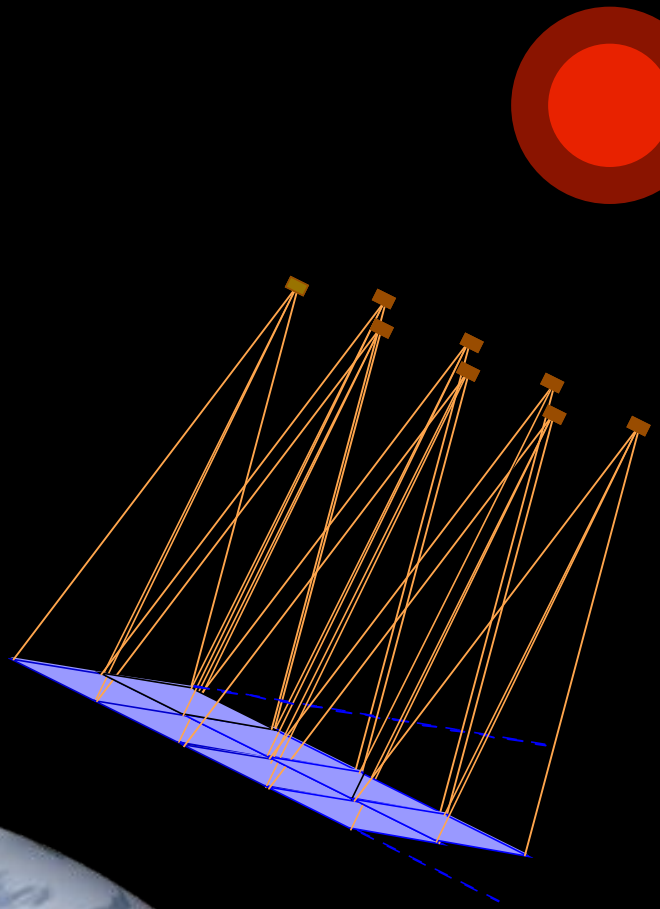
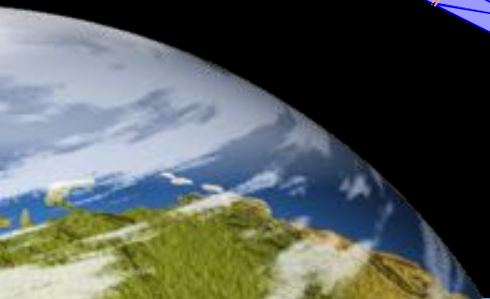
Important Issues to be Considered in the SSPS Road Map

- In the Case of Tether SSPS -





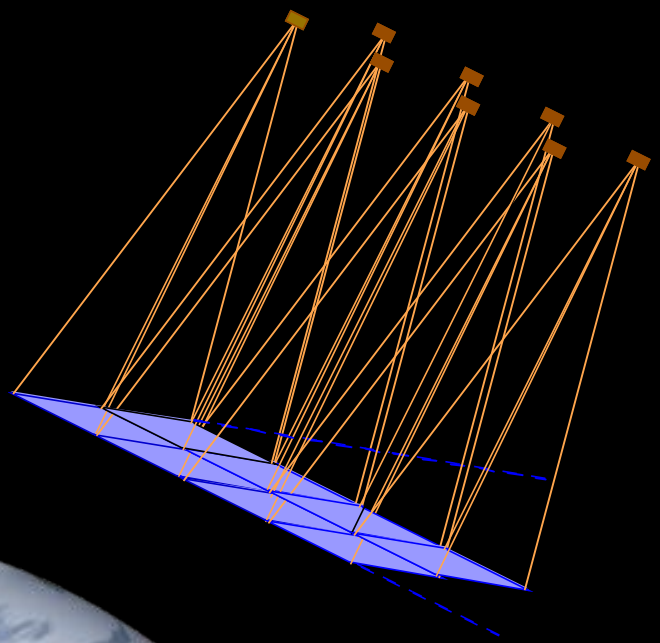
Original Version: December 2016
English Version: June 2017

Road map is required to facilitate the research and development of SSPS, as a proposal from the SSPS community to the public.

Basic Requirements

1. *A clear and specific goal*
2. *A common target in the SSPS community*
3. *High technical feasibilities*
4. *Goal within 30 years*
5. *Go/no go decision at the major milestones based on objective evaluation*

1. A clear and specific goal



Target needs to be illustrated so that the non-expert people can easily understand the concept and principle of operation. Variety of illustrated ideas can not be the target.

