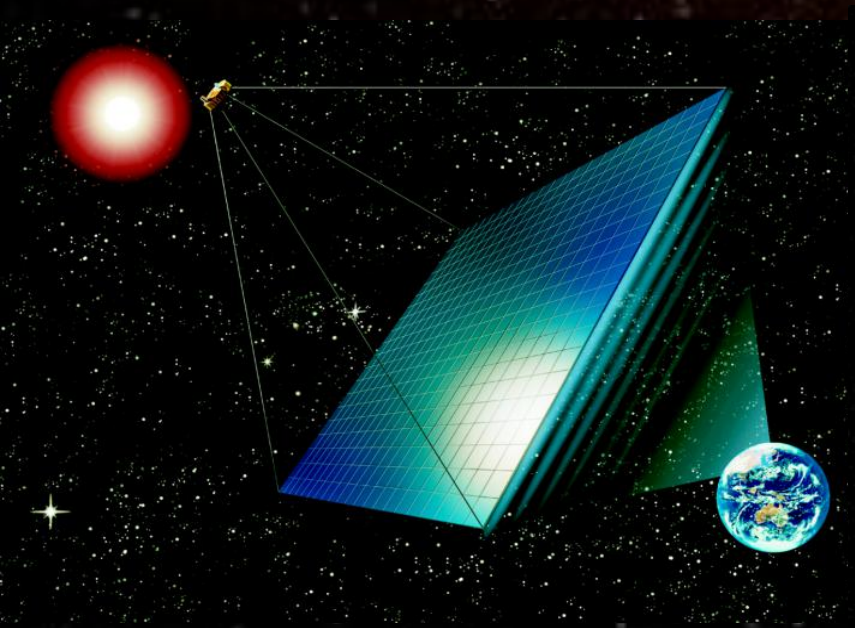
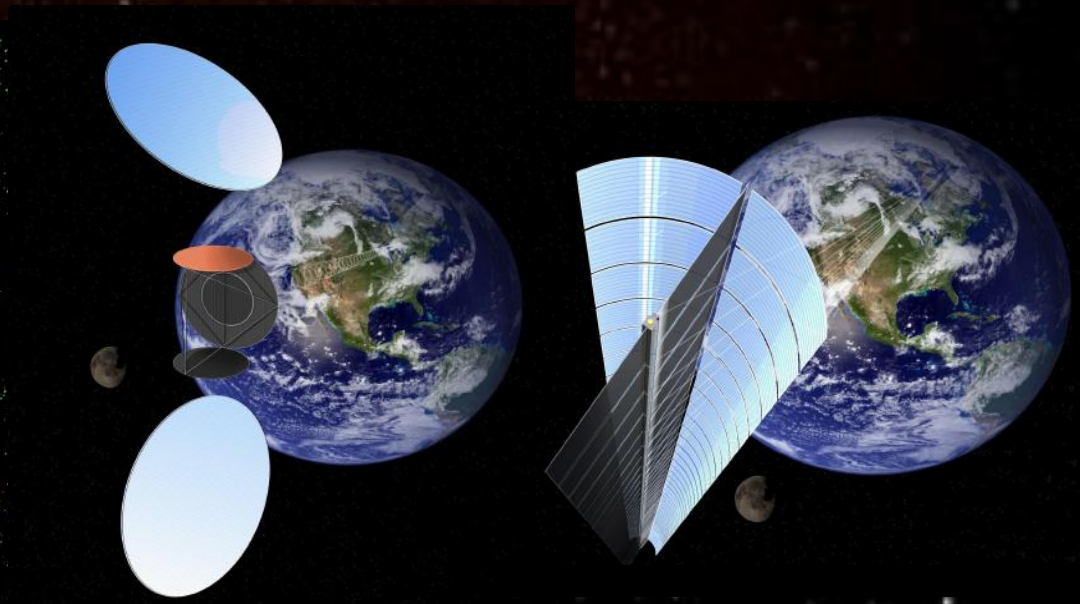
Updated Technology Road Map for Solar Energy from Space

- Milestones for SSPS Development
- SSPS Technology Road Map
  - Research Phase
  - Development Phase
  - Development Steps
- SSPS Requirements for Space Transportation

