National Space Society
International Space Development Conference
Tucson, Arizona
May 26-29, 2000

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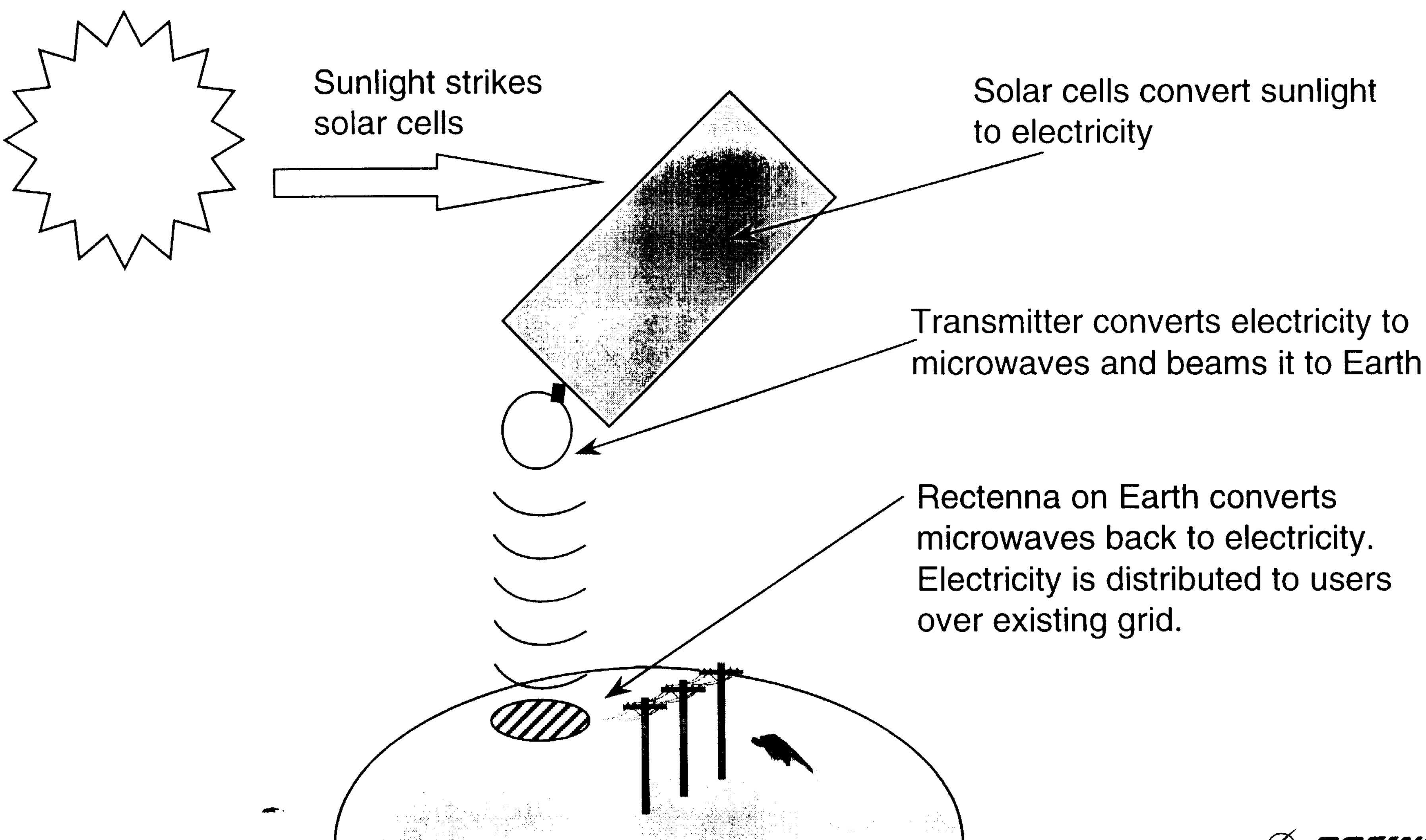
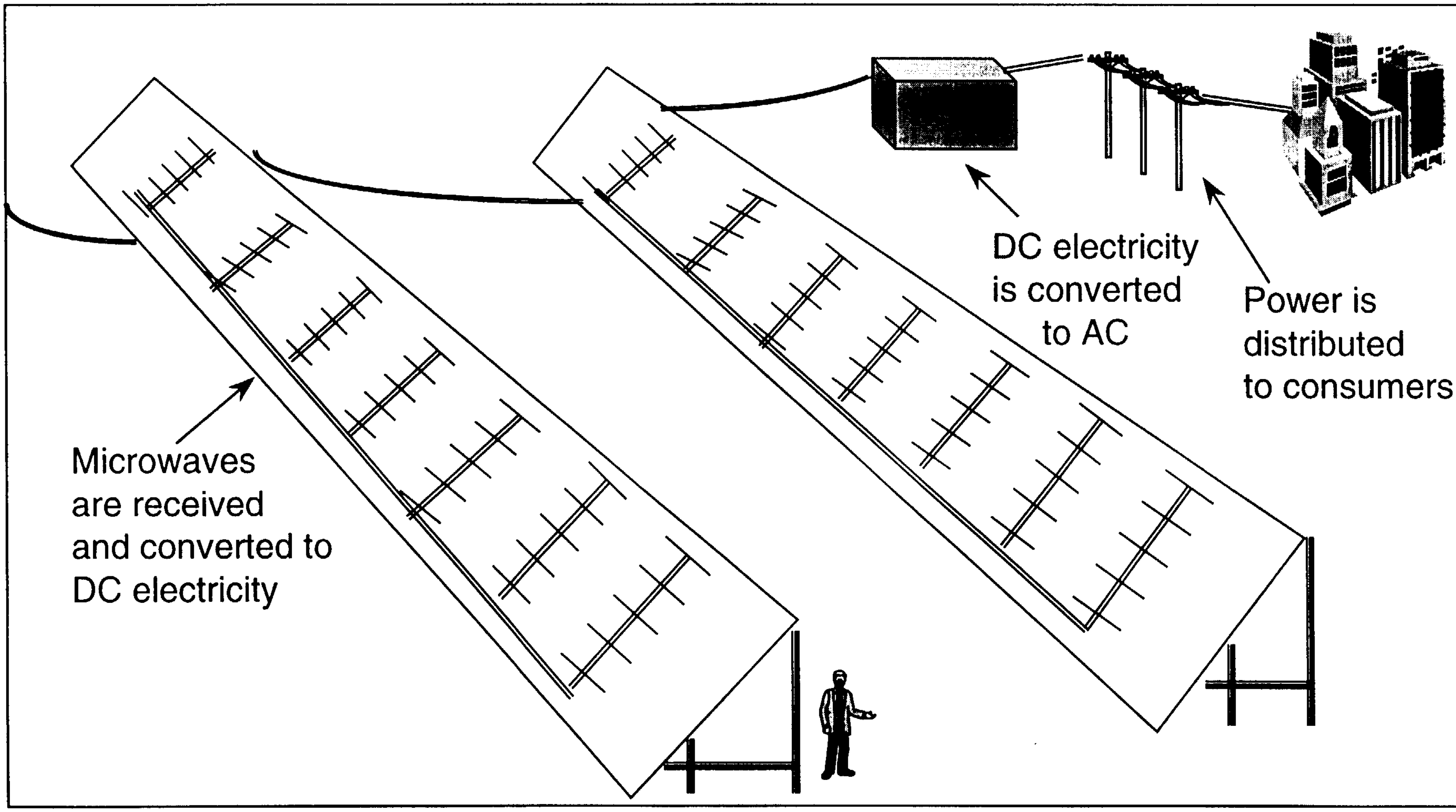
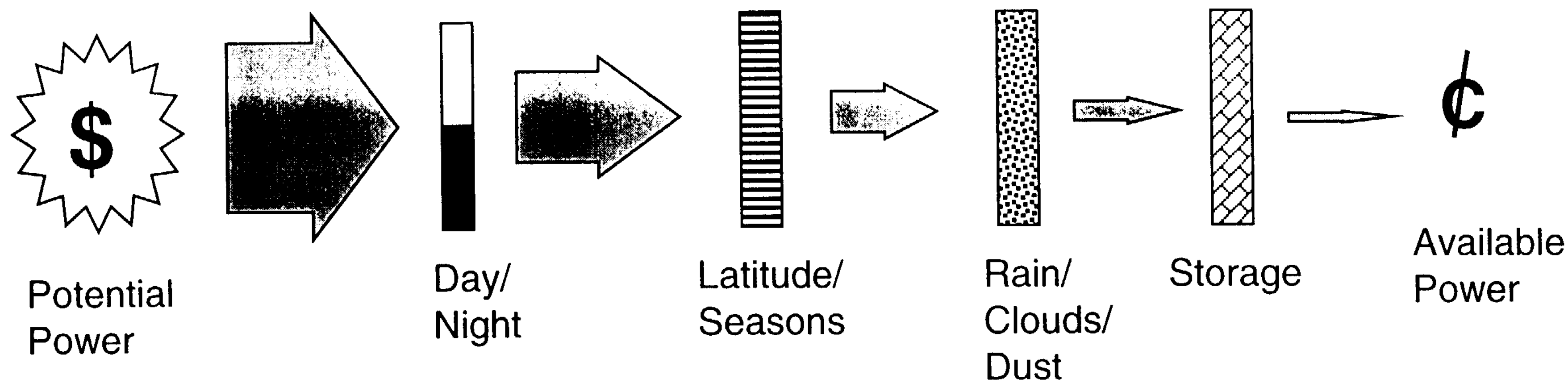

Sunlight strikes solar cells
Solar cells convert sunlight to electricity
Transmitter converts electricity to microwaves and beams it to Earth
Rectenna on Earth converts microwaves back to electricity. Electricity is distributed to users over existing grid.

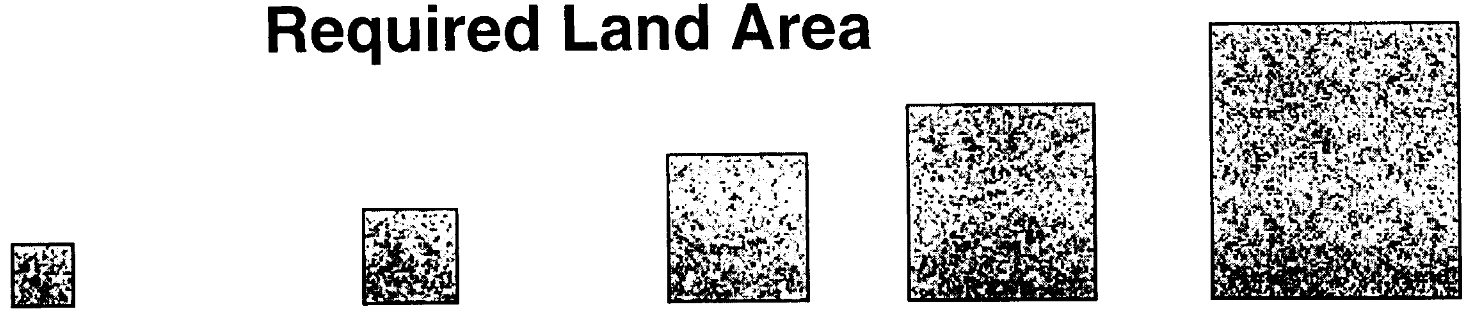

Microwaves are received and converted to DC electricity
DC electricity is converted to AC
Power is distributed to consumers

- Inexhaustible “fuel” supply -- sunlight
- No emissions of carbon dioxide or other gases (except for launch vehicles)
- No nuclear waste
- Land use advantages over other renewables:
  - Less land required per unit power
  - Rectennas not opaque, so dual use of land may be possible (e.g., for agriculture or conventional solar cells)
- Well-understood principles
  - However, a great deal of engineering needs to be done
- Need for long-distance transmission over land is reduced -a global power grid is possible
- Need for storage reduced - power can be continuous
- Multiple-use: terrestrial and space applications