Examples of SSPS System Design

- Typical model needs to be selected as a target for the SSPS road map -

Solar Power Satellite

Microwave

Laser

Non-concentrator

Concentrator

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

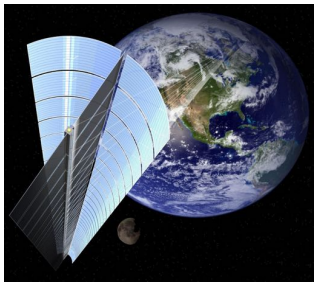
NASA Reference Model

USEF Tether SSPS

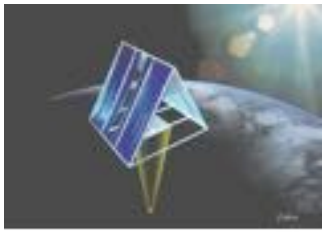
Target selected in this paper

NASA Sun Tower

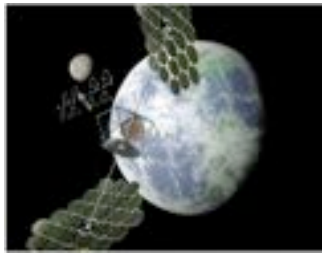
NASDA 2001



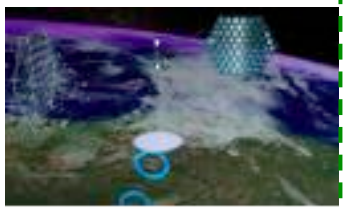
JAXA L-SSPS



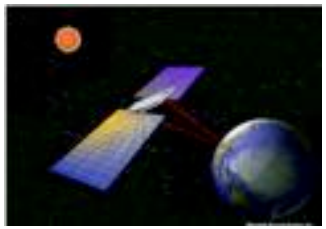
SPS2000



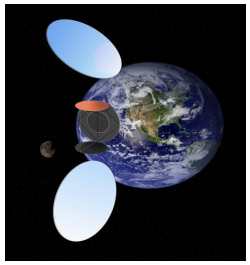
NASA ISC



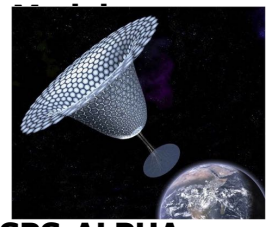
IAA Study



NEDO Grand Design



JAXA M-SSPS

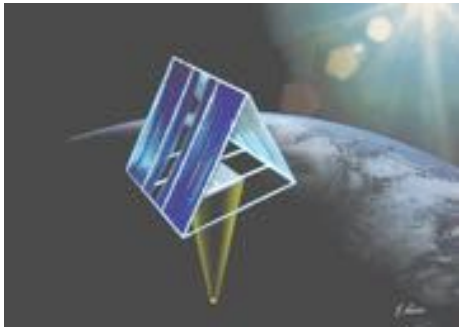


SPS-ALPHA

What is the Tether SSPS?

- Background and history -

SPS 2000, designed around 1990 by the SPS 2000 Task Team led by M.Nagatomo



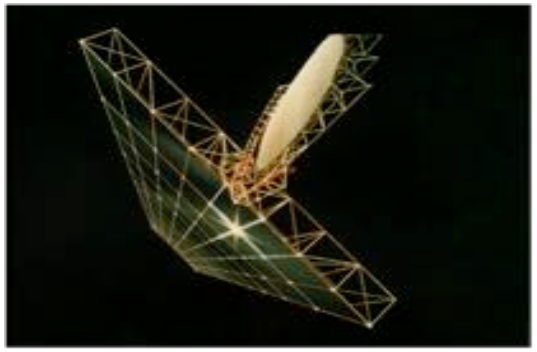
High priority on technical feasibility.

antithesis

Small scale
Simple (no attitude control, no movable mechanism)
Low earth orbit

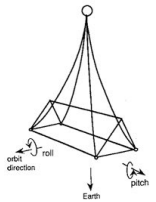
Large scale
Complex (Attitude control & movable mechanism)
Geo-synchronous orbit

NASA Reference System in the 1970's

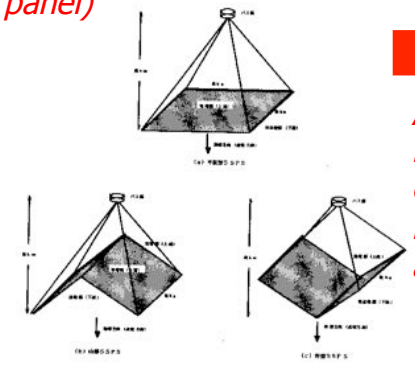


Highly challenging, lack of technical feasibility

Absorption of the idea "power generation/ transmission panel (sandwich panel)"



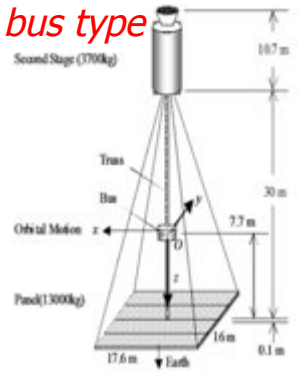
SPS2000 (Option)



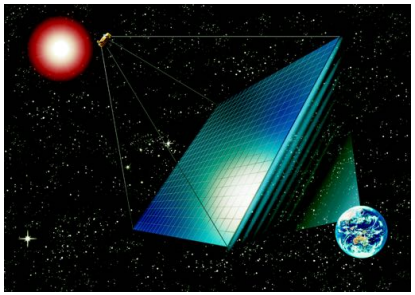
Designed early in 2001 for commercial use

Absorption of the idea "combination of solar cells and microwave antennas"

