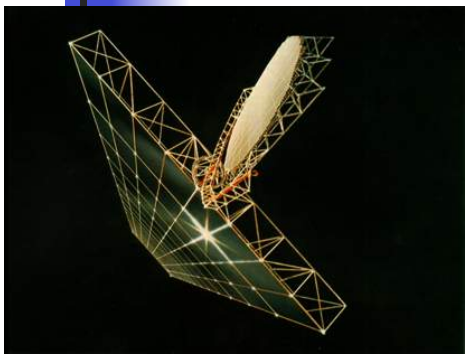
Feasibility Study of Tethered Solar Power Satellite

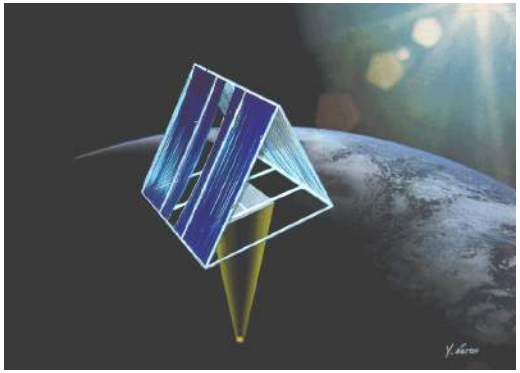
- Concept of New Tethered-SPS
- Special Features
  1. Attitude Stabilization
  2. Modularization
  3. Thermal Characteristics
  4. Construction and Maintenance
  5. Evolutionary Development
  6. Easy Investment
  7. Coexistence with Other Geostationary Satellites

October 2005

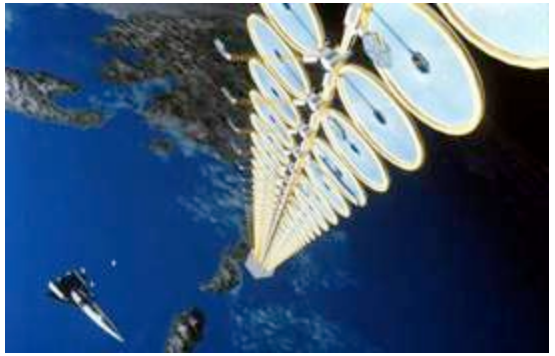
Typical Examples of SPS



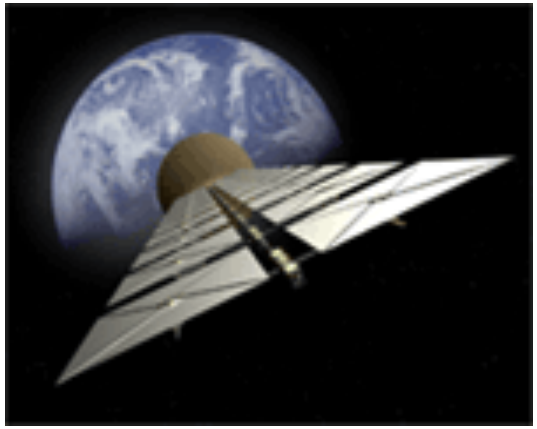
NASA Reference System



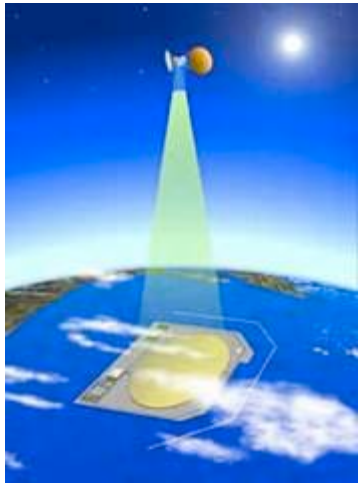
ISAS SPS 2000



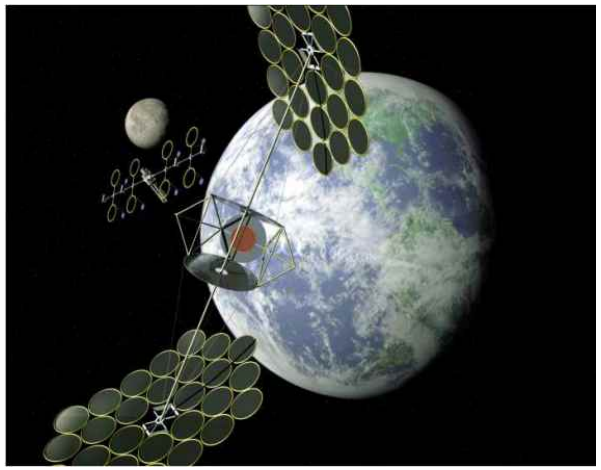
NASA Sun Tower



European Solar Sail Tower



NASDA(JAXA) SSPS Model



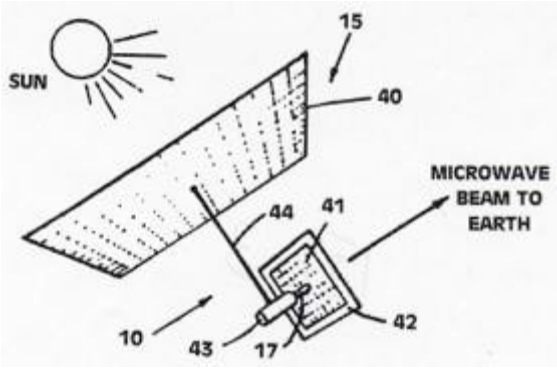
NASA Integrated Symmetrical Concentrator

Feasibility Problems in the Past Models

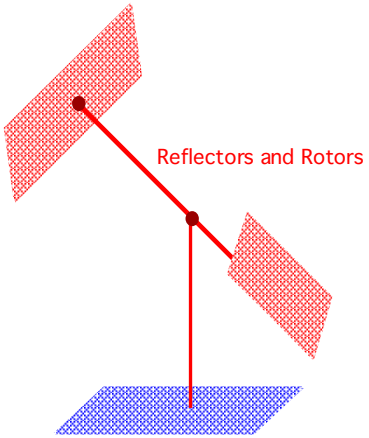
Most difficult point: to direct large solar panel to the sun while transmitting antenna be pointed to rectenna on ground

⇨ movable mechanism (rotary joint) or rotating mechanism for mirrors are required.

