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TOWARDS TEN MOON VILLAGE AND BEYOND

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Orbital Space Solar Power Option for a Lunar Village

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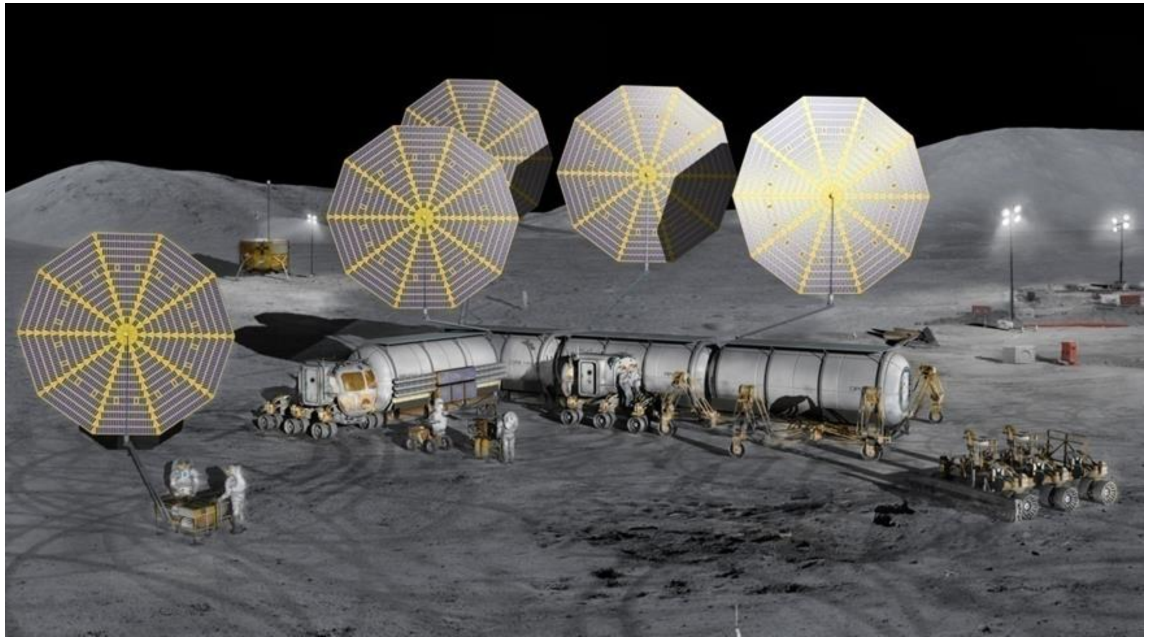
Notional Lunar Village Power Requirements and Options

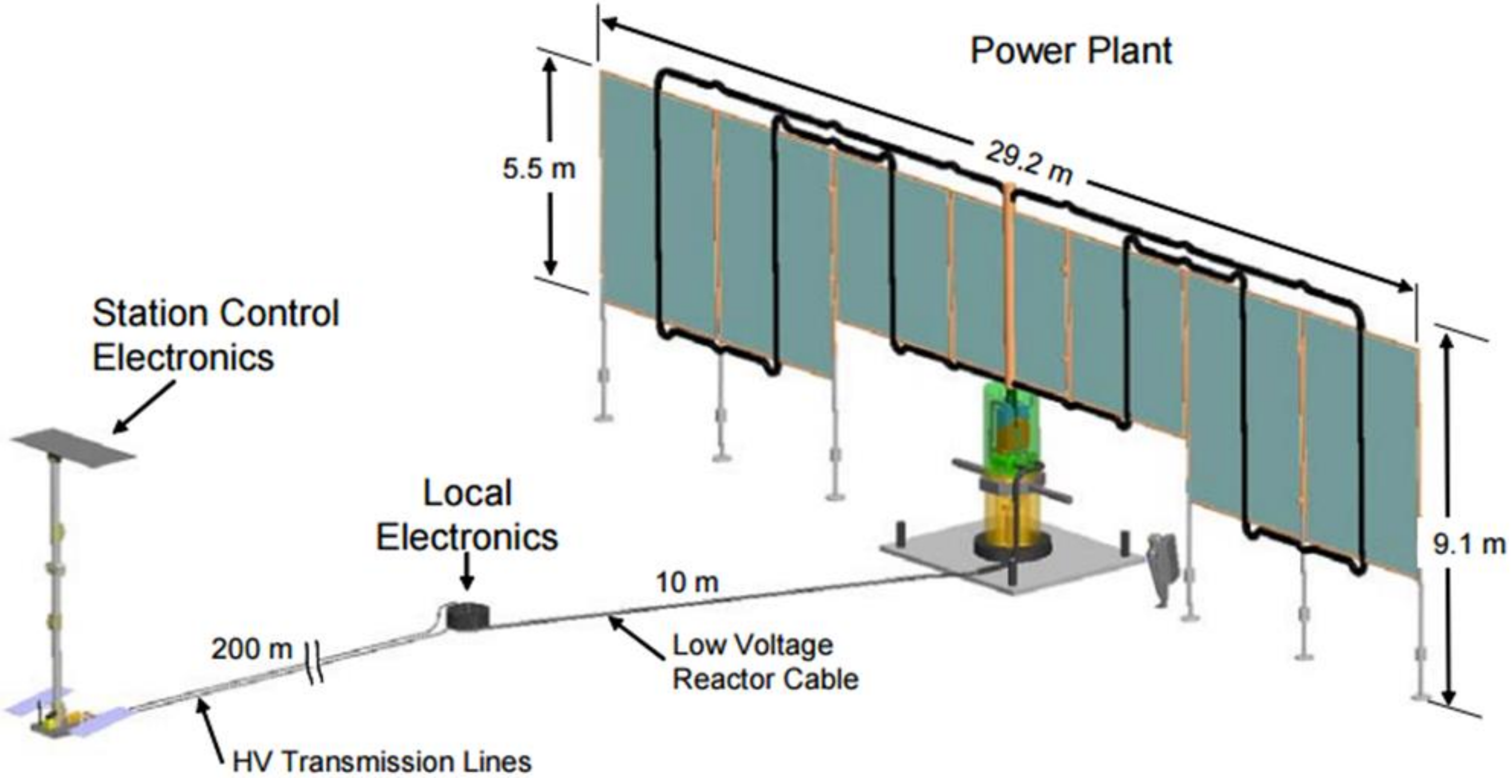
- A crewed lunar outpost will require ~ 35kW continuous power
- Optimally provided by ground-based solar arrays during the lunar day
  - Nighttime outpost occupancy is an issue due to lack of sunlight
- Need for continuous power restricts location to the lunar south pole