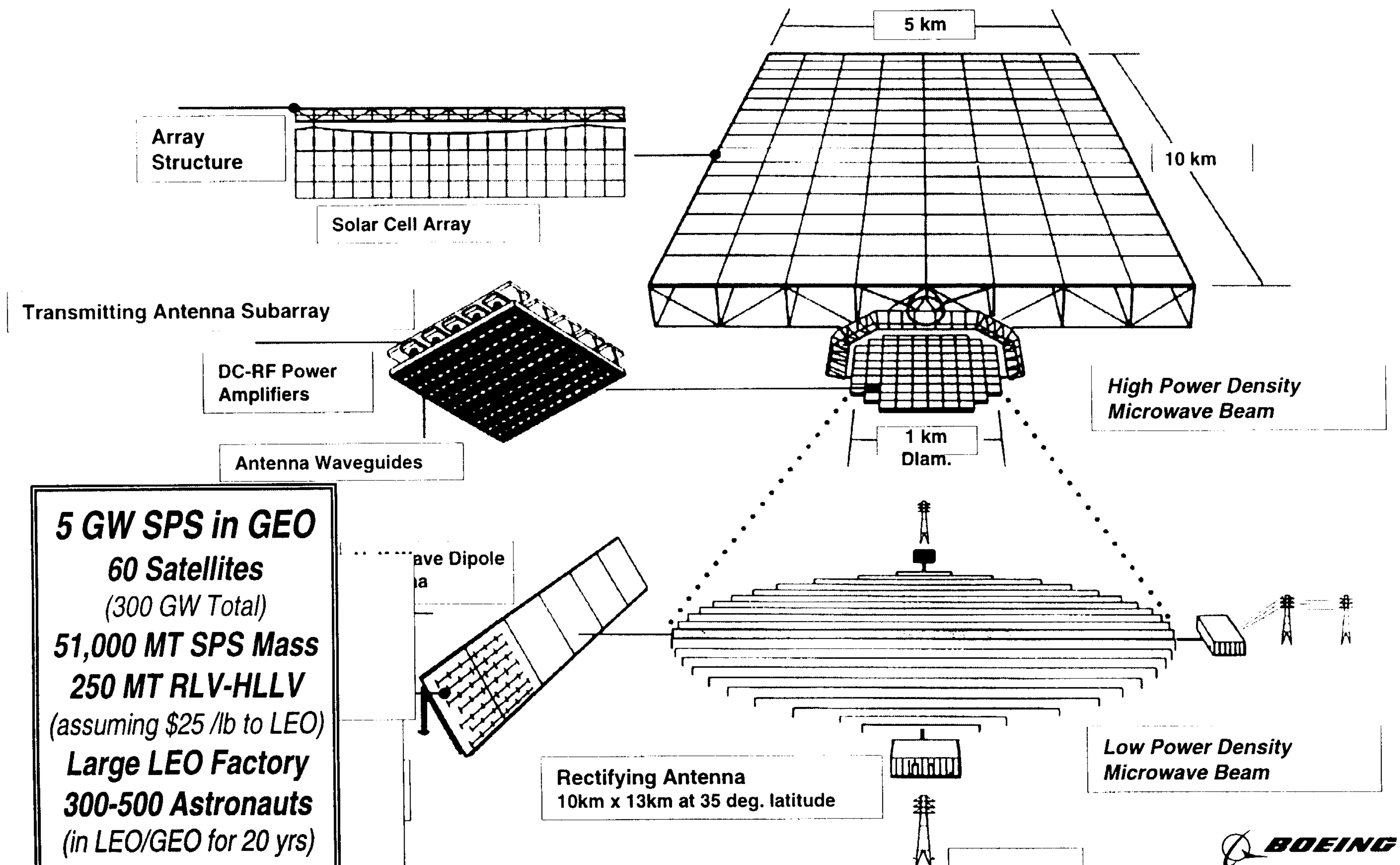
Available Power



Required Land Area



Note: Conversion loss not shown.



5 GW SPS in GEO
60 Satellites
(300 GW Total)
51,000 MT SPS Mass
250 MT RLV-HLLV
(assuming $25 /lb to LEO)
Large LEO Factory
300-500 Astronauts
(in LEO/GEO for 20 yrs)

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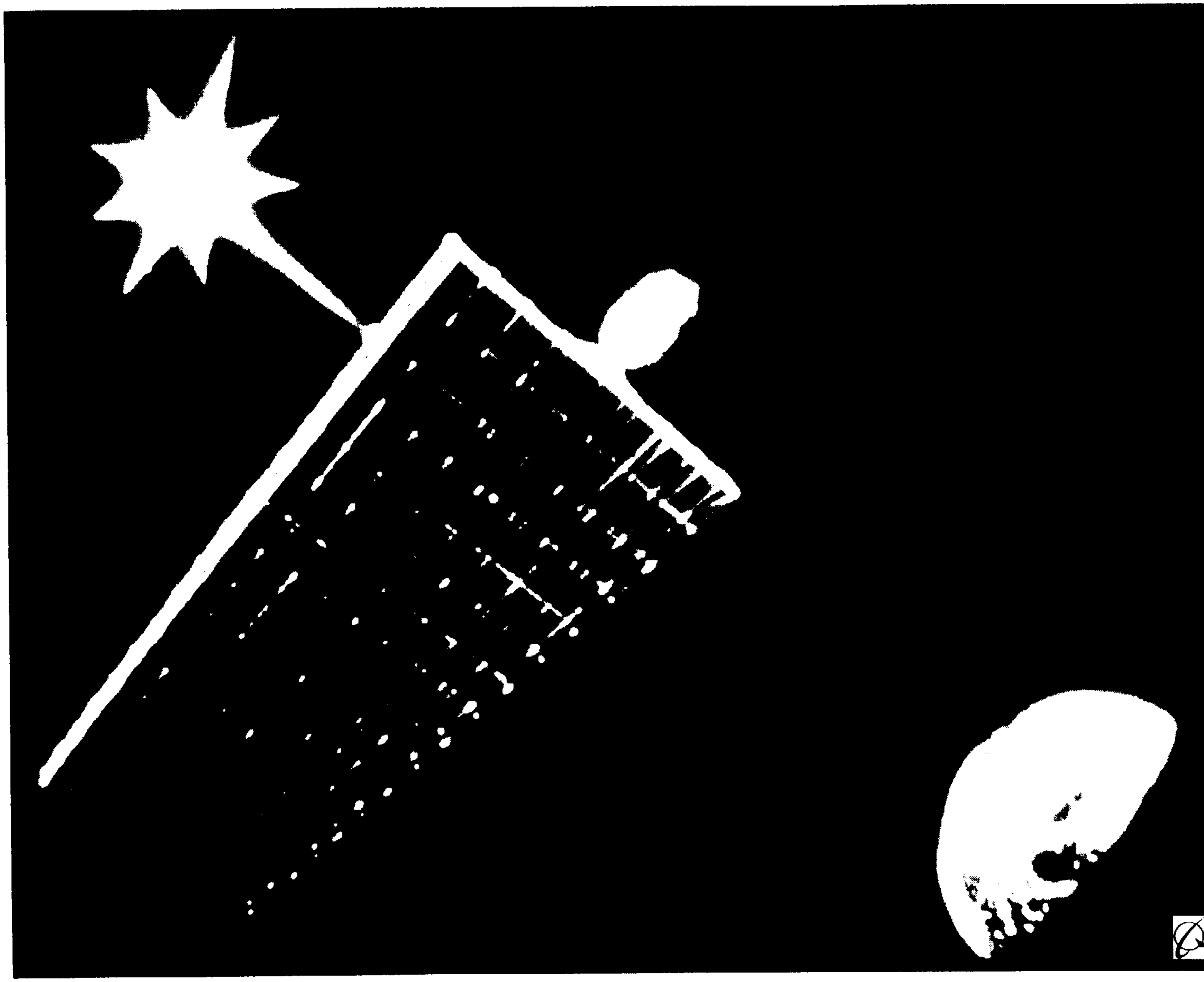
NASA/DoE 1970s Reference SPS



