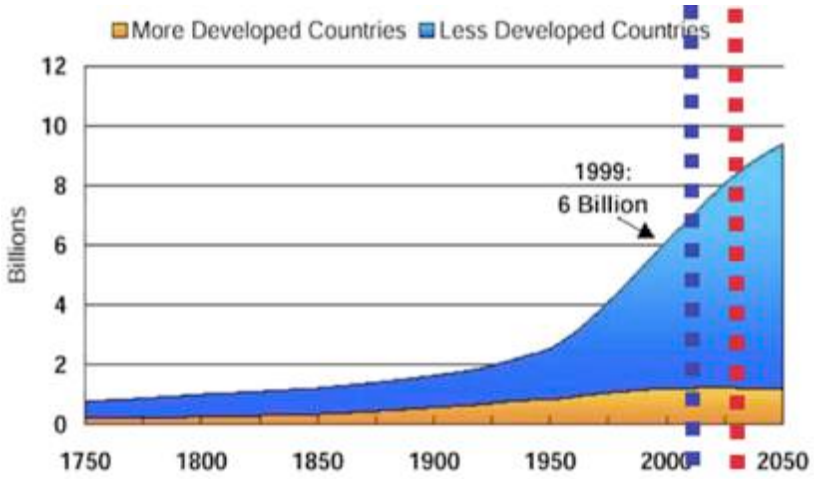
Space Solar Power Systems (SSPS) for a Sustainable Energy Future

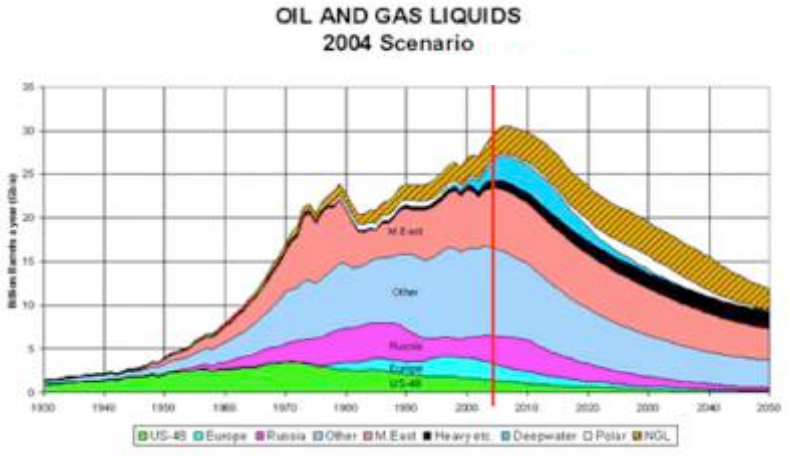
- *Concept of SSPS*
- *Technologies Required for SSPS*
- *Demonstration Experiments in the Past and Future*
- *Roadmap towards Commercial SSPS*

Oct. 2013

Why New Energy System Required?

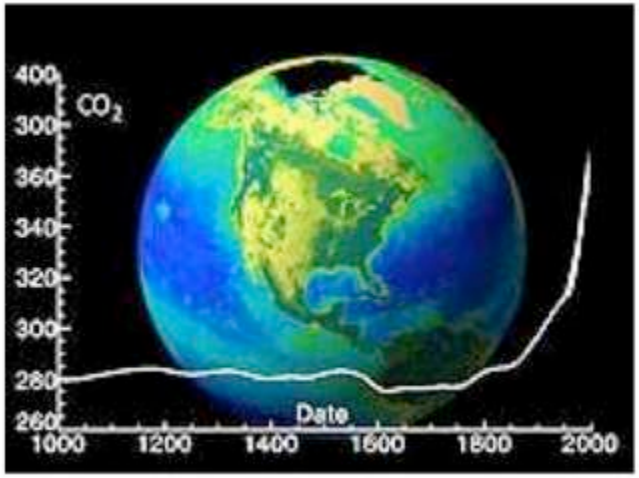


Population



Fossil Fuel

*Ref:*Abundant & Affordable Space-Based Solar Power Realizing the Opportunity*John C.Mankins(2007)*



CO_2 Emission

New Energy System Required

Clean

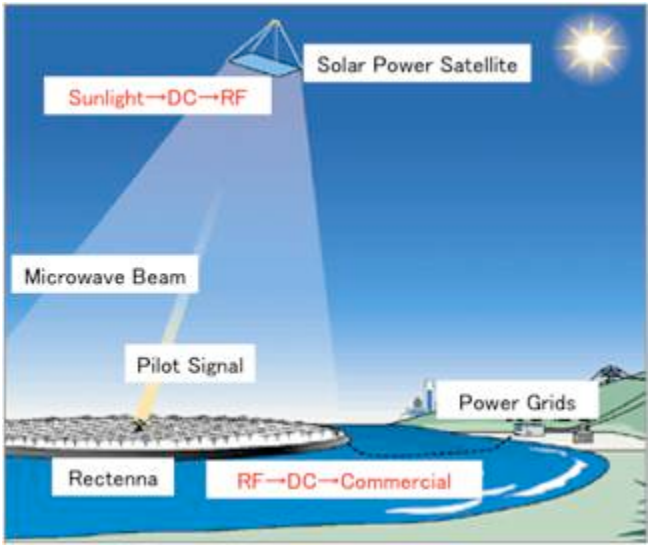
Safe

Large-scale

What's and Why Space Solar Power

Ground-based Solar Power Plant（USA, 250MW)

In orbit



Space-based Solar Power Plant (1 GW class)