However,
Rotary joint: no practical technologies without serious power loss
Rotating mirror: almost infeasible technologies for attitude control and stabilization of the large-thin film structure
Movable mechanism: one-point failure problem



Glaser's original idea



Sun Pointing System

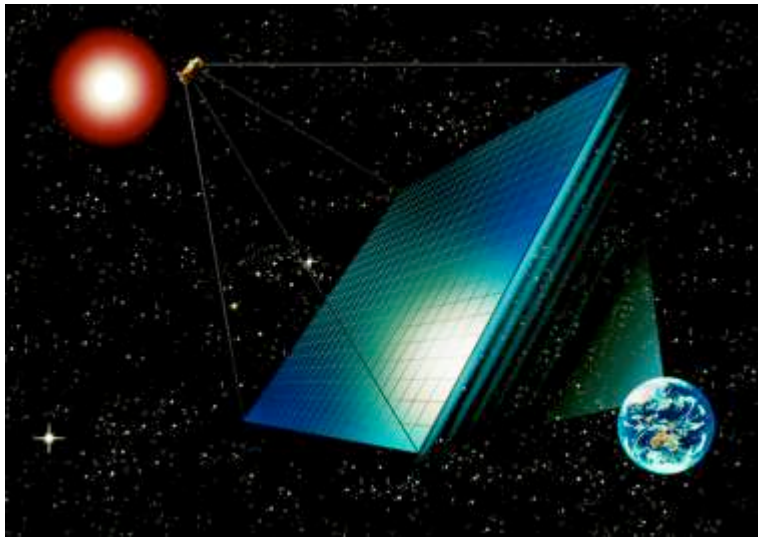
Why Tethered-SPS ?

⇨Investors have been doubtful of the cost analysis because of lack of technical feasibility and robustness

⇨ need to alter our perspective on the SPS system configuration: simple and feasible configuration

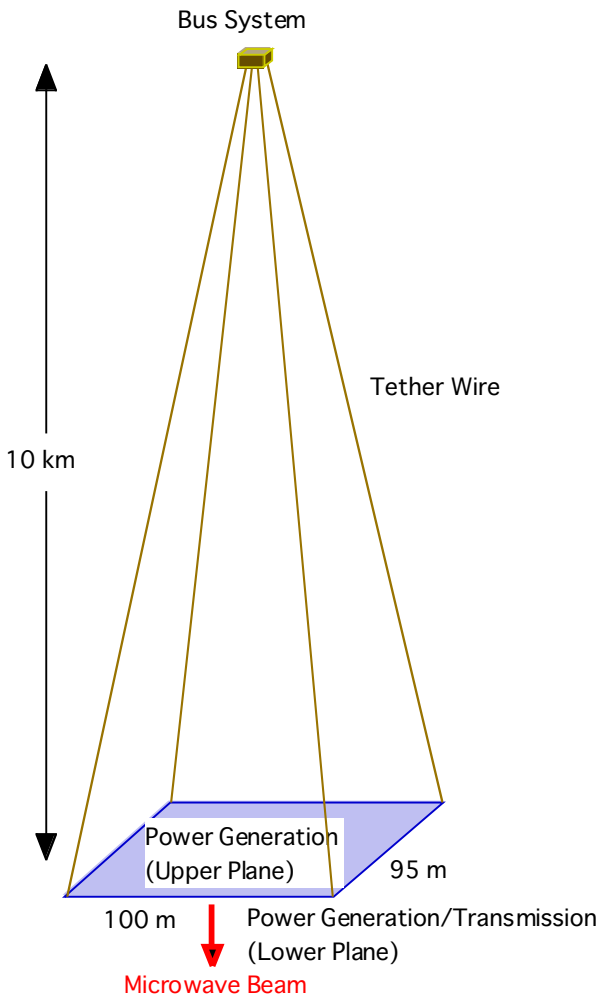
⇨ Tethered-SPS

Automatically stabilized by gravity gradient force.
No sun-pointing mechanism.
Less power efficiency but robust and costless.

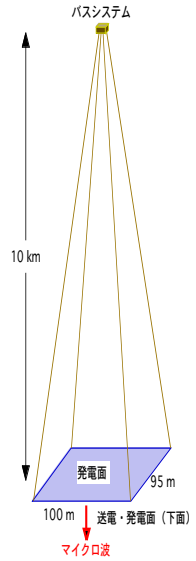


Unit of Tethered-SPS

Total Weight:	42.5 MT
Tether Length:	10 km
Tether Tension:	10 gw
Output Power:	2.2 MW

