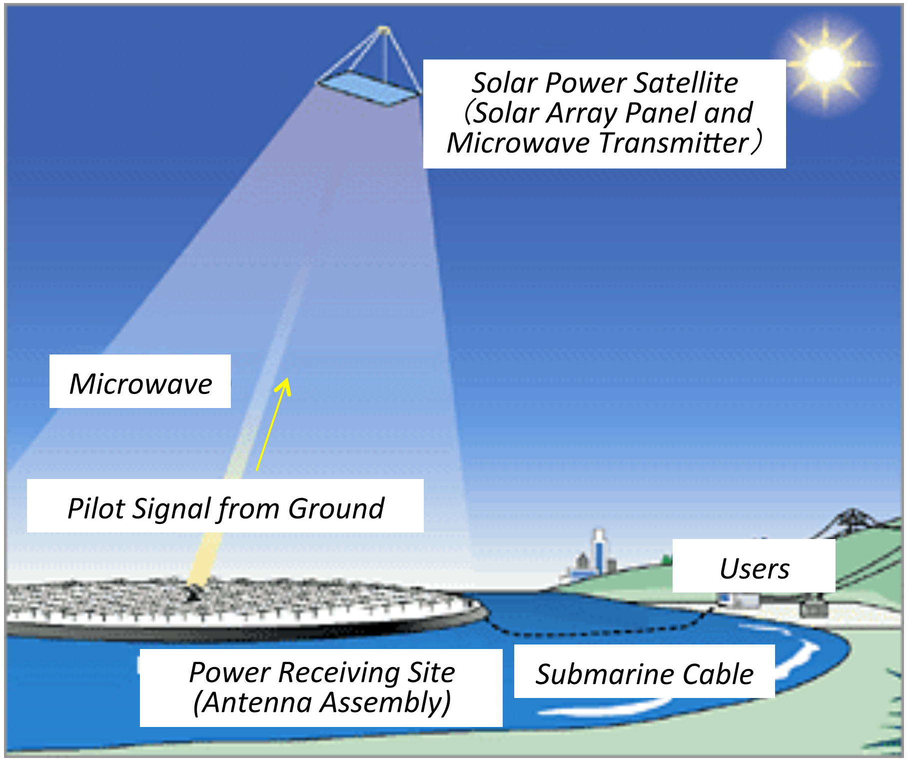
Power density of solar energy in space near the earth is 1,370 W/m^2.
Power density of solar energy on the ground is reduced to100～200 W/m^2 on average, due to the day/night cycle and weather/atmospheric effects.

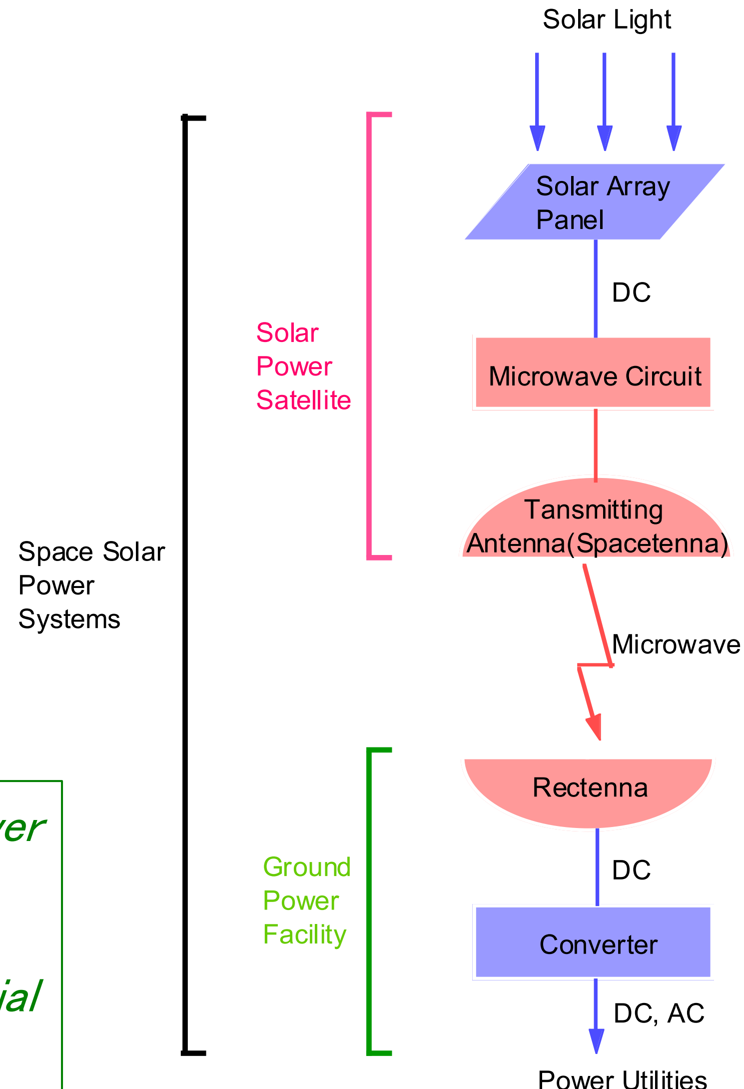
▶ If efficient power transmission from outer space to the ground is possible, it is advantageous to acquire solar energy in space.



Density of solar power on ground and in space

Configuration of Solar Power Satellite System





- *SPS converts solar energy into electric power in space and transmits the power using microwave to the ground. On the ground, the received microwave is converted to commercial power and distributed to users through the existing power grid.*

Advantages of Solar Power Satellite System

Solar energy can be collected more and stably in space.

Solar Power Plant on Ground

Rainy and cloudy days

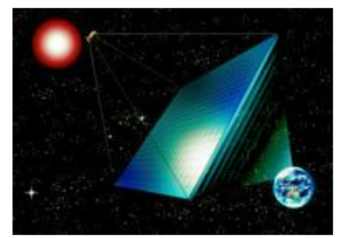
Night

Land problem

Contrast

Solar Power Plant in Space

No rainy or cloudy day



No night (depending on the orbit)

No land problem

Can Solar Power Satellite System get enough energy?
–Example of energy flow model–

Efficiency %

Process	NASA Reference System	USEF Tether System	JAXA Reference Model (2004)
Light collection	–	–	90
Power generation	17.3 (Si)	35	17.3
Power collection	93.7 x 99.95 x 96.3	57	93
Power storage	–		–
DC–microwave conversion	85	85	75
Antenna efficiency	96.53		
Microwave propagation	98	97	98
Rectenna power collection	88	90	76
Microwave–DC conversion	89	85	
DC–Grid	97		75
Total	9.53	12.6	7.7

▶ Considering that the average intensity of solar power in space is 5 to 10 times larger than that on the ground, the total efficiency of space solar power generation is higher than that of ground power generation.

Is Solar Power Satellite System clean?

–CO_2 emission compared with existing power plants–

($g\text{-}CO_2/kWh$)

Power Plant	Operation Phase	Construction Phase	Total
Space Solar Power Systems	0	20	20
Coal Fired Power Plant	1222	3	1225
Oil Fired Power Plant	844	2	846
LNG Fired Power Plant	629	2	631
Nuclear Power Plant	19	3	22

Yoshioka et al., 1999

- *It has been analyzed that CO_2 load of Solar Power Satellite System is only a few percent of the power plant using fossil fuels.*

Does SPS Produce Sufficient Energy?
– Calculation of energy payback time –

System	SPS		Power Station on ground
Location of Power Module Production	On the Ground	On the Moon	On the Ground
Input Energy [10^9MJ] (A)	53	37	8. 2
Production of Module	22	22	8. 2
Transportation of Module	31	5.1	—
Power Generation [10^9Wh/year]	7.88	7.88	1. 23
Energy [10^9MJ/year] (B)	76.7	76.7	12. 0
EPT [year] (=A/B)	0.69	0.35	0. 68

"Energy payback time" is an index of how many years it takes to recover the energy required to construct the energy system.

▸ The energy payback time of SPS is analyzed to be less than one year, which is sufficiently small compared to the life of SPS (about 40 years).

Is SPS economically viable?
-Cost estimation for major SPS models-

Model	Report	Life years	Total Cost	Power Cost	EPT years
NASA Reference System	1980	30	12 B＄(1977 $ base)	4 ¢/kwh	–
NEDO Grand Design	1994	30	2,400 B¥	23 ¥/kwh	2
NASA Fresh Look Study Sun Tower: ST, Solar Disc; SD	1997	40	ST:35～40 B＄(3.5～4GW) SD:150 B$(30GW)	ST:4 ¢/kwh SD:2 ¢/kwh	–
NASDA1998 Model	1999	30	2,700 B¥	23.2 ¥/kwh	5
JAXA 2004 Model	2005	40	1,260 B¥	8.6 ¥/kwh	1.23
USEF Multi-Tether Model	2008	40	1,300～2,100 B¥	9.3～15.9 ¥/kwh	–
SPS-ALPHA(DRM-4)	2012	＞30	12.2 B$	15 ¢/kwh	–

▸ *It is analyzed that the power cost of SPS can be close to the power cost of the other ground power plants by using commercial products and reducing the space transportation cost to about 1/50 of the current cost.*

Comparison between solar power plant on ground and Solar Power Satellite

Subject	Solar Plant on Ground	Solar Power Satellite (SPS)
Solar Power Density (Time Average)	140 W/m^2 (Tokyo)	1370 W/m^2 (Sun-pointing Type) 880 W/m^2 (Earth-pointing, Power Generation on Both Sides)
System Configuration	Solar Cells-Power Collection/Conversion	Solar Cells-Power Collection/Conversion in Space-Wireless Power Transmission-Power Collection/Conversion on Ground
Ratio of Power Generation Efficiency(per Unit Area) (Average Solar Power Density) x (System Efficiency)	1	6～2 (60 % : Efficiency of Wireless Power Transmission)
System Life	30 Years (Weatherability)	30～40 Years (Space Radiation, Debris Impact)
Operation	Power System	Power System & Spacecraft
Ratio of Land Use Efficiency	1	2 (Tether SPS) , 7 (JAXA M-SPS)
	Sun light is Shielded by Solar Panel.	Sun Light Transmission (60-80%)
Power Supply	Fixed, Dependent on Power Grid	Switchable, Using Wireless Power Transmission
Power Fluctuations	Wheather, Day & Night	Constant(Sun Pointing Type), Local Time Variation(Earth Pointing Type)
Constraints in Scale	Limitation in Land Use	Essentially no limitation
Positioning in Future Society	Extension of Existing Technology	Paradigm Shift (Advance into Space)
Energy Payback Time	1-3 Years	0.69～5 Years
CO_2 Load	53 g/kWh	20 g/kWh
Electricity Cost	14 Yen/kWh (2017) 7 Yen/kWh (2025) (Goal by NEDO)	4～23 Yen/kWh