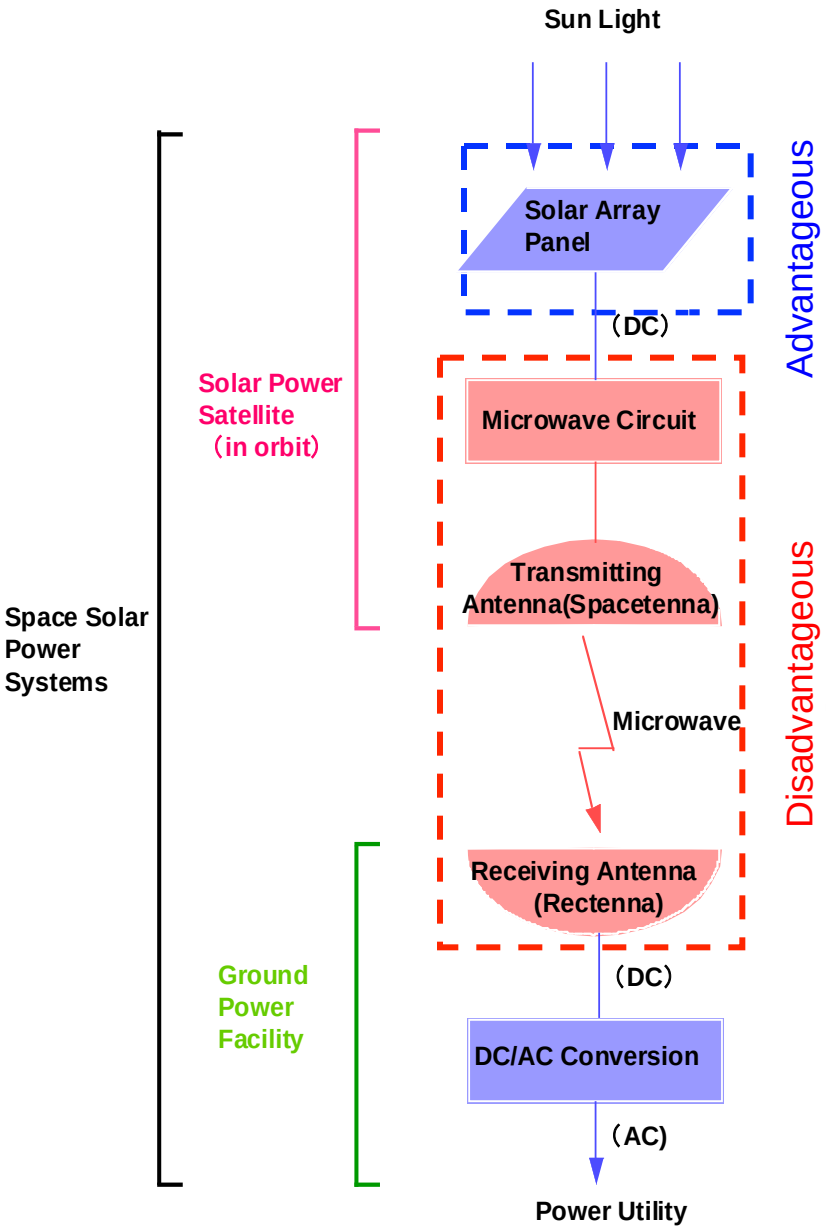
Why Solar Power?

Power from Sun to Earth:
1.77×10^{17}Watt
10,000 times more than global power consumption
⇒large potential for power source for human activities

Why Space?

Power density in space: 1,350W/m^2
Power density on ground:
100-200W/m^2 due to night, weather dependence, atmospheric loss
⇒"Space" is preferable to obtain solar power, if we have an efficient wireless power transmission system from space to ground.

Configuration of SSPS



Solar power density 10 times larger than ground on average

Wireless power transmission efficiency more than 0.5

Totally, 5 times better than ground solar power plant.

Possibility of a large-scale clean energy system

- ***Stable, independent on local time and whether conditions***
- ***Practically unlimited amount of energy***
- ***Energy payback time, power cost, and cleanness are promising.***

CO_2 Emission, Power Cost, and Energy Payback Time(EPT)