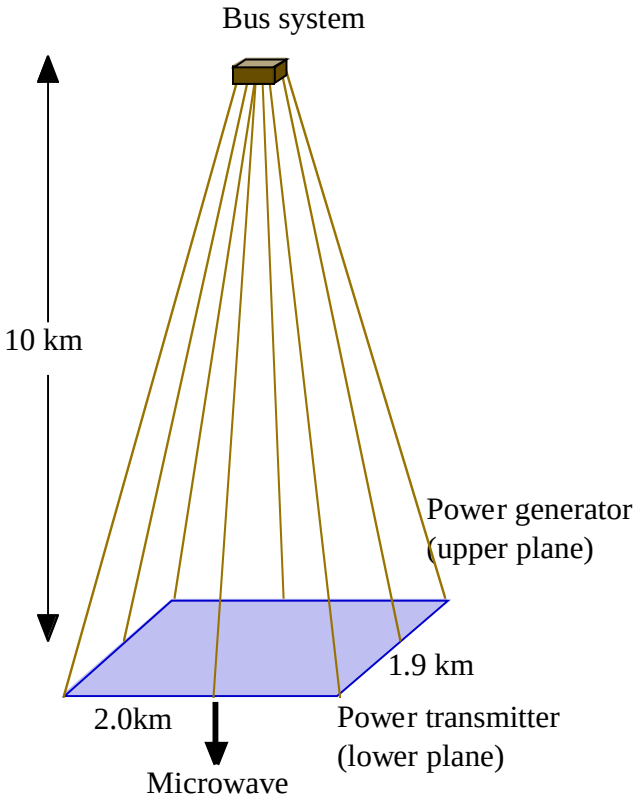


Concept of Tethered-SPS (Former Type)

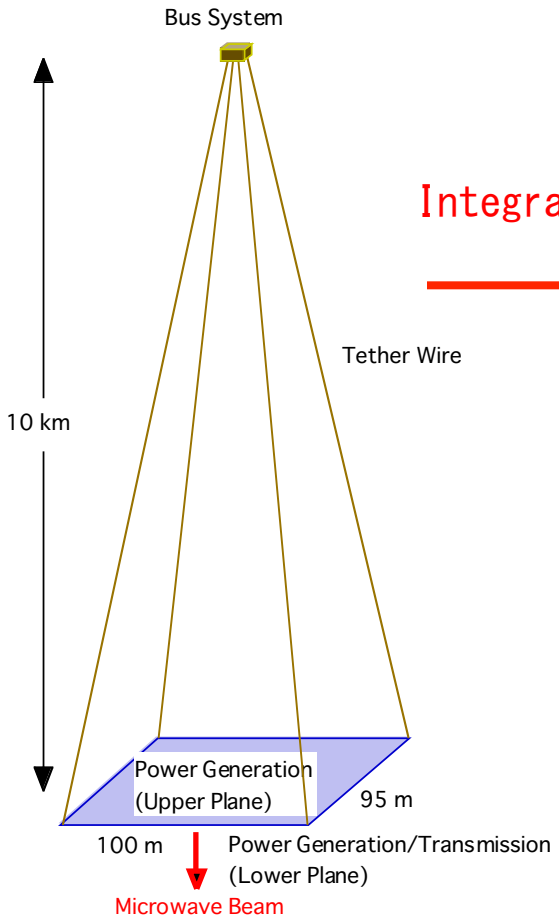


Unit of Tethered-SPS

Integration

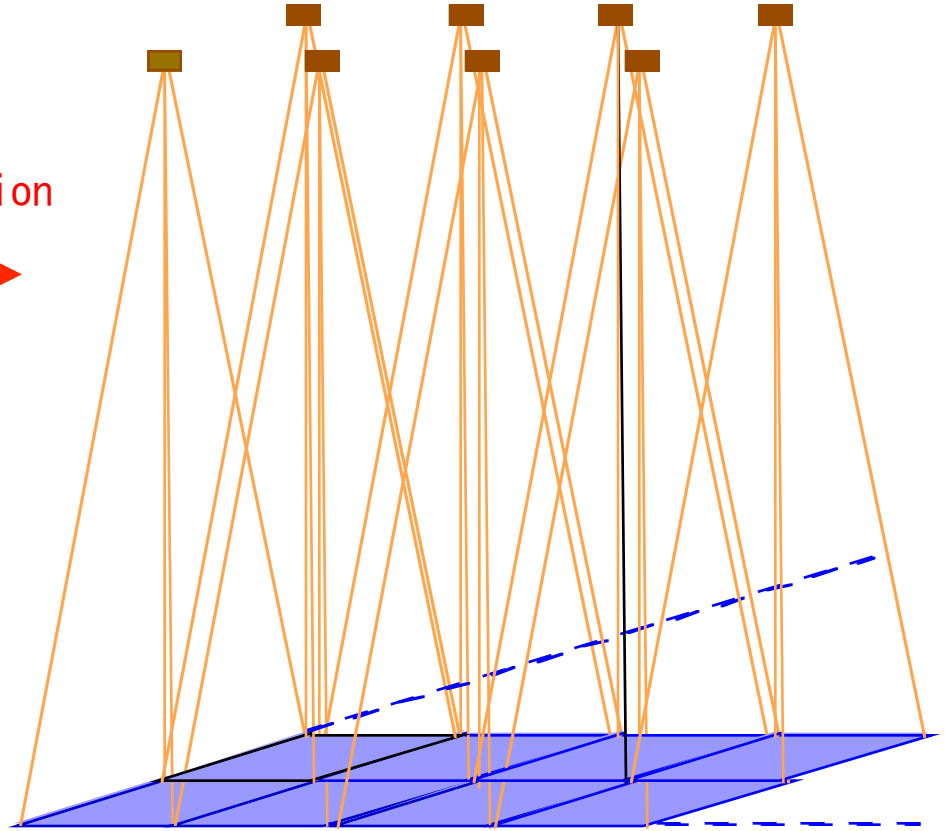


Concept of Tethered-SPS (New Type)