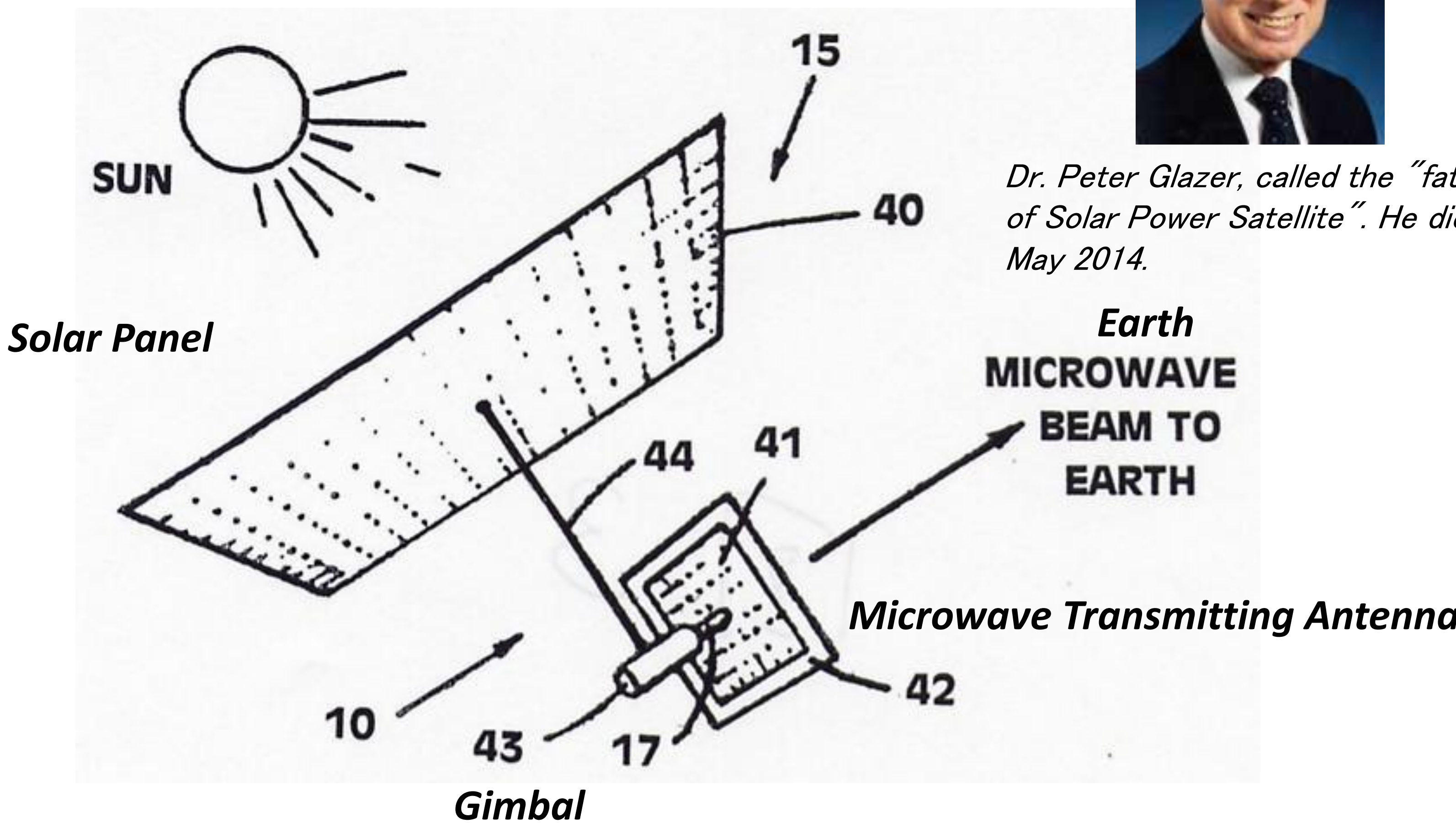
▶ SPS is superior to terrestrial solar power plant in many respects.

Fill cell shows superiority.

3. Research history

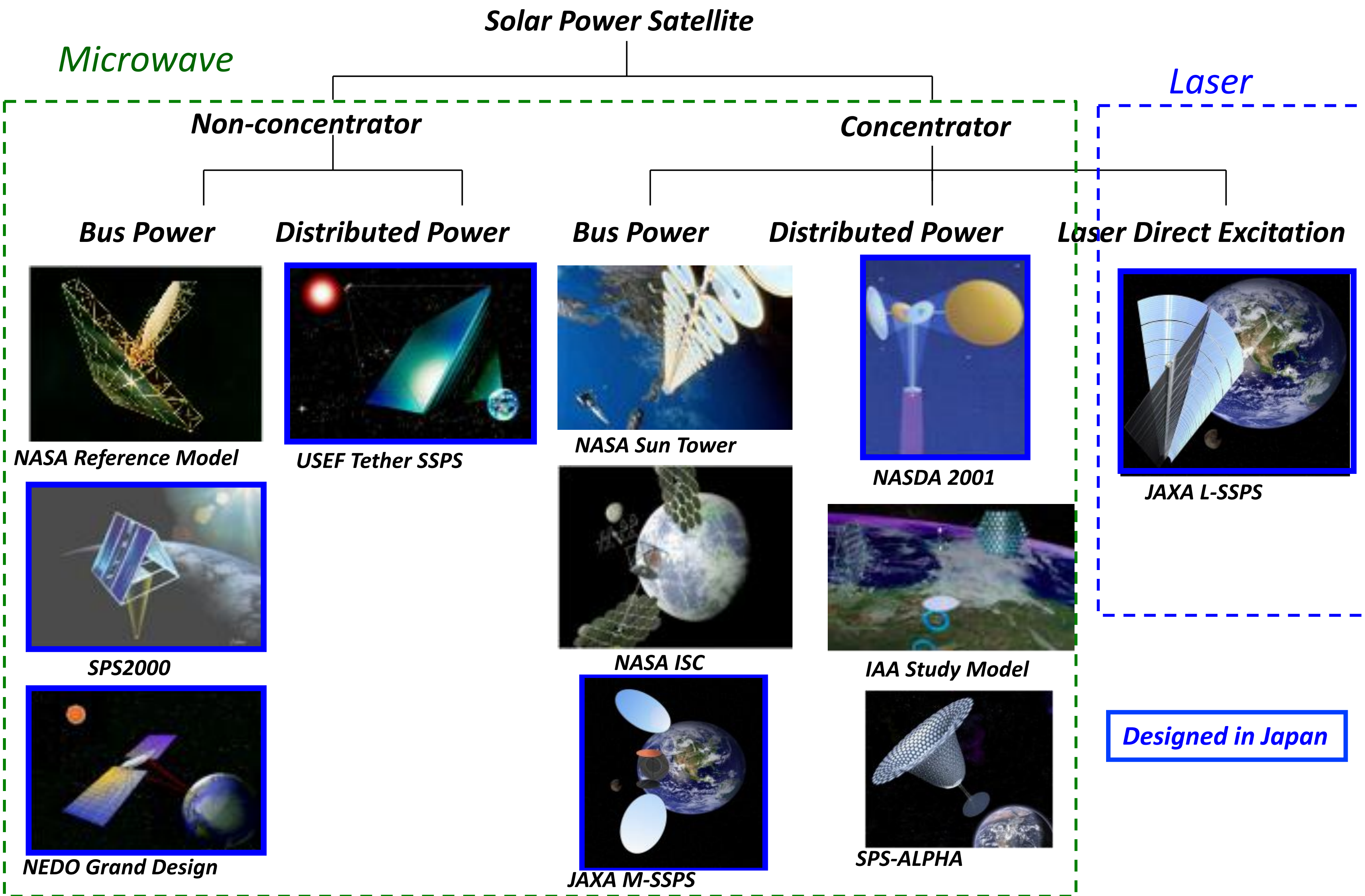
Inventor of Solar Power Satellite

Dr. Peter Glazer, called the "father of Solar Power Satellite". He died in May 2014.



Patent Announcement by Peter Glazer (1973)

Typical SPS Models



Which is better, microwave or laser, for SPS?

Transmission Band	Microwave	Laser
Frequency/Wave Length	~several GHz	~1 µm
Power Conversion	Solar-DC-RF・・・DC	Solar-DC-Laser-・・・DC Solar-Laser・・・DC
Conversion Efficiency	Higher	Lower
System Size	Larger	Smaller
Beam Energy Density	Lower(Safer)	Higher(smaller beam size)
Electromagnetic Compatibility	Lower	Higher
Weather Dependence	Smaller (typically 97% transmission)	Larger (typically 35-40 % transmission)
Technology Maturity	Higher	Lower
Application	Space-Ground	Space-Space Space-Ground

Fill cell shows superiority.

▶ *Microwave is considered to be more advantageous than laser for wireless power transmission from space to ground.*

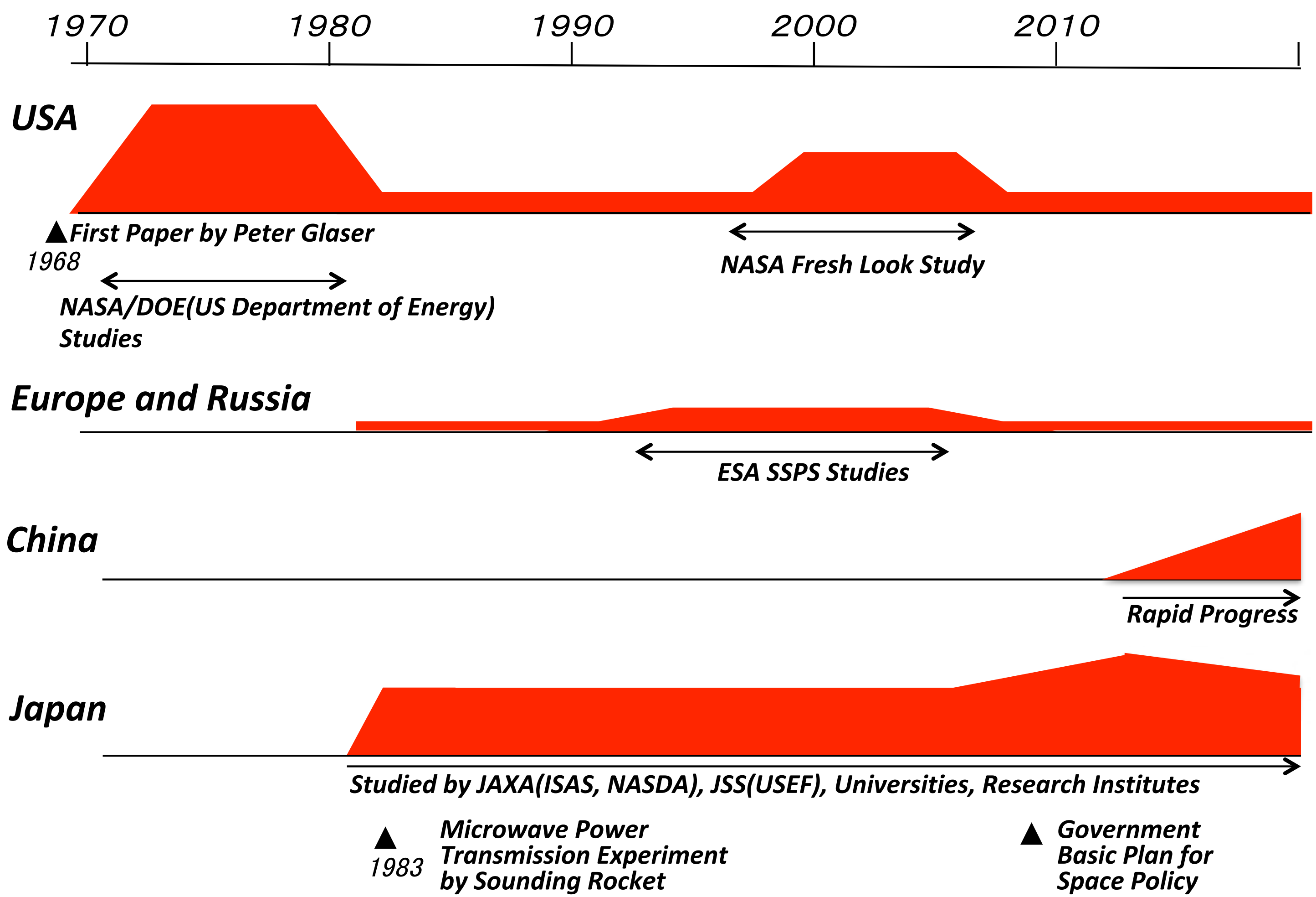
Output Power, Total Weight, and Specific Weight of Typical SPS Models

Phase	Model	Output Power	Weight	Specific Weight
Commercial	NASA Reference Model	6.5 GW	50,000 Tons	7.7 g/W
Commercial	NEDO Grand Design	1.3 GW	20,000 Tons	15.3 g/W
Commercial	JAXA M-SSPS Model	1.34 GW	9,907 Tons	7.4 g/W
Commercial	USEF Tethered SPS	1.32 GW	26,500 Tons	20 g/W
Commercial	SPS-ALPHA	500 MW（Ground Output Power）	11,800 Tons	23.6 g/W (per Ground Output Power)
Commercial	Sun Tower(GEO)	1.2 GW	22,300 Tons	19 g/W
Commercial	Integrated Symmetrical Concentrator	1.2 GW	18,000～31,500Tons	15g/W～26g/W
Commercial	European Sail Tower	275 MW	2,140 Tons	7.8 g/W
Demonstration	SPS2000	10 MW	240 Tons	24 g/W
Experiment	Tethered SPS Experiment Model	420kW	18.1 Tons	43g/W
Experiment	Small Scale Experiment Model	3.8kW	500 kg	132g/W

▶ *Specific weight of commercial model is approximately 10 g/W to 20 g/W. The experimental model in the near future has a larger specific weight.*

International Research Status

The international research activities on Solar Power Satellite is shown below. The height of red area indicates the research activities qualitatively. The research started almost 50 years ago in the USA. Now, Japan is the leading country in the research and development. China is rushing lately.