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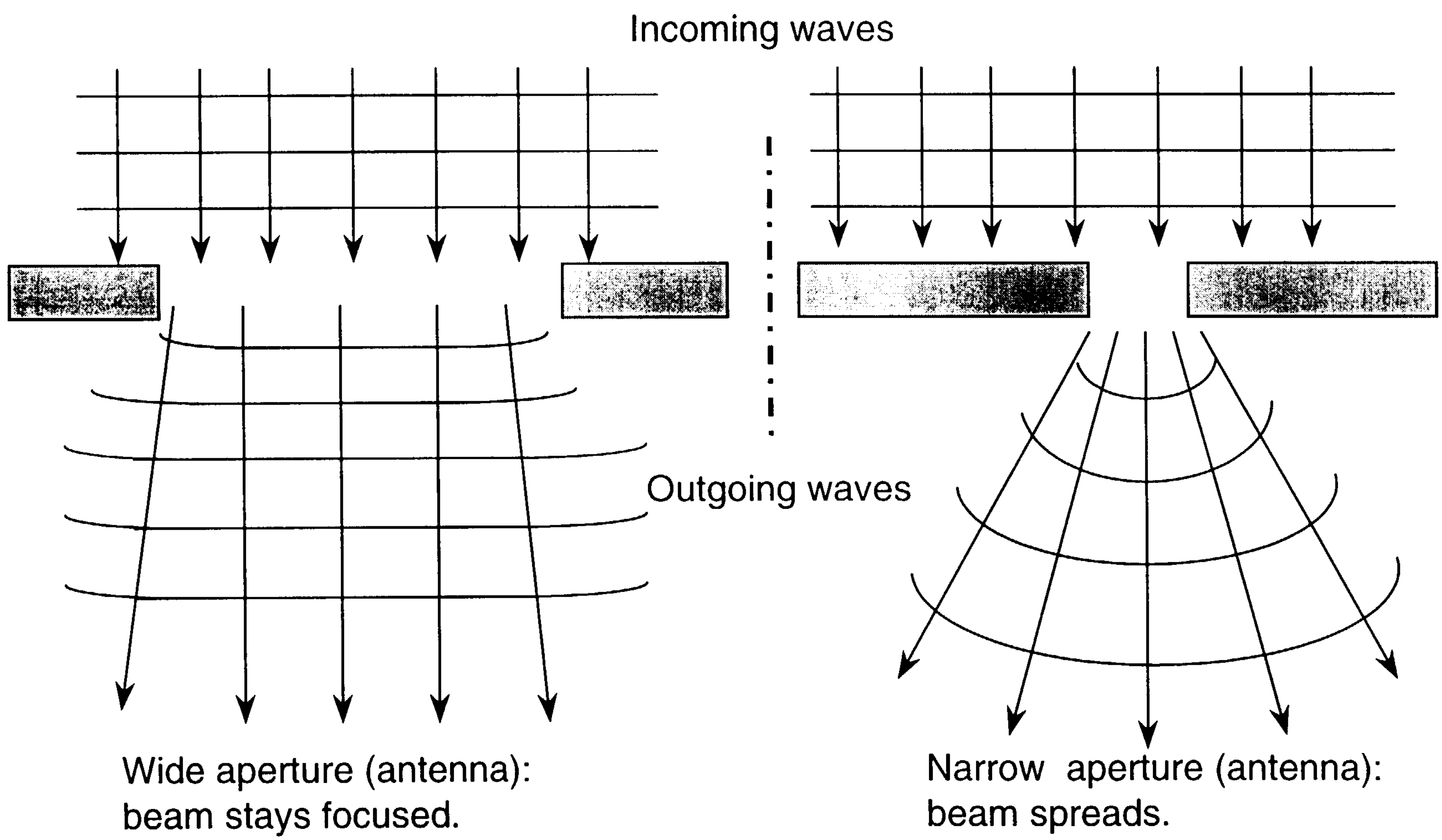
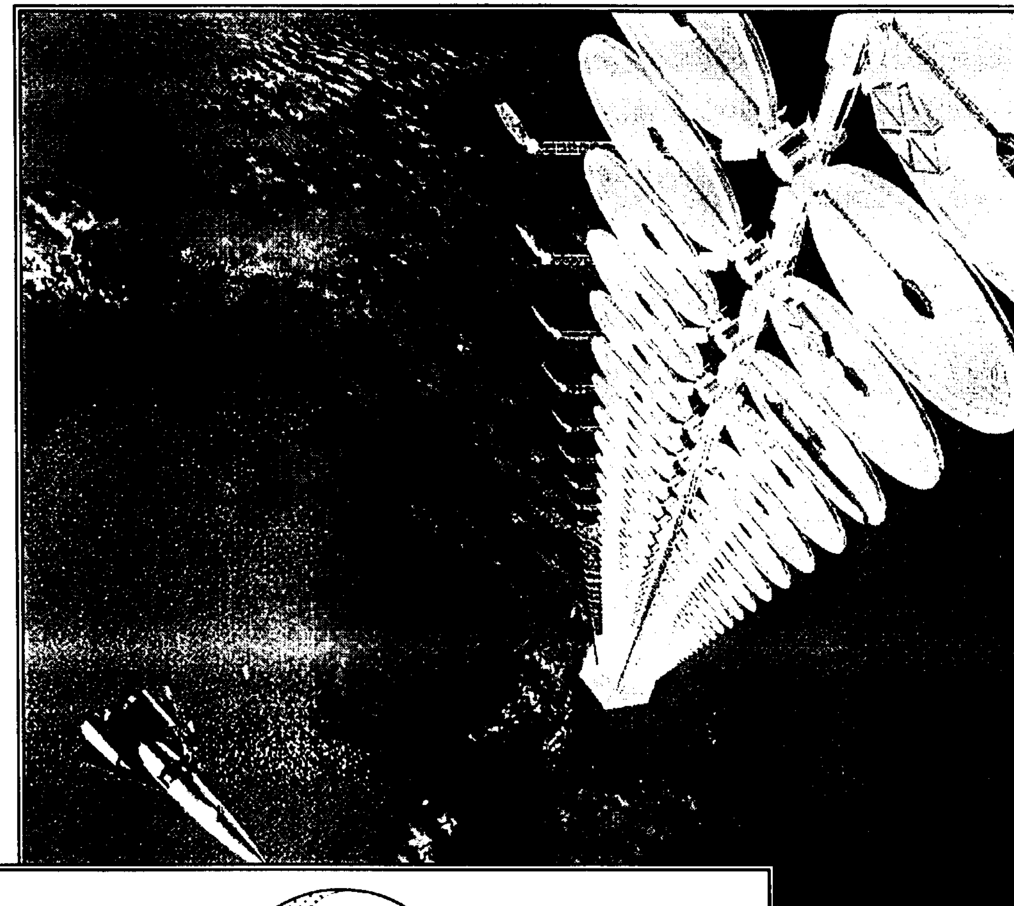
Beam diffraction: the tendency of waves to bend around edges.

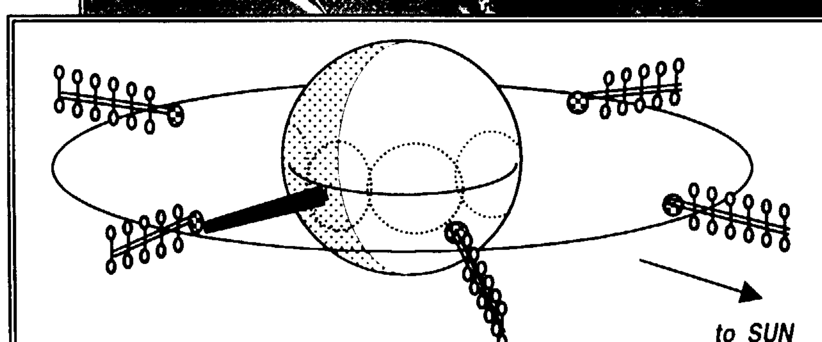


Beam width does not depend on power level.

NASA Sun Tower SPS
(Fresh Look Study 1997)

- **System Concept**
  - Modular systems; self-assembling at high LEO
  - Gravity-gradient / GN&C stabilized
  - Aggressive technology for solar arrays, integrated propulsion, others
  - RF phased array for Wireless Power Transmission
    - ± 15 degrees Beam Steering
- **Architecture**
  - 12,000 KM equatorial orbit
  - ± 30 degrees Latitude Coverage
  - Power services of ~ 400 MW (example)
  - Requires moderate terrestrial energy storage (level varies depending on platform configuration and specific orbit)
  - ~12 SPS yields power to 12 sites, etc.
  - Power for Emerging Markets: South & Central America, Africa, Asia, India...
- **Transportation**
  - Deployment using Commercial Launch Services (RLV-class @ $400/kg)





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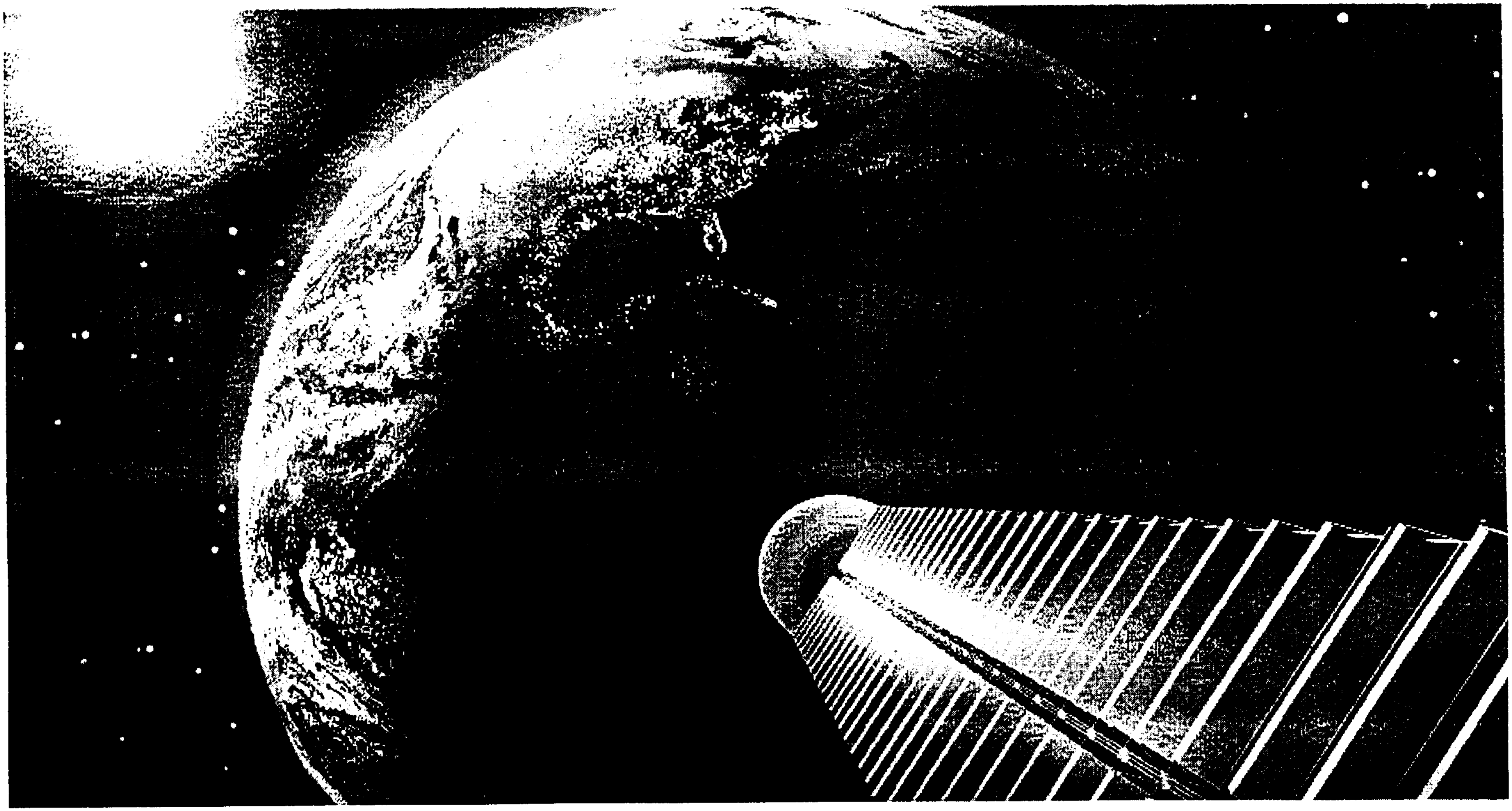
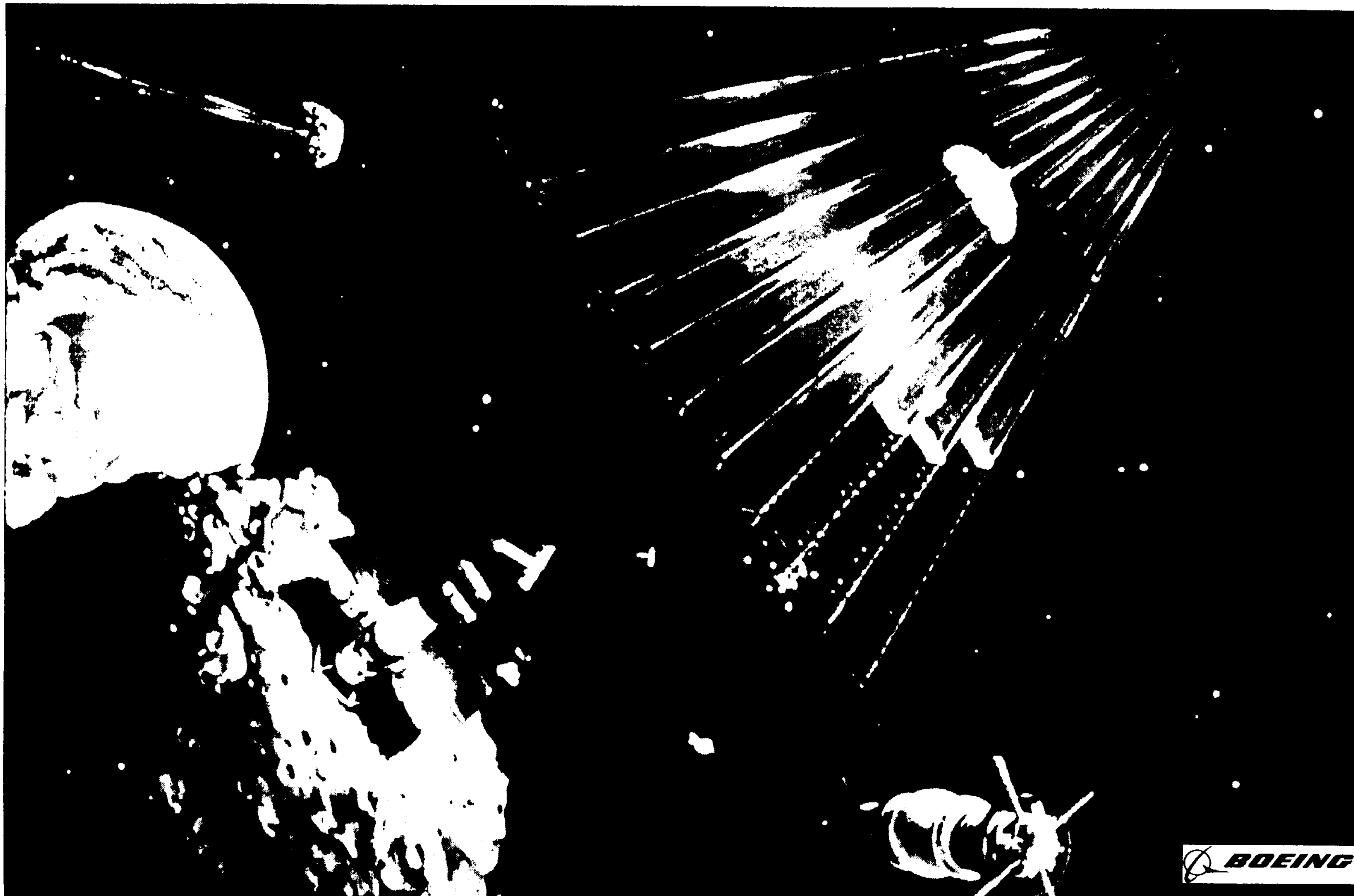