Integration

Total Weight: 26,500 MT Output Power: 1 GW(constant)

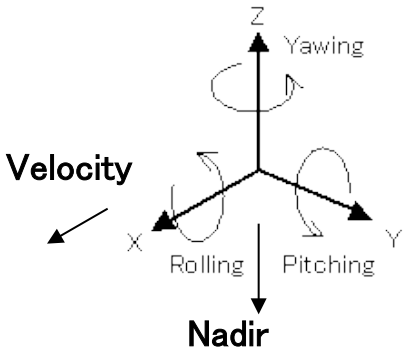


Enhanced flexibility, expansibility,
and maintenance performance

System Characteristics of Tethered SPS (Constant Power)

	Item	Performance	Note
Tethered SPS	Weight	26,562 MT	25,234MT(Panel)、1,328MT(Bus)
	Size	2.5 km x 2.375 km x 10 km	250 Tethered SPS modules
	Output Power	1.36 GW	Microwave frequency 2.45 GHz
Tethered SPS Module	Weight	42.5 MT	40,375 kg(Panel)、2,125 kg(Bus)
	Tether Length	10 km	Width 1cm, Para-aramid fiber (Kevlar/DuPont), UV protection coating
	Panel Size	100m x 95 m	100x 95 Power generation/ Transmission modules
	Output Power	2.2 MW	Microwave frequency 2.45 GHz
Power Generation/ Transmission Module	Weight	4.25 kg	Microwave circuit 2.3kg(10g/W) Solar cell 0.45kg(0.5g/W) Batteriies 1.0kg(2000Wh/kg) Structure 0.5kg(0.025g/cc)
	Size	1 m x 1m x 2 cm	
	Output Power	230 W	Microwave frequency 2.45 GHz

(1) Attitude Stability of Tethered-SPS



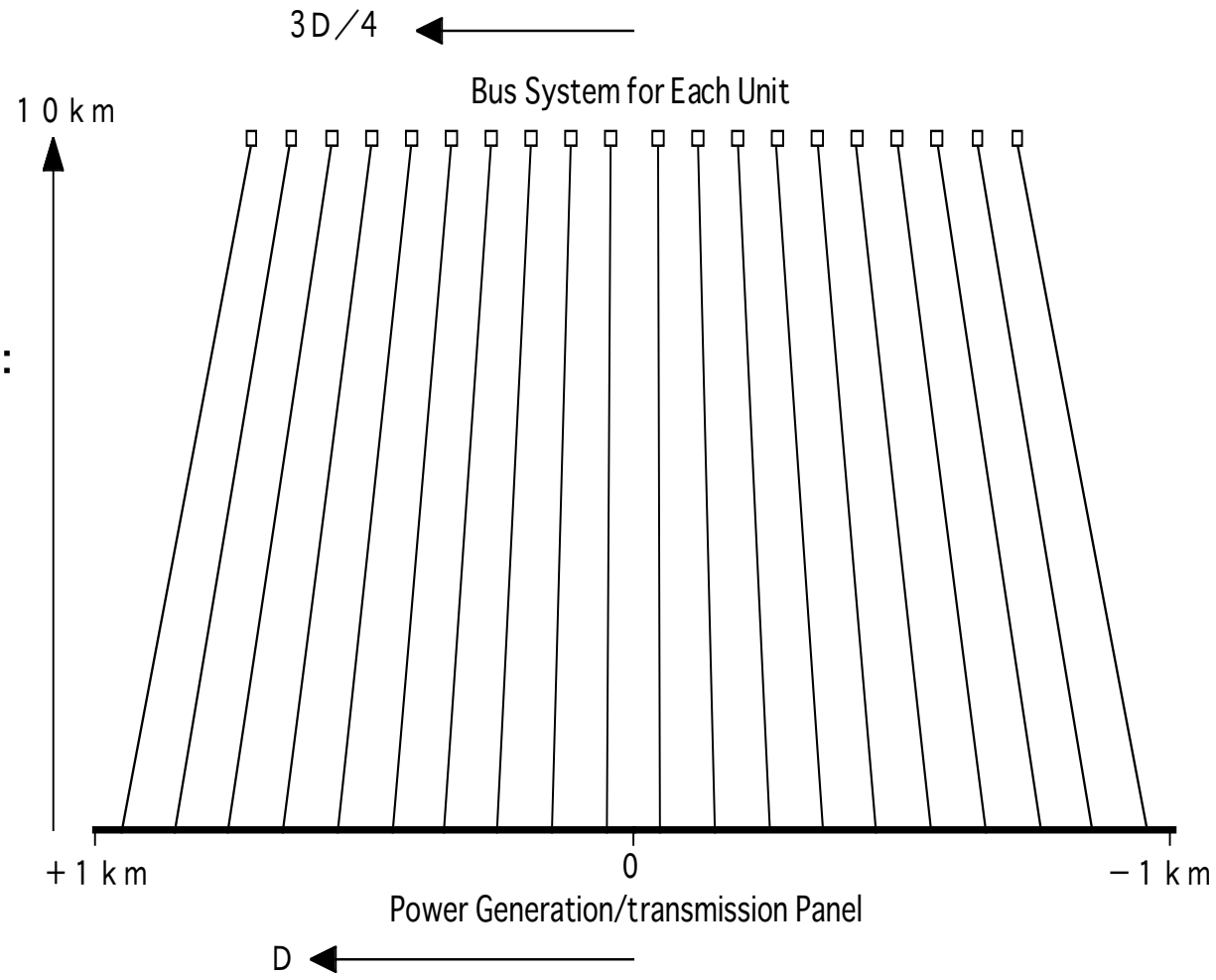
Amplitude of attitude fluctuation induced by solar radiation pressure when deviation between the center of gravity and the center of shape is 1 %.