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

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

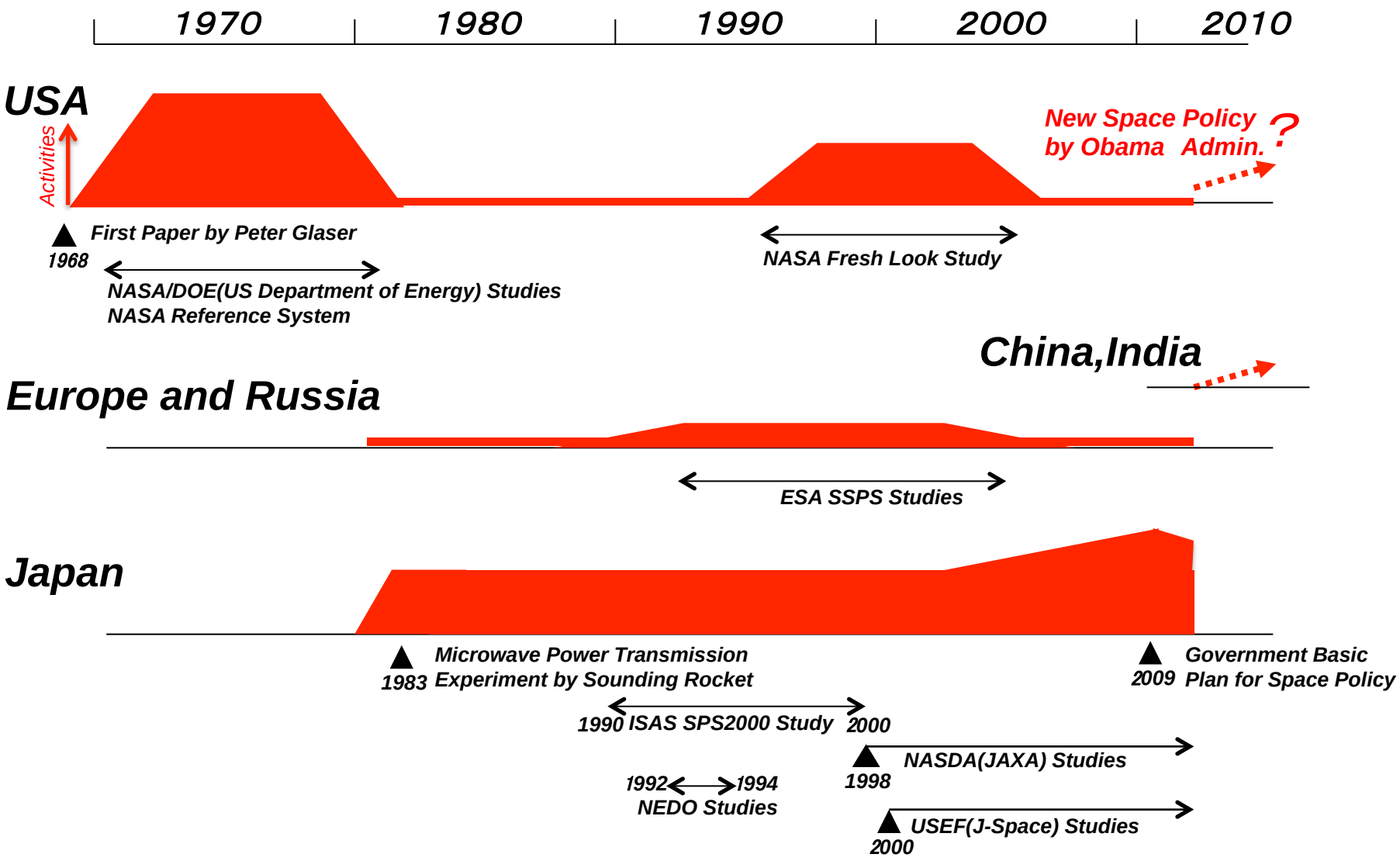
Yoshioka et.al., 1999

Model	Year	Life	Construction Cost	Power Cost	EPT
NEDO Grand Design	1994	30 years	24 B$	23¢/kWh	2 years
NASA Fresh Look Study	1995		1～10B$	1～10¢/kWh	
NASDA1998 Model	1998	30 years	27 B$	23.2¢/kWh	5 years
NASDA2003 Model	2002	30 years	12.5 B$	8.5¢/kWh	0.91 years
USEF Model	2003	40 years	17～7,8 B$	13.4～7.7¢/kWh	

$1＝¥100

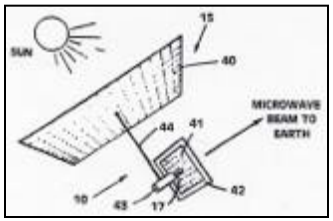
Note: The figures can be achieved only when we have an evolutional advancement in the field of semi-conductor, space construction, and space transportation.

History and Global Trend of SSPS Research



Concept of SPS

Category of SSPS Models



Peter Glaser's Original Idea

Solar Power Satellite

Microwave

Laser

Non-concentrator

Concentrator

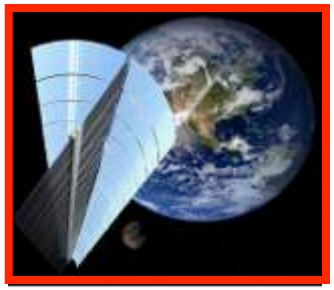
Bus Power | **Distributed Power** | **Bus Power** | **Distributed Power** | **Laser Direct Excitation**