SPS Major History (International)

1968	*First concept by Peter Glaser "Power from the Sun: its Future" in "Science (Journal)"*
1970'	*NASA/DOE (Department of Energy) joint study*
1980	*Study in US terminated by President Reagan*
1983	*First sounding rocket experiment in Japan to study microwave/plasma Interaction*
1990	*ISAS study "Demonstration Model SPS 2000" in Japan*
1995	*NASA study (Flesh Look, SCDS,SERT,SCTM) （−2004）*
1998 -	*NASDA (now JAXA) SSPS study in Japan*
2000 -	*USEF (now Japan Space Systems) SSPS study in Japan*
2002 - 2004	*ESA SPS study*
2009	*SPS research included in Government Basic Plan for Space Policy in Japan*
2010 -	*China SPS study*
2011	*First international assessment of SPS by International Academy of Astronautics*

SPS Major History (United States)

1970s NASA/DOE (Department of Energy) joint study

1977-1980 NASA Conceptual Design (20 M$)

1978 DOE's SPS Concept Development and Evaluation Program(CDEP)

1980 Because the construction cost and the power price were considered very high, systematic study was suspended due to NAS (National Academy of Sciences) evaluation (freezing of SPS R & D investment) and the Reagan administration's austerity policy.

1995 NASA study resumption

1995-1997 Fresh Look Study (30 SSP system concepts)

1998 SSP Concept Definition Study（2 M$)

1999-2000 SSP Exploratory Research and Technology (SERT) program(2.2 M$)

2001 US National Research Council(NRC) Report on SSP Strategic research and technology road map

2001-2002 SSP Concept and Technology Maturation (SCTM) program（3 M$）

2001- Budged reduction

-2004 Joint investment in SSPS technology research and studies by NASA and NSF(National Science Foundation)

2004 "New Space Exploration Program" by Bush Administration
SPS-related technology development was incorporated into research and development as part of advanced technology.

2005−08 Low level NASA budget for SPS

2007 Pentagon (National Security Space Office) investigated Space Solar Power from the perspective of securing power in combat units and disaster areas（M.Smith (NSSO), J.Mankins, D.Preble）.

2008 The longest microwave power transmission experiment (160km) in history using the retro directive system in Hawaii. Under the planning of the US team, Kobe University was in charge of power transmission technology. It aired on Discovery Cannel.
A WPT demonstration on the ISS was considered. NASA JSC lead the study. DOD and universities participated, but the study was terminated in nine months.

2010 The Obama administration proposed a budget that emphasizes advanced technology development.

2011 SPS was selected as one of the research themes of NIAC (NASA Innovative Advanced Concepts). However, the budget for the following project was not available

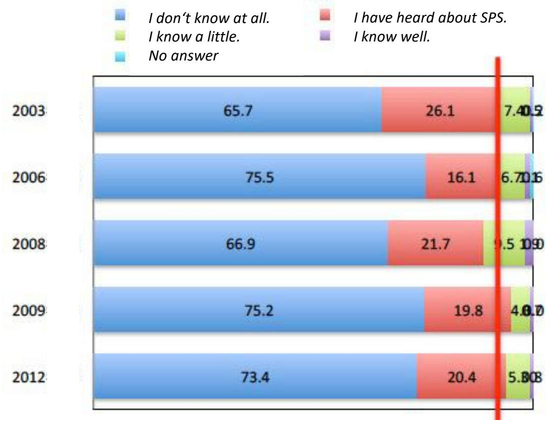
2015 SPS research agreement signed with California Institute of Technology Caltech) sponsored by Northrop Grumman Corporation

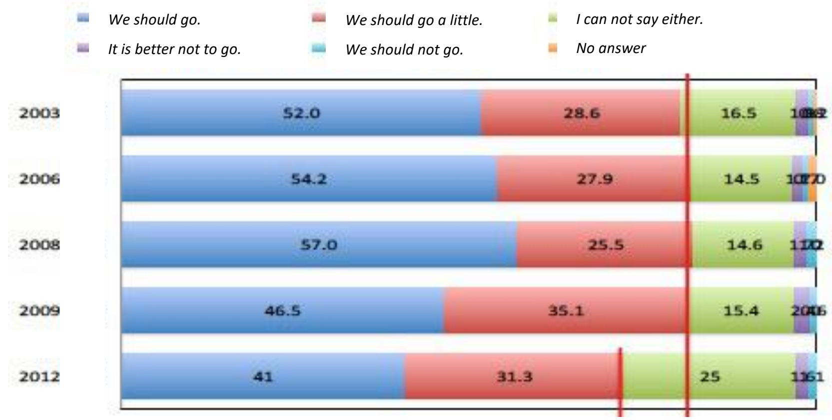
2019 Laser power transfer experiment at US Naval Research Laboratory（2kW, 325m）

History of SPS Research in Japan

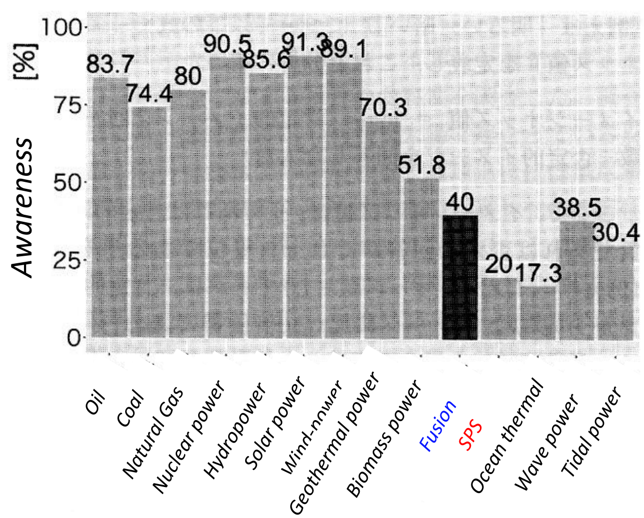
1983	MINIX experiment(Space experiment to study the interaction of microwave with the ionosphere by sounding rocket) (2.45GHz)
1987	SPS Working Group was organized at ISAS and started design of SPS demonstration model SPS2000
1992	MILAX Airplane experiment(microwave power transmission to small airplane) (2.45GHz)
1993	ISY-METS experiment (space experiment to study the interaction of microwave with the ionosphere by sounding rocket) (2.45GHz)
1994～	Microwave garden experiment (microwave exposure experiment for plant growth, Advanced Industrial Science and Technology) (2.45, 5.8GHz)
1995	ETHER experiment(microwave power transmission to an airship) (2.45GHz)
1997	Space Solar Power Research Society (SSPRS) in Japan was organized.
1998 ～	NASDA (JAXA) SPS Study
2000 ～	USEF/METI (Ministry of Economy, Trade and Industry) SPS Study
2006	Sounding rocket experiment for antenna deploy and active phased array
2009	Microwave power transmission experiment from an airship(2.45GHz)
2009	SPS research was included in Government Basic Plan for Space Policy.
2010	All Japan project (USEF/JAXA) for microwave power transmission experiment started.
2014	Space Solar Power Systems Society was organized by the evolutionary dissolution of Space Solar Power Research Society.
2015	1.8 kW Microwave power transmission experiment (55 m, JSS/JAXA) 10 kW Microwave power transmission experiment (500 m, JSS)
2016	Laser power transmission experiment in vertical direction (JAXA)
2019	Microwave power transmission experiment to drone (JSS/JAXA)

Social Awareness and Reality of SPS

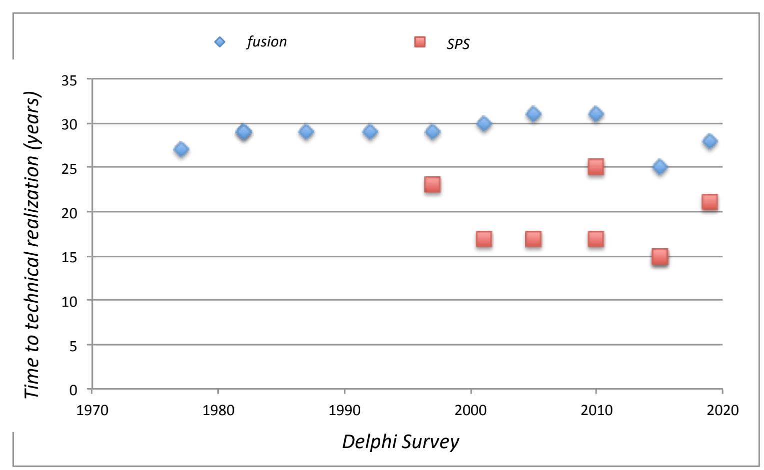




▶ Results of five surveys conducted by JAXA from 2003 to 2012 on the awareness and necessity of SPS. Little is known to the general public (65–75% did not know), but they are positive about the concept.

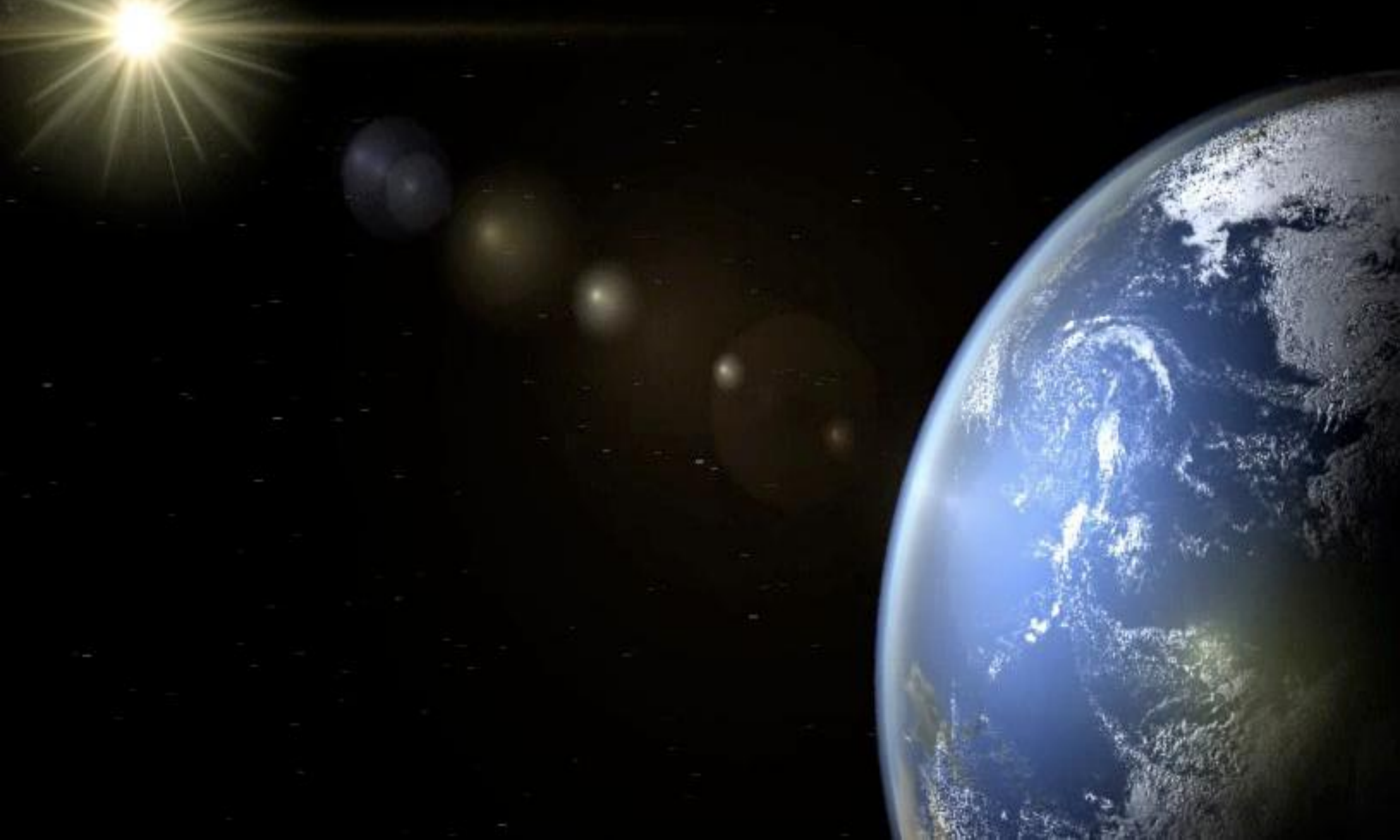


▶ Awareness of various energy sources in questionnaires conducted by fusion researchers. Compared to nuclear fusion, SPS was less well known.



▶ Comparison of the time required to realize SPS and fusion (excluding inertial fusion) in the Delphi survey. Scientific research experts believe that SPS will be realized sooner than fusion.