Direction of Fluctuation	Amplitude [rad]
Pitch angle by disturbance along pitch axis	2.8×10^{-3} (0.16 degrees)
Roll angle by disturbance along roll axis	1.3×10^{-4}
Yaw angle by disturbance along roll axis	1.2×10^{-4}
Roll angle by disturbance along yaw axis	5.8×10^{-5}
Yaw angle by disturbance along yaw axis	2.4×10^{-3}

Ishimura (Hokkaido Univ.) 2005

Inclination of Tether Wires

Panel size: 100 m
Distance of bus: 75 m
Allowable tether fluctuation:
0.21 degrees

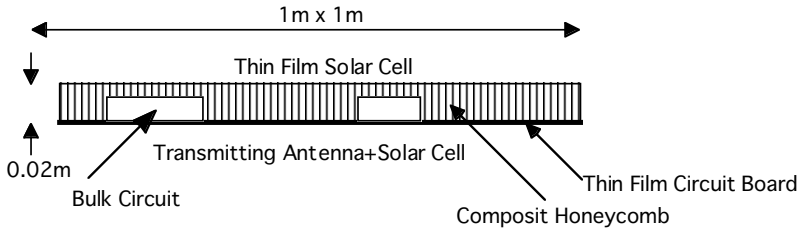


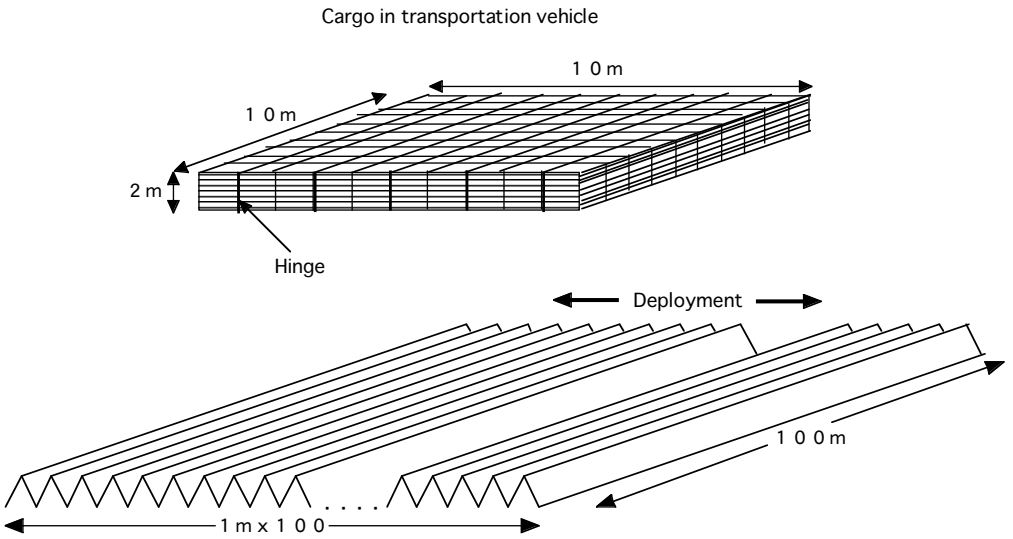
(2) Modularization

- Power generation and transmission panel is composed of perfectly equivalent modules.
- Power generated by the solar cell is converted into microwave power in a module.
- All modules are controlled by wireless LAN.

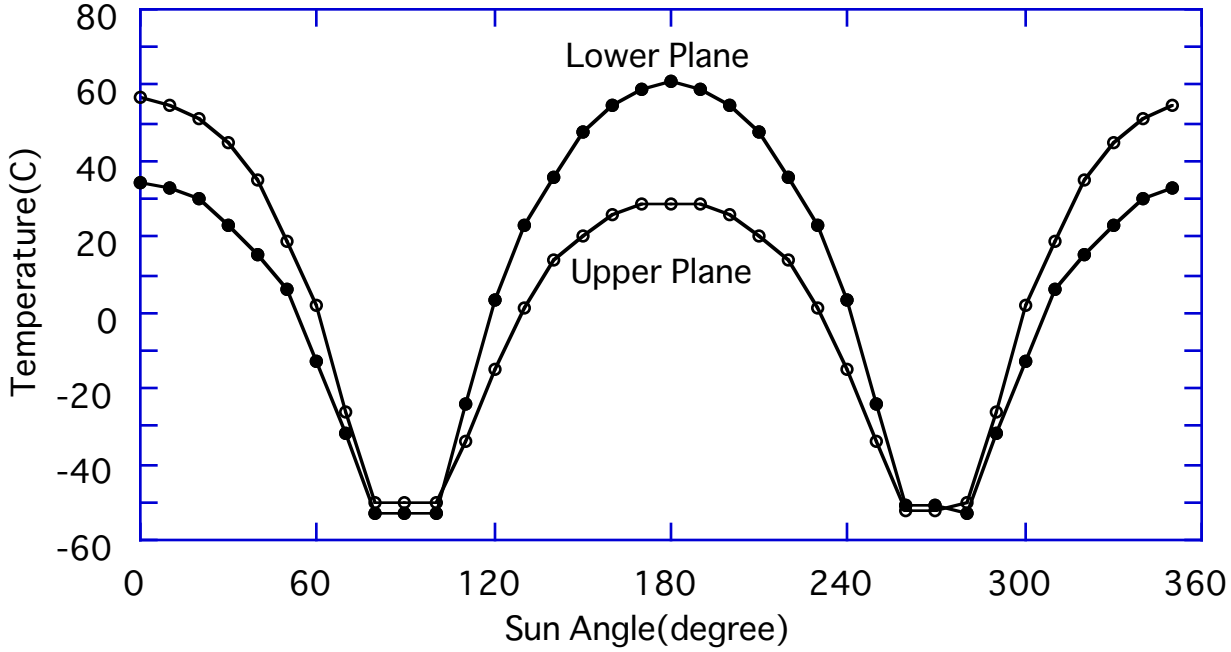
⇨No power/signal cabling between the modules.