Space Resources May Enable SSP



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		Power Transmission	
		Microwaves	Light
Power Generation	Photovoltaic Cells	✓	✓
	Solar Dynamic (heat engines)	✓	✓

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ATTRIBUTE	MICROWAVES	OPTICAL
Aperture Size	Large, so system must be large	*Small; gives flexibility of system design*
Interference	Electromagnetic spectrum	*None, except perhaps astronomy*
Rain, Cloud Attenuation	*Lower frequencies can penetrate clear clouds, and light rain*	Optical wavelengths are attenuated by clouds and rain
Legal Issues	FCC, NTIA, ITU	ABM treaty, if power density high
Dual Use of Infrastructure	Rectennas used for SSP only (possibly communication)	*Terrestrial PV arrays: can* receive *sunlight*
Dual Use of Land	Crops or PV under rectennas	PV arrays on rooftops, etc.
Perception Issues	Public fears of "cooking"	Governments may fear weapons application
Safety	Safe, but must keep aircraft out of beam	Safe, if power density is kept low
Efficiency of space segment	*High*	Improving
Efficiency of ground segment	*High*	Improving
Traceability	Heritage to communications and radar	MSC 1 and 3
PMAD	Heavy due to centralized WPT	*Light; WPT can be distributed*

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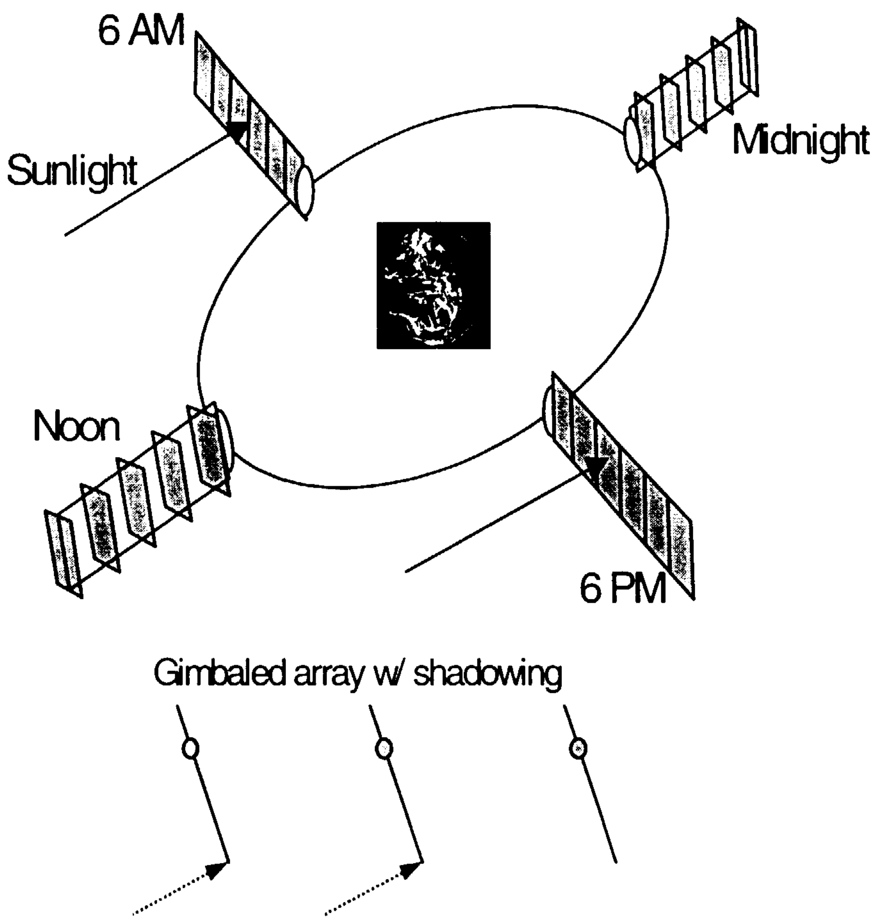
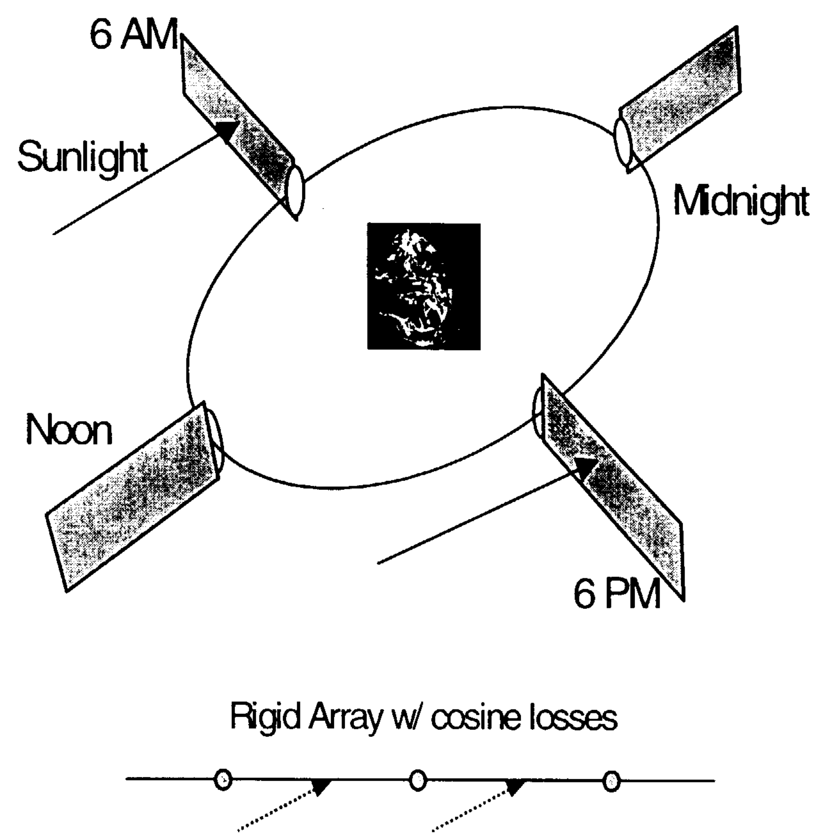
ATTRIBUTE	PHOTOVOLTAIC	SOLAR DYNAMIC
Solar Collector Area	Moderately high, but improving	*Low*
Radiation Tolerance	Degrades	*Excellent*
Specific Power	Moderate	Low, but should be high in far term
Efficiency	*~25% SOA with rainbow cells*	*Currently 29%; expect 35% in far term*
Heat Tolerance	Loses efficiency as Temp. rises	*Excellent; requires heat*
Moving Parts	*None*	Rotating machinery, fluids
Modular Construction	*Yes*	Less so
Experience in Space Environment	*Extensive use on satellites*	Vacuum chamber only





Gimbaled Array

- Gimballing mechanisms avoid cosine losses
- Shadowing losses around noon & midnight cannot be avoided
- Shadowing complicates cell arrangement and PMAD operation

Rigid Array

- Cosine losses around noon & midnight cannot be avoided
- Balanced electrical and thermal loads
- Closer packing reduces overall length

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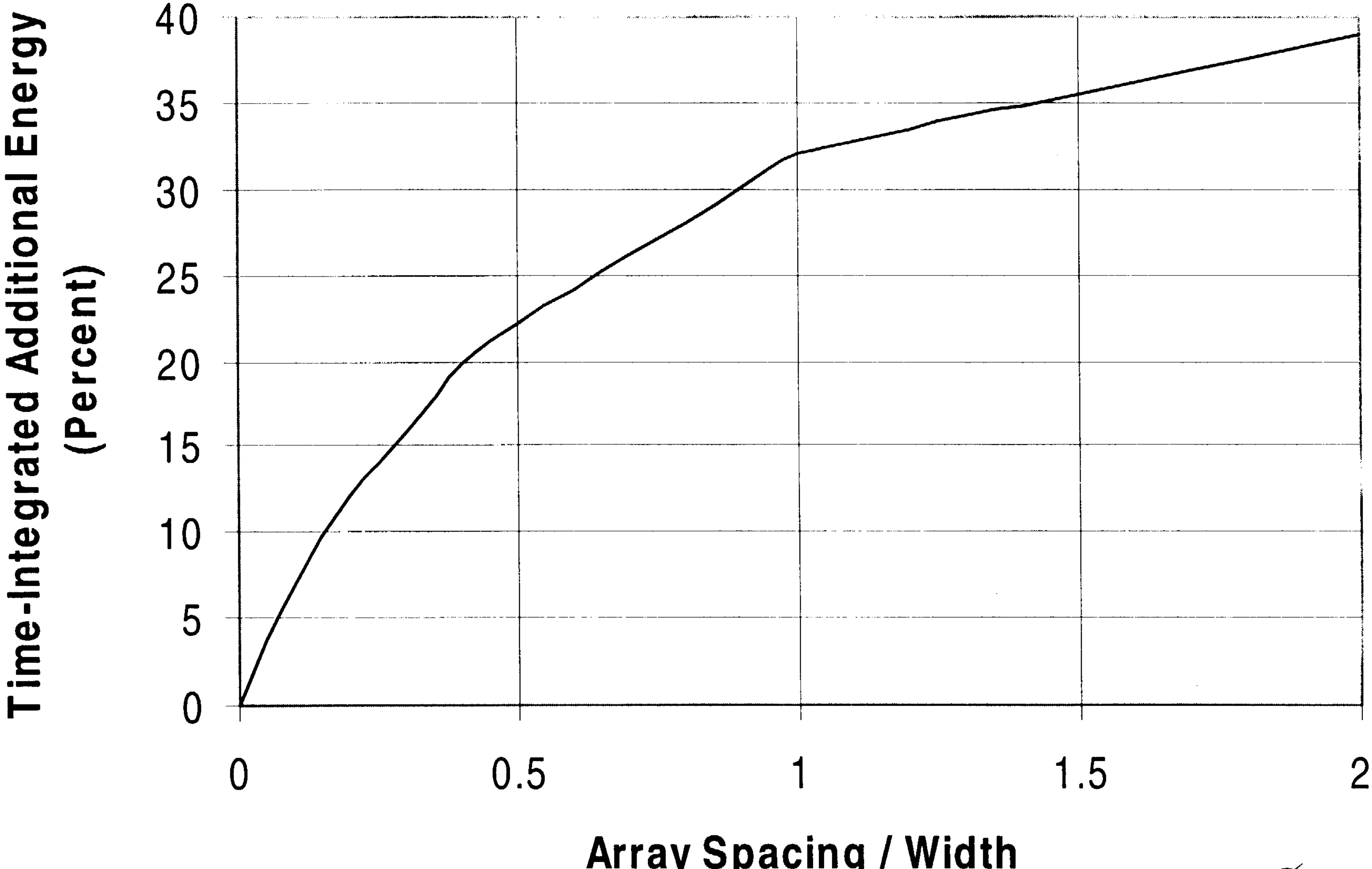