NASA Reference Model

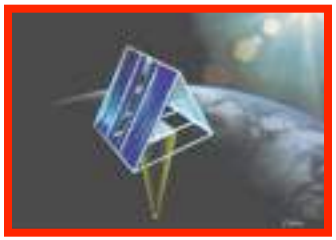
USEF Tether SSPS

NASA Sun Tower

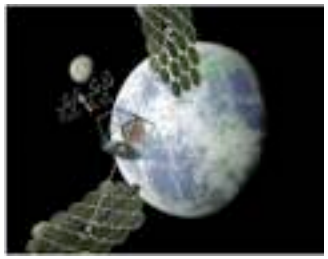
NASDA 2001



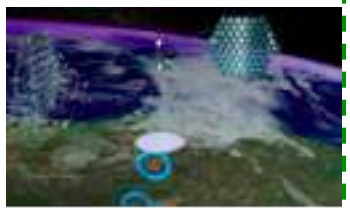
JAXA L-SSPS



SPS2000



NASA ISC



IAA Study Model

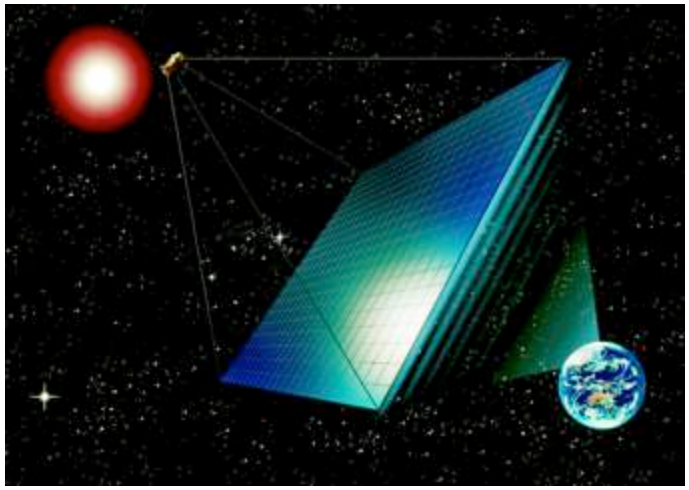
NEDO Grand Design

JAXA M-SSPS

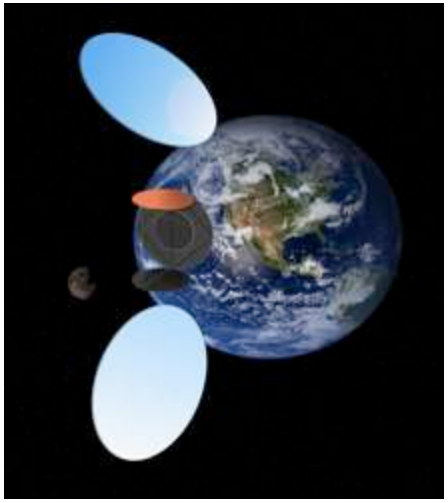
SPS-ALPHA

Designed in Japan

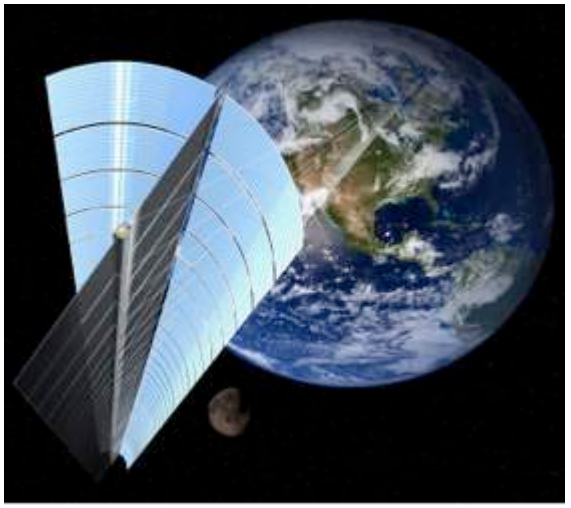
Three Commercial SSPS Models Currently Studied in Japan



Basic Microwave-type Power generation/transmission panel suspended by wires Simple, but lower power efficiency (USEF/METI)



Advanced Microwave-type Sun-pointing using mirrors Higer power efficiency, but complicated (JAXA/MEXT)



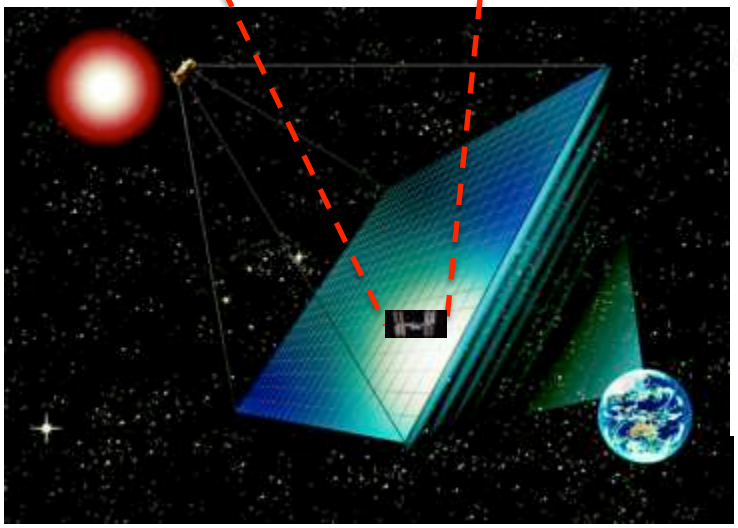
Laser-type (JAXA/MEXT)

USEF/METI:Unmanned Space Experiment Free Flyer(J-Space Systems)/ Ministry of Economy, Trade and Industry
JAXA/MEXT:Japan Aerospace Exploration Agency/ Ministry of Education, Culture, Sports, Science and Technology

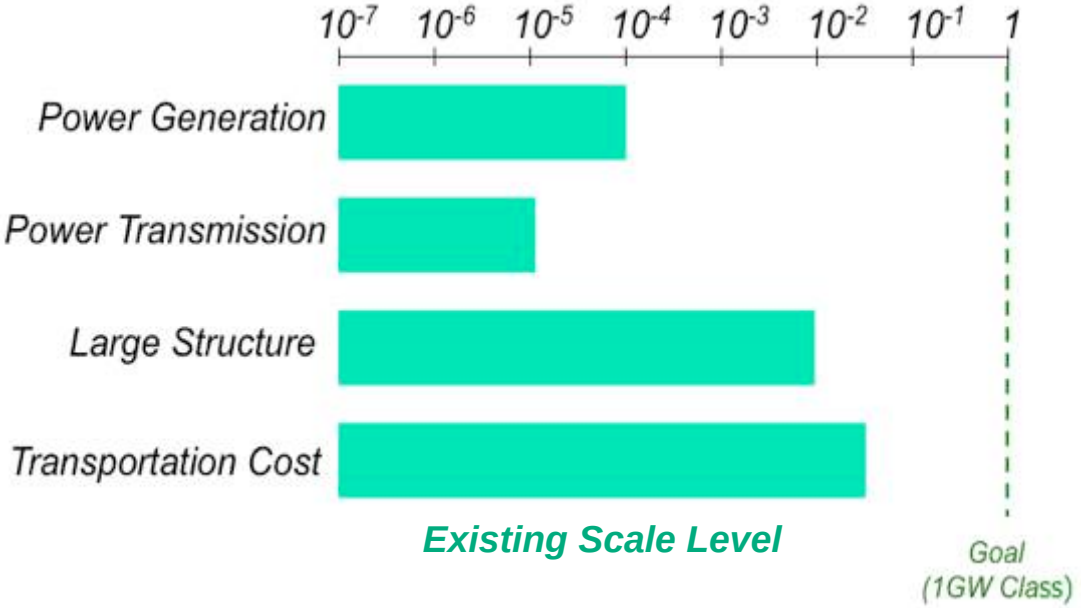
Current and Target Level for SSPS Technologies (in scale)

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	100(area)
Space transportation	5,000-10,000 $/kg	100 $/kg	1/50-1/100