Single bus type



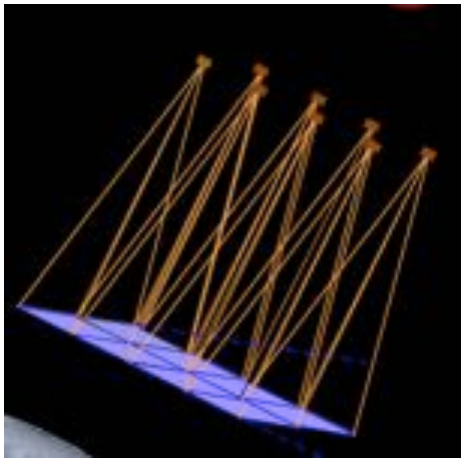
Designed in 2002 for demonstration



Designed in 2001 and 2003 for commercial use

Highly modular structure and high flexibility

Multi-bas type

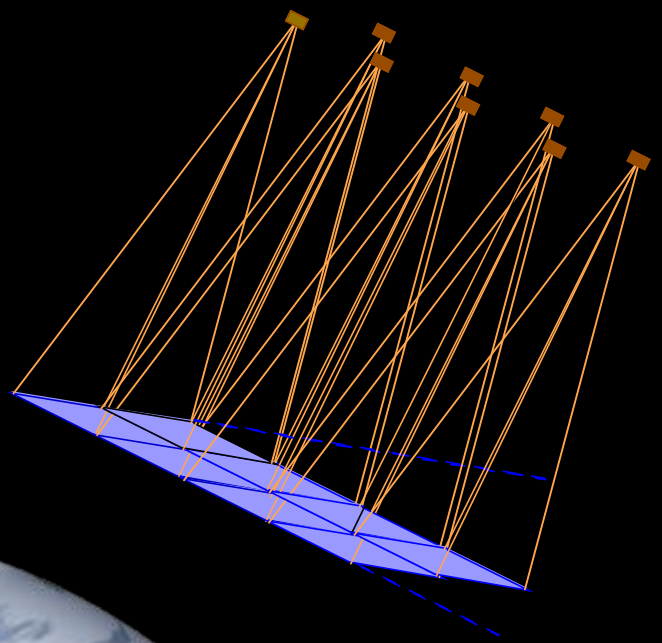


Designed in 2006 and 2007

USEF SSPS Study Sub-committee (S.Sasaki)

USEF SSPS Study Team (Prof.Y.Kaya)

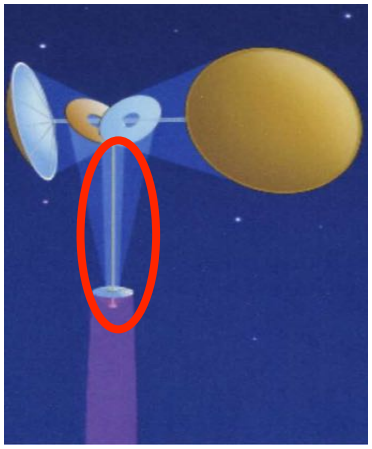
2. A single and common target in the SSPS community should be selected.



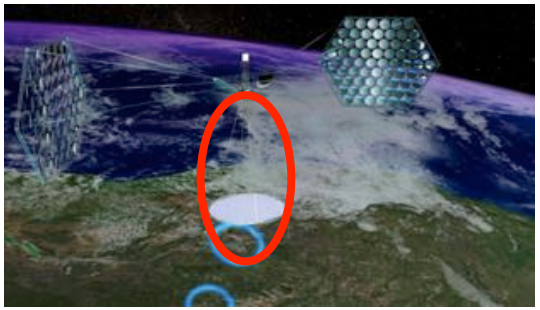
Since SSPS is a long-future concept, many targets can exist at this stage, depending on design philosophies. Also, uncertainties are extensively included in the targets. A target having essential elements in common should be selected.

Tether SSPS: common/basic part of Sandwich type SSPS

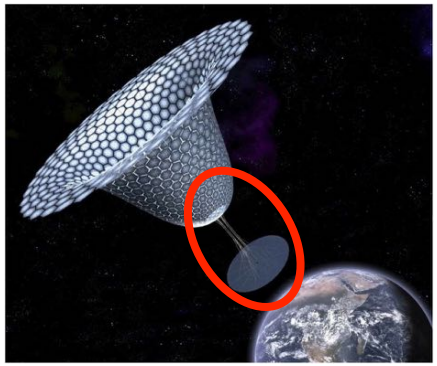
NEDO Option
(Kaya Model)



NASDA 2001Reference Model



IAA Study Model



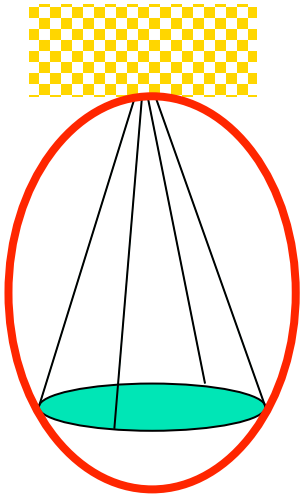
SPS-ALPHA

Sandwich type SSPS

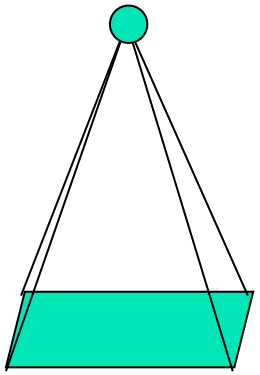
Sun tracking mechanism (mirrors)

Attitude stabilization by gravity gradient force using tethers

Sandwich panel (power generation and transmission panel)

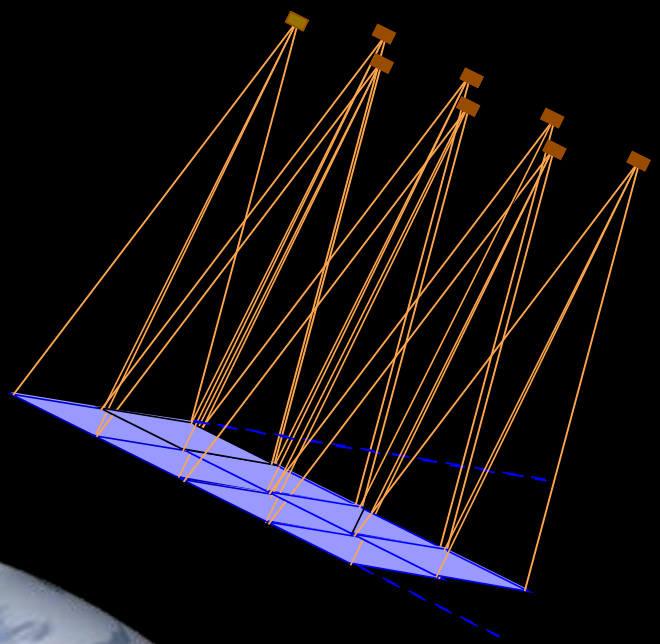


Basic Part



Tether SSPS
(Basic Model)

3. High technical feasibilities



A high level of technical feasibility needs to be shown for the target and its way in the roadmap. Otherwise, the road map is regarded as a science fiction.