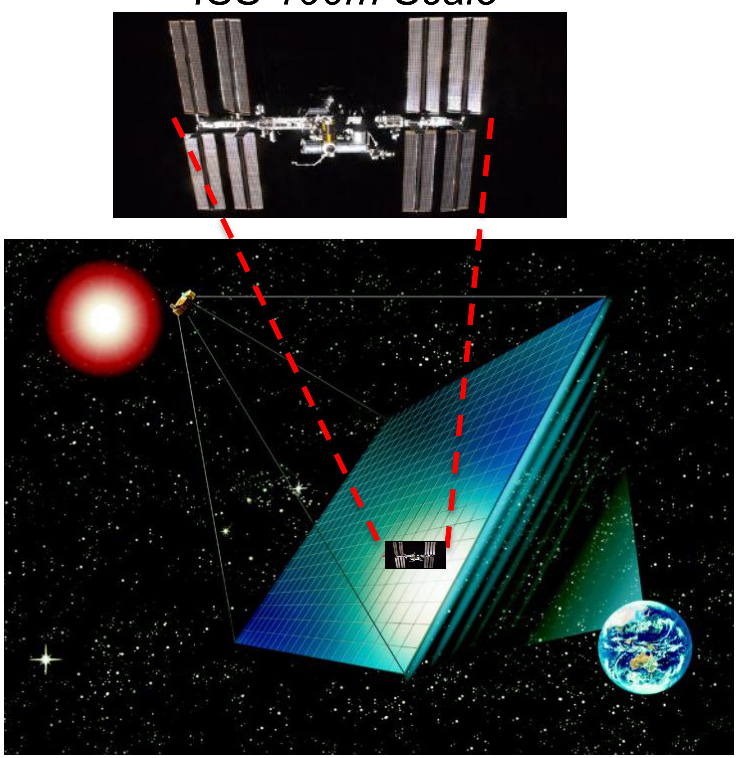
4. Required technologies



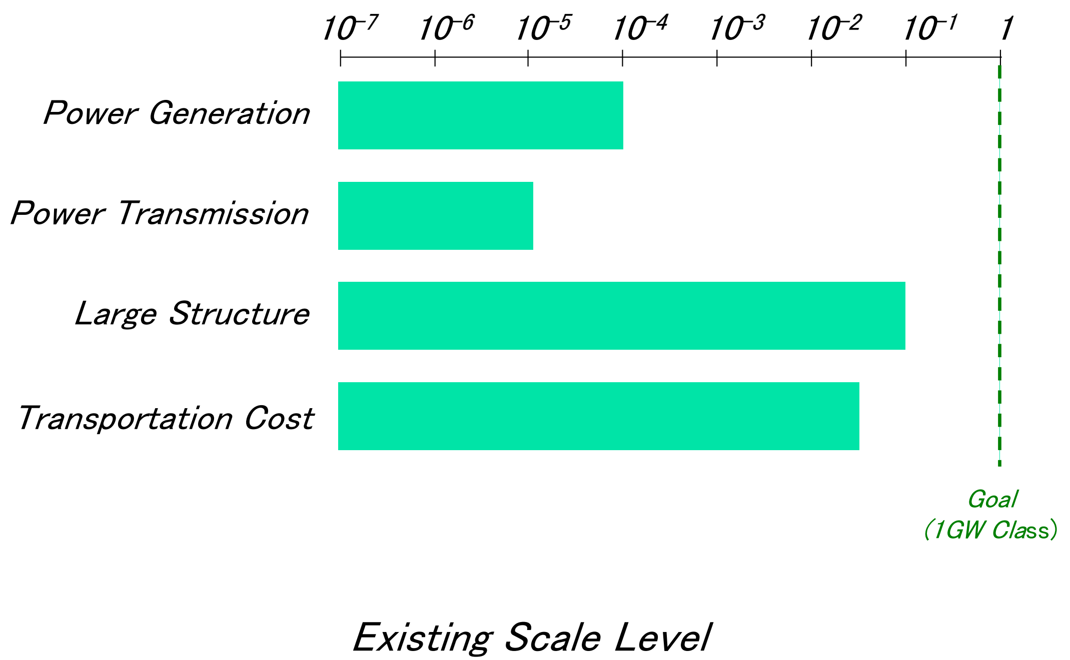
Current and Target Level for SPS Technologies

Primary technology	Existing level	Target level	Order of magnitude
Solar power generation	100 kW(space)	1 GW	10,000
Microwave power transmission	10 kW (ground)	1 GW	100,000
Large space structure	100 m (space)	1 km	10
Space transportation	5,000 $/kg	100 $/kg	1/50

ISS 100m Scale



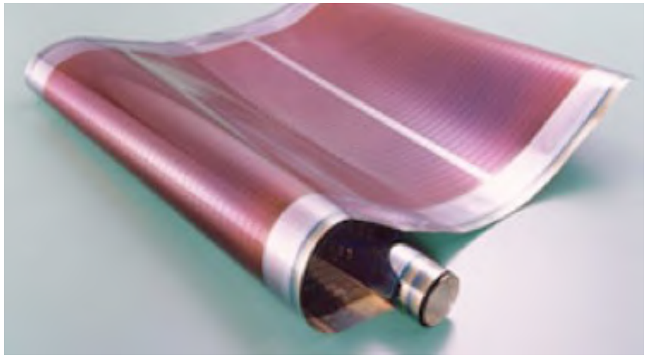
SPS 1-2 km Scale



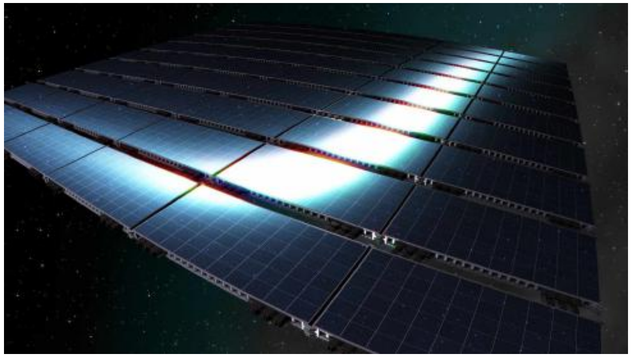
Power Generation

	Current	SPS Target
Conversion Efficiency	15-30 %	35-40 %
Specific Weight	1-100 g/W	1 g/W
Life in Space	10 years	30-40 years
Cost	4-6 $/W	1-0.5 $/W

Conventional solar array panel for space use, with high performance cells, but heavy

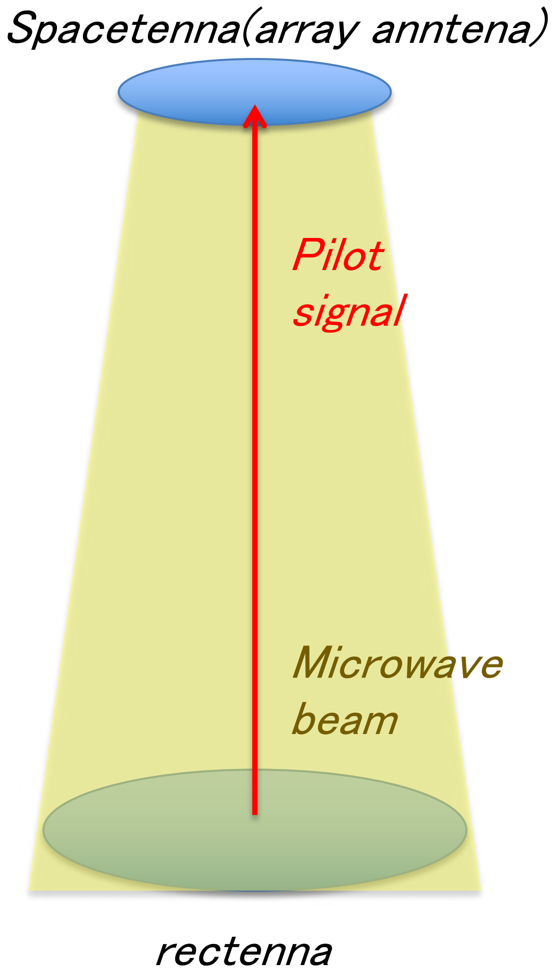


Light-weight thin film solar cell for ground use, a candidate for SPS



Installed on light-weight SPS structure

Technologies for Microwave Beam Direction Control



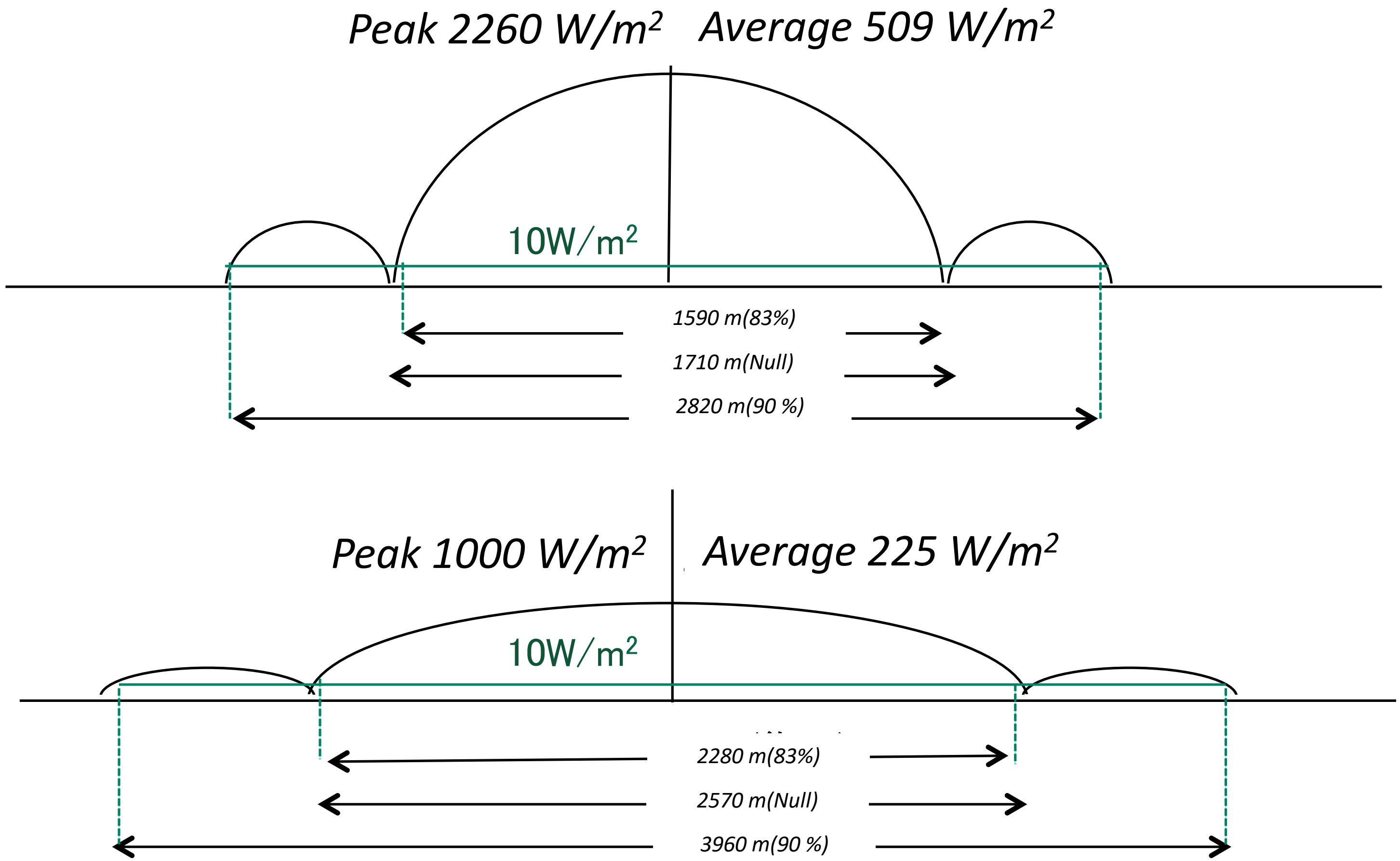
Required Technologies

1.Determination of rectenna position by detecting and processing pilot signal from the rectenna site.

2.Controling the phase of microwave from each antenna (or sub-array) so that the microwave beam as a whole directs to the rectenna center precisely.