ISS 100m Scale



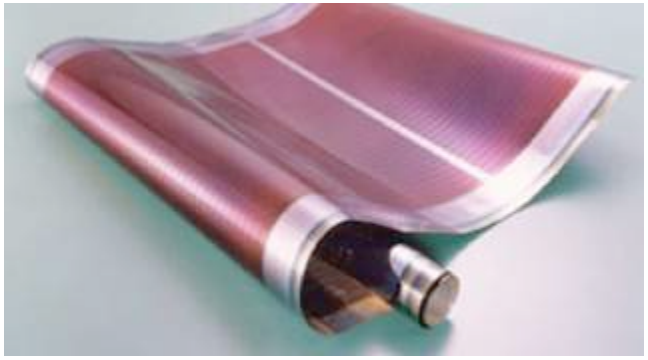
SSPS 1-2 km Scale



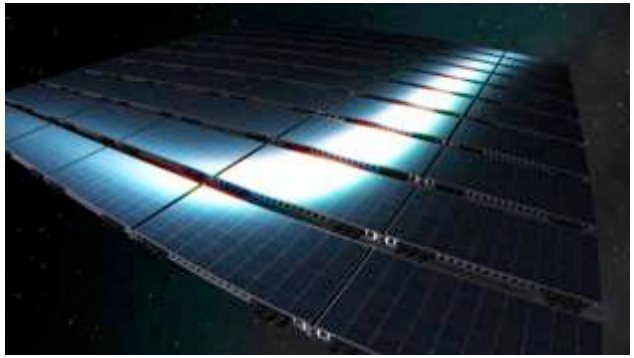
Power Generation

	Current	SSPS 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



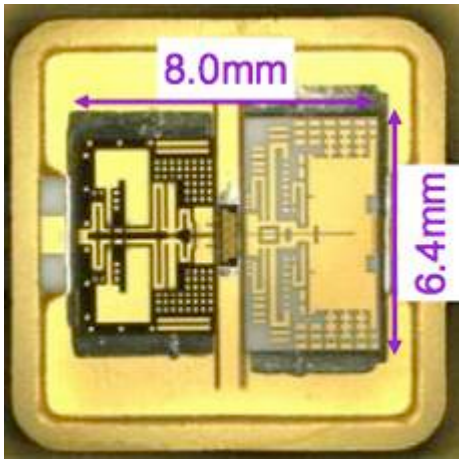
Light-weight thin film solar cell for ground use, a candidate for SSPS



Installed on light-weight SSPS structure

Wireless (Microwave) Power Transmission

	Current	SSPS Target
Conversion Efficiency (DC to RF)	50-70 %	85 %
Conversion Efficiency (RF to DC)	60-80 %	85 %
Specific Weight	50-100 g/W	1-10 g/W
Life in Space	10 years	40 years
Cost	20 $/W	1 $/W



HPA for ground experiment
PAE more than 70%

Rectenna for rover experiment
Array efficiency more than 60%

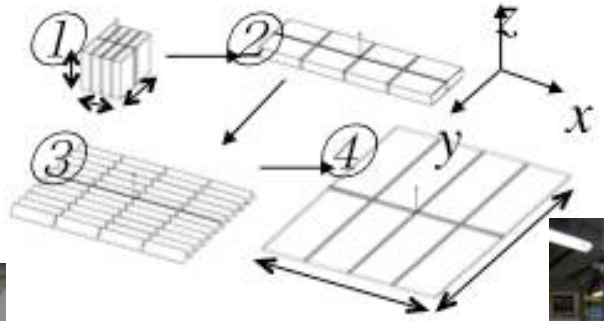
Large Space Structure

	Current	SSPS Target
Two-Dimensional (manned)	100 m	1,000-2,000 m
Two-Dimensional (unmanned)	20-30 m	
One-Dimensional	20,000-30,000 m	5,000-10,000 m
Weight	400 tons	10,000-20,000 tons