⇨ Robust and low cost (mass production, easy quality control)



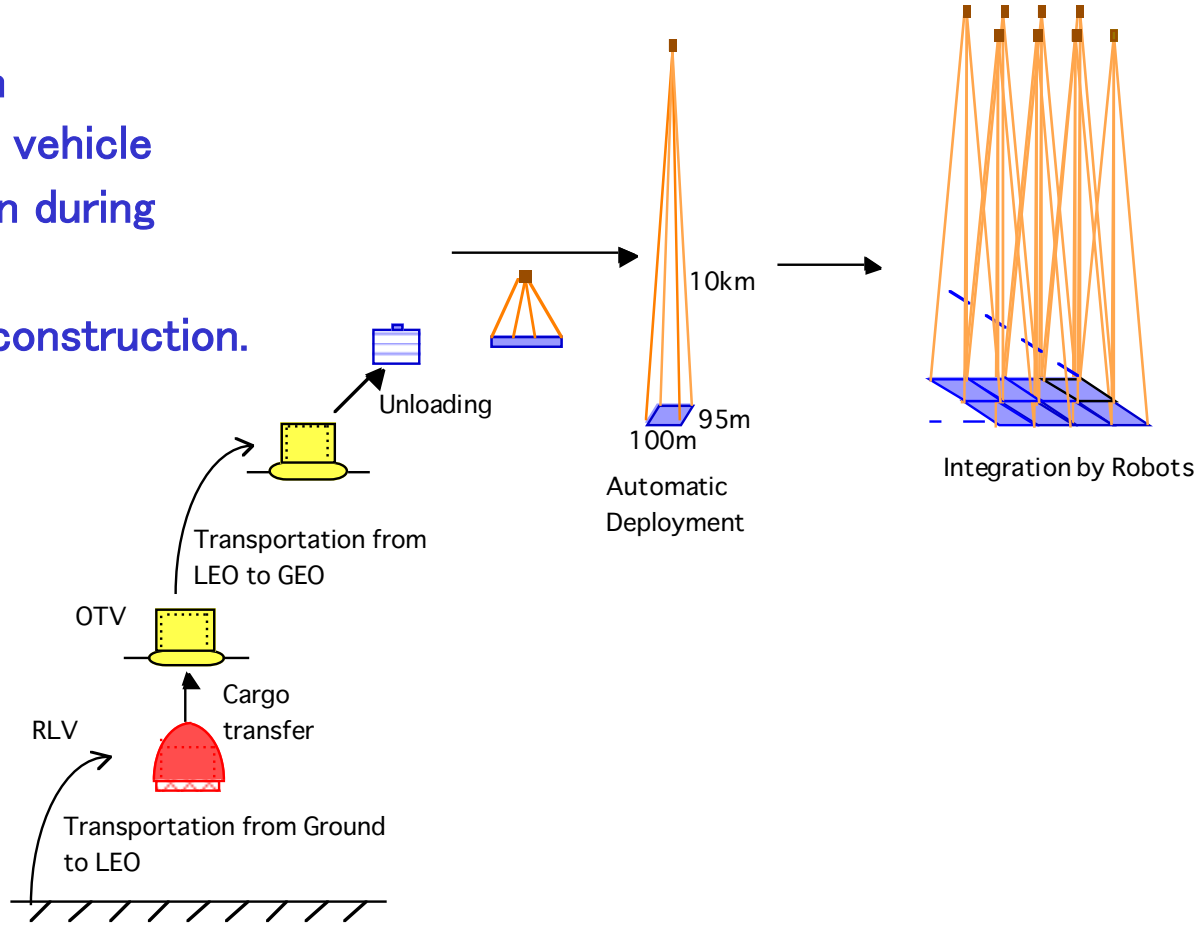


(3) Temperature variation of the upper and lower planes

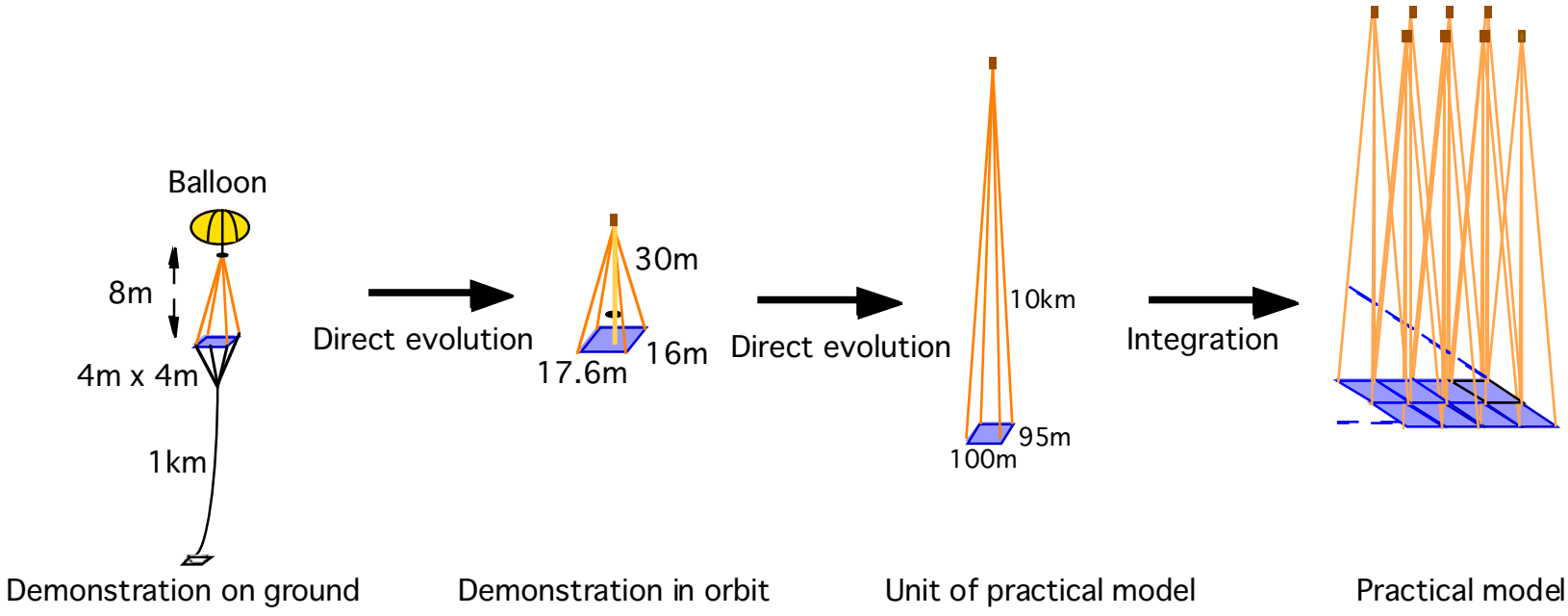


(4) Construction and Maintenance