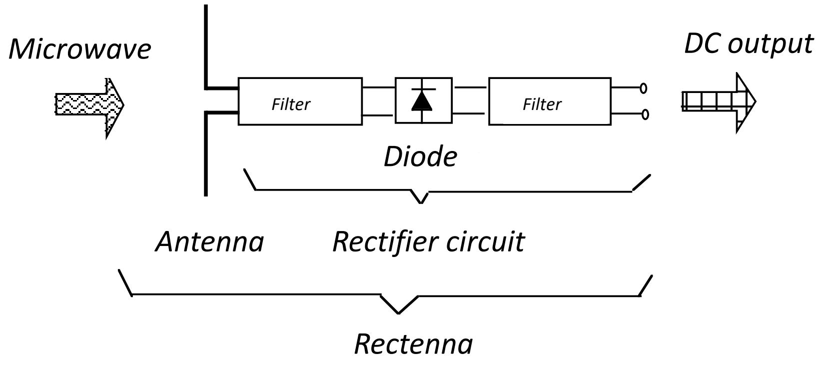
Item	*Target*
Beam forming	*100 μrad*
Beam control accuracy	*10 μrad*
Beam control range	*± 10 degrees(tentative)*
Power concentration	*90 % inside the rectenna*
Response (phase control)	*sec scale for small antenna area(m)*
	hour scale for large antenna area(100m)

Microwave Intensity on the Ground (depending on the SPS Model)

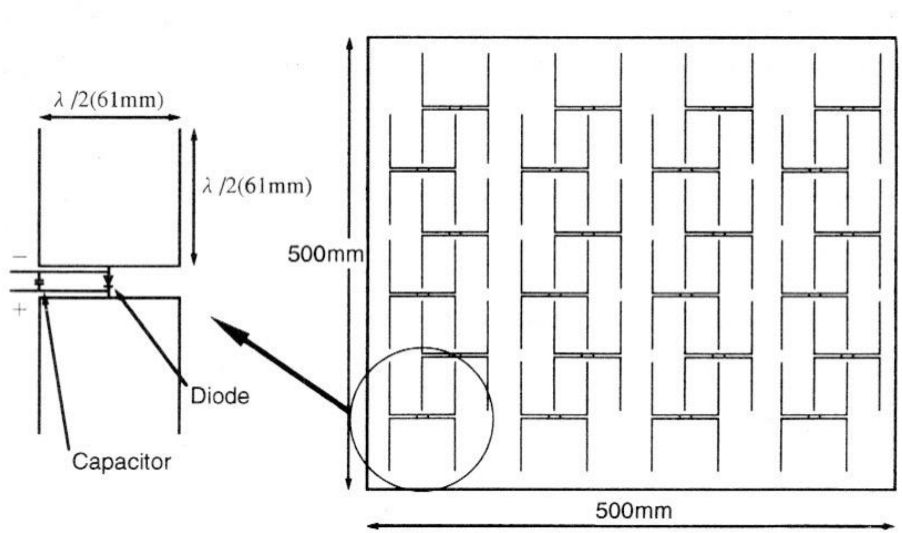


Ground power density for tether SPS with a 2.5 km x 2.375 km antenna (approximated as a circle). 1.4GW transmission power. 37,333km distance (from geostationary satellite orbit to Tokyo).
Upper panel: All antenna elements are in the same phase.
Lower panel: The phases of antenna elements are controlled so that the peak intensity is lowered at 1,000 W/m^2.

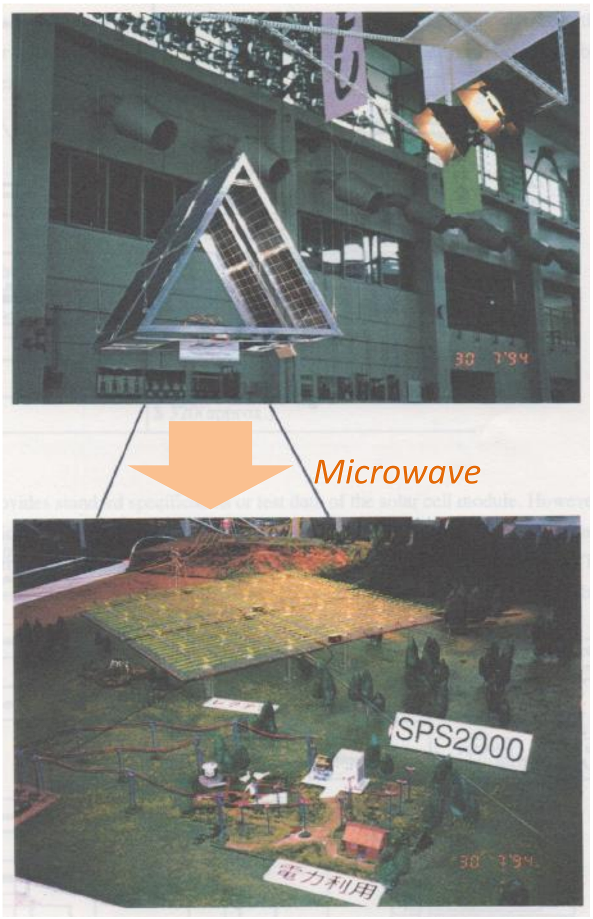
Rectenna (Microwave Receiving Circuit) Technologies



Rectenna operating principle (Circuit diagram)



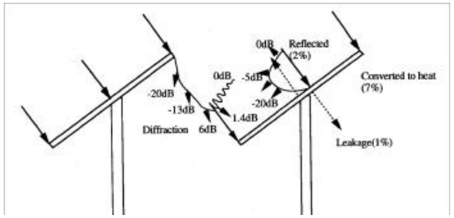
Rectenna prototyped in the laboratory



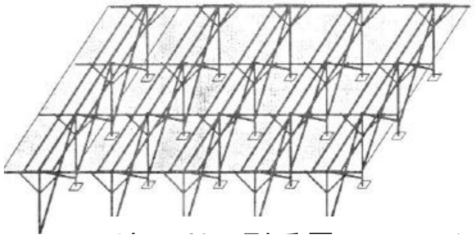
SPS model and rectenna in the laboratory test. Microwaves (2.45GHz) from a model simulating the solar power satellite SPS2000 are received by a rectenna simulating a ground power receiving station. A motor and illuminant are operated by the received power on the ground.

▶ *Many prototypes of small power receiving antennas have already been made and tested. A rectification efficiency of about 80% has been already achieved.*

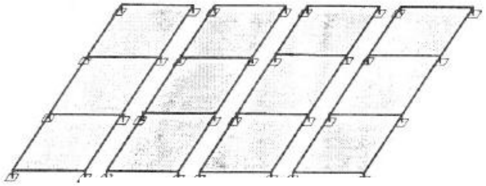
Microwave Receiving Antenna（Design Examples)



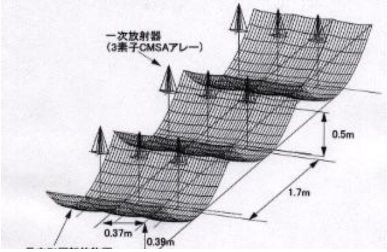
Receiving antenna of NASA Reference System



Receiving antenna above the ground (SPS2000)



Receiving antenna on the ground (SPS2000)



Parabola type receiving antenna (Tether SPS)

Image of receiving antenna site (NASA Reference System)

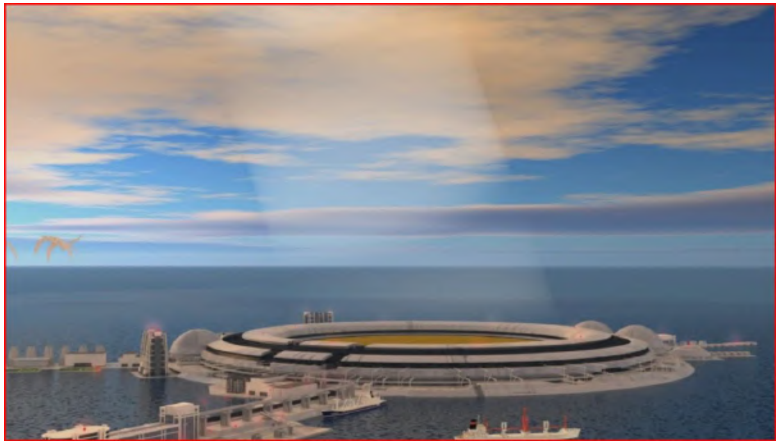
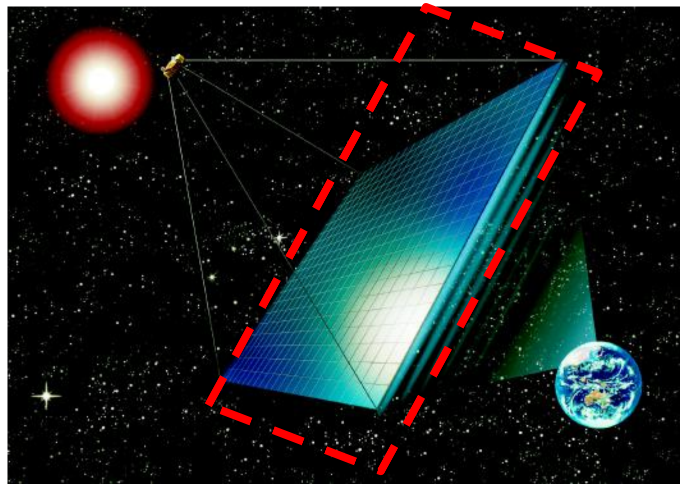


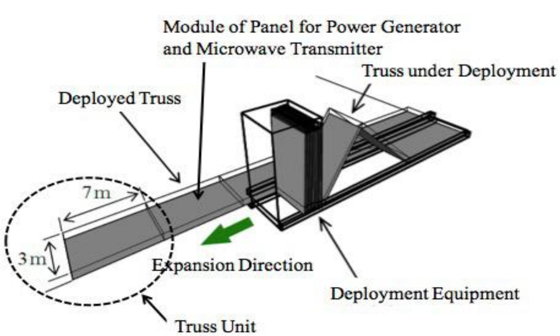
Image of marine receiving antenna site（JAXA)

Technology for building large structures in space

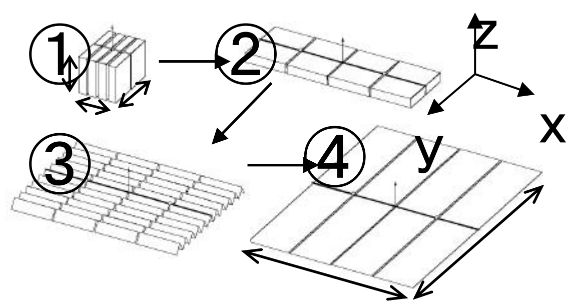
1 GW class SPS requires a structure of km size.



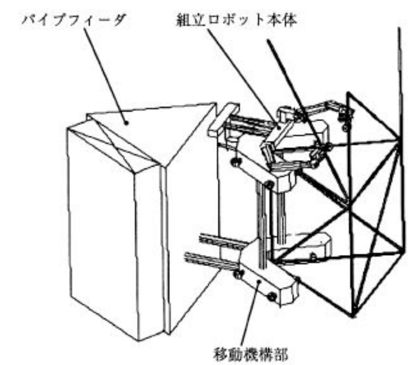
The basic structure is a large thick panel. Several construction methods have been proposed and prototyped.



▶ Deployment and assembly at the same time



▶ Automatic self-deployment



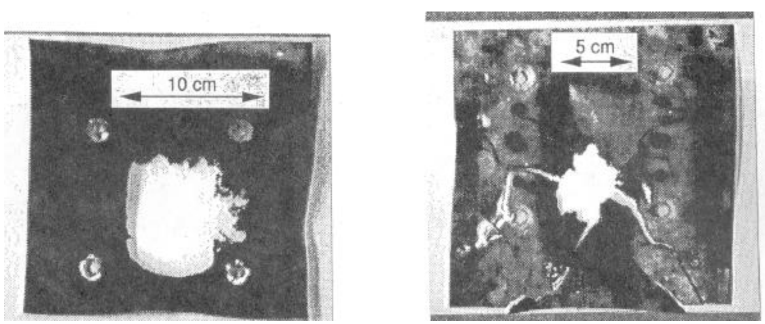
▶ Construction by robot

Will Solar Power Satellite be destroyed by the debris or meteorites impacts?

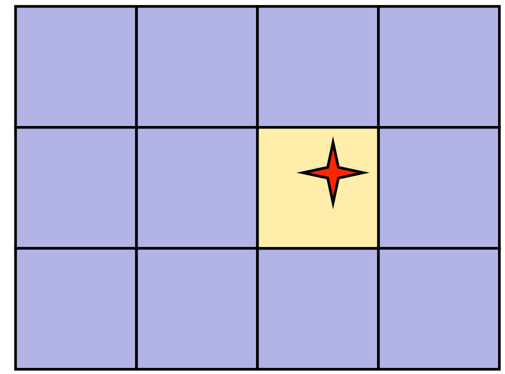
Debris or meteorites impacts are inevitable. The structure can be designed to localize the damage so as that the damage is within an allowable range of SPS.