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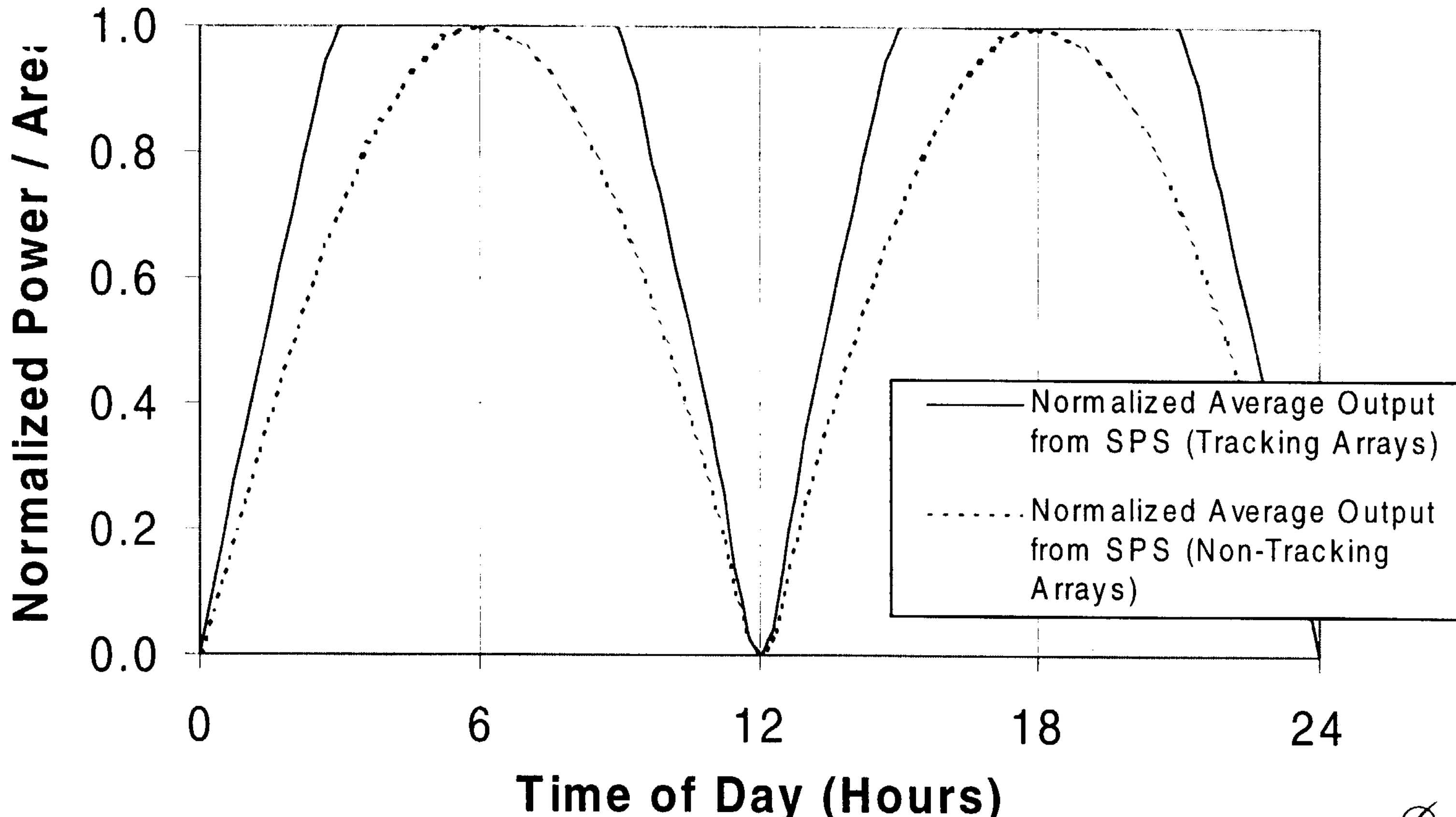
Tracking Vs. Non-Tracking SPS Arrays

(Arrays spaced 41% of width)



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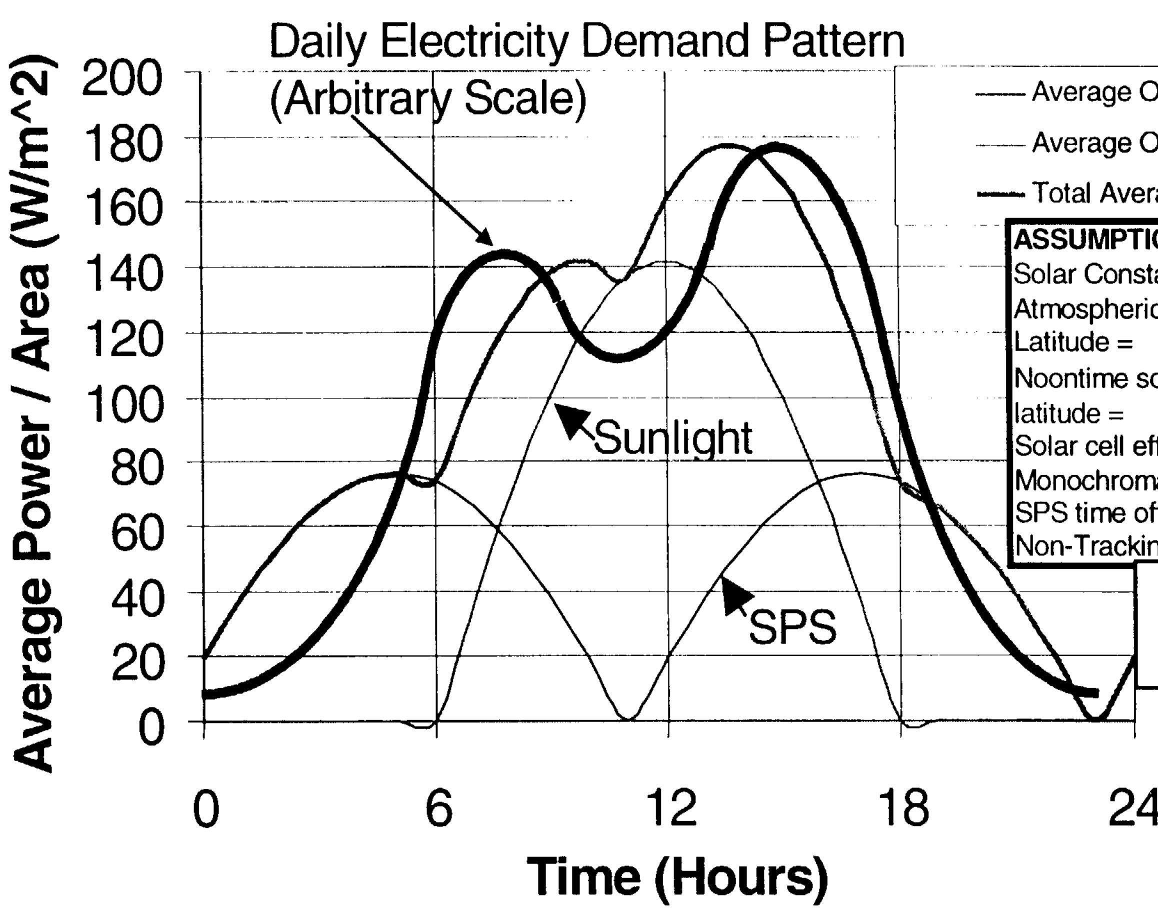
Terrestrial PV Array Output



ASSUMPTIONS:

Solar Constant in Space =	1370 W/m^2
Atmospheric Transmittivity =	0.7
Latitude =	35 degrees
Noontime solar constant at latitude =	785.6 W/m^2
Solar cell efficiency =	0.18
Monochromatic solar cell eff. =	0.36
SPS time offset =	1 hour
Non-Tracking Array	

Average SPS Power at Ground = 1/4 x Noon Sun
Peak SPS Power at Ground = 1 x Noon Sun

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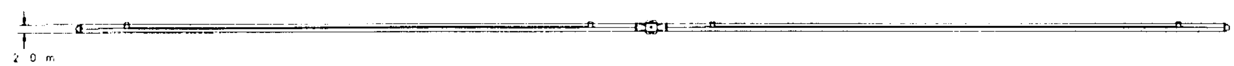
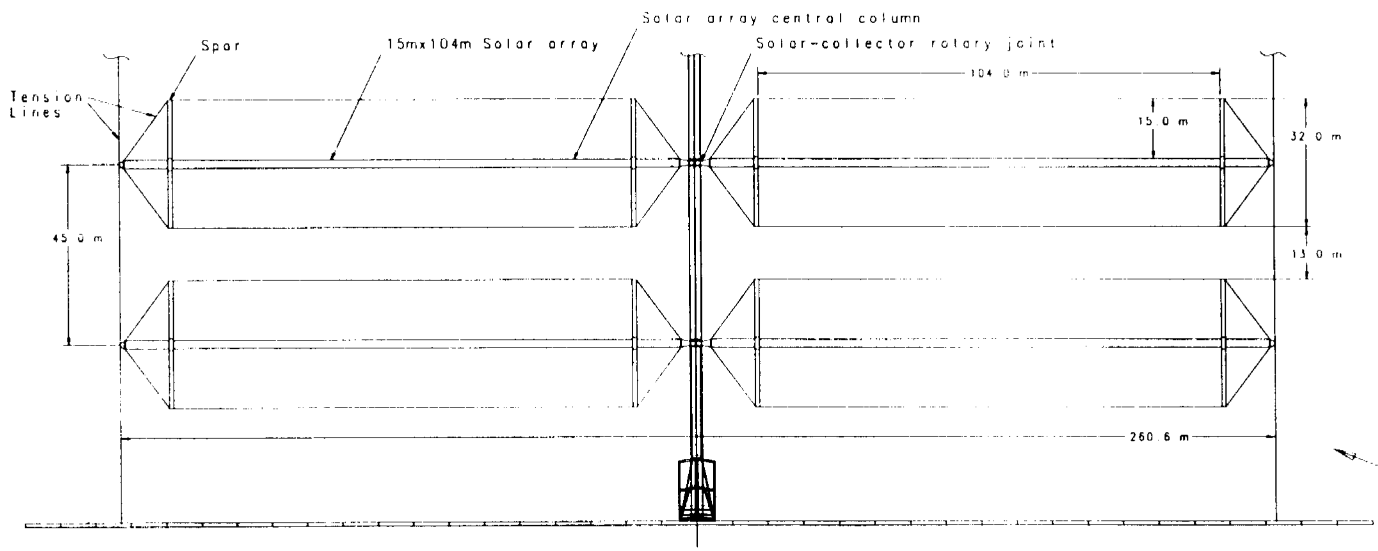
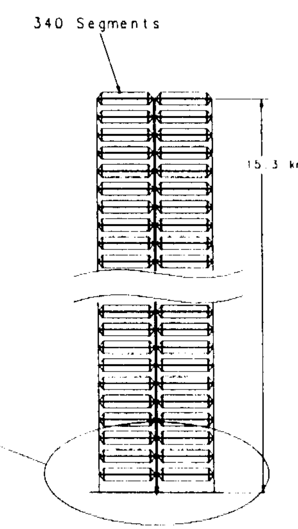