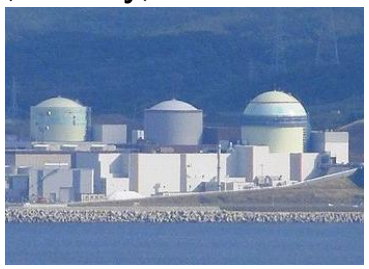




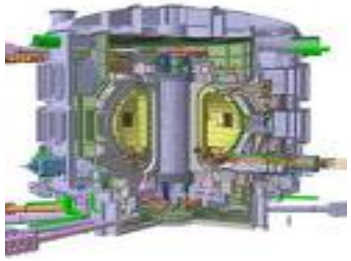
September 2011

SSPS Development Milestones as Compared with Nuclear Fission and Fusion

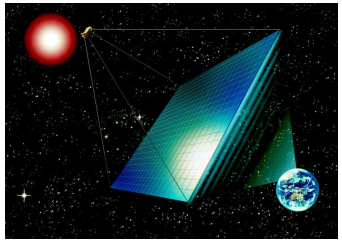
Nuclear Fission Plant (History)



Nuclear Fusion Plant (Plan)



Space Solar Power Systems (Plan)



Experimental Verification of Principle

+10 years | +20 years | +30 years

1942 — Critical Nuclear Chain-reaction Success

1951 — First Electricity from Nuclear Reactor (200kW)

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

2025 — Fusion Verification (Q>10)

2035 — Proto Model Reactor

2045-50 — Commercial Phase

2015 — On-orbit Verification

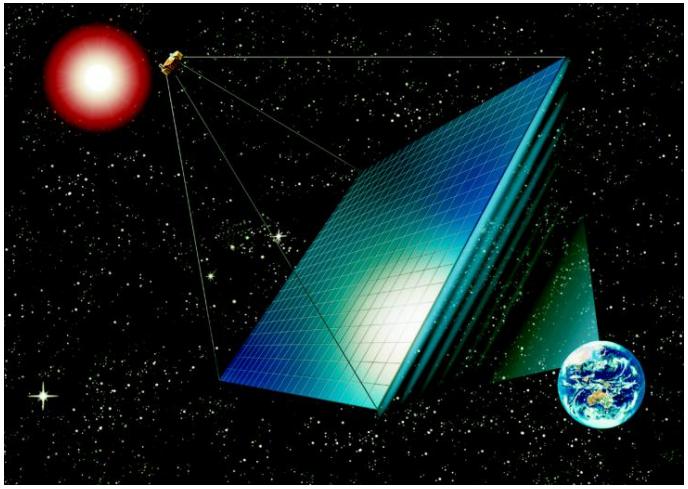
2020 — Initial End-End Verification (100kW)

2025 — Plant (2MW)

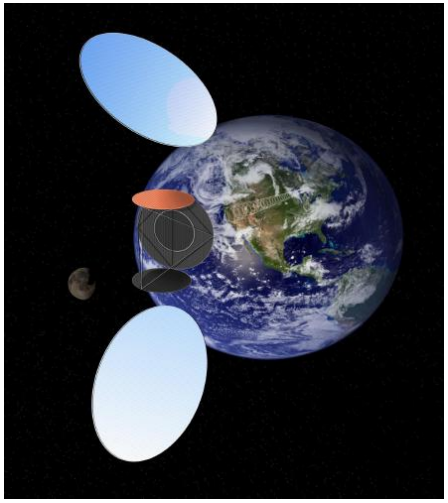
2030 — Plant (200MW)

2035 — Commercial SSPS (1GW)

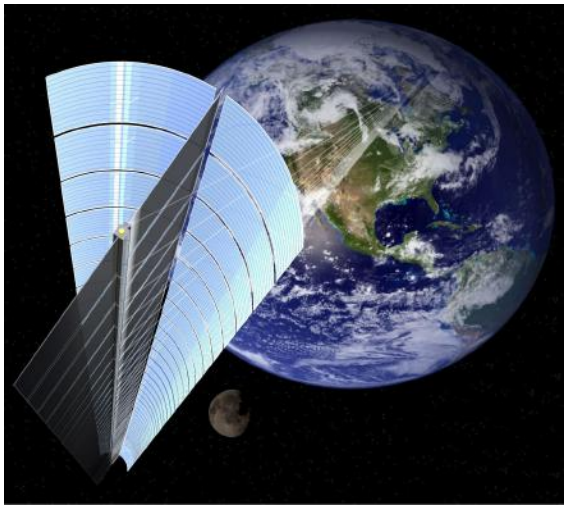
Commercial SSPS Concepts Currently Studied in Japan



Basic Microwave-type Model (USEF/METI)



Advanced Microwave-type Model (JAXA/MEXT)



Laser Model (JAXA/MEXT)

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

Roadmap

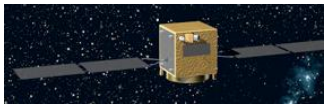
Research Phase

09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19

Ground demonstration

Small-scale on orbit demonstration

WPT Selection (microwave or laser)