Automatic Building Machine

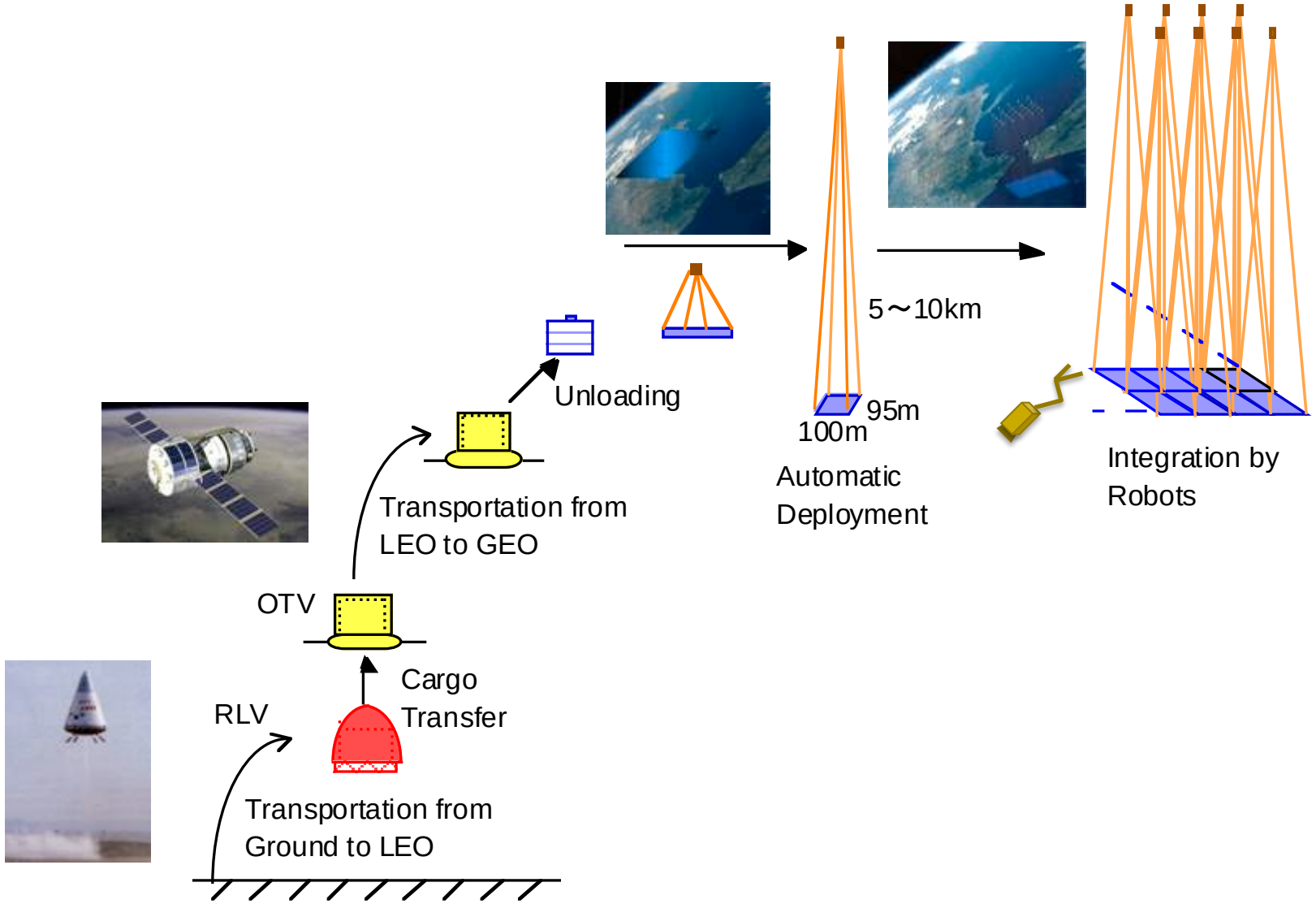
Ground Testing at ARD/JAXA

Automatic Self-Deployment System



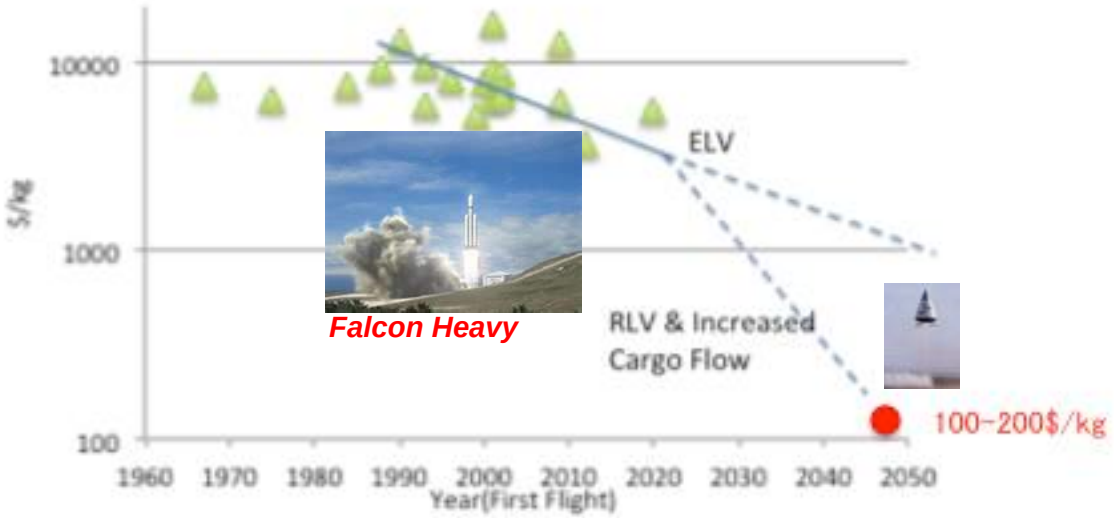
Ground Testing at ISAS/JAXA

Typical Example of Construction Scenario



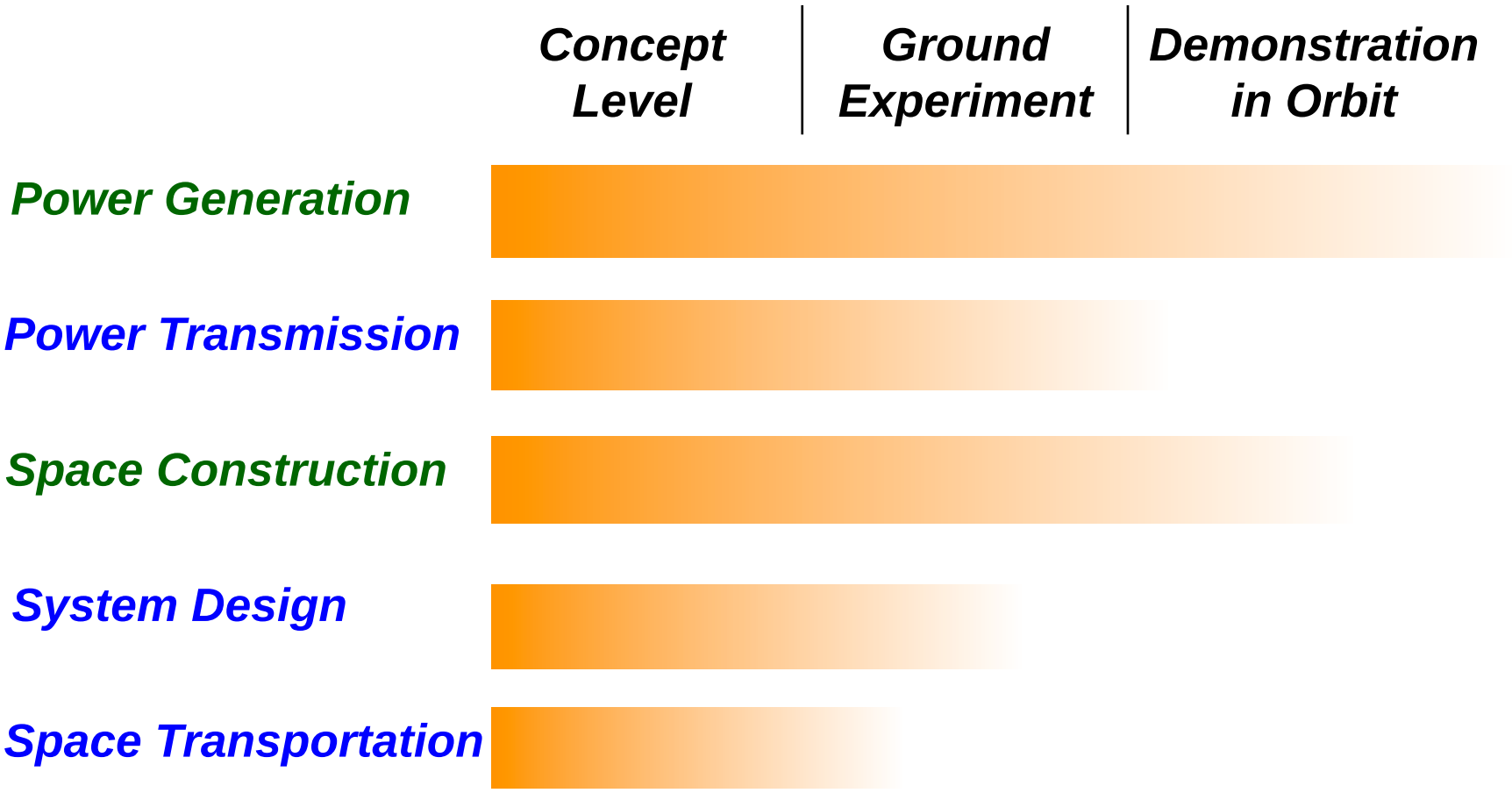
Space Transportation

	Current	SSPS Target
Cargo Weight	30 ton	50 ton
Cargo into Space	Several hundreds tons/year	10,000 tons/year
Launch Vehicle	Expendable	Reusable
Transportation Cost (Ground to LEO)	5-10 k$/kg	100 $/kg
Orbit Transfer Vehicle	100 mN Level	100 N Level
Transportation Cost (LEO to GSO)	No reliable data	10-50 $/kg



JAXA/ISAS RTV Reusable vehicle testing

Technology Readiness Level



Demonstration Experiment in the Past

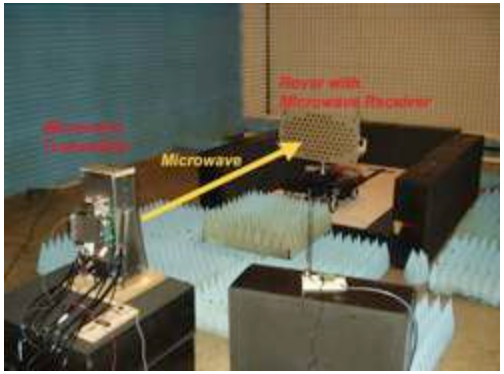
