Towers: Critical Initial Infrastructure for the Moon, Such as a Power Module Support

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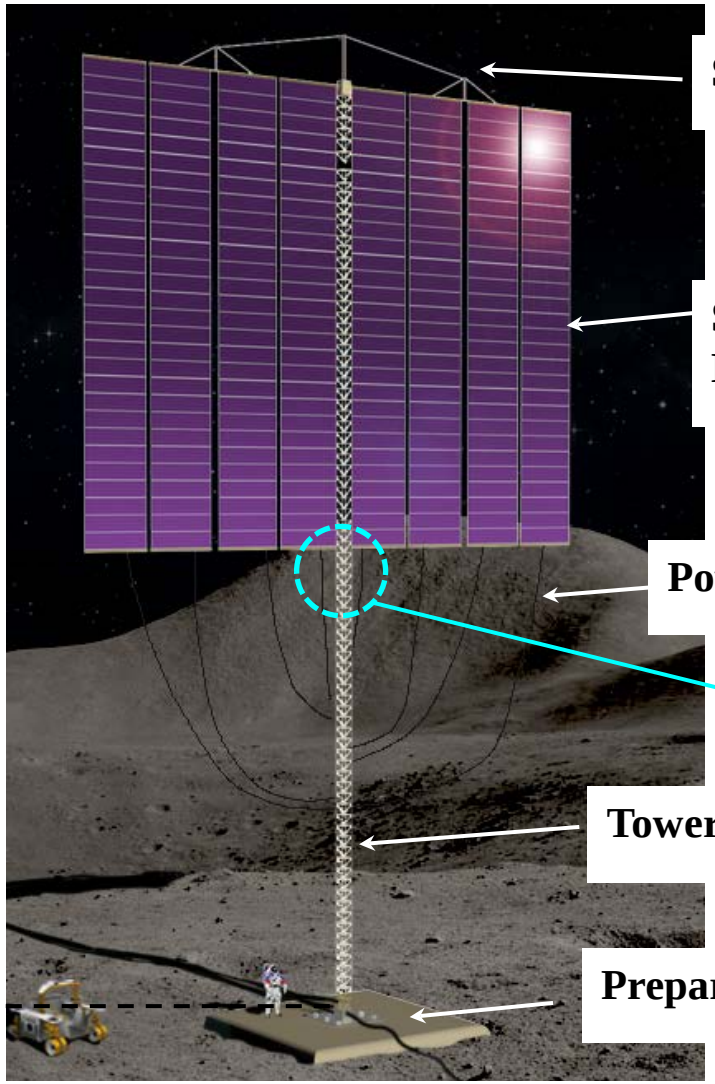
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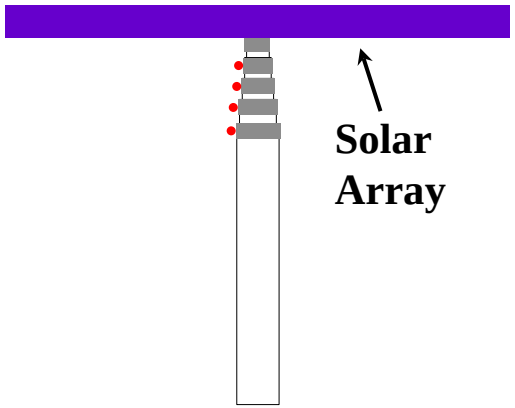
Introduction: Towers as a Lunar Infrastructure Element Illustrated Through a Solar Power Module Application