100kW class on orbit demonstration

Configuration selection

Development Phase

20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29

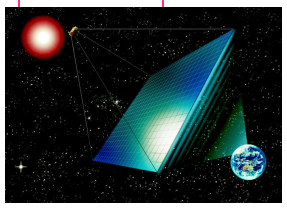
2MW class demonstration

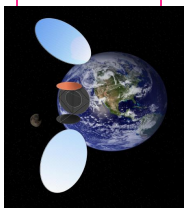
200MW class plant

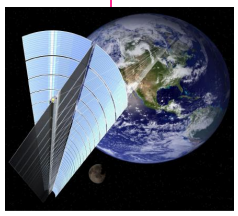
Commercial Phase

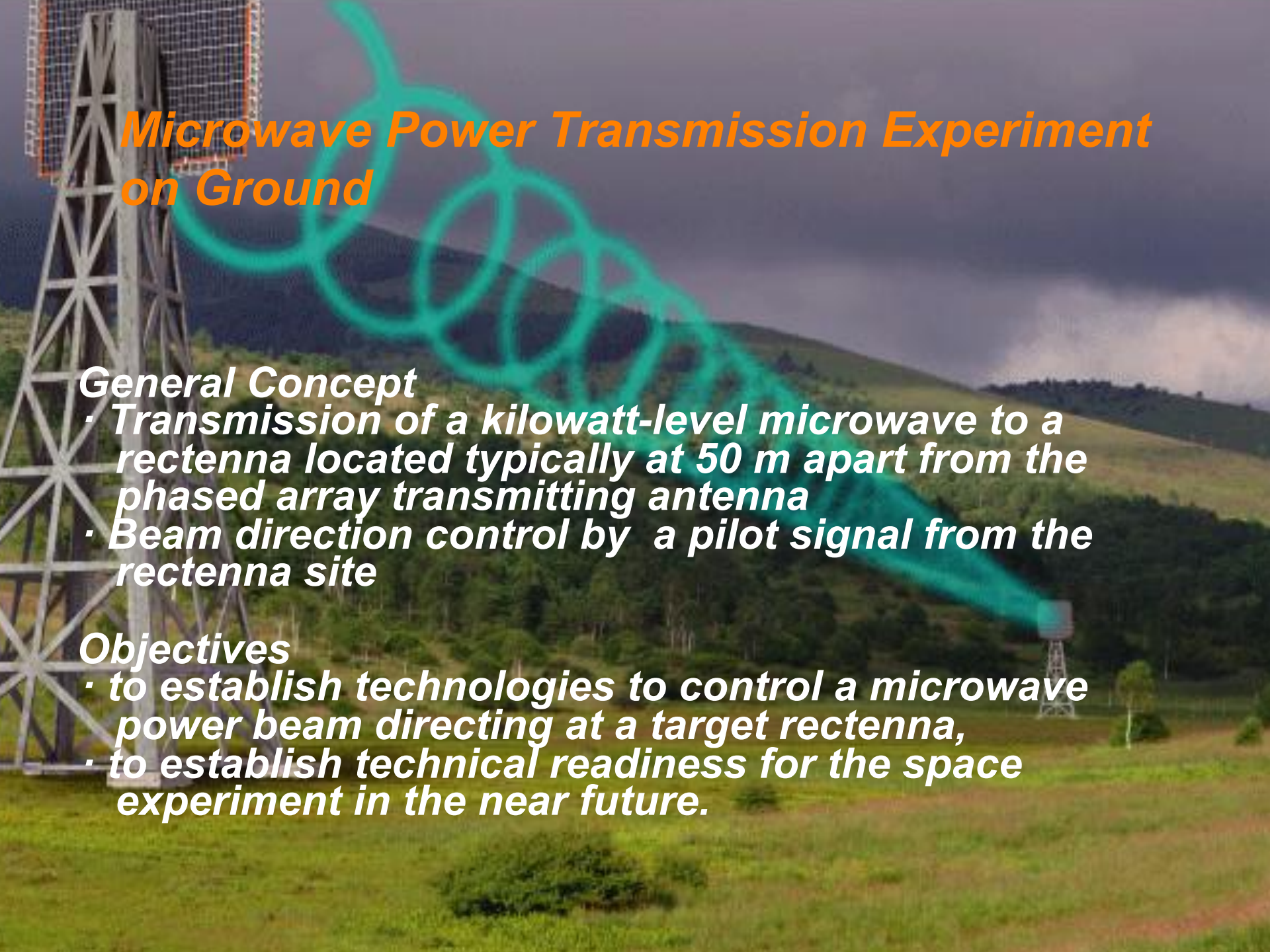
30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39