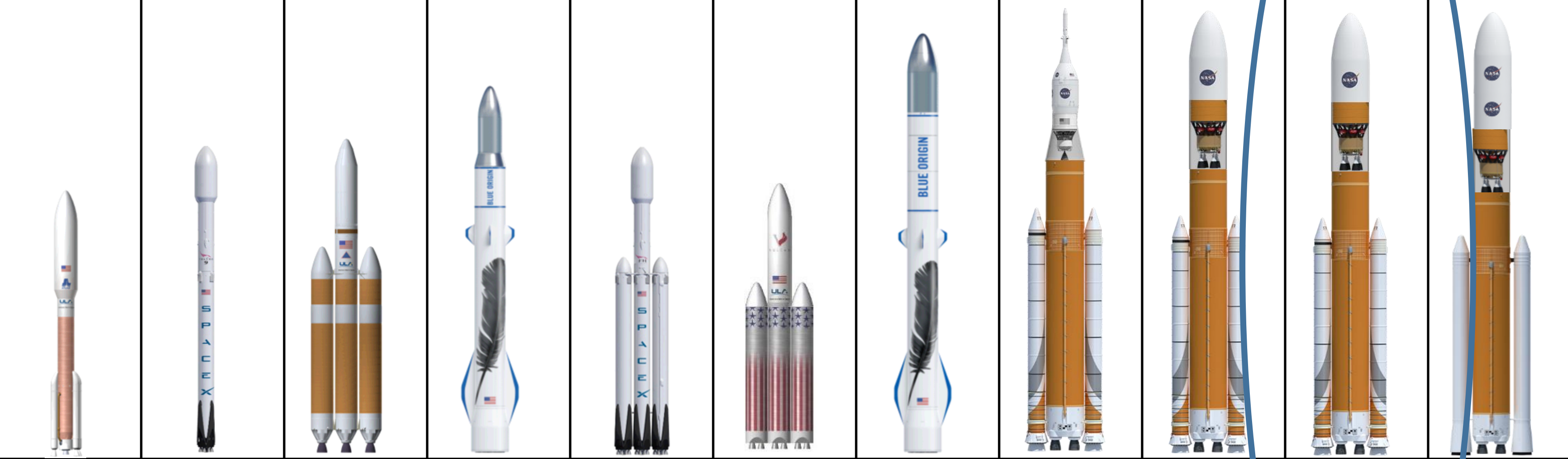
The spin axis of the Moon is nearly perpendicular (off from the vertical by 1.5°) to the plane of its orbit. This means that at the poles, the Sun is always close to the horizon. As the Moon slowly rotates during the course of a lunar day, the Sun tracks a 360° circle around the pole, sometimes just above the horizon, sometimes dipping just below it.

Nuclear Power: The Conventional Answer to the Power Problem

- 50 Kilowatt fission reactor can provide continuous electrical power
- Issues:
  - Safety
  - Cost ($B)
  - Political Considerations



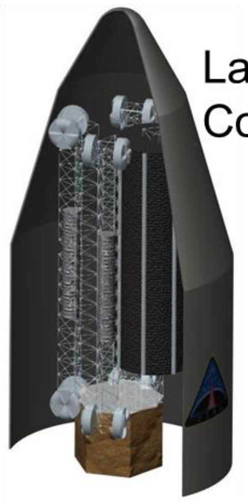
The Space Launch System Capability Enables an Alternative

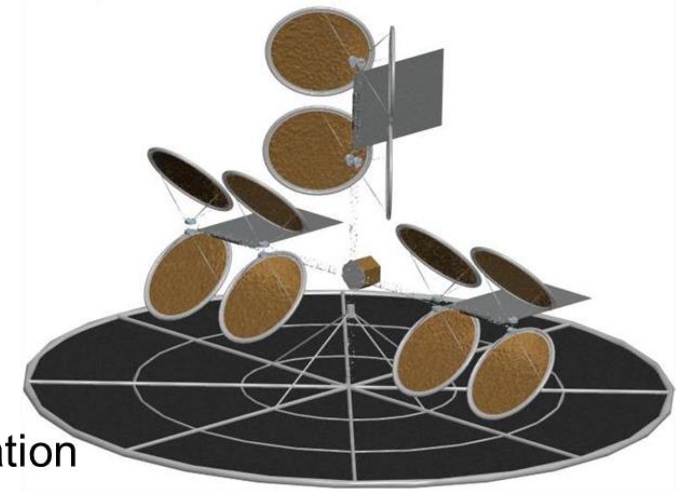
Launch Vehicle Performance											
Mission	ULA Atlas 551	SpaceX Falcon 9	Delta IV Heavy	Blue Origin New Glenn 2 Stage	SpaceX Falcon 9 Heavy	ULA Vulcan Heavy	Blue Origin New Glenn 3 Stage	SLS Block 1	SLS Block 1B	SLS Block 1B+	SLS Block 2B
											
Units	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)	lbm (mt)
LEO	40,300 (18.3)	50,200 (22.8)	57,900 (26.3)	98,200 (44.5)	119,900 (54.4)	118,675 (53.8)	135,100 (61.3)	191,500 (86.9)	216,000 (98.0)	232,000 (105.2)	294,000 (133.4)
Direct Europa (C3=83)	2,600 (1.2)		3,400 (1.5)	n/a		7,742 (3.5)	8,000 (3.6)	11,500 (5.2)	15,000 (6.8)	16,000 (7.3)	23,400 (10.6)