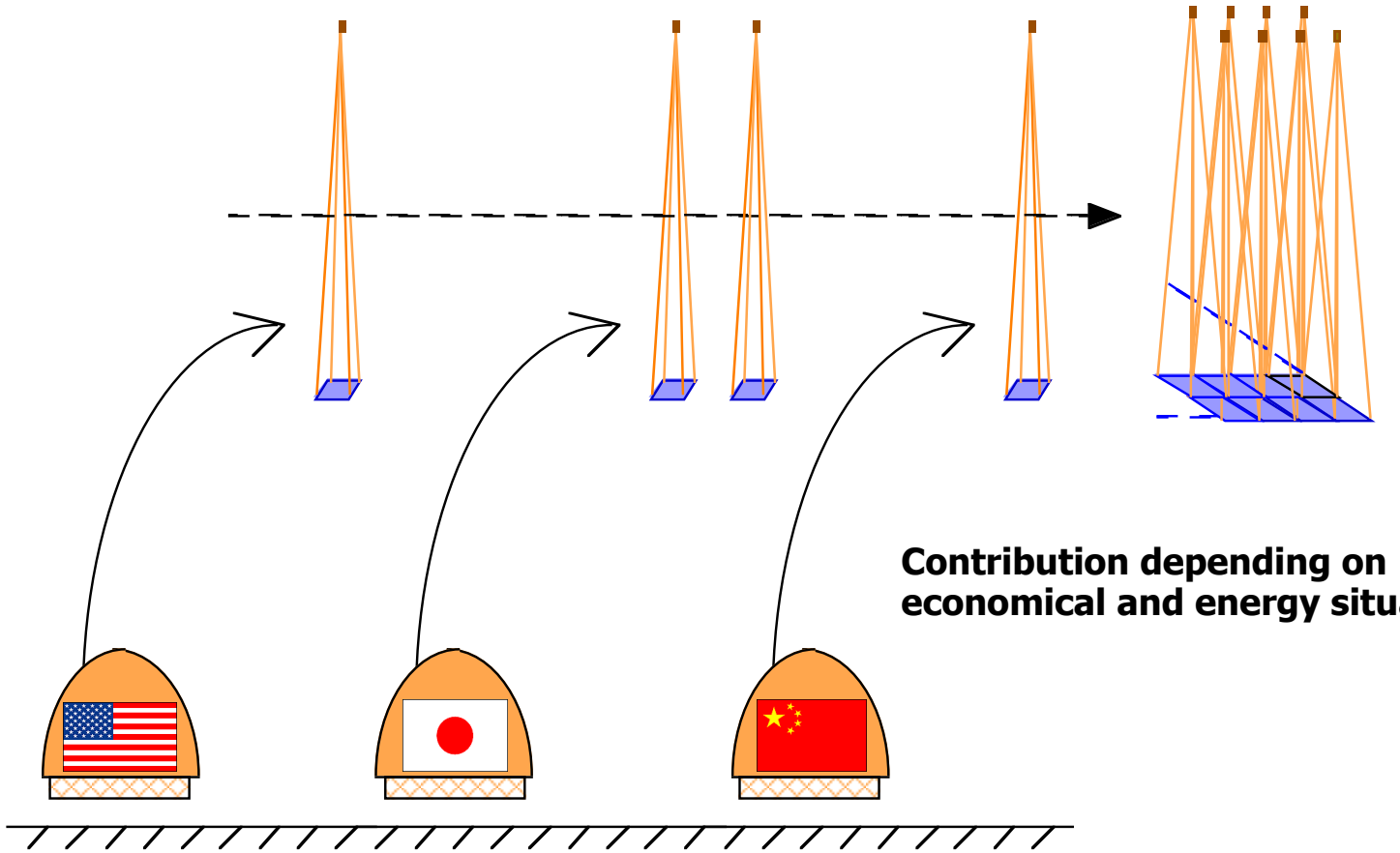
1. Unmanned construction
2. Moderate orbit transfer vehicle
3. No radiation degradation during transportation
4. Full verification during construction.
5. Easy maintenance and scale-up