Sun Tower Segment Edge View



Sun Tower Base View (Horizontal "Along" Velocity Vector)



Sun Tower Profile View

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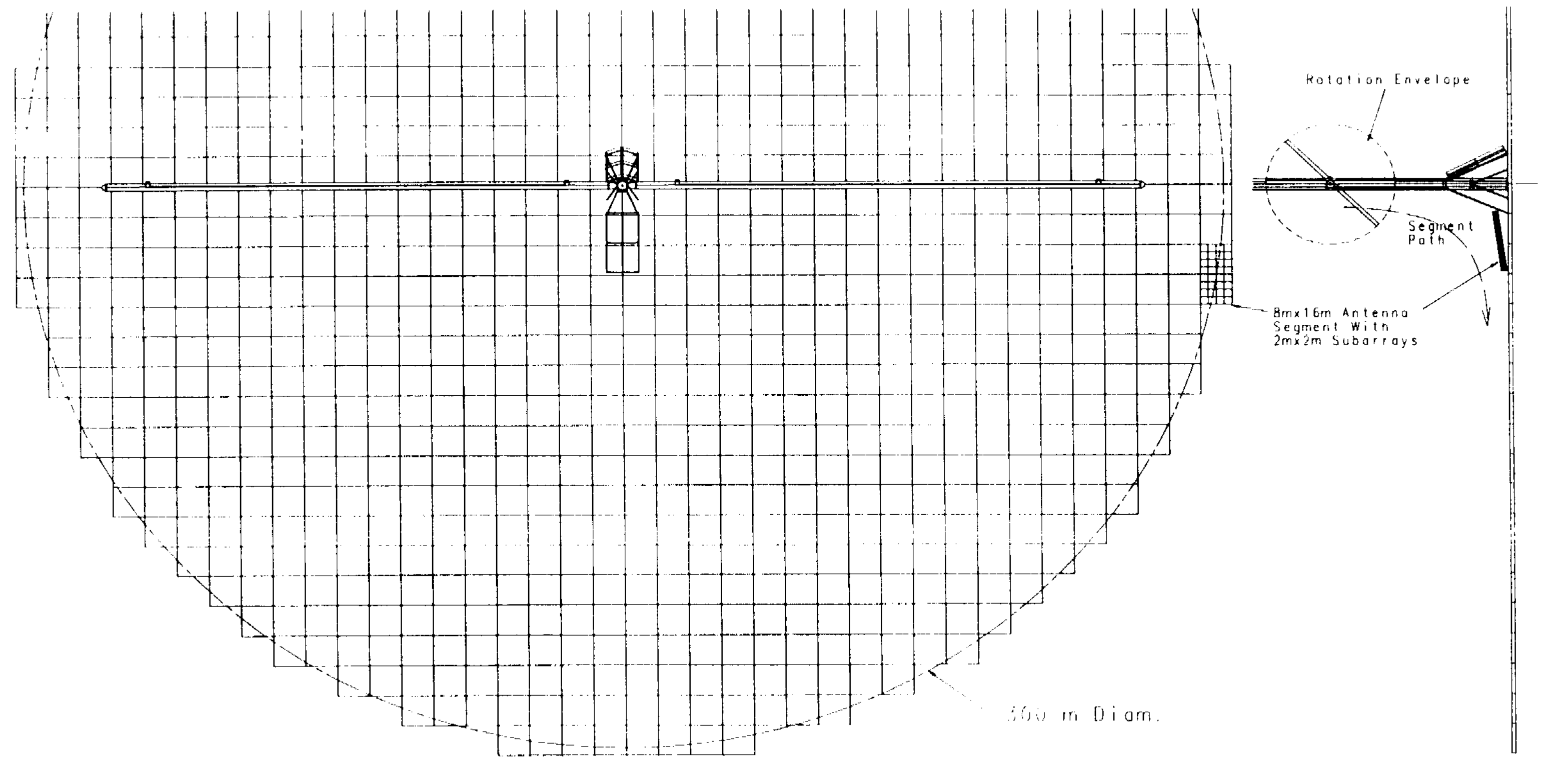

Sun Tower Base View ("Down" Local Vertical)

Perpendicular to Orbital Plane

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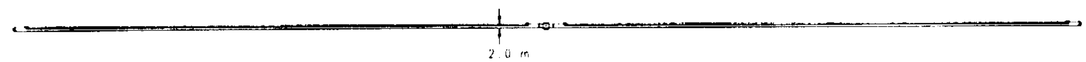
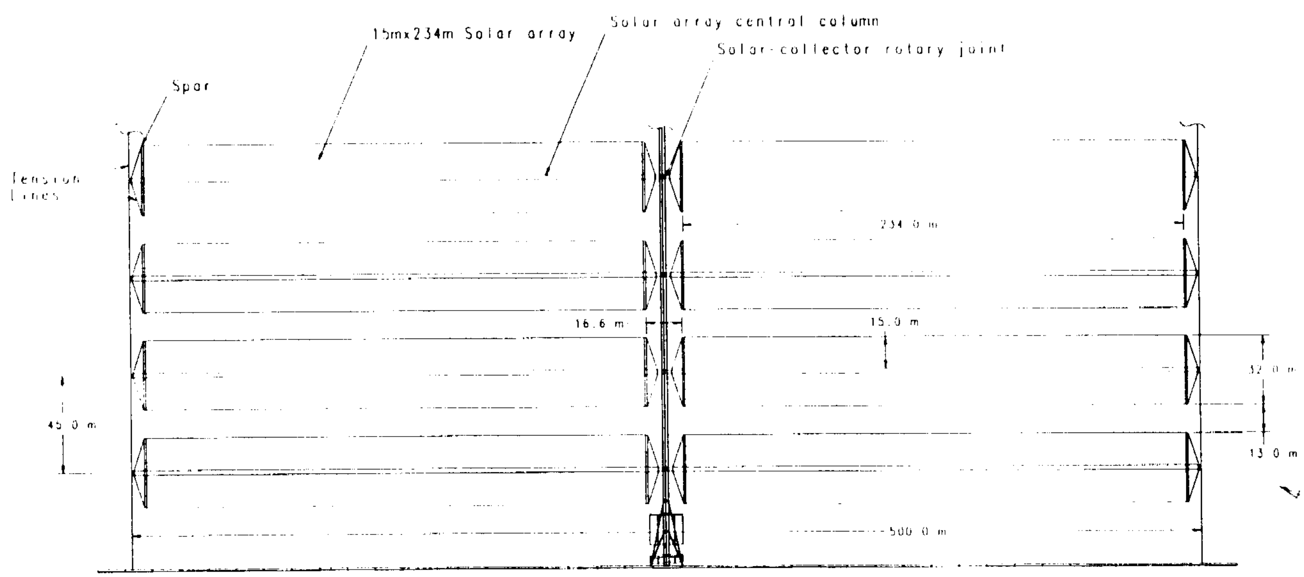
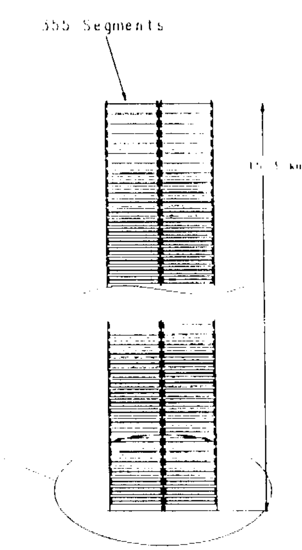


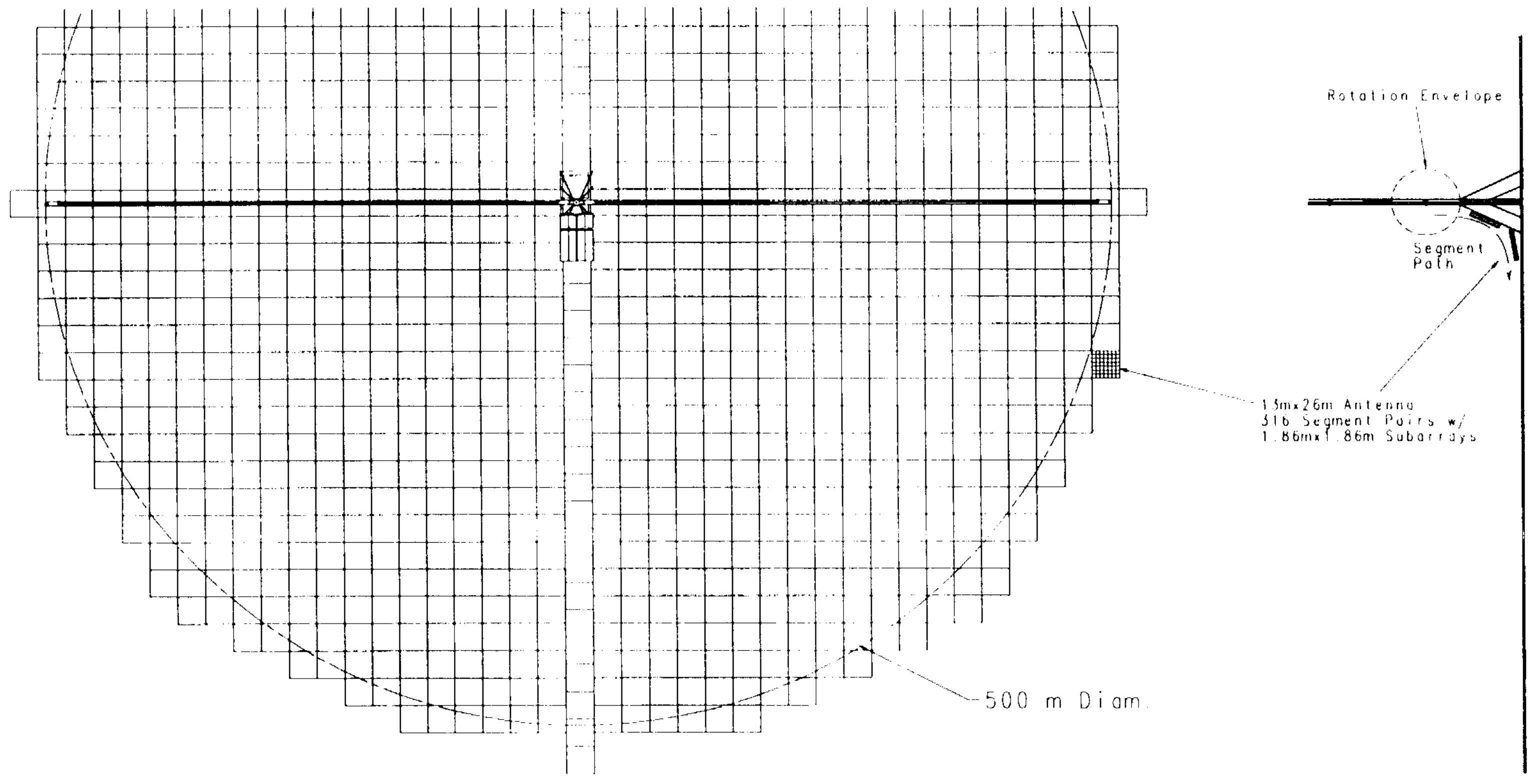
Sun Tower Segment Edge View



Sun Tower Base View (Horizontal "Along" Velocity Vector)