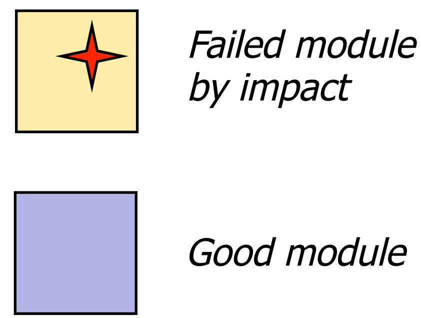
Collision frequency (impacts/km^2) for the geosynchronous orbit is:
once per 70 years for 10 cm size object,
once per 3 years for 1 cm size object, and
2400 times per year for 1mm size object.

The solar panel will be designed so as that the impact damage is localized in a module. If we adopt a module size of 0.5 m x 0.5 m, the power loss during 40 years will be 4.8%.



An example of damage observed in hyper-velocity impact experiment. The target is a plate simulating the solar panel. The damage size often reaches 10 times larger than the size of the projectile.

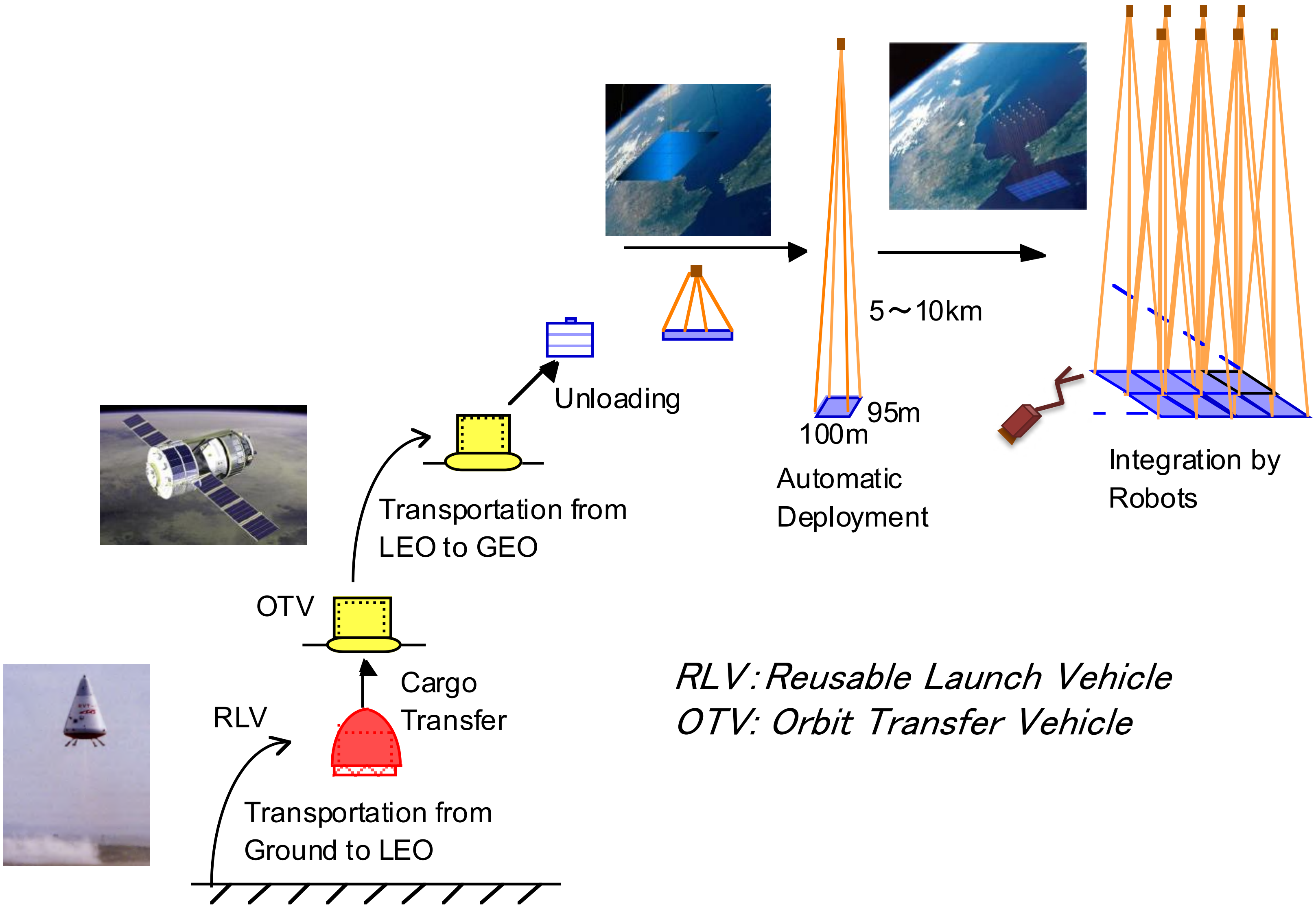




The solar array panel is designed that the impact damage does not propagate to other modules.

5. Required space transportation

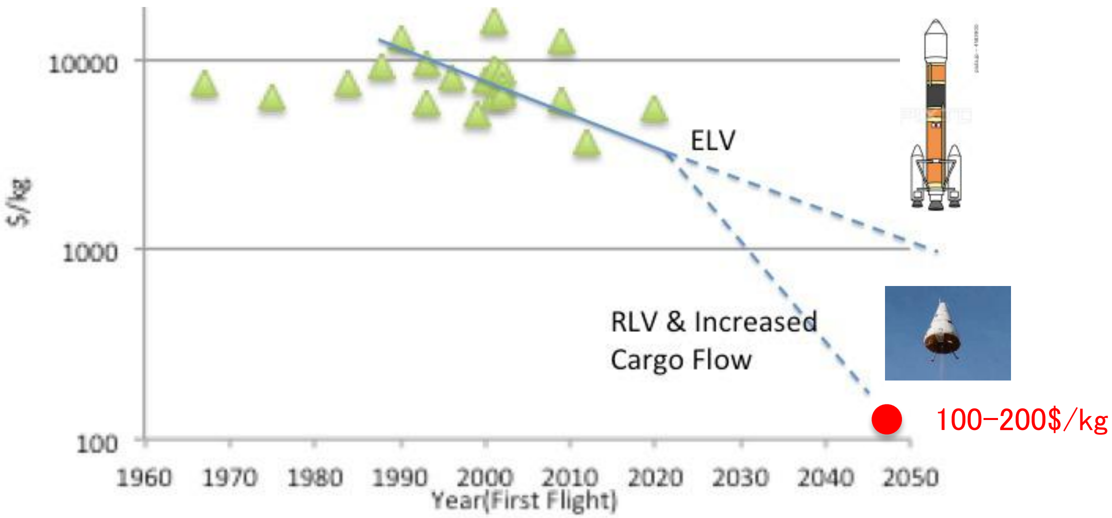
Typical Construction Scenario (An Example for Tether SPS)



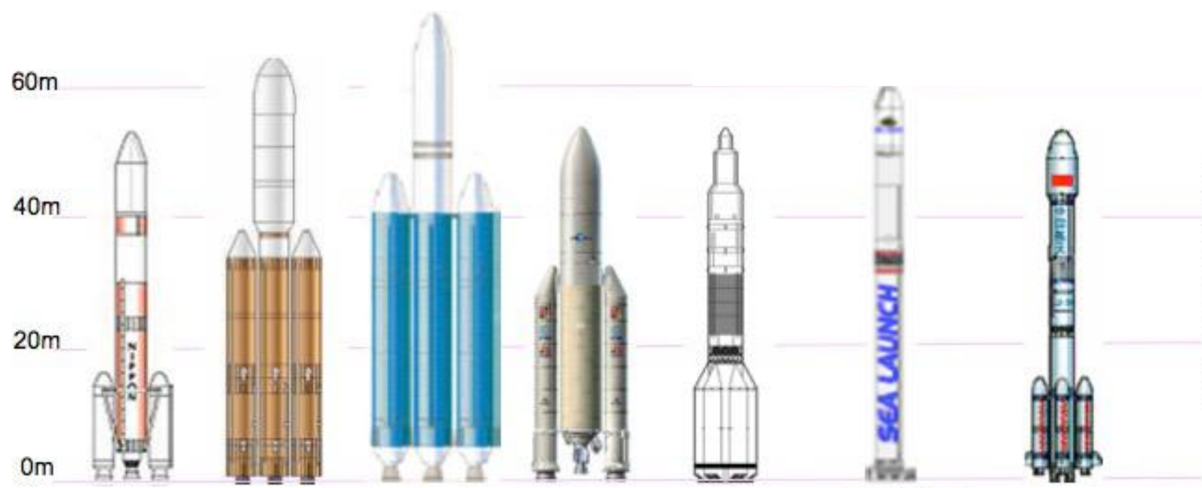
RLV: Reusable Launch Vehicle
OTV: Orbit Transfer Vehicle