1GW class first commercial model







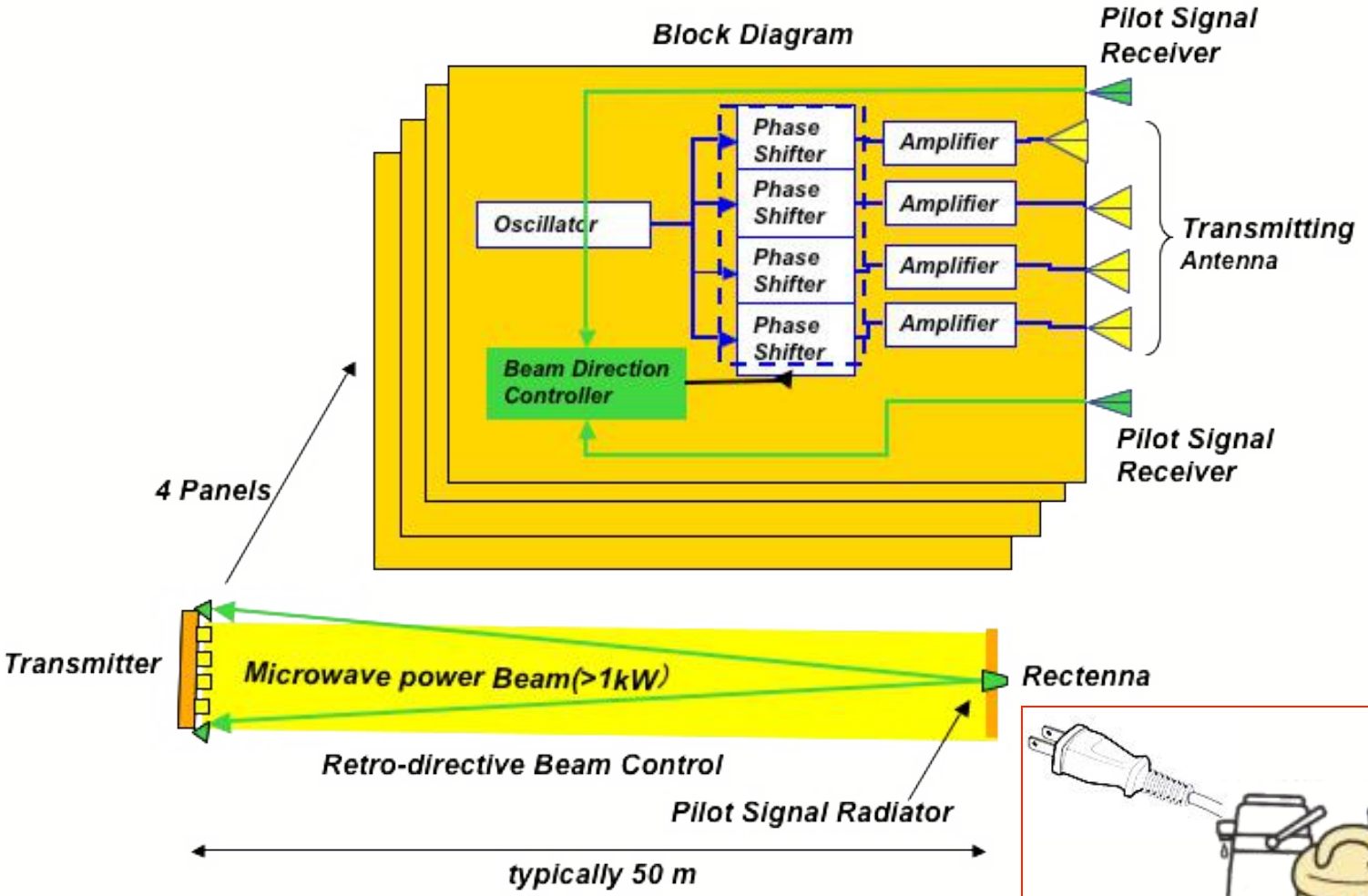


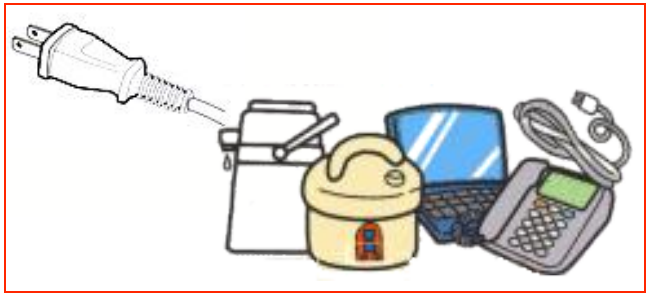
Microwave Power Transmission Experiment on Ground

General Concept
- Transmission of a kilowatt-level microwave to a rectenna located typically at 50 m apart from the phased array transmitting antenna
- Beam direction control by a pilot signal from the rectenna site

Objectives
- to establish technologies to control a microwave power beam directing at a target rectenna,
- to establish technical readiness for the space experiment in the near future.