Feasibility Analysis Required for SSPS Model

SSPS feasibility needs to be demonstrated so that majority of experts in the fields of energy and space development recognizes its possibility as the future energy system.

Weight

Realistic weight as a space infra-structure?

Structure

Technological feasibility as a space facility?

Social acceptability

Acceptable from the standpoints of biological effects, environmental effects, and impact to the existing infra-structure?

Power system

Useful and practical power system (power characteristics, reliability, cost)?

Thermal feasibility

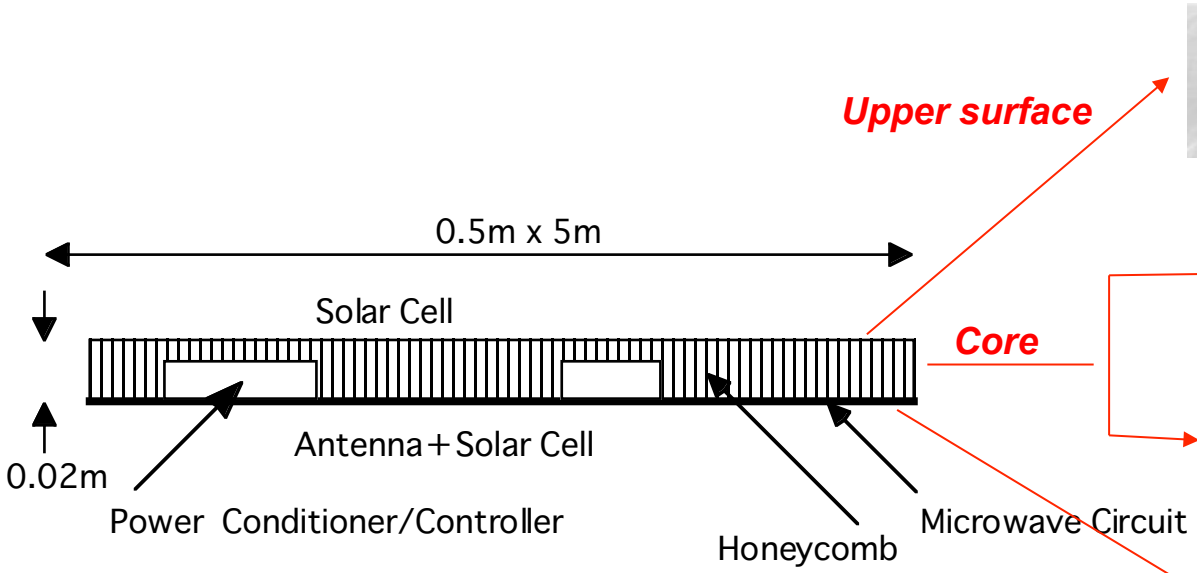
Feasible thermal design for high power radiation system?

Construction

Realistic construction scenario using plausible space transportation system in the future?

Realistic weight as a space infrastructure?

– Weight should be estimated based on detailed design and physical models –

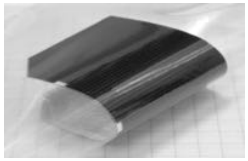


Structural Module: 0.5 m x 5 m (10 sub-modules)

Upper surface

Core

Lower surface



Flexible solar cell
0.16g/W, 15g/(0.5mx0.5m)