SLS Application for a Single Launch Solar Power Satellite for the Lunar Outpost

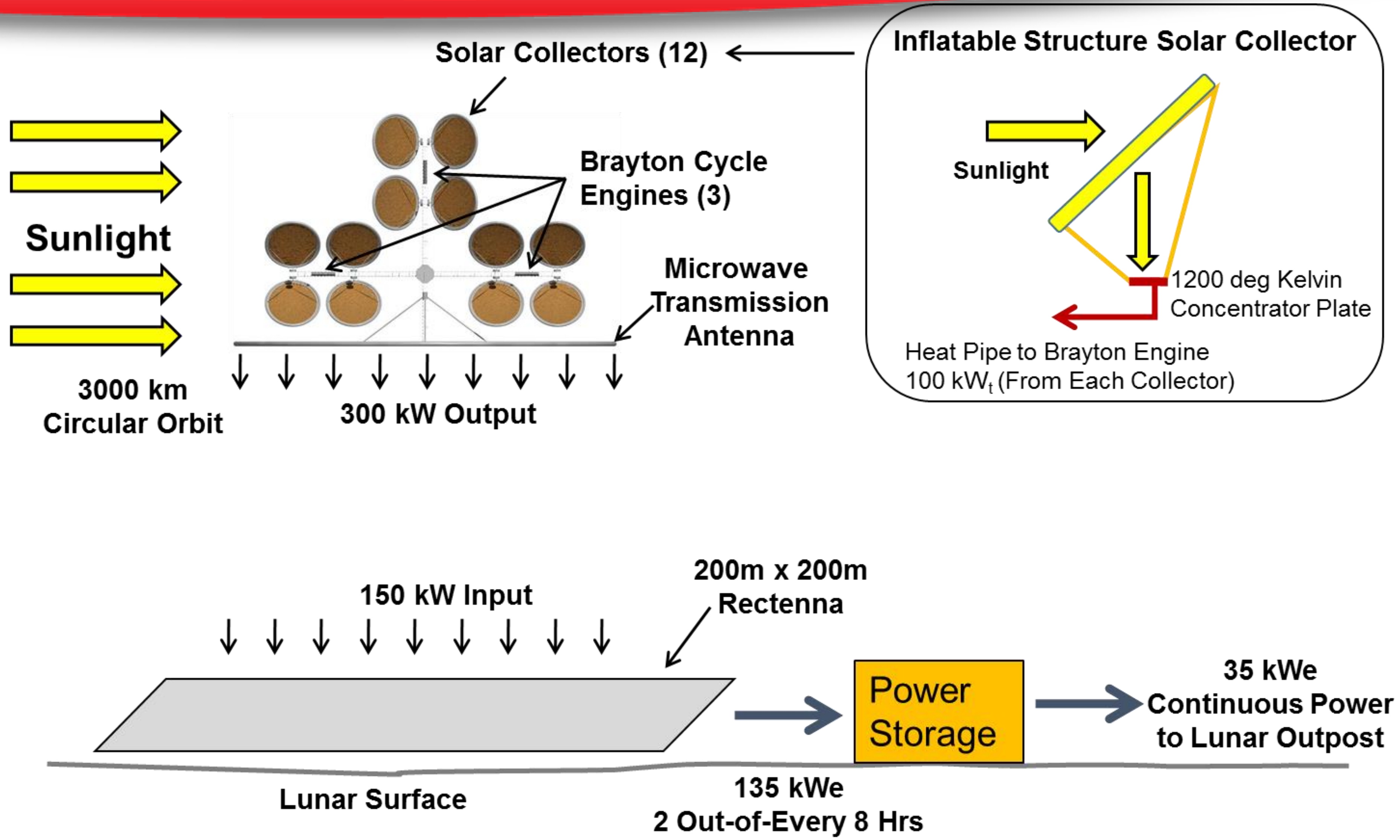
- SLS 1B+ Can Deliver a 41.5 mt Solar Power Satellite to Lunar Orbit
- Includes an upper stage to circularize in lunar orbit
- 3,000 km Altitude Lunar Polar Orbit
- Allows Two Hour Power Transmission to Surface Every Eight hours
- 200 m^2 Surface Rectenna delivered separately via Cargo Lander(s)

- Solar Power Satellite Overview
- 12 Inflatable Solar Collectors (14 m x 28m)
- Solar Energy Focused onto High Temperature Concentrators
- Heat Transferred to Three 100 kW Brayton Cycle Engines
- 85 m Diameter Transmission Antenna
- Total delivered power to lunar outpost = 35 kW


Launch Configuration


Deployed Configuration

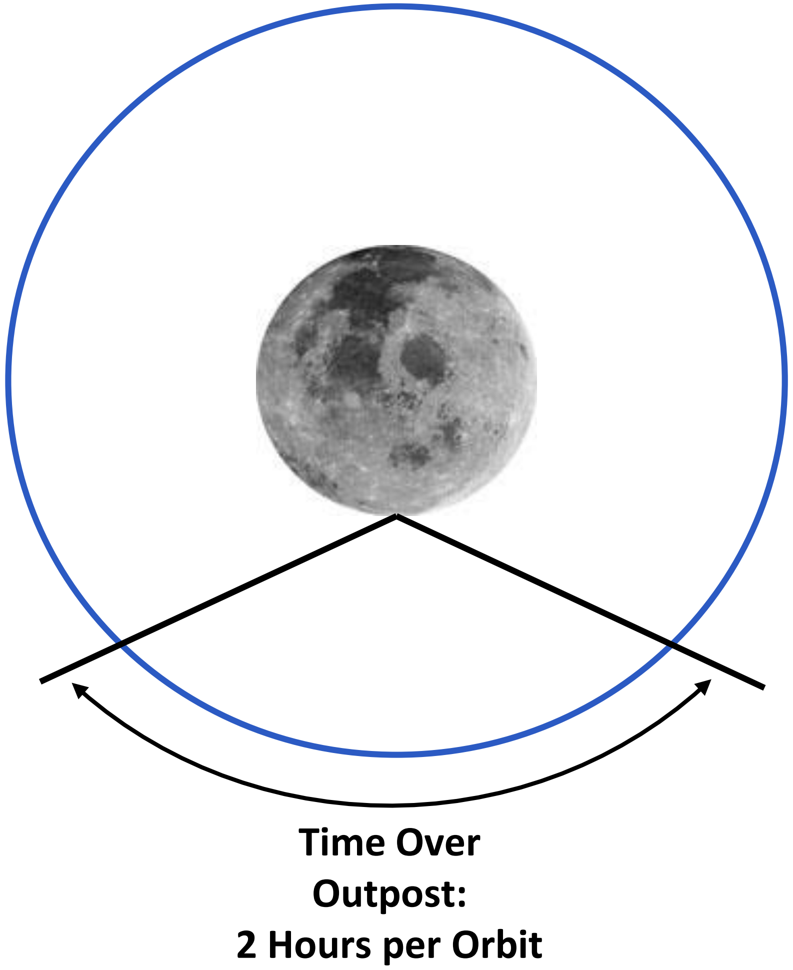
Lunar Outpost
Solar Power Satellite Concept