Transportation Cost for Launch Vehicle

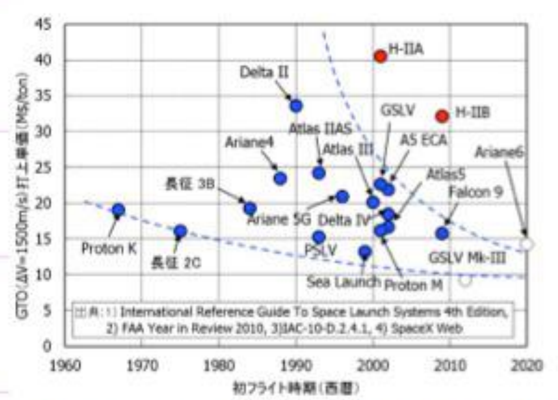
LEO Launch Cost



RVT-9 Weight: 500kg、Length: 3.5m

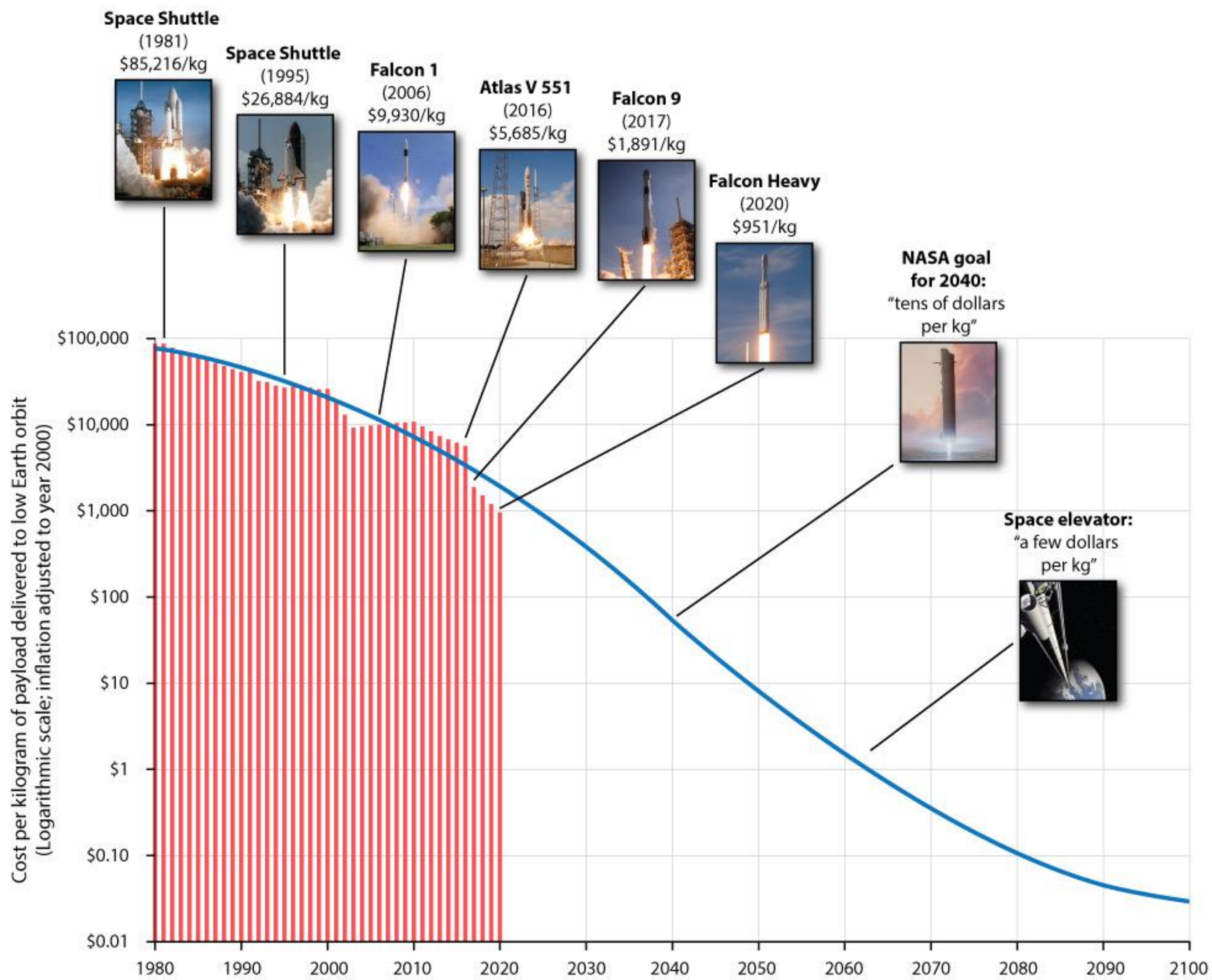


H-2A Atlas 5 Delta 4 Arian 5 Proton Sea Launch Long March 3



GTO Launch Cost

Long-term Prediction of space transportation costs



Prediction by Future Timeline Net

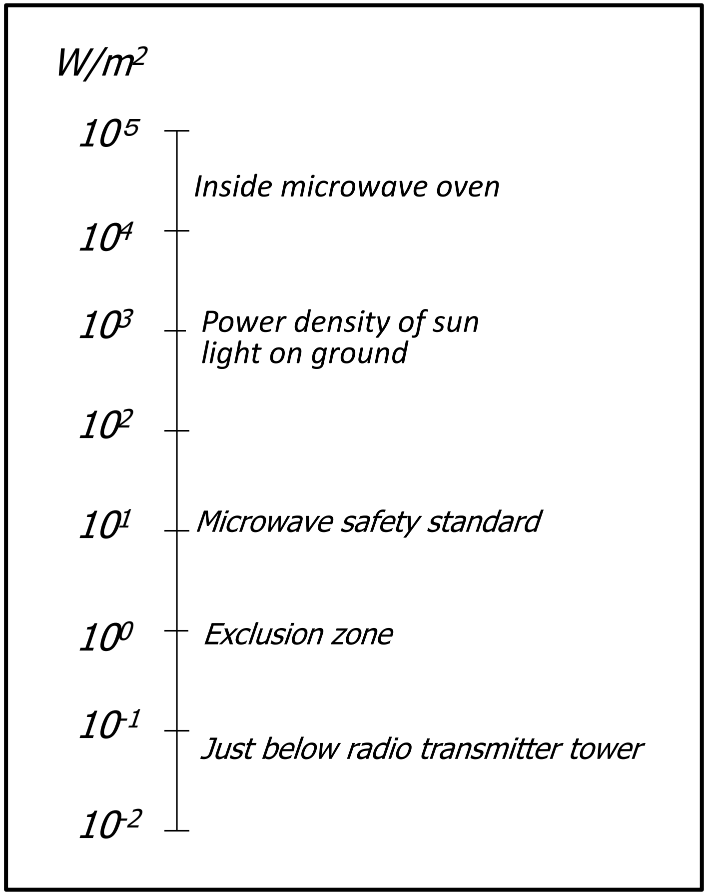
6. Safety and environmental issues, and legal aspects

Microwave Safety Issues

- In accordance with Japan's and international safety standards, it is considered that areas with strength above the standards are designated as an exclusion zone, and areas up to 1/10 of the standards are restricted areas in principle for safety reasons. The signal strength outside the restricted area is about the same as or even lower than that of mobile phones.
- Even within the exclusion zone, the maximum power intensity is about the intensity of the sun light, so it is considered that there will be no effect on birds or other animals that temporarily invade.
- It is possible to control to stop the transmission of microwave power immediately when the microwave is about to deviate from the power receiving station due to some kind of failure.

Agency, Country	Exposure limit in general public		Exposure limit to professional personnel	
	Electric Field Strength (v/m)	Power Density (mW/cm^2)	Electric Field Strength (v/m)	Power Density (mW/cm^2)
The Ministry of Internal Affairs and Communications, Japan (1990,1997)	61.4	1 General	137	5 Controlled
ANSI/IEEE (USA) C95.1-1999	–	3.87 Non-controlled	–	10 Controlled
ICNIPP 1998 (International)	61	1 Public	137	5 Controlled

Microwave protection guideline value (5.8 GHz example). The guideline values for Japan and ICNIRP are the same for 2.45 GHz.



General ideas on the impact of microwaves on the human body, social infrastructure, and ecology

In order to use microwave for wireless power transmission, it is necessary to have the ITU (International Telecommunication Union) assign a new frequency to be used for power transmission business. The basic idea of the effects of microwaves on the human bodies, social infrastructure, and ecology can be summarized as follows.

(1) Effects on human bodies
In accordance with international protection guidelines, an area of 1 mW/cm^2 or more will be an exclusion zone.

(2) Effects on communication infrastructure
Since it is difficult to use the same frequency as that already used in the communication infrastructure, it is necessary to receive a dedicated frequency allocation for the wireless power transmission from the ITU. For harmonics, a power transmission system that does not have the same phase in the harmonics shall be used to avoid interference.

(3) Effects on existing infrastructure
For aircraft and satellites, filters are used in the onboard electronic devices to prevent interferences during the flight in the microwave beam. No measures will be required for standard electronic devices used on the ground. However, if some special consideration is required for such as medical facilities, the receiving facility will be placed so as to keep a distance from them.

(4) Effects on ecology
Regarding the impact on the ecology in the beam (long-term exposure for plants and surface animals with low mobility, short-term exposure for animals with high mobility such as birds and insects), it is considered there will be no problem at the sunlight level (100 mW / cm^2). Regarding the effect on the ecology under the rectenna, the microwave effect is small considering the power receiving efficiency (80% or more). Rather, it seems that the sunlight blocking effect by the rectenna is important, but it is believed that the ecosystem can be maintained if the rectenna's solar transmittance is 60% or more.

Considerations as an activity principle associated with SPS (by Prof. Toshio Kosuge)

1. The use of space solar power is the freedom of use of space, and is permitted as long as it complies with space law and general international laws. However, it is necessary to consider the activities and developing countries for the benefit of all countries.

2. Outer space, including the moon and other celestial bodies, is not subject to national acquisition by use, utilization, elections or any other means (Outer Space Treaty Article 2, Moon Treaty Article 11).

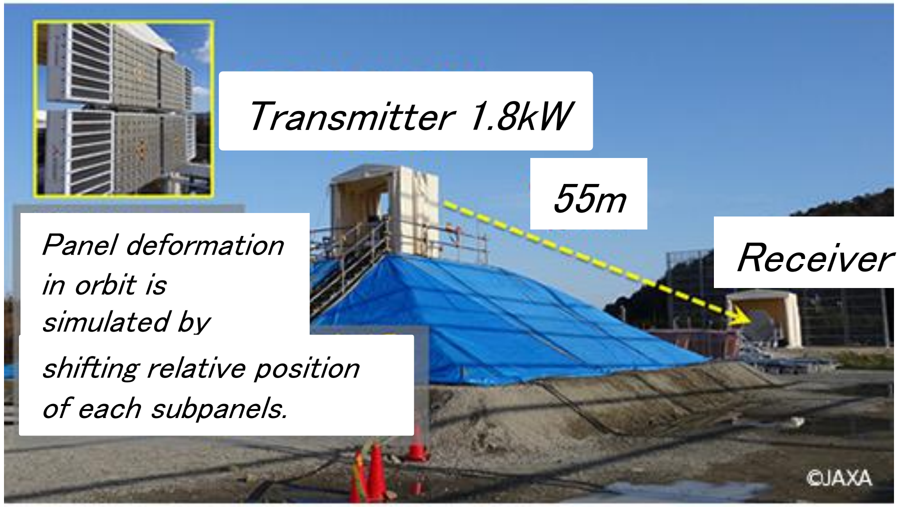
3 The treaty, whether by government agencies or non-governmental organizations, have international responsibility for space activities (Article 6 of the Outer Space Treaty).

4. For damages caused by space activities, the parties concerned shall be liable for damages, and in the case of damages on the ground or in the air, they shall be liable for strict liability, and ultimately the nation shall be liable (Space Liability Convention 7). Article, Space Liability Convention).

5. It is not allowed to cause harmful interference to the environmental protection of space, the earth, and the space activities of other parties (Article 9, Moon Treaty, ITU Charter, etc.).

7. Current R & D status and roadmap for realization

Recent microwave power transmission experiments on ground



Microwave power transmission experiment conducted in 2015 (distance 54m, 5.8GHz, microwave output 1.8kW, power receiving output 340W (JSS / JAXA)

Transmitter

Receiver

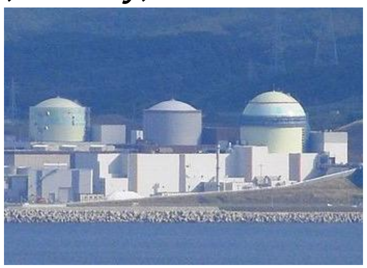
Microwave power transmission experiment conducted in 2015 (distance 500m, 2.45GHz, microwave output 10kW, power receiving output 32W (JSS)

SPS Development Roadmap as Compared with Nuclear Fission and Fusion

Experimental Verification of Principle

+10 years | *+20 years* | *+30 years*

Nuclear Fission Plant (History)

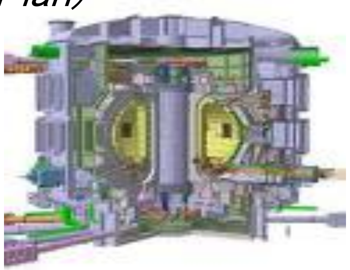


1942 — *Critical Nuclear Chain-reaction Success*

1951 — *First Electricity from Nuclear Reactor(200kW)*

1960 — *Commercial Light Water Reactor(180MW,GE)*

Nuclear Fusion Plant (Plan)

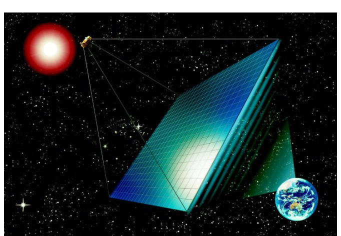


2025 — *Fusion Verification*

2035 — *Proto Model Reactor*

2045-50 — *Commercial Phase*

Solar Power Satellite (Plan)



2024 — *On-orbit Verification*

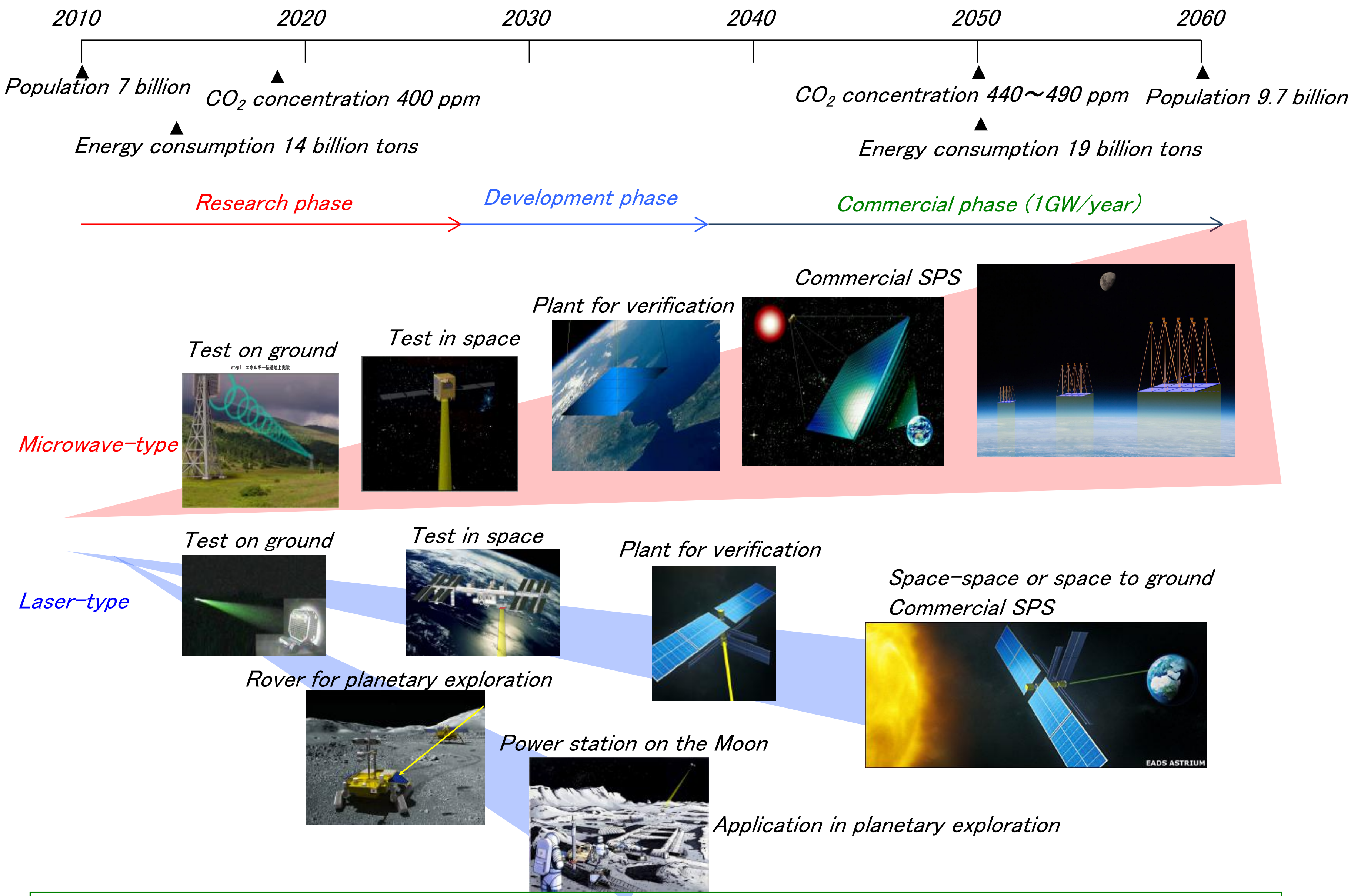
2028 — *Initial End-End Verification (100kW)*