Aluminum Honeycomb
0.026g/cc

Alumimum foam
0.018–0.027g/cc

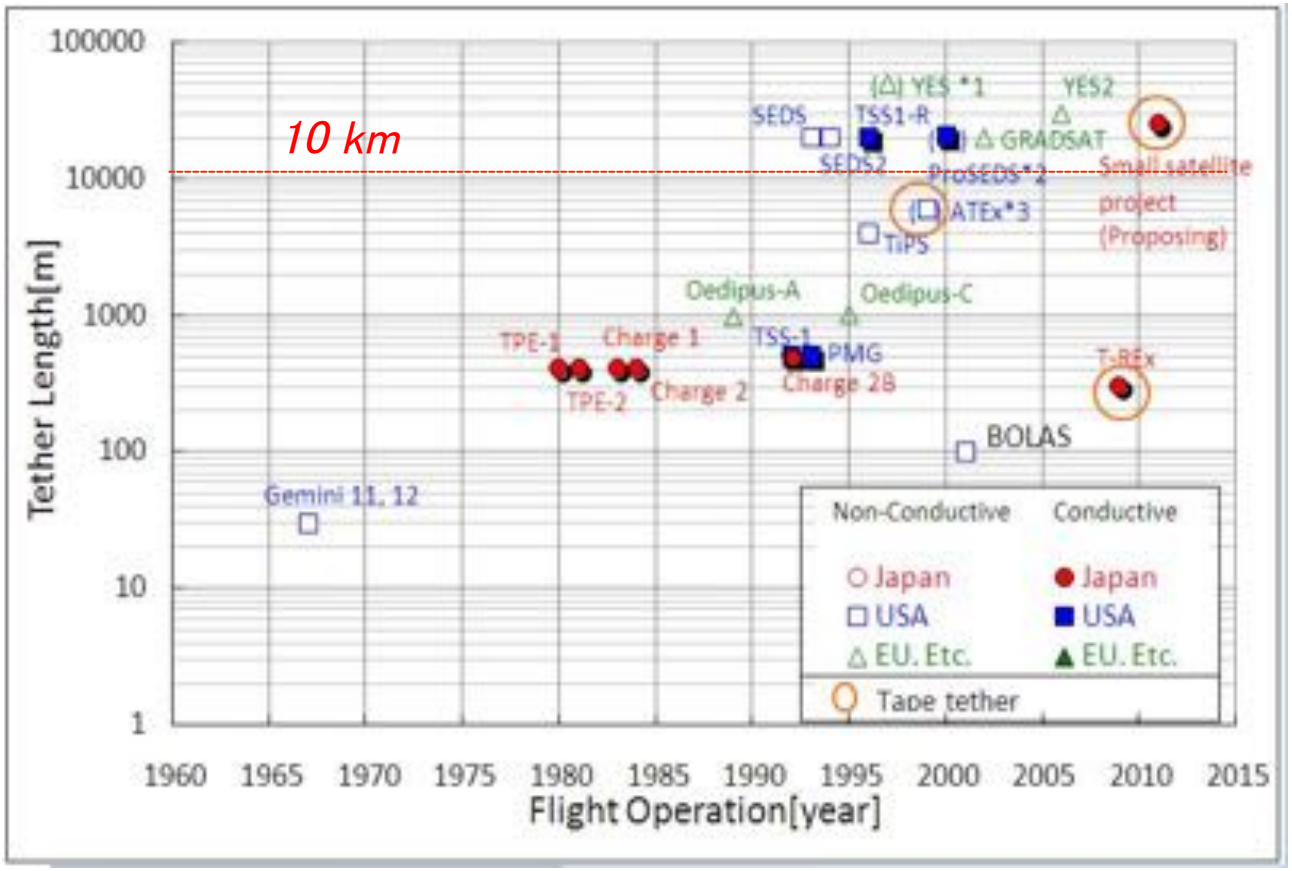
Printed circuit board and solar cells with printed antenna 2g/cc

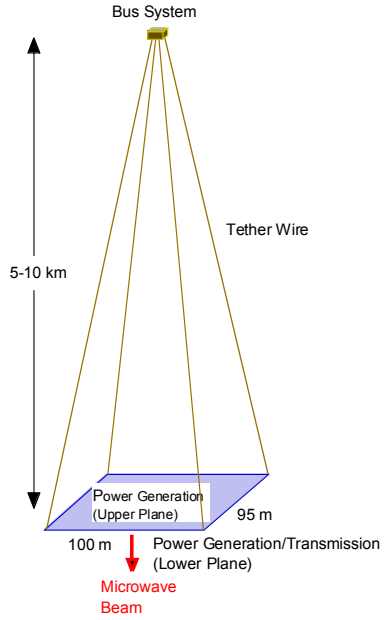
Sub-module : 0.5m x 0.5m x 0.02 m, Weight : 1.060 kg

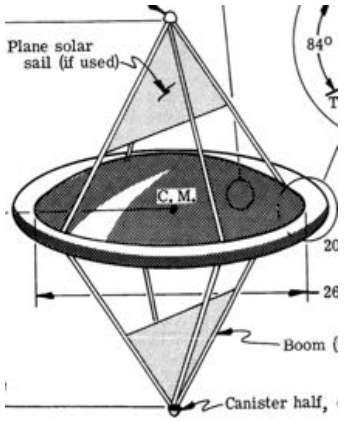
Microwave Circuit (Controller、Power supply、Antenna、55.5 W) :	*277.5 g (5 g/W)*
Solar Cell (including cables、118.1 W) :	*120 g(1.016 g/W)*
Batteries (362.5 Wh) :	*517.9 g (700Wh/kg)*
Structure (Honeycomb、Mechanism, Others)	*144.6 g (0.029 g/cc)*

Technological feasibility as a space facility?

- Feasibility should be demonstrated by design and past achievements -





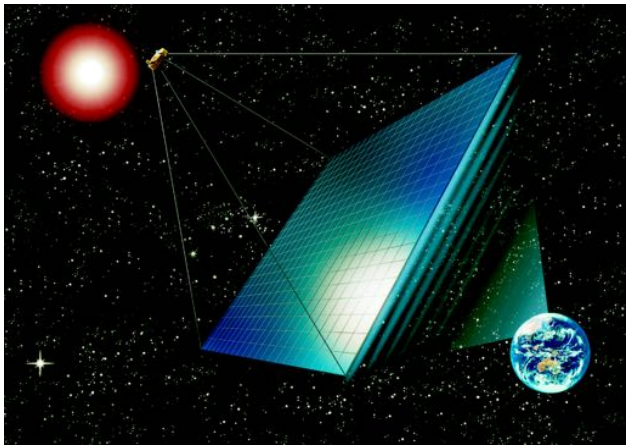


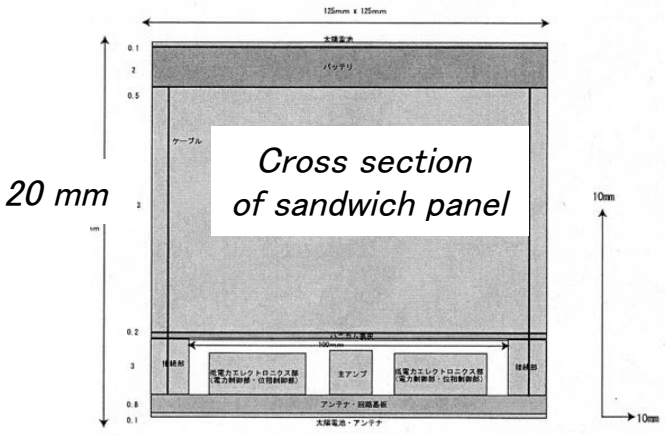
Space Tether Experiments, Takeo Watanabe et al., ISTS 2009. Chart includes planned experiments. Tethers more than 5 km have been demonstrated several times.