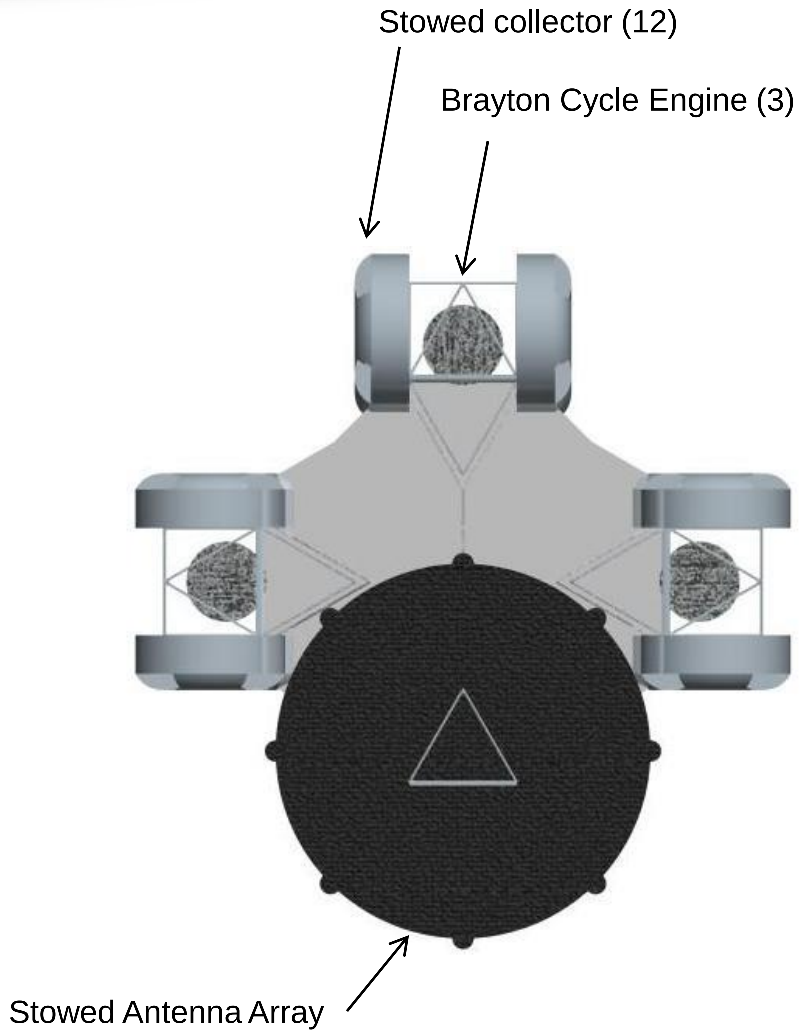
Lunar Orbit Assumptions

Lunar Solar Power Satellite can Transmit Power to Outpost Two Out-of-Every Eight Hours

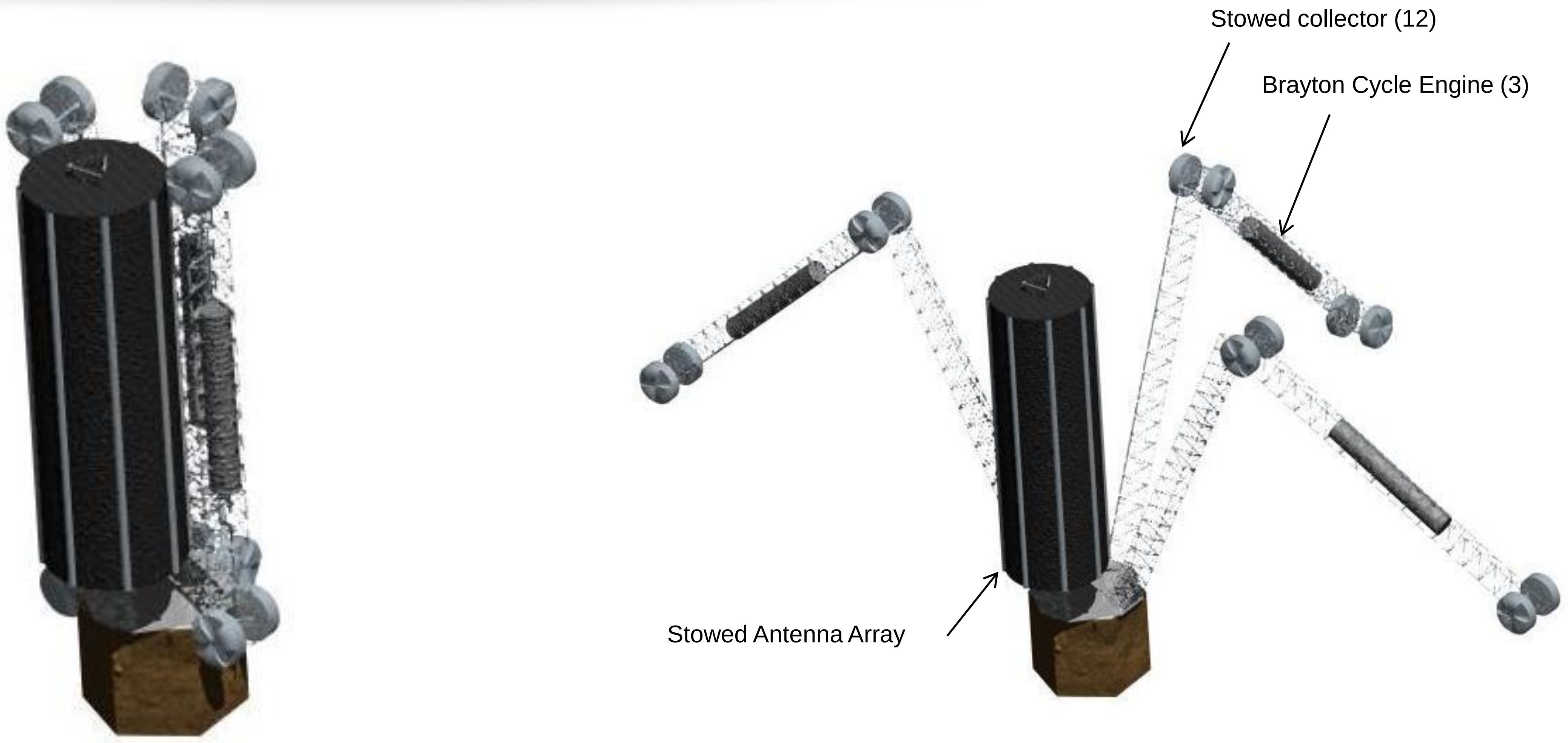
- Lunar Solar Power Satellite Orbit
- 3000 km Circular Polar Orbit (Inclination = 90 Degrees)
- Period = 8 Hours