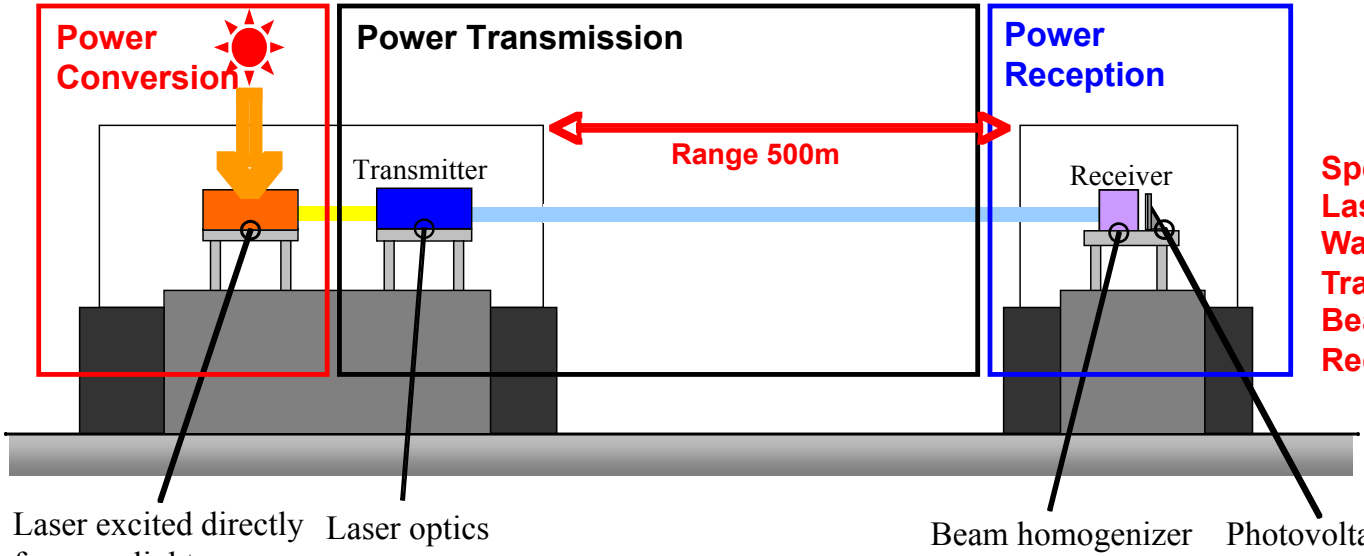
Microwave Power Transmission Demonstration





Rectenna output power will be used to operate household electric appliances for public demonstration.

Laser Power Transmission Experiment on Ground



Specification
Laser output 1kW
Wave length 1.06μm
Transmission 500m
Beam control several μrad
Receiver output 0.2kW

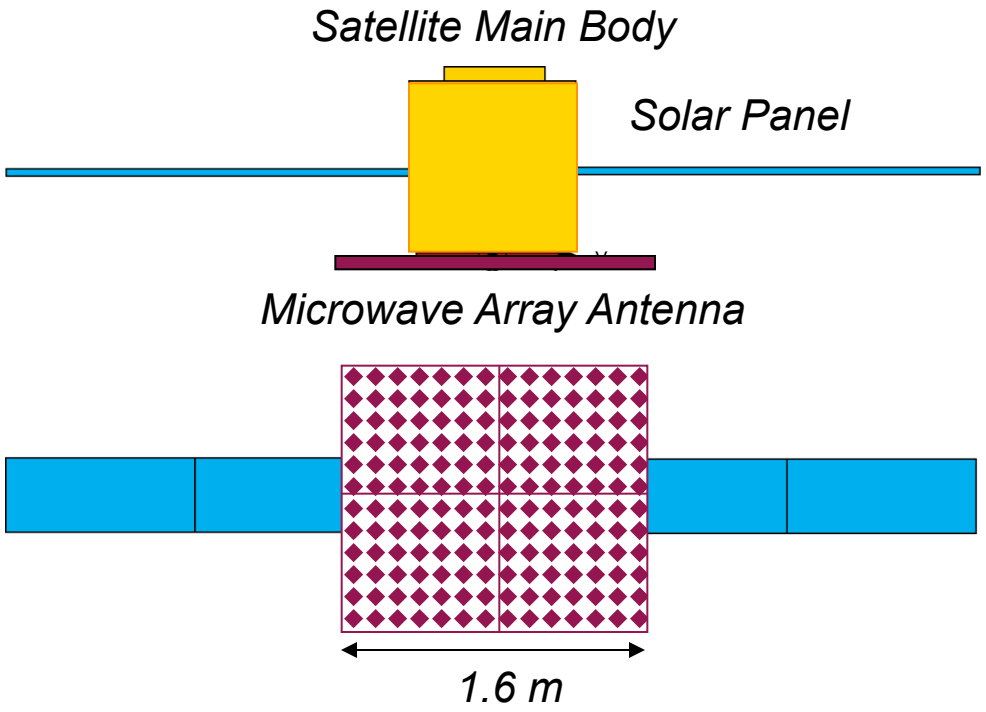
Laser Power Transmission experiment(200W class) at Kakuta/JAXA