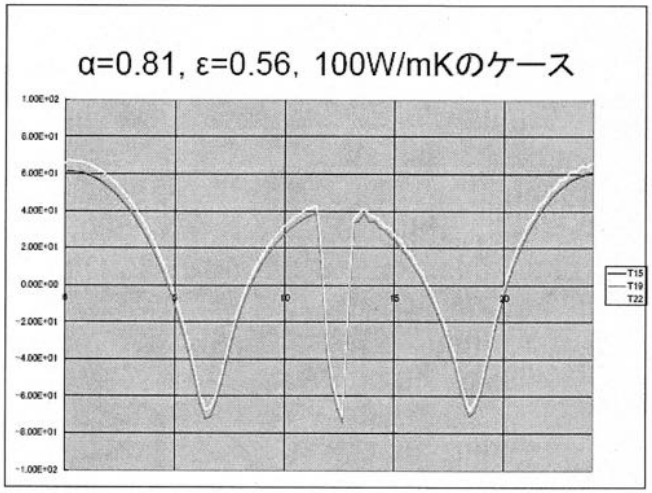
Lenticular Communication Satellite (NASA,1965)

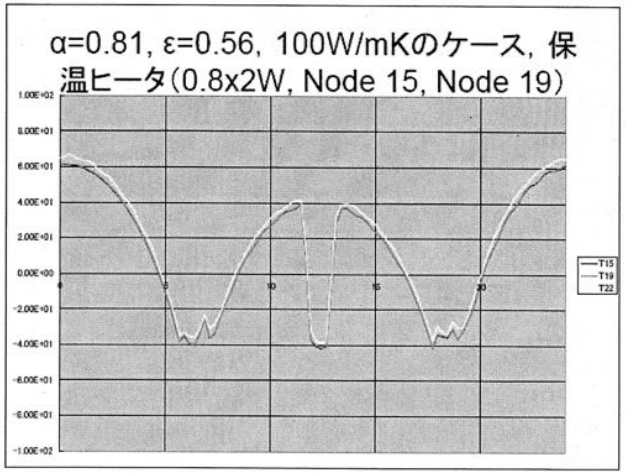
Feasible thermal design for high power radiation system?

- Thermal analysis based on SSPS design -
（predictable within 10 % ）









Temperature of circuits can be kept from −40 ℃ to +60 ℃

Realistic Construction Scenario?

- A practical and feasible scenario for space transportation and assembly in space needs to be shown.-

RLV

Transportation from
Ground to LEO

Cargo
Transfer

OTV

Transportation from
LEO to GEO

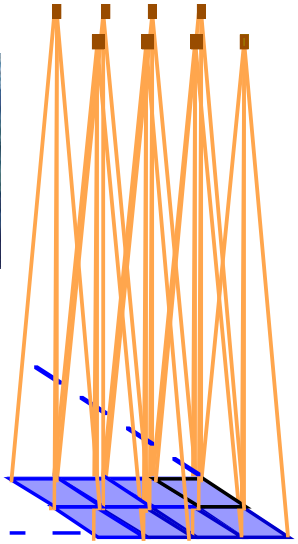
Unloading

100m

95m

5～10km

Automatic
Deployment

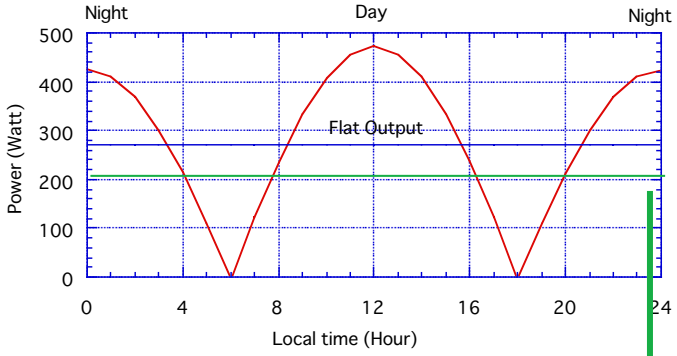


Integration by
Robots

Useful and practical power system?

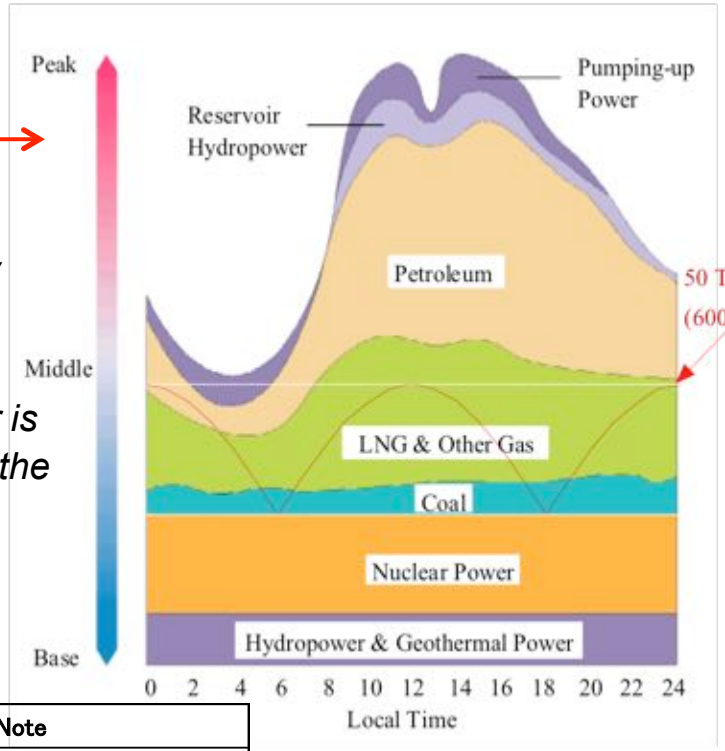
– Conformity with power demand needs to be ensured–