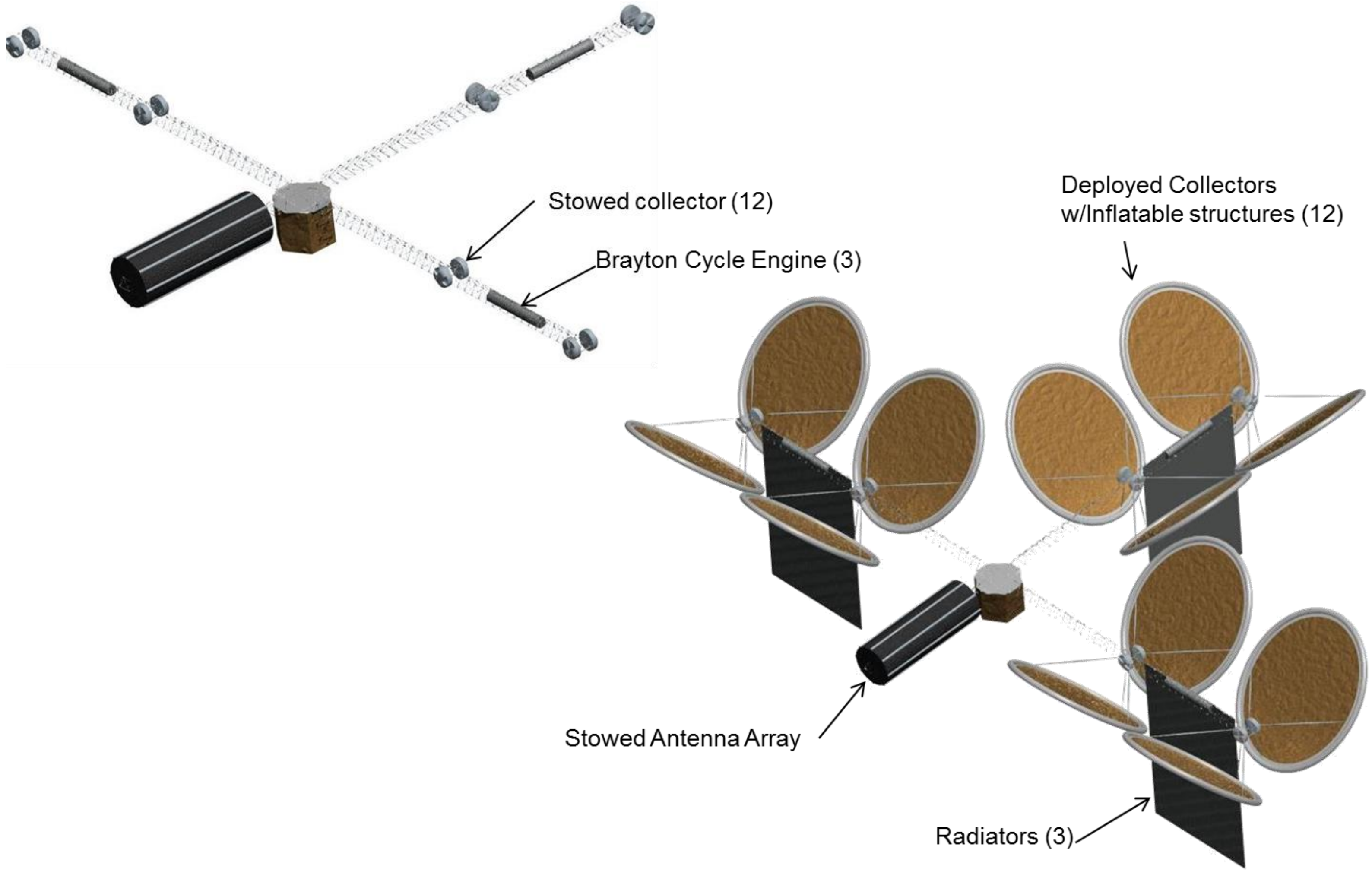
SLS Launch (Stowed) Configuration



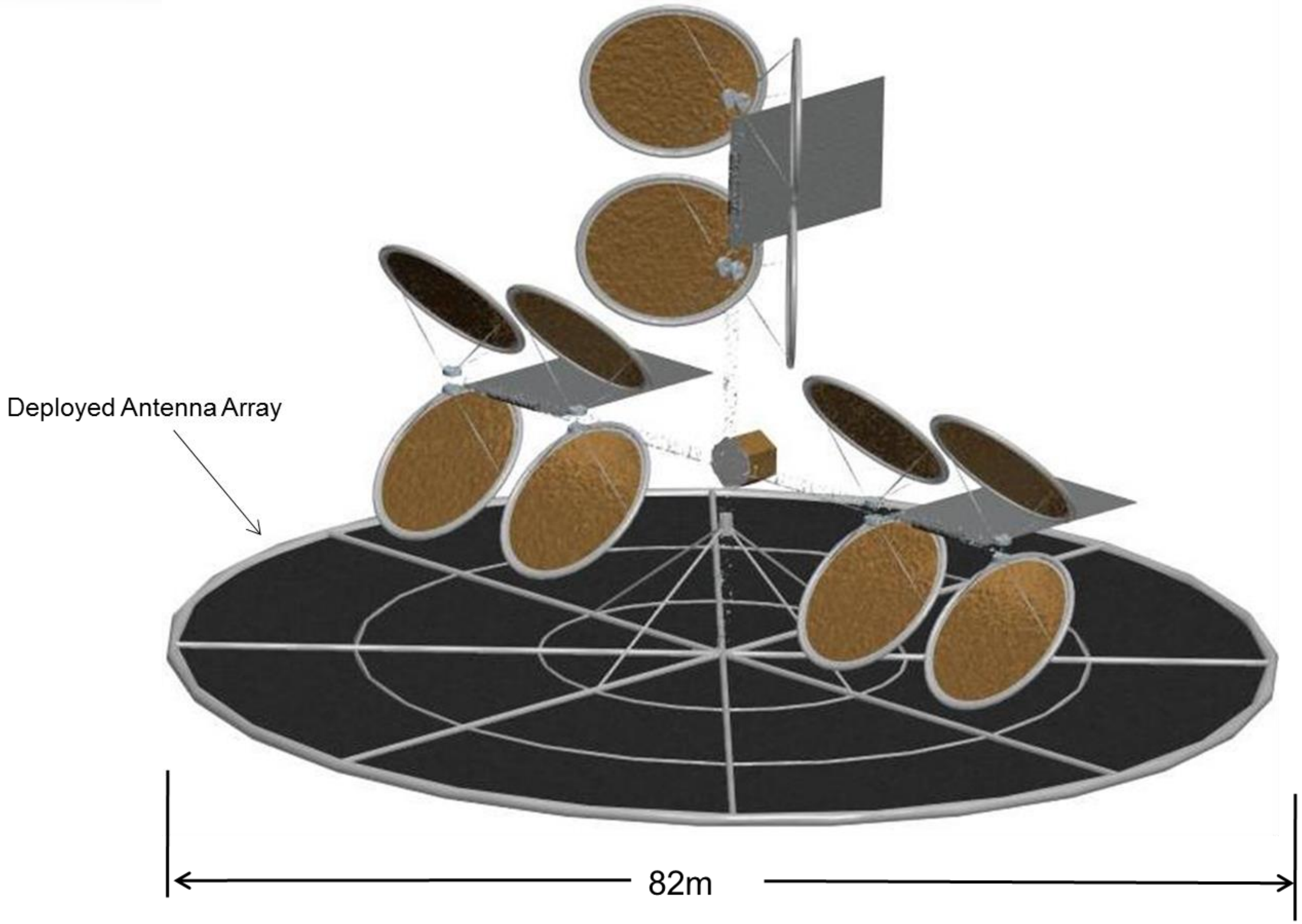
Solar Collector Truss Deployment



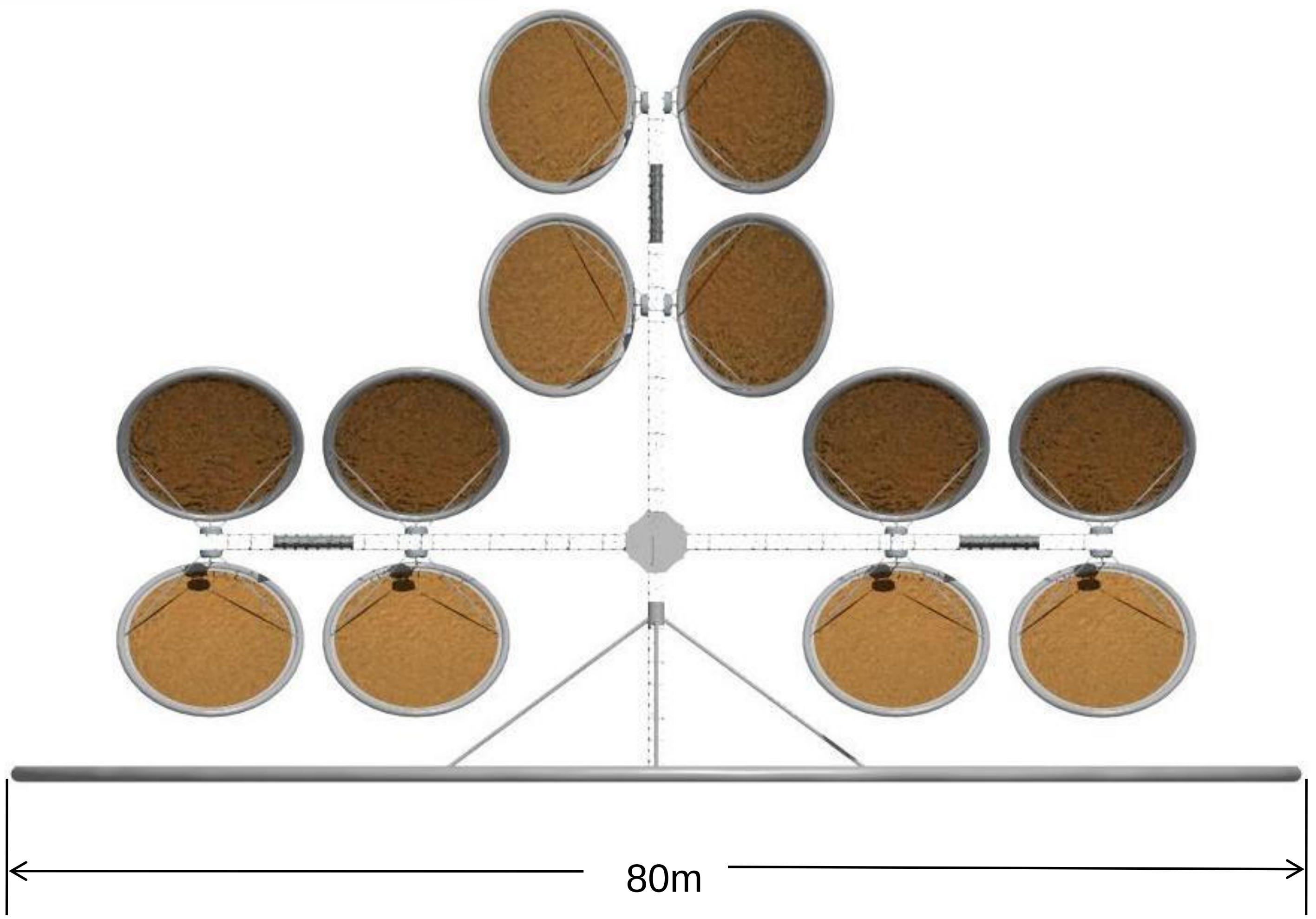
Solar Collector Deployment



Operational Configuration



Deployed Configuration Facing Sun

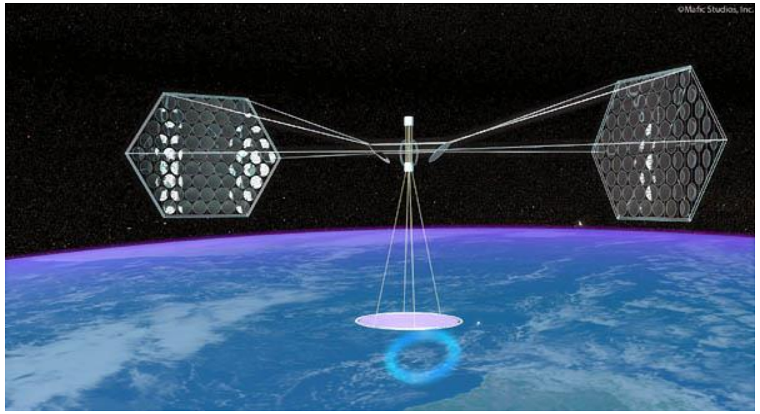


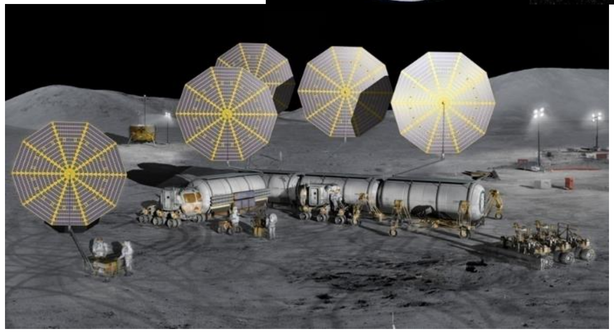
Solar Power Satellite Mass Breakdown

System	Qty	Mass (kg)	Power (kW)	Area (M^2)	Mass Total (kg)	Mass w 30 % Cont. (kg)
Thermal						
Brayton engine	3	600	400 kW ea	1 per truss	1800	2340
Heat pipes	3	270	100 kW ea	4 per truss	810	1053
Radiators Brayton	3	3165		161 m^2 ea	9495	12343.5
Radiators PMAD	0	0			0	0
Radiators ACS	0	0			0	0
		4035				
PowMan&Dist (PMAD)						
Collector	12	100			1200	1560
Collector plate	12	10			120	156
		110				
Solar panel (SP)	0	0			0	0
Power cables	3	130			390	507
Battery	2	50			100	130
µwave convertor	1	7500			7500	9750
Transmitter antenna	1	5550		84 m dia	5550	7215
Antenna deployment	1	400			400	520
		13450				
Attitude Cont Sys (ACS)						
CMGs	4	100			400	520
Propulsion	1	350			350	455
Comm & Data Sys (CDS)	1	100			100	130
Structures						
Solar trusses	3	930			2790	3627
Bus	1	2400			2400	3120
Totals					**33405**	**43426.5**