2033 — *Plant (2MW)*

2038 — *Plant (200MW)*

2043 — *Commercial SPS (1GW)*

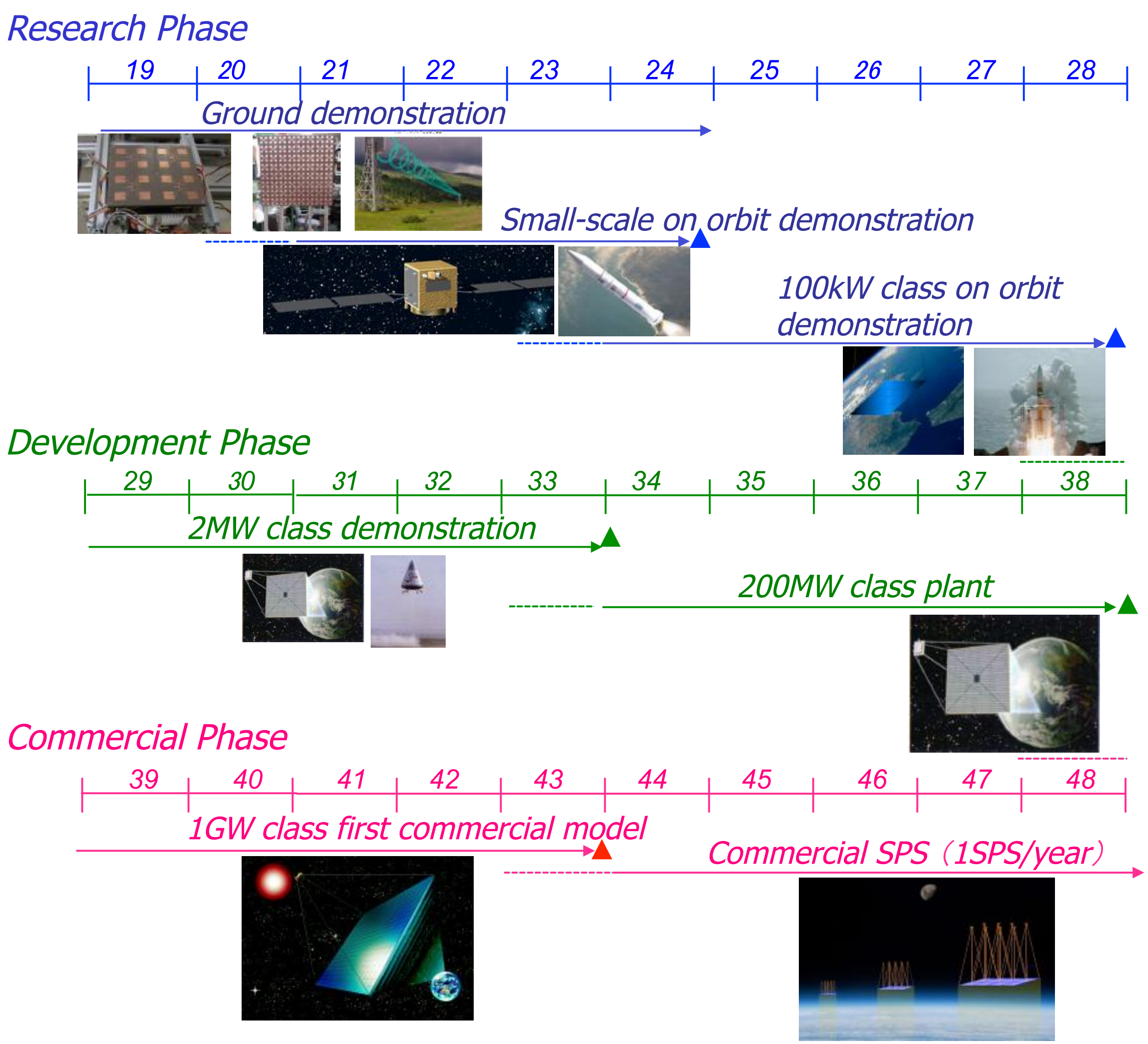
SPS Research and Development



▶ Since the laser transmission is strongly affected by the weather, it is more likely to be used for spacecraft-to-spacecraft or lunar-planetary exploration than power transmission to the ground.

Roadmap towards SPS Commercialization

If we follow the roadmap below, we will be able to realize the first commercial Solar Power Satellite of 1GW class in mid-2040's. Increasing the number of the Solar Power Satellites year by year , both the issues, the depletion of energy resources and deterioration of the global environment, will be overcome before 2100.



SPS Requirements for Space Transportation

Phase	Small scale demonstration	Large scale demonstration	Small plant	Large plant	First commercial model	Commercial
Target year	～2015	～2020	～2025	～2030	～2035	2035～
Orbit	LEO	LEO	1000 km	GEO	GEO	GEO
Power level	1～5kW	100 kW	2 MW	200 MW	1 GW	1 GW
System weight	500 kg	15 tons	42.5 tons	5300 tons	26600 tons	26600 tons
Construction	NA	NA	6 months	3 years	5 years	1 year
Payload weight	500 kg	15 tons	10 tons	50 tons	50 tons	50 tons
Launch vehicle	Small ELV LEO	Large ELV LEO	1 RLV 1000km 5 Round trips 1 launch/month	1 RLV 500 km 207 round trips 1 launch/5 days 5 days turn around	3 RLV 500 km 345 round trips 1 launch/2 days 5 days turn around	15 RLV 500 km 69 round trips 2.8 launch per day 5 days turn around
Orbit transfer vehicle	NA	NA	NA	14 OTV 500 km-GEO 9 round trips*	42 OTV 500 km-GEO 15 round trips*	206 OTV 500 km-GEO 3 round trips*

*: fuel 38 tons for a round trip

Epsilon Launch Vehicle

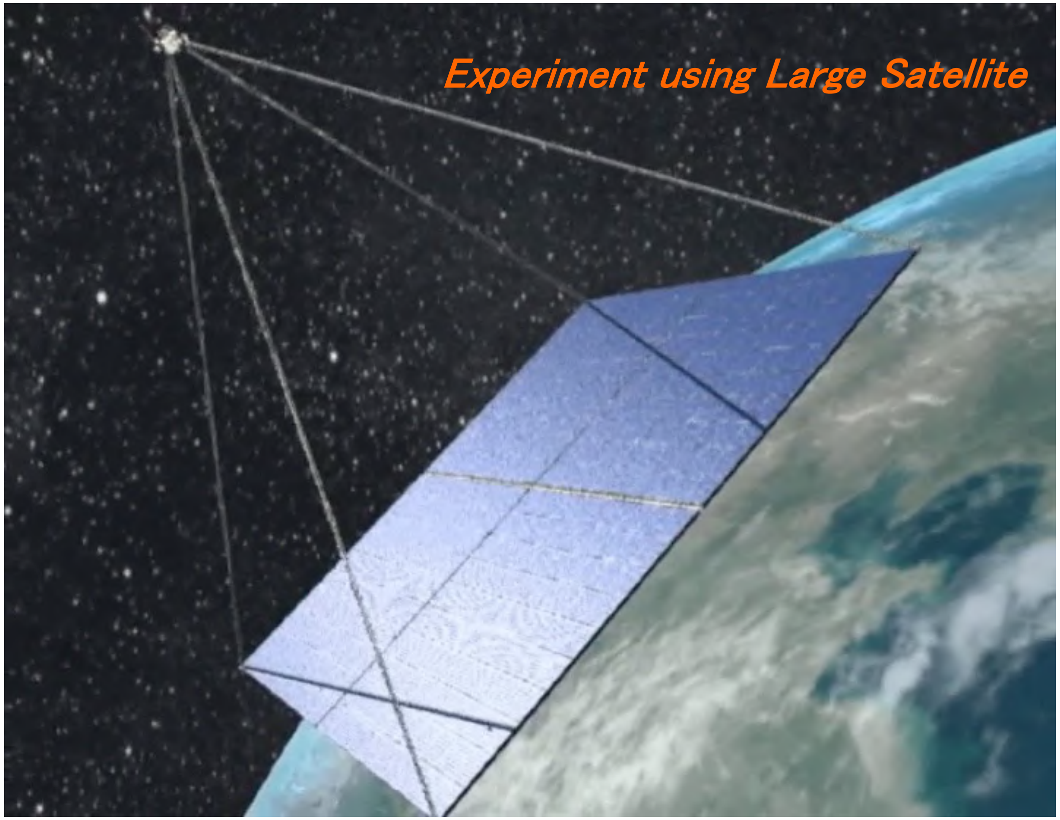
H-II Launch Vehicle

Reusable Sounding Rocket

OTV (Image)

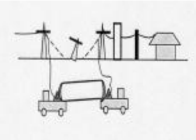
Space experiment for demonstrating wireless power transmission technology that should be carried out at an early stage

Altitude: about 400km
Power level: about 1-5kW.
Demonstration of microwave beam control technologies and propagation in the ionosphere.



Altitude: about 400km
Power level: about 100-400kW
Demonstration of power transmission.

Spin-off of wireless power transmission technologies (application to industrial and space development)

Usage	*Example*	*Illustration, photos*	*Required microwave technology*
Power supply to maintenance, inspection, and diagnostic equipment in difficult situations for power line.	*Power supply to forest environment survey sensor network*		*Transmission technology Receiving technology Direction control (coarse)*
Small power supply for disasters (weak power supply from balloons, etc.)	*Transmission of power and information from airships (Kyoto University, 2009)*		*Transmission technology Receiving technology Direction control (coarse)*
Medium-sized power transmission (in disaster, temporary use)	*Wireless connection of disconnected transmission lines (Takano, 2011)*		*Transmission technology Receiving technology Direction control (fine)*
Microwave power space aimed at supplying power to electronic devices (low power density)	*Wireless power space (Kyoto Univ.), Wireless charging (Ossia demo.)*		*Transmission technology Receiving technology Direction control (coarse)*
Power supply to batteries of vehicles, etc.	*Charging a car battery (Mitsubishi Heavy Industries, Kyoto University)*		*Transmission technology Receiving technology*
Power supply to flying objects	*Power transmission to airships, small planes, and small helicopters*		*Transmission technology Receiving technology Direction control (fine)*
Wireless power supply system for lunar/planetary exploration	*Lunar microwave power transmission (University of Colorado)*		*Transmission technology Receiving technology Direction control (fine)*

8. Concluding remarks

If SPS system is realized …

- *limitless clean energy will be obtained,*
- *global environment will be restored and preserved,*
- *international conflicts over energy resources will be terminated,*
- *creative and comfortable society will be established,*

・・・ and, new civilization and culture will be developed in the creative and vigorous society expanding into space.