Power generation varies with local time



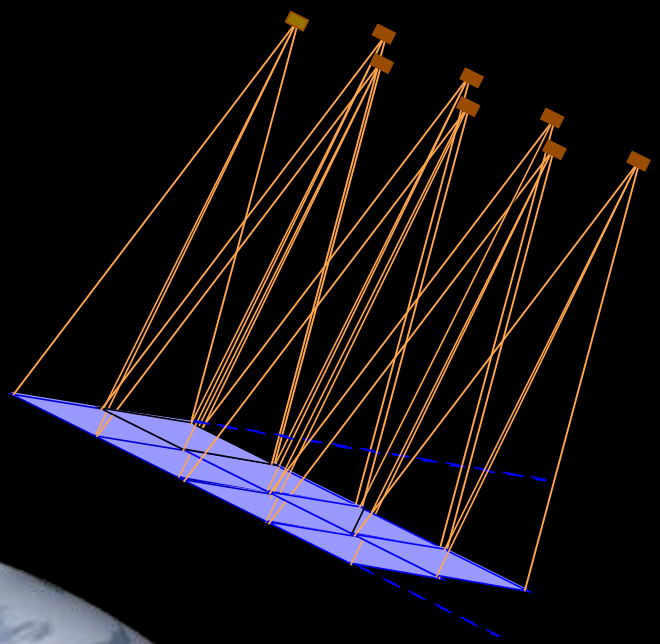
Advanced type of Tether SSPS has batteries to level off the output power. Since the variation is periodic and predictable, required storage capacity is much less than the ground solar power plant.

The time-varying power supply can conform with daily variation of power demand so long as the SPS power is less than 10 % of the total demand.



	Module Power	Total Power	Note
Solar Power	1,350 W(max)	8.0 GW	Module size1m², x0.92 in summer and winter(0.97 on average)
Power Generation (Peak)	473 W(Upper) 425 W(Lower)	2,8 GW(Upper) 2,5 GW(Lower)	Solar cell area of lower plane is 90 % of the upper plane. Solar cell efficiency 35 %
Power Storage in Batteries	1000 Wh	5.9 GWh	Flat power output 60 % Charge/ discharge efficiency 90 % Charging only when more than 25 %of peak power
Power to Transmitters	270 W	1,6 GW	
Power Transmission	228 W	1,4 GW	DC/RF conversion efficiency 85 %
Rectenna Input	–	1,2 GW	Transmission 97 %、Collection 90 %
Rectenna Output	–	1 GW	RF/DC conversion 85 %

4. Goal must be within 30 years



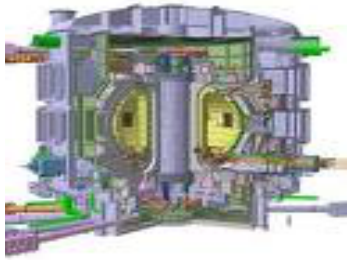
Target more than 30 years from now has no reality. It is regarded as a dream. Dream is not invested in. The budget for dream is limited to academic research.

A Scenario for SSPS Realization in 30 Years

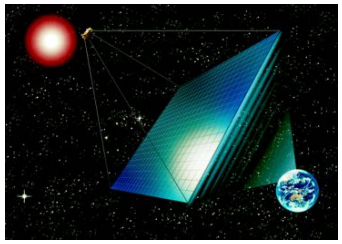
- Comparison with Nuclear Fission and Fusion -

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

Way to go for SSPS realization

2020 — On-orbit Verification

2025 — Initial End-End Verification (100kW)