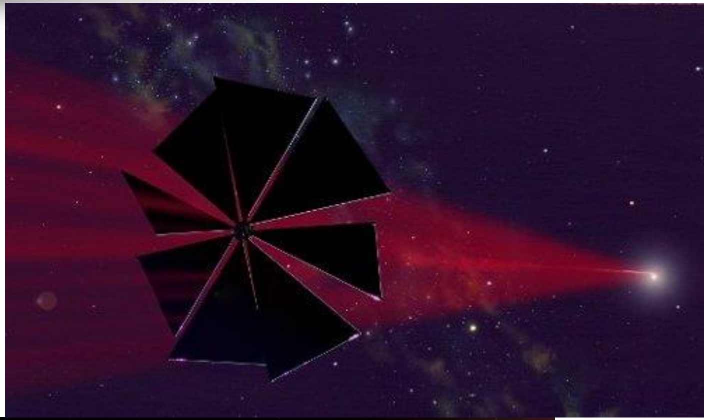
Space Based Solar Power Also Enables Robust Solar System Exploration

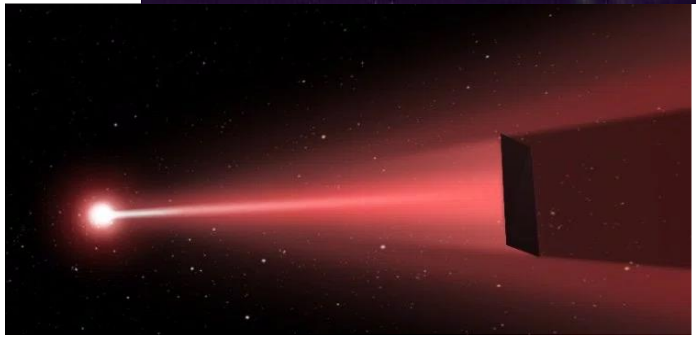
Terrestrial Space Solar Power





Powering Lunar Bases



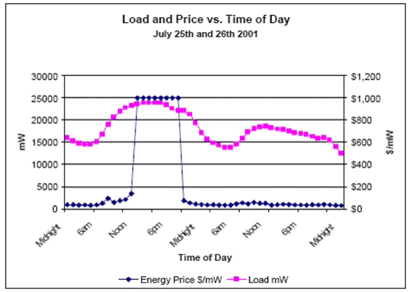


Rapid Robotic Solar System Exploration

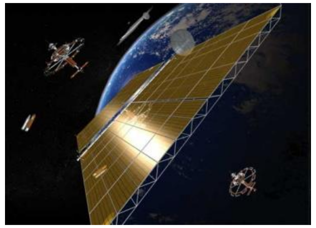
Evolutionary Space Solar Power Development for Terrestrial Use

Capability
(No. Launches, Efficiency, etc.)

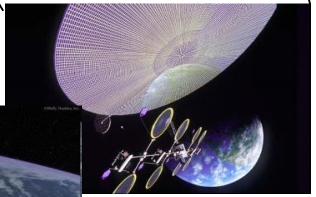
- Phasing: Start with what we can do now to meet real NASA needs
- Stakeholders: Develop an evolutionary capability that can meet other near-term national needs
- Strategic: For the nation, in the long-term, this potentially represents a "game changing" energy strategy
- Heritage: Don't let previous "grand" scenarios bias against a methodical and realistic engineering approach. Don't let entrenched notions of "how it should be done" limit thinking.



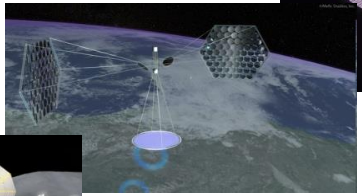
Supplement the grid when the demand and cost are high



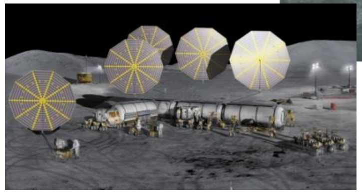
Large Scale Space Solar Power for Domestic energy



Peak Power Supplement
To alleviate brownouts/blackouts



Disaster Relief and
Forward Power for DoD



Night/Day Power
For the Lunar Outpost

Time

Conclusion

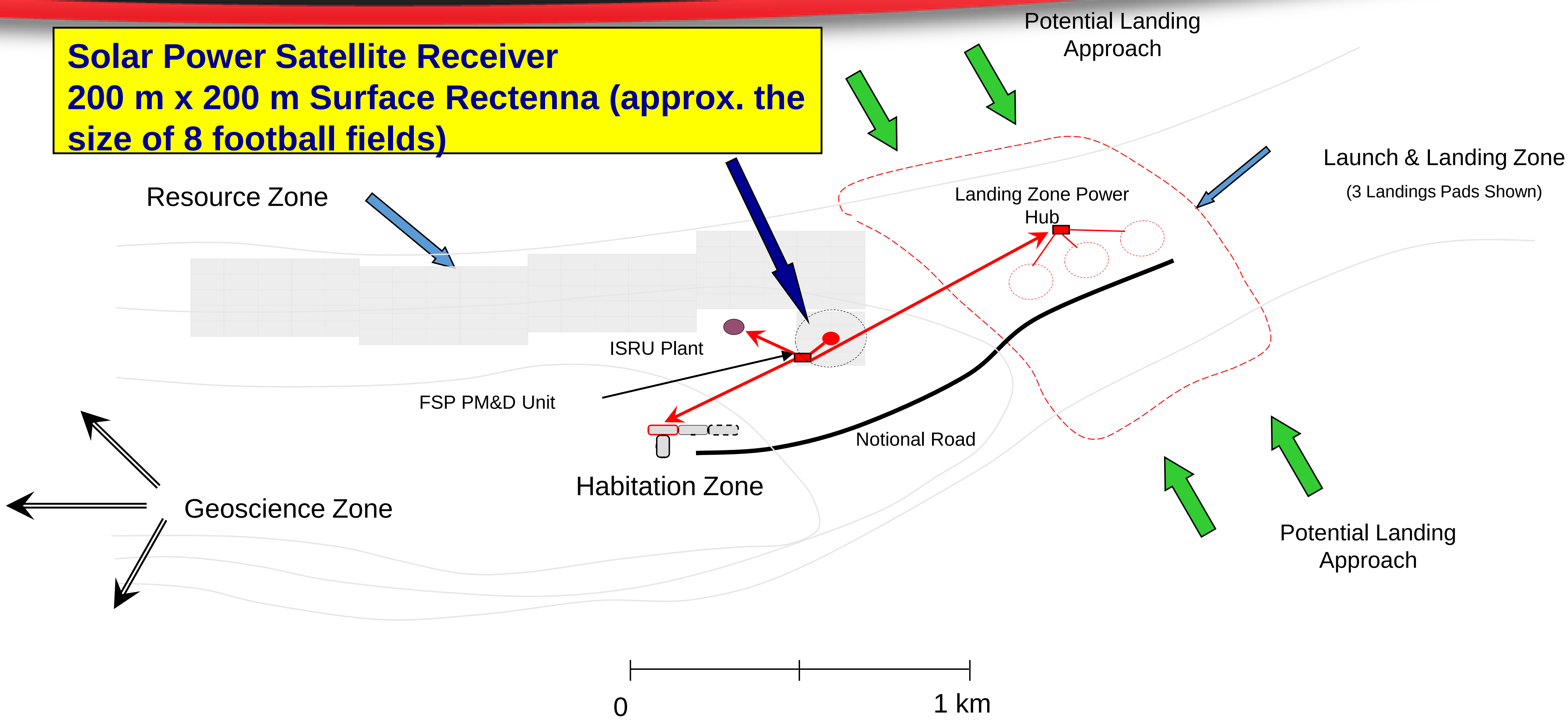
- Solar Power Satellite in Lunar orbit may be able to provide power to the lunar outpost during the 14-day lunar night (and during the lunar day)
  - 35 kW system appears to be compatible with a single SLS launch
  - Higher acceptable Power Flux Densities enable smaller surface rectennas
  - Power conversion system technology development will be required