Sounding rocket exp.(1983, 1993, Kobe Univ., Kyoto Univ.), ISAS

Small airplane exp.(1992, Kobe Univ., Kyoto Univ.)

SPS 2000 demonstration exp. (1994、ISAS)

Yamasaki 50 m transmission exp.(1994、Kyoto Univ. Kobe Univ.)

Transmission to balloon exp. (1995、Kobe Univ.)



Transmission to rover exp. (2006、USEF)

Hawaii long-range transmission (2008, Kobe Univ. & US team)

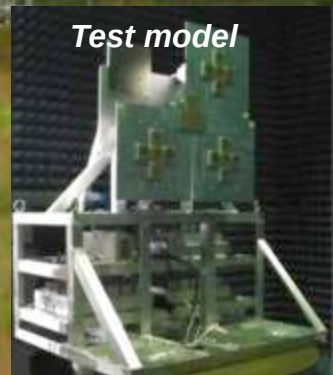
Microwave Power Transmission Experiment now Underway

Microwave Power Transmission

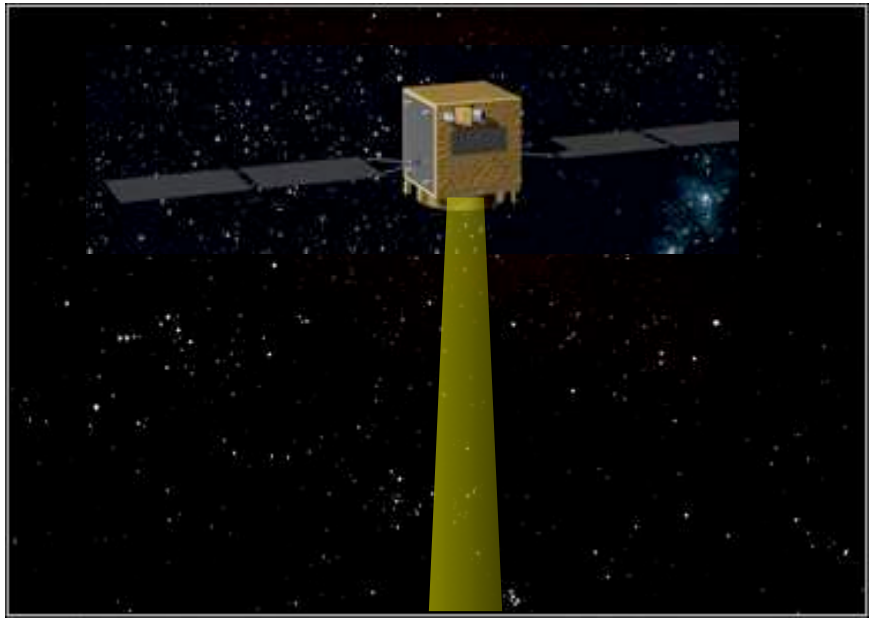
- 1.6 kW power
- 50 m range
- 3 ° sharp beam
- 0.5° pointing accuracy

Objectives

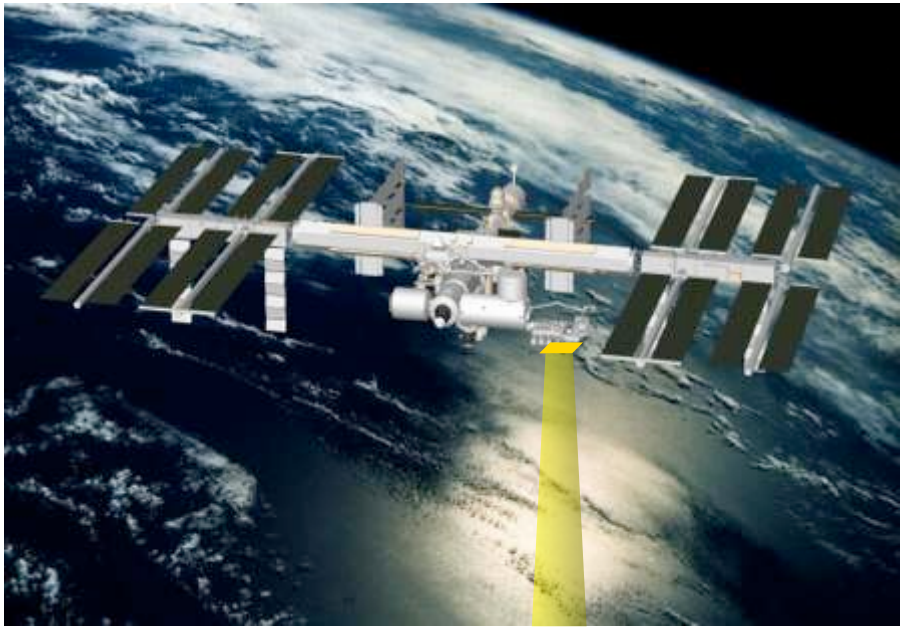
- to demonstrate technologies to control a microwave power beam and to prepare for the space experiment in the near future.