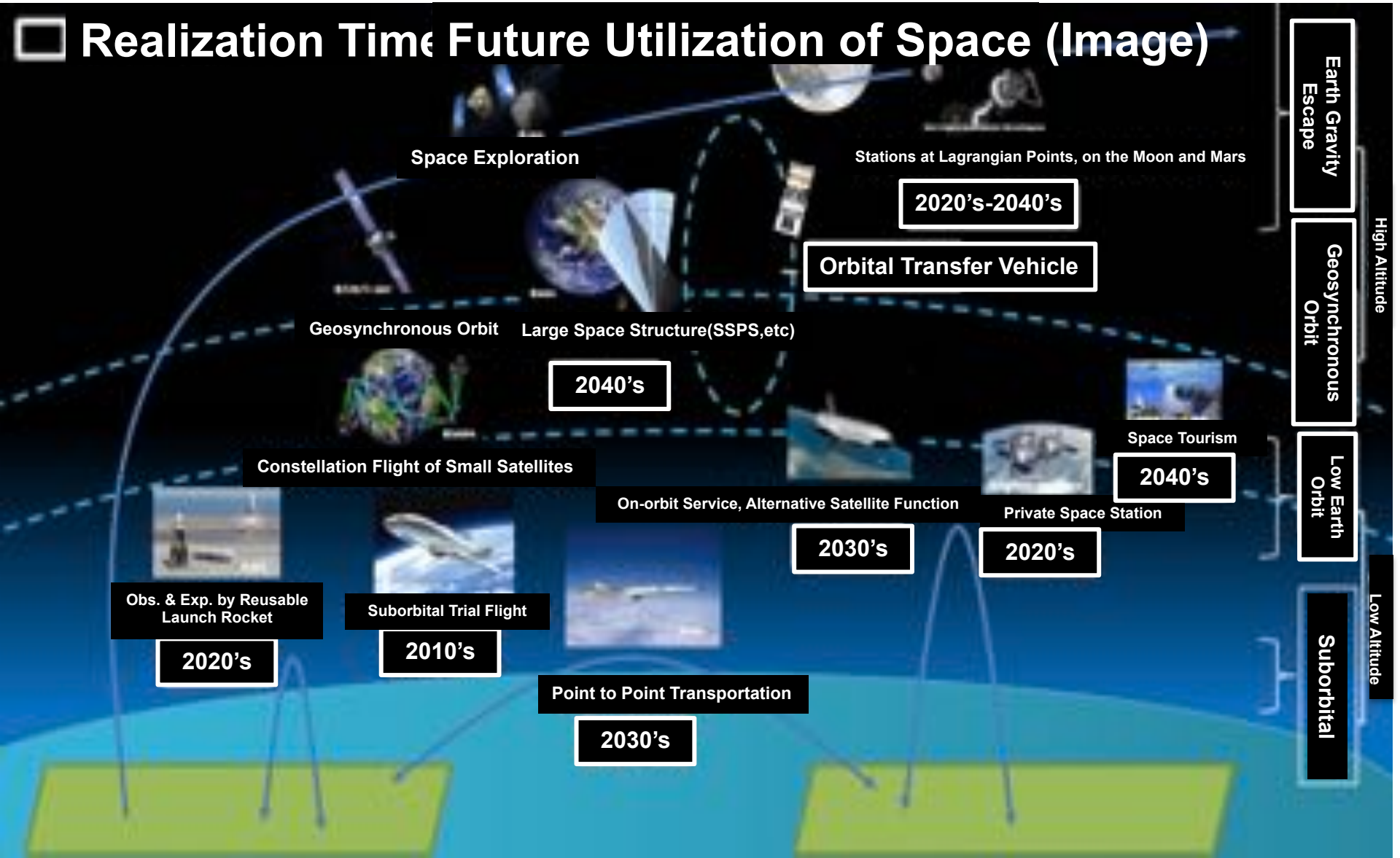
2030 — Plant (2MW)

2035 — Plant (200MW)

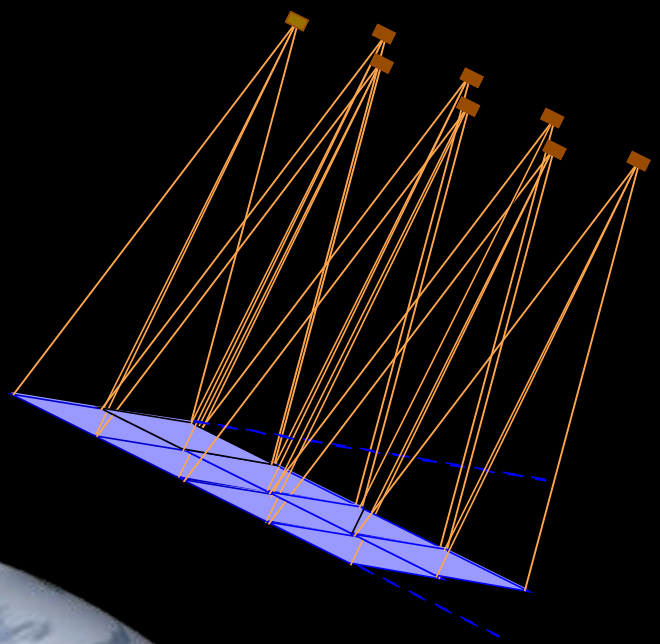
2040 — Commercial SSPS (1GW)

Future of Space Transportation Expected for SSPS

Long-term Vision for Space Transportation System (Draft), Office of Japan National Space Policy, predicts operation in 2040's for SSPS construction.



5. Go/no go decision should be made at the major milestones based on objective evaluation.



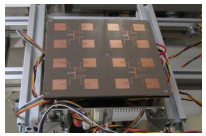
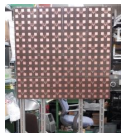
Objective evaluation at each development phase assures the project is promoted for general public, not for SSPS community.

Research Phase

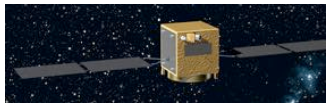
▲ GO/NO GO Decision Point

14 15 16 17 18 19 20 21 22 23 24

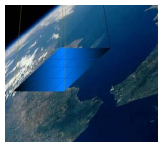
Ground demonstration


Small-scale on orbit demonstration



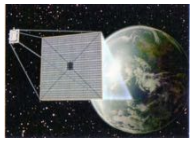

100kW class on orbit demonstration




Development Phase

25 26 27 28 29 30 31 32 33 34

2MW class demonstration

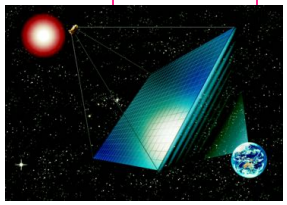



200MW class plant

Commercial Phase

35 36 37 38 39 40 41 42 43 44

1GW class first commercial model



Commercial SSPS（1SSPS/year）