(5) Evolutionary Development from Demonstration Model to Commercial Model

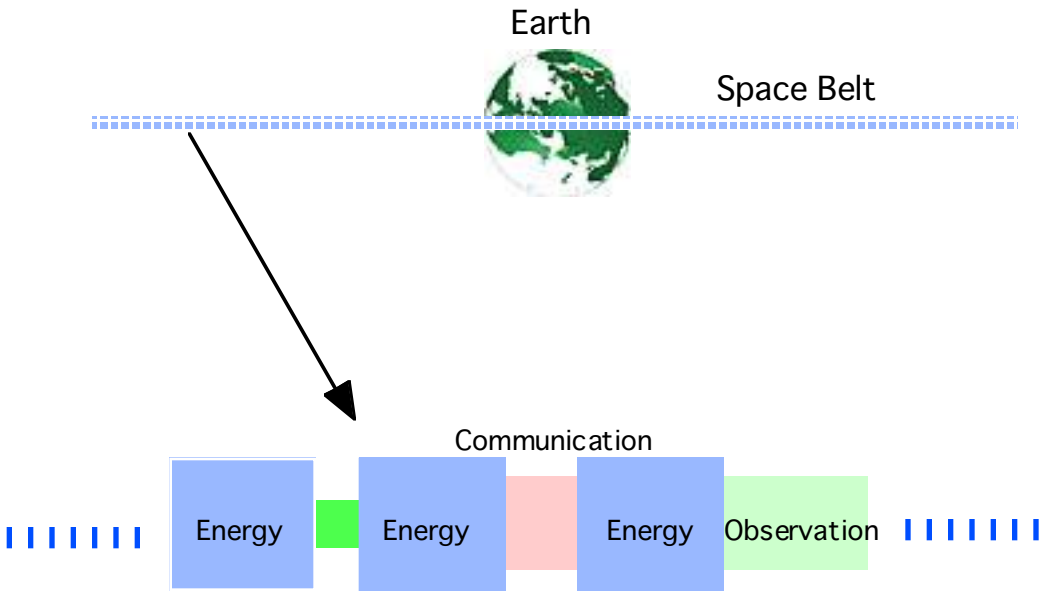


(6) Easy Investment with Clear Work Interface



Contribution depending on economical and energy situation.

(7) Coexistence with Other Geo-stationary Satellites



Complex of facilities for Energy, Communication, Earth Observation, Space Telescope, Space Experiment, and Maintenance in Geosynchronous orbit.

World primary energy(13,000 GW) can be supplied from space belt with the length of 32,500 km (14 % of total space belt).

Solution of Problems by the Tethered-SPS

Problem Area	Tethered-SPS
Rotary joint, Movable mechanism for rotation mirror	No movable mechanism
Power collection cable or super conduction cable	No power collection cable (power generation/ transmission panel)
Light condensing mirror	No light condenser
Operation starts after full construction	Phased construction from low to high power system
Construction in LEO and transportation to GEO	Construction in GEO
Independent study on demonstration and commercial SPS	Direct evolution from demonstration model to a part of practical SPS

Technology Target for Tethered SPS

¥110 = 1$

Item	Cost, Performance	Final Target	Near-term Target	Present Status	Note
Solar Cell	Cost	¥50/ W	¥100/ W	¥500 ～1000/ W	at 1 kW/ m^2
	Efficiency	35 %	20～25 %	10～20 %	
	Power per unit weight	2 W/g	1.5 W/g	1 W/g	5 W/g has been achieved for thin film bare cell.
Microwave Circuit	Cost	¥100/ W	¥500/ W	¥1000～10,000/W	
	Efficiency	85%	60 %	40%	
	Power per unit weight	0.1 W/g	0.02 W/g	0.01 W/g	
Energy Storage	Cost per unit energy	¥10/Wh	¥50/Wh	¥100/Wh	
	Energy per unit weight	2 Wh/g	1 Wh/g	0.2 Wh/g	
	Charge/Discharge Efficiency	90 %	85 %	70 ～ 80 %	DOD 50 % Charge/discharge Life 30,000(40years)
Transportation Cost	Cost per unit weight (to LEO)	¥10,000/ kg	¥500,000/kg	¥1,000,000/kg	
	Cost per unit weight(LEO to GEO)	¥5,000			50 % of launch cost to LEO
Rectenna	Specific Price	¥50/ W			
	Efficiency	85 %	75 %	50～70 %	

Summary and Conclusion

- New model Tethered-SPS is a highly practical SPS concept, with a number of advantages in the production, integration, construction, operation, and maintenance, as compared with the past SPS models.

- Since the technologies employed in the Tethered-SPS are essentially achievable, this model can be used as a realistic reference model to evaluate the cost and CO_2 load as a future energy system.

- Our current study still remains an initial conceptual stage. Further investigations are required to confirm the technical feasibilities, especially for microwave control, integration of the units, and orbit maintenance of the large structure.