Sun Tower Profile View

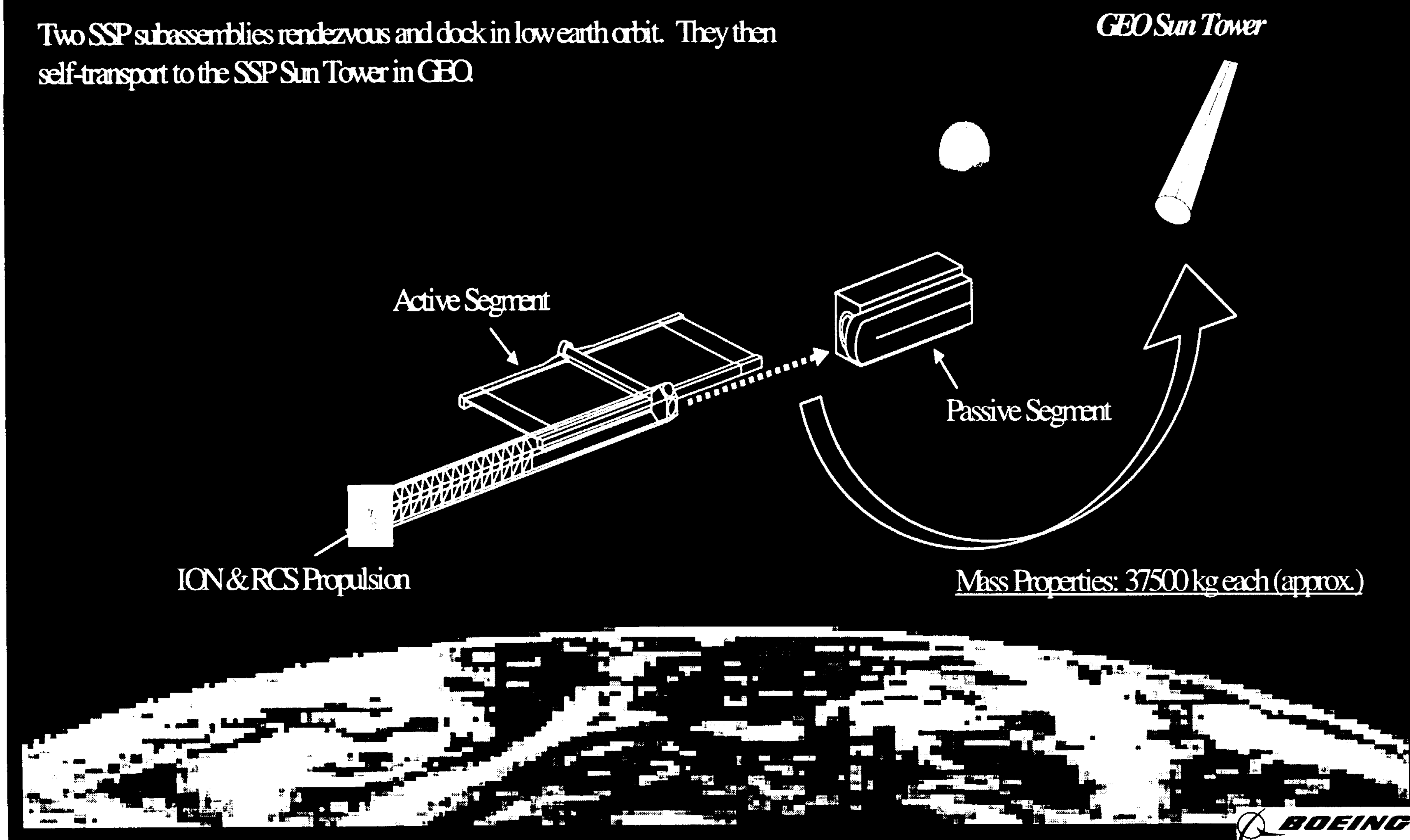


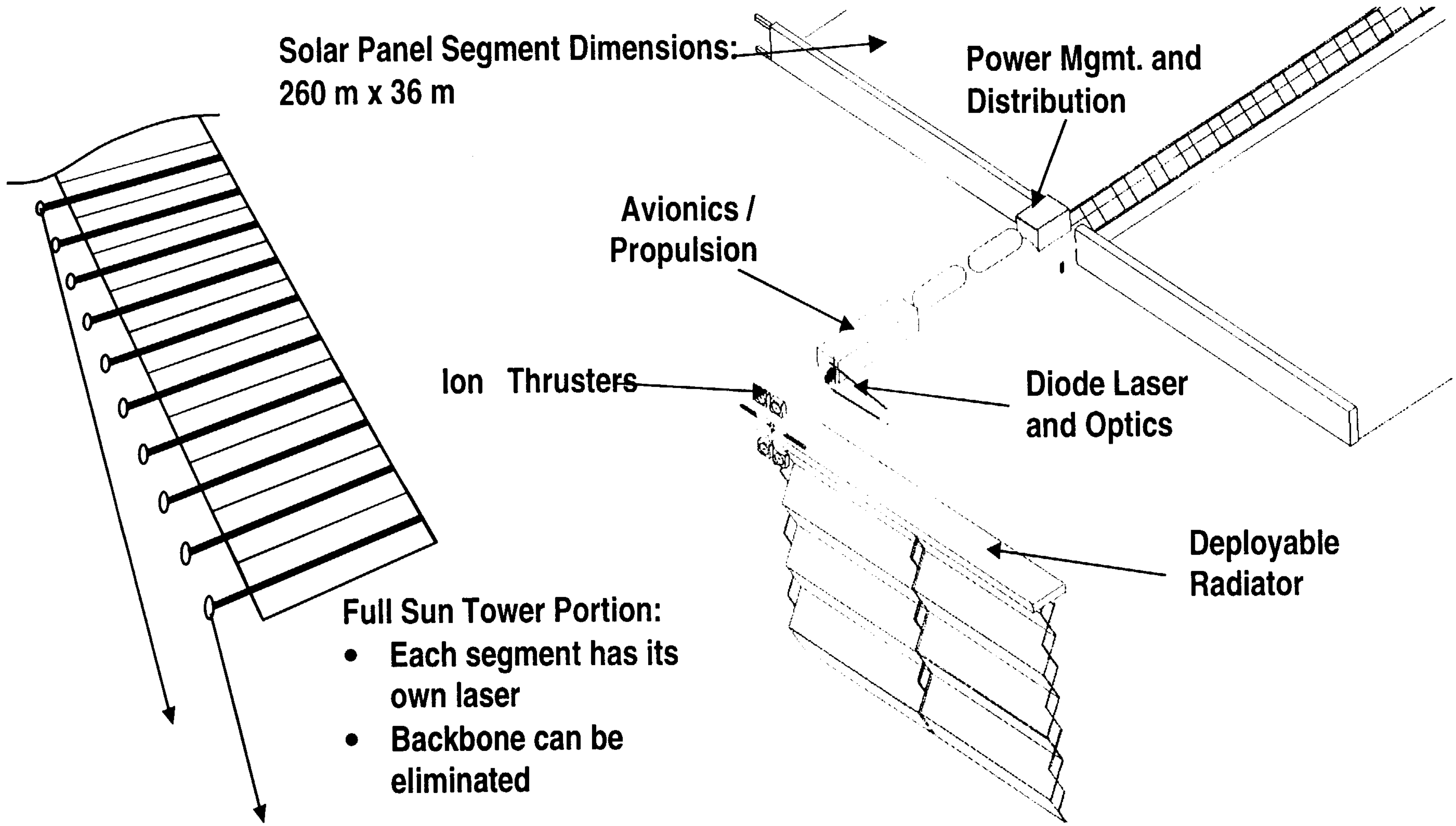
Sun Tower Base View ("Down" Local Vertical)

Perpendicular to Orbital Plane

Rendezvous and Dock with Sun Tower

Two SSP subassemblies rendezvous and dock in low earth orbit. They then self-transport to the SSP Sun Tower in GEO.





Solar Panel Segment Dimensions:
260 m x 36 m
Power Mgmt. and
Distribution
Avionics /
Propulsion
Ion Thrusters
Diode Laser
and Optics
Deployable
Radiator
Full Sun Tower Portion:
• Each segment has its own laser
• Backbone can be eliminated

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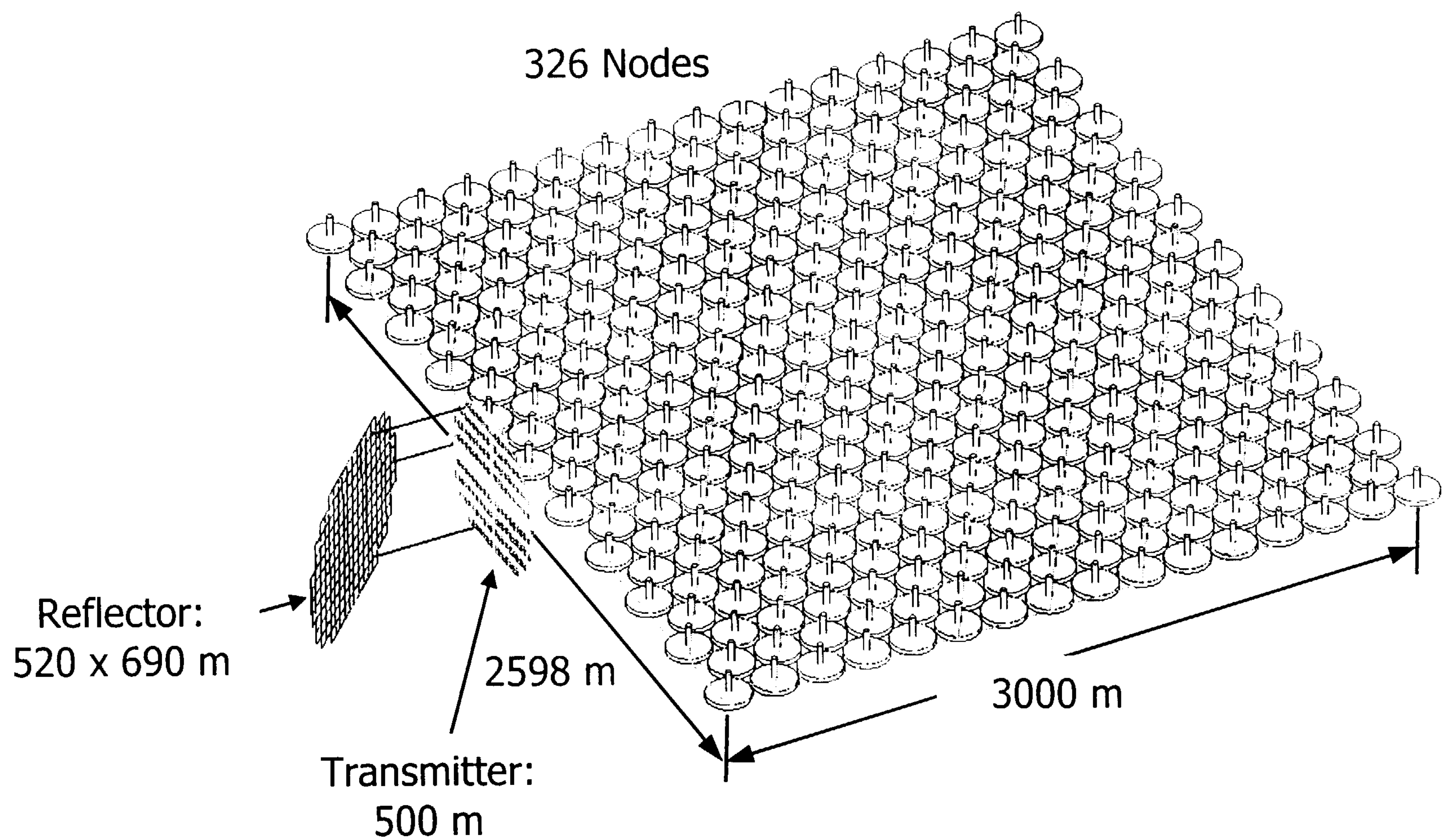
326 Nodes
Reflector:
520 x 690 m
Transmitter:
500 m
2598 m
3000 m