- **Focus: Support Tower for a Solar Power Module**

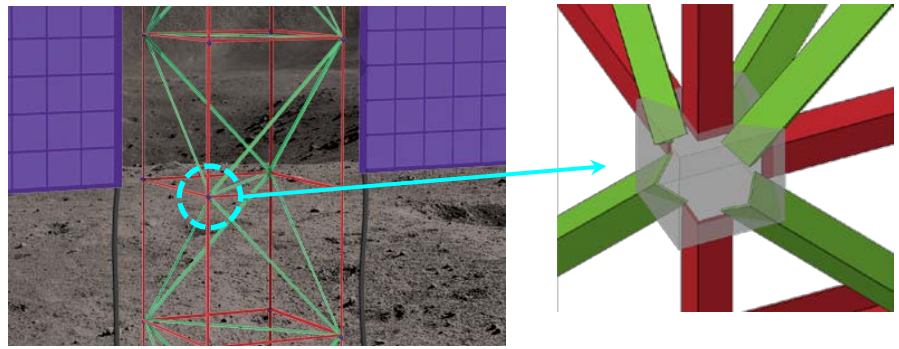
- **2 Structural Forms compared**
  - **Telescoping Tube Tower**
  - **Assembled Truss Tower using Angle Members**
    - **1/3rd Mass of Tube Tower**
    - **1/14th to 1/25th Packaging Volume**



Artist Depiction of 200 kW Solar Power Module



Telescoping Tube Tower



Assembled Angle Truss Tower

Key Point

Truss assembly is an approach which leverages Lunar derived components as they become available.

Credit Artist: Ronald Neale

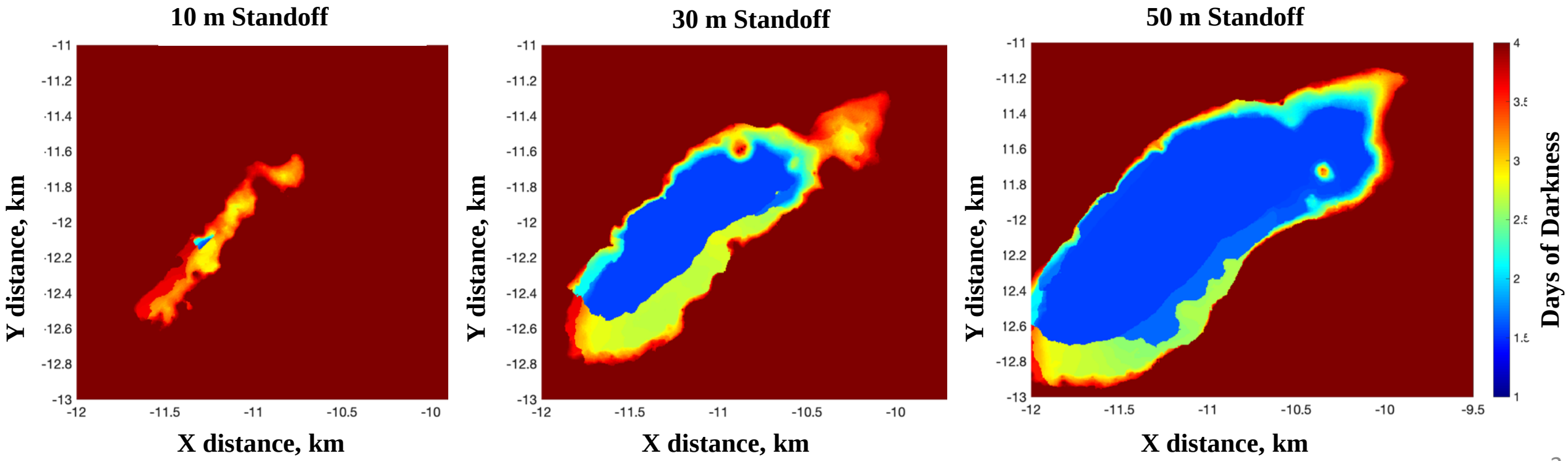
Background: Towers Near Lunar South Pole can be used to Elevate Solar Panels for Nearly Continuous Illumination and thus Power Production

Increased Height:

- **Increases Number of Sites Available and Allows Location of Power Closer to Users**
- **Enables Solar Panels to be Staggered to Prevent Shadowing Neighboring Power Modules**
- **Reduces Total Mass Required as Stand off Height Increases**
- **Reduces Sensitivity to Terrain Errors**

Shackleton Connecting Ridge

Plots Credit: Erwan Mazarico



Unique Lunar Environment Results in Slender Structure Forms Without Terrestrial Heritage

Unique Lunar Environment