Wireless Power Transmission Experiment (kW level) from Space to Ground Proposed for Near Future Projects



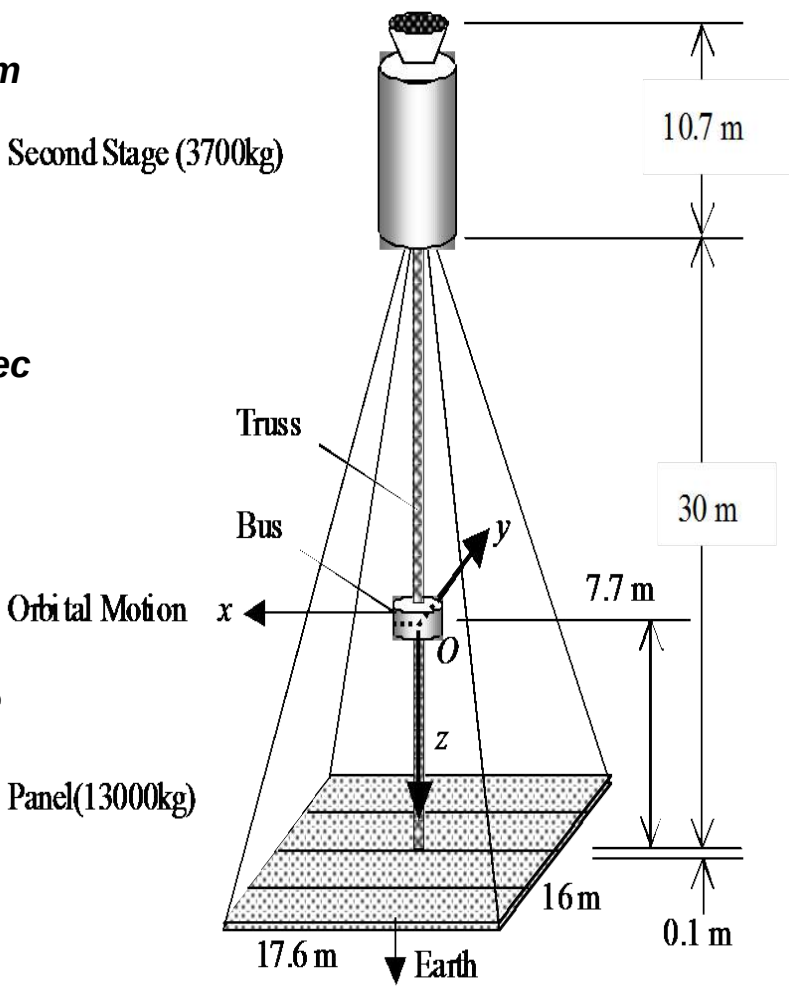
Microwave transmission experiment from a small satellite



Microwave or laser transmission experiment from Japanese Experiment Module Kibo on the International Space Station (ISS)

100 kW class Demonstration Experiment

Size	40.8m x 17.6m x 16.0m
Total Weight	18,100 kg
Power Generation	36 kW max
Power Transmission	420 kW～140 kW
Beam Control	retrodirective control
Microwave Frequency	5.8 GHz
Operation	full power for 16 sec 10% power for 4 min
Configuration	panel, truss, tether, weight mass
Panel Configuration	80 foldable panels 400 power modules 250,000 antennas
Attitude Control	gravity gradient force
Altitude	370 km
Rectenna type	parabola collector
Rectenna output	30 kW～10 kW (500 m diameter)



Development Roadmap towards Commercial SSPS

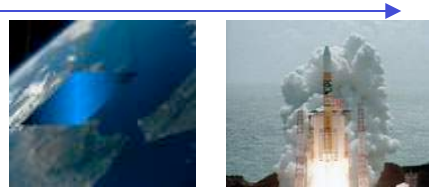
Research Phase

11 12 13 14 15 16 17 18 19 20

Ground demonstration

Small-scale on orbit demonstration

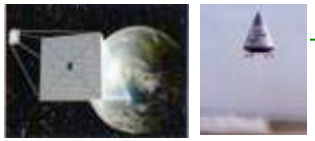
100kW class on orbit demonstration



Development Phase

21 22 23 24 25 26 27 28 29 30

2MW class demonstration

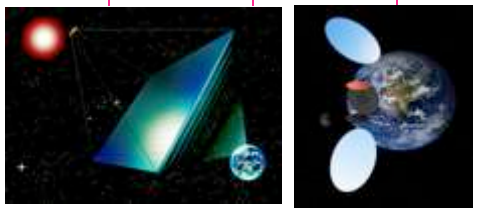


200MW class plant

Commercial Phase

31 32 33 34 35 36 37 38 39 40

1GW class first commercial model



Commercial SSPS（1SSPS/year）

Summary and Conclusion

- *There is the sun's unlimited energy supply in space free from the weather conditions and day/night cycles.*
- *Space Solar Power Systems (SSPS) is to tap the solar energy in space and to transmit it to the ground using wireless power transmission.*
- *This energy system, essentially clean and safe, could resolve global environmental and energy problems.*
- *Although the required technologies are quite challenging, continuing research activities will lead to opening the new SSPS era in 2030's.*