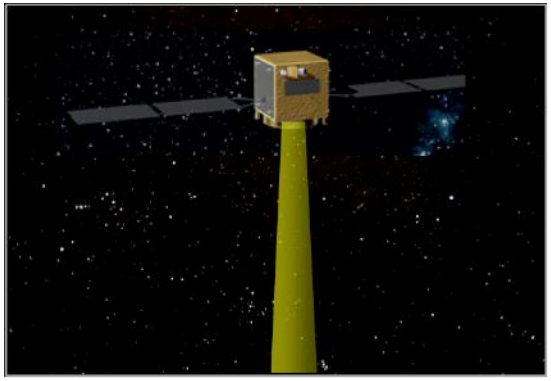
Laser power generation experiment(100W class)

Experiment on Small Satellite

Orbit: Low Earth Orbit (370 km)
Satellite Weight: 500 kg
Mission Weight: 200 kg
Attitude Control: 3-axis Stabilization
Transmission Power: 3.8 kW

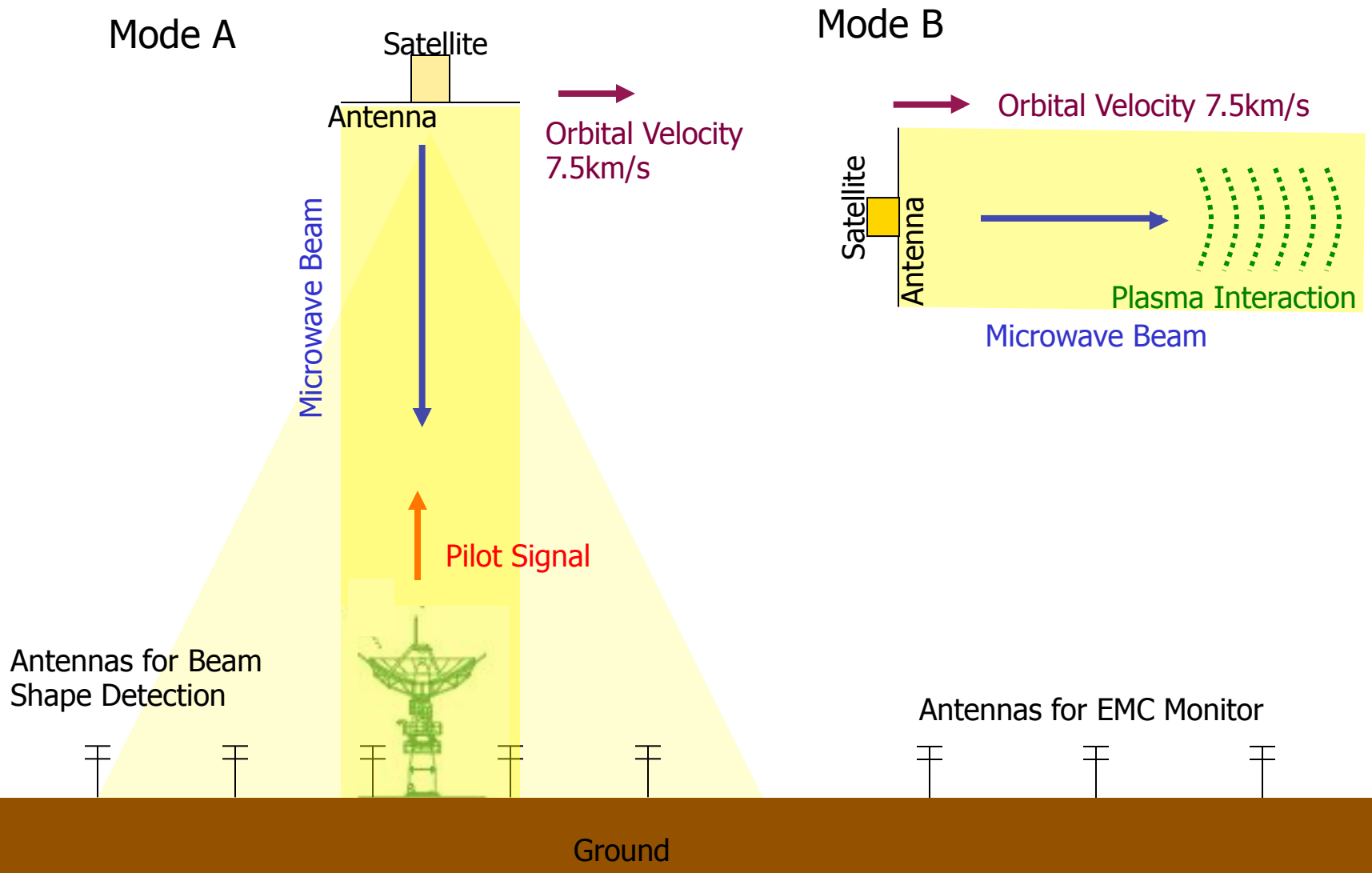
Epsilon Launch Vehicle for small satellite. Next-generation solid propellant rocket after the former M-V launch vehicle.