Back Up Information

Power System Results

Item	Qty	Mass	Comment
Solar Collector	12	100 kg	App 1 kg / m^2
100 kWe Brayton Generator	3	600 kg	Incl. turbine, generator, cooler
200 Ghz Converter array	1	7500 kg	25 kg / kW, 300 kW
Phased Array Antenna	1	4700 kg	1 kg / m^2; 42m Radius

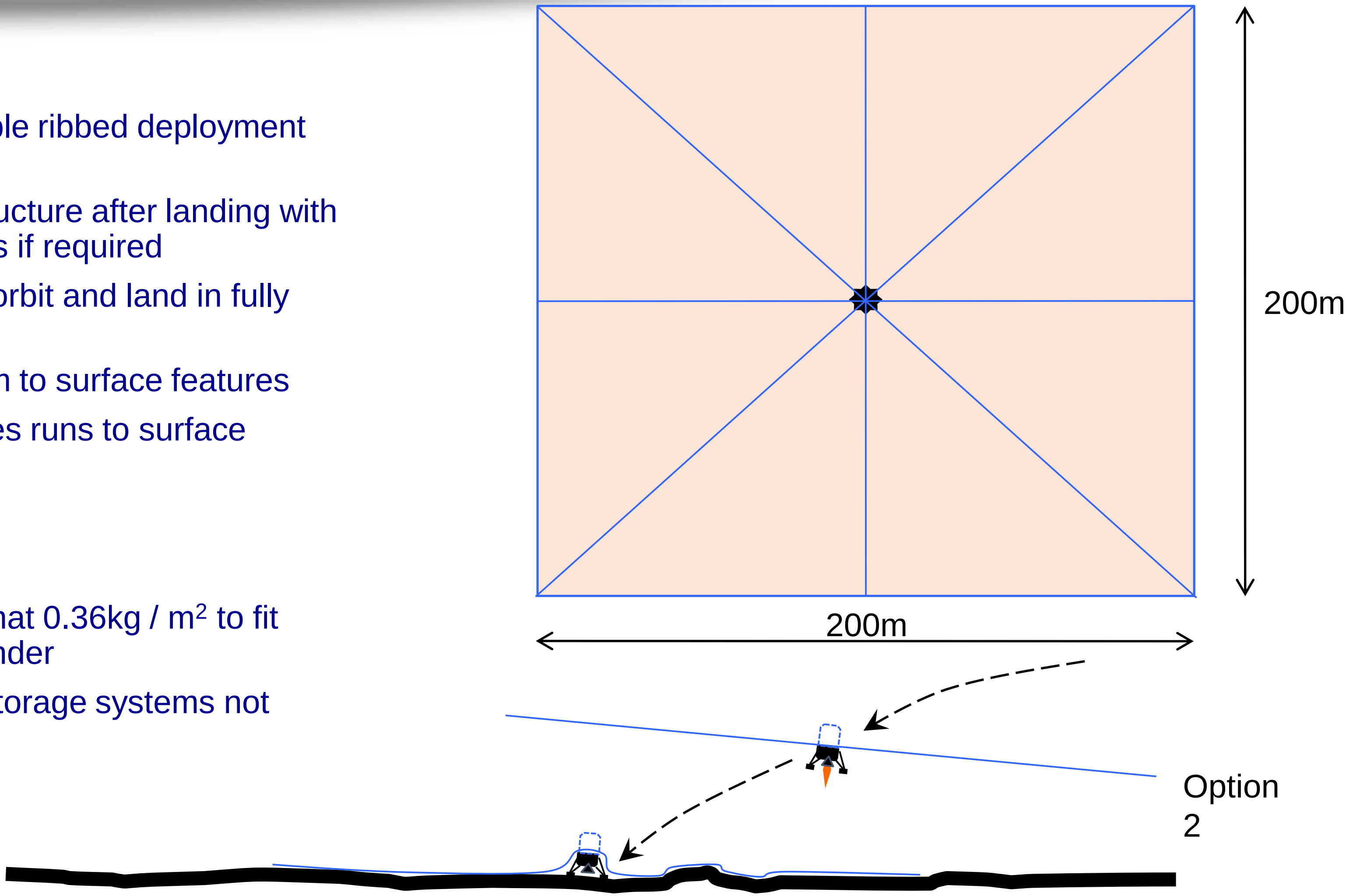
Representative Lunar Outpost Layout Master Plan [LS-5.0]



Adapted from file "LSS_Outpost_Master_Planning_v3.ppt" by NASA/JSC/Kriss Kennedy

Surface Rectenna Deployment Concept

- Deployment:
  - Rectenna folded with an inflatable ribbed deployment structure
  - Option 1: Inflate and deploy structure after landing with assistance from crew and rovers if required
  - Option 2: Inflate and deploy in orbit and land in fully deployed configuration
  - Rectenna will settle and conform to surface features
  - Crew to attach and deploy cables runs to surface elements
- Issues:
  - Rectenna mass unknown
  - System would have to be less that 0.36kg / m^2 to fit payload capacity of 1 Cargo Lander
  - Connecting cables and power storage systems not included.



Mass Comparisons

- In order to fit on a single Cargo Lander the Rectenna system will have to be less than 0.36 kg per square meter. This is less than the inflatable collector mass

Comparisons			
Description	**Area (m^2)**	**Mass (kg/m^2)**	**Total Mass**
Transmitter (total)	5,411	2.35	12,715
Transmitter wire mesh	5,411	1.00	5,411
Transmitter electronics	5,411	1.35	7,304
Collector	212	0.47	100
Rectenna	40,000	0.36	14,400

- For earth applications, the rectenna structure is commonly referred to as a wire mesh that light can pass through, allowing use of the ground area below. A common 20 gauge mesh is available in 0.21 kg – 0.45 kg per square meter.