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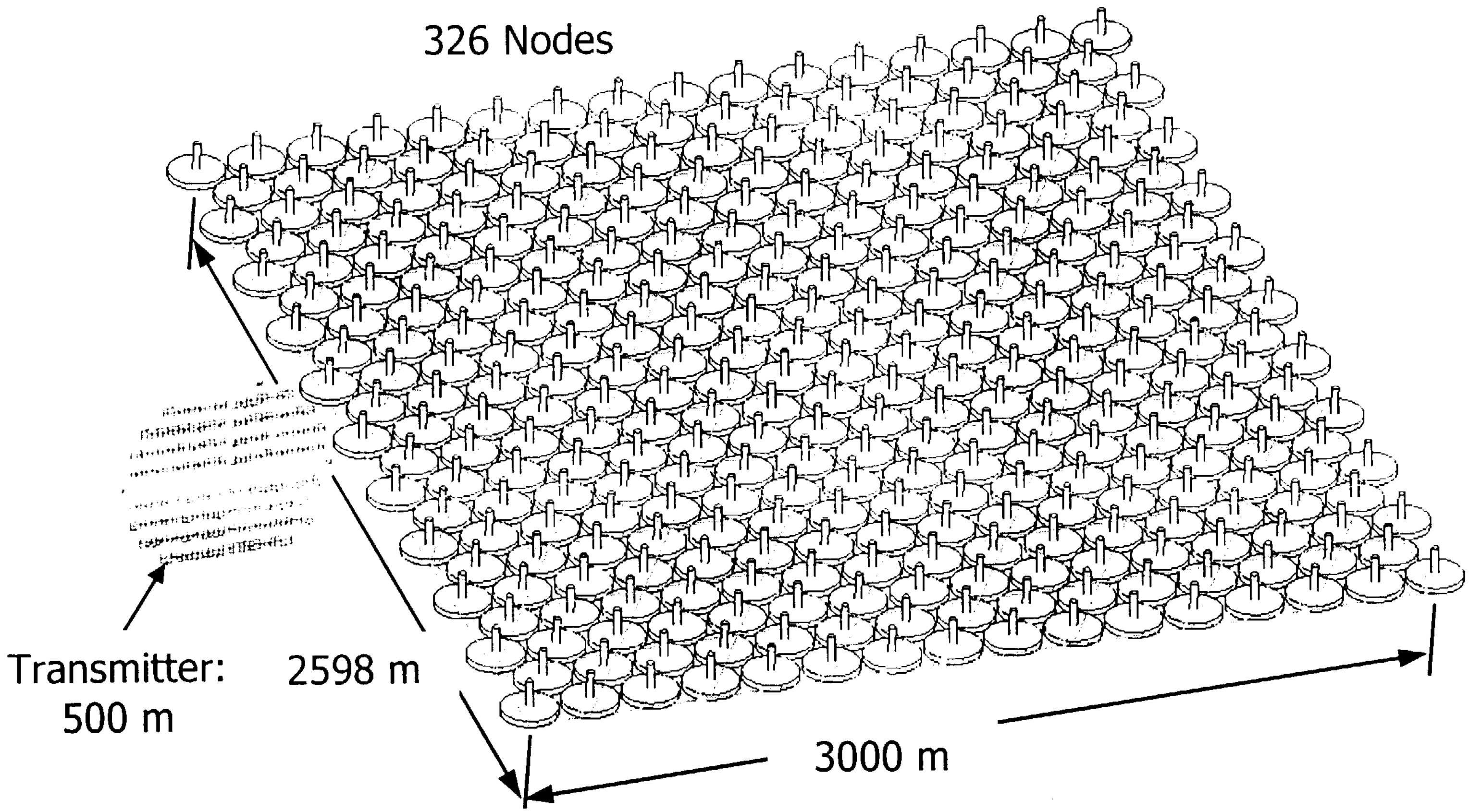

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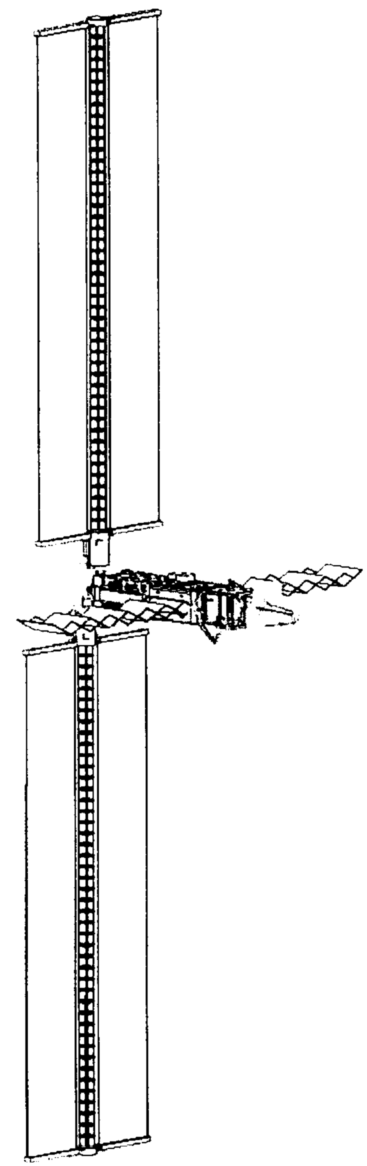
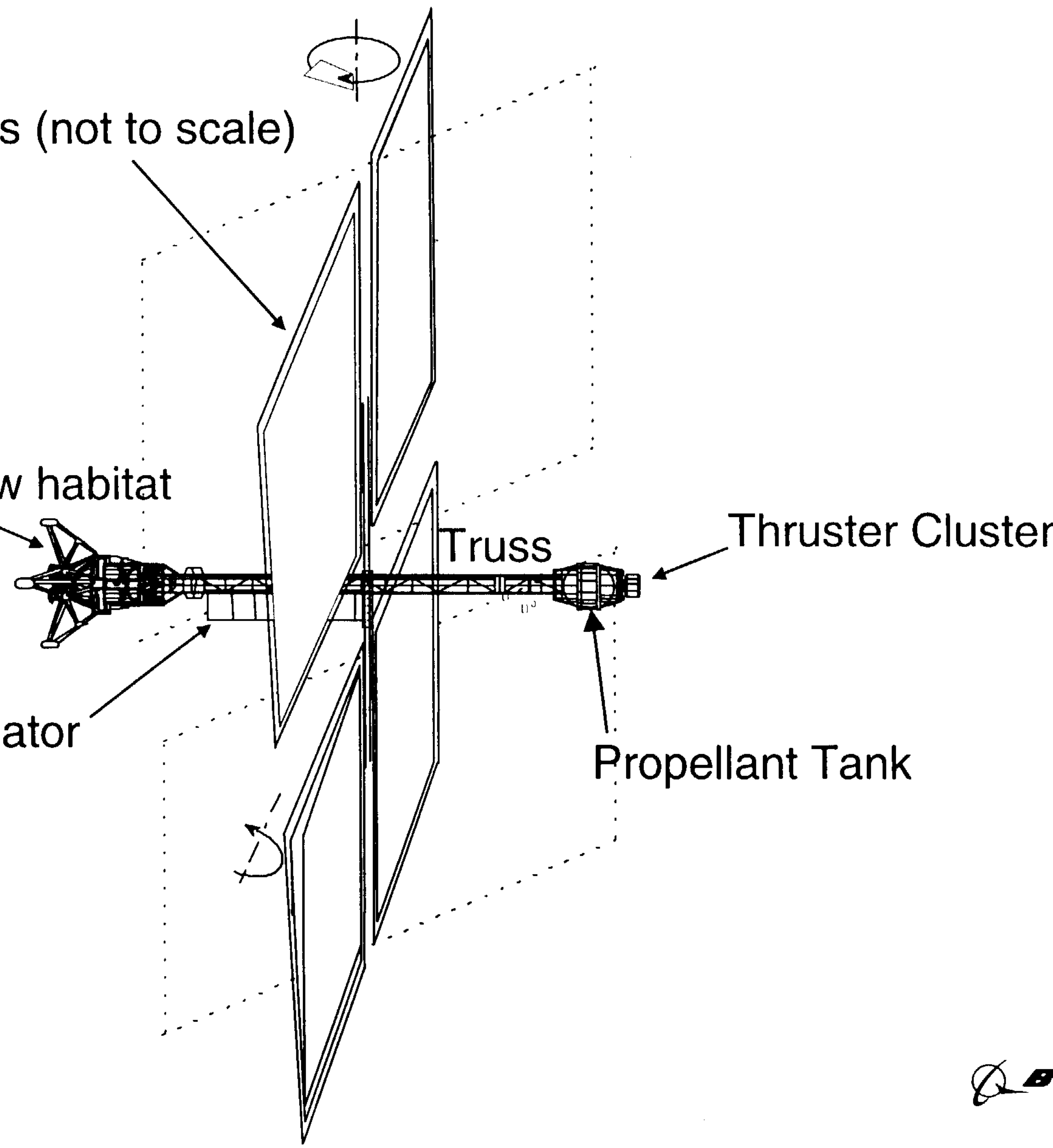
Criteria	*Sub-Criteria*	*Comments*
Cost	Cost/Power Delivered	Standard metric for terrestrial power
	Installed Cost	Standard metric for terrestrial power
	Launch Cost	Total system mass
	Cost to First Power	Minimum size of an economical system
Technological Difficulty		Technology readiness, $R\&D^3$, Modularity, ease of assembly, and ease of stationkeeping
Reliability/ Maintainability		MTBF, fault tolerance, system life
Market Issues	Market Compatibility	Matching energy and geographic demand
	Growth Potential	Ability to expand to TW power levels
	Infrastructure compat.	Interaction with existing infrastructure
Dual Use of Technology		Application to other missions/architectures
Environmental Issues	Env. Impact on Earth	Launch vehicle exhaust, microwave/laser
	Env. Impact on Space	Debris creation, orbital slots
	EMC/EMI	Interference with satellites, terrestrial com.
Political Issues	Perception	Microwaves cooking, weapons in space
	Legal	International laws and treaties

Criteria	Sub Criteria	Criteria Rating	Sub-Criteria Rating
COST		0.22512	
	$/POWER		0.07067
	INSTALL$		0.05990
	LAUNCH$		0.02869
	1STPOWER		0.06587
TECH-DIF		0.21570	
RELIABLE		0.18323	
MARKET		0.13490	
	COMPATIB		0.06567
	GROWTH		0.01912
	INFRASTR		0.05011
DUAL USE		0.10446	
ENVIRON		0.07455	
	EARTHIMP		0.03629
	SPACEIMP		0.01057
	EMC/EMI		0.02769
POLITIC		0.06203	
	PERCEPTN		0.01772
	LEGAL		0.04430

The overall inconsistency is 0.00639 which shows a very high degree of consistency

- Deploys in low Earth orbit from Space Shuttle
- Spirals to operational orbit using solar electric propulsion
- Transmits power to satellites during eclipse period
  - Option 1: store power while in sunlight for transmission during eclipse
  - Option 2: Power Plug always stays in sunlight, e.g., ~12° inclined orbit is always in sunlight when GEO satellite is in eclipse





Arrays (not to scale)
Lander with crew habitat
Truss
Thruster Cluster
Radiator
Propellant Tank

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- Solar power satellites in geostationary orbit using solar cells for energy conversion and microwaves for power transmission continue to show promise
- The use of heat engines instead of solar cells and/or low-intensity laser light to transmit power also shows promise
  - Level of detail in studies done so far is not sufficient for a fair comparison with systems using solar cells and microwaves
- Near-term applications of SSP technology can make an important contribution to the exploration and development of space, while paving the way toward commercial SSP.