Microwave power transmission from small satellite.

Experiment Configuration



Laser Power Transmission Experiment from JEM (an example)

International Space Station JEM

Transmitter
1 kW, 1.06 μm
20 cmΦ Optics

Laser Beam

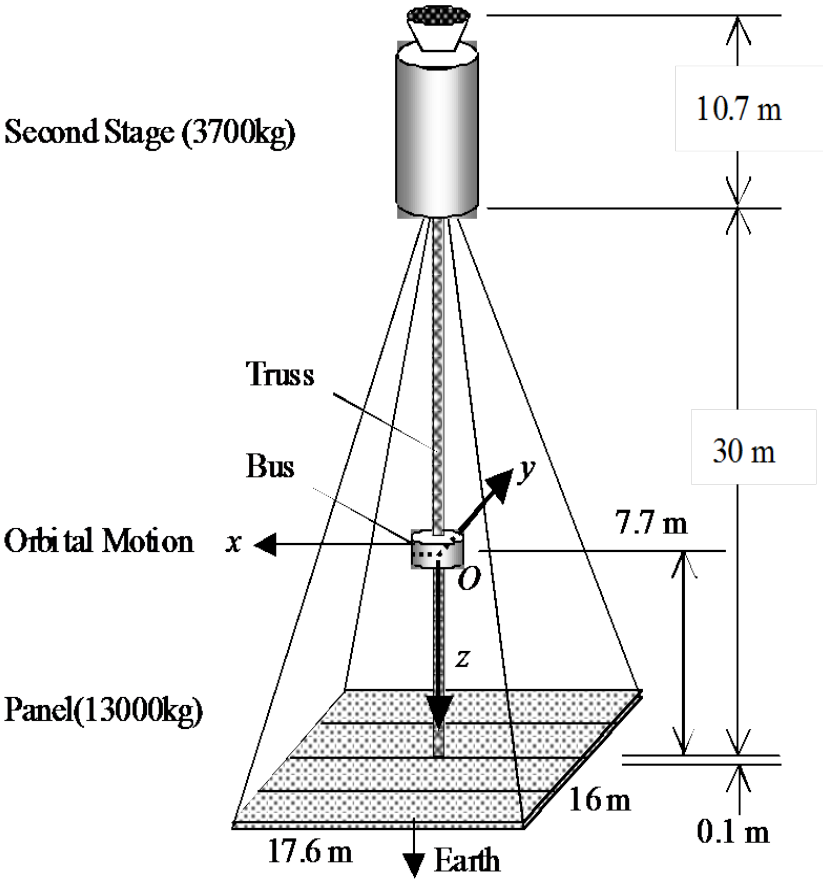
Divergence 15 μrad
Pointing 1 μrad

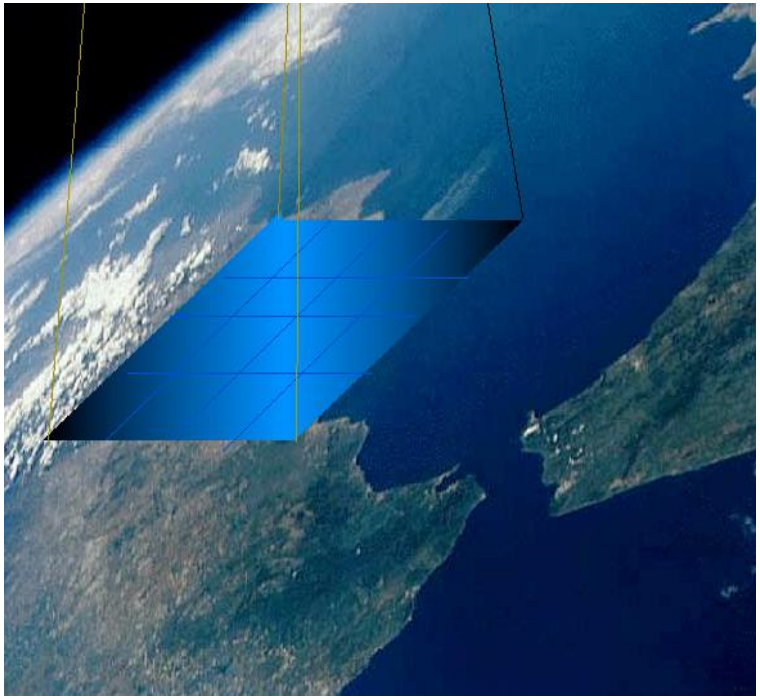
Pilot Beam

Receiver
10 mΦ Area
200 W Output

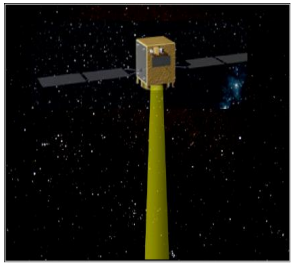
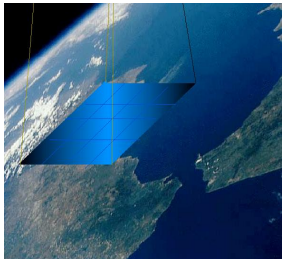
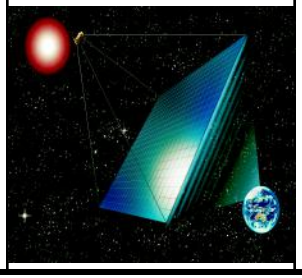
Photovoltaic Cell Array

Configuration of Experiment System





Development Steps towards Commercial SSPS

Steps	Ground Demonstration	Small-scale Flight Demonstration	Large-scale Flight Demonstration	Small Plant	Large Plant
Transmission	Ground	LEO to Ground	LEO to Ground	1000 km to Ground	GSO to Ground
Range	50-500 m	400 km	400 km	1000 km	36000 km
Power Level	kW level	kW level	100 kW level	2 MW level	200 MW level
Structure Scale	several m	several m	20 m	100 m	500 m
Ionosphere/ Atmosphere Transmission	—	1kW/m^2	1kW/m^2	1kW/m^2	1kW/m^2
Power at Receiver	several hundreds Watt	—	10kW	1.8MW	160MW
System(in case of Basic Model)					

SSPS 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	50 tons	5000 tons	20000 tons	20000 tons
Construction	NA	NA	1 year	3 years	5 years	1 year
Payload weight	500 kg	15 tons	10 tons	50 tons	50 tons	50 tons
Launch vehicle	1 ELV LEO	1 ELV LEO	1 RLV 1000km 5 Round trips 1 launch/2.4 months	4 RLV 500 km 160 round trips 1 launch/week 4 weeks turn around	8 RLV 500 km 640 round trips 1 launch/3 days 3 weeks turn around	28 RLV 500 km 640 round trips 2 launch per day 2 weeks turn around
Orbit transfer vehicle	NA	NA	NA	17 OTV 500 km-GEO 6 round trips*	40 OTV 500 km-GEO 10 round trips*	200 OTV 500 km-GEO 2 round trips*

Epsilon Launch Vehicle

H-II Launch Vehicle

Reusable Sounding Rocket

OTV(Image)

*:fuel 30 tons for a round trip

Summary and Conclusion

- *An updated technology road map towards commercial SSPS that accommodates the requirements from the Japanese space policy has been introduced.*

- *The projects for the wireless power transmission experiments on the ground have been already started, and then we will have small scale flight demonstration experiment around 2015.*

- *After completion of the small scale demonstration, we will make a 100 kW-class experiment and then the plant level demonstration up to 200 MW before 2030.*

- *This approach will contribute in timely manner to resolving the global problem, combined with CO_2 issue and shortage of natural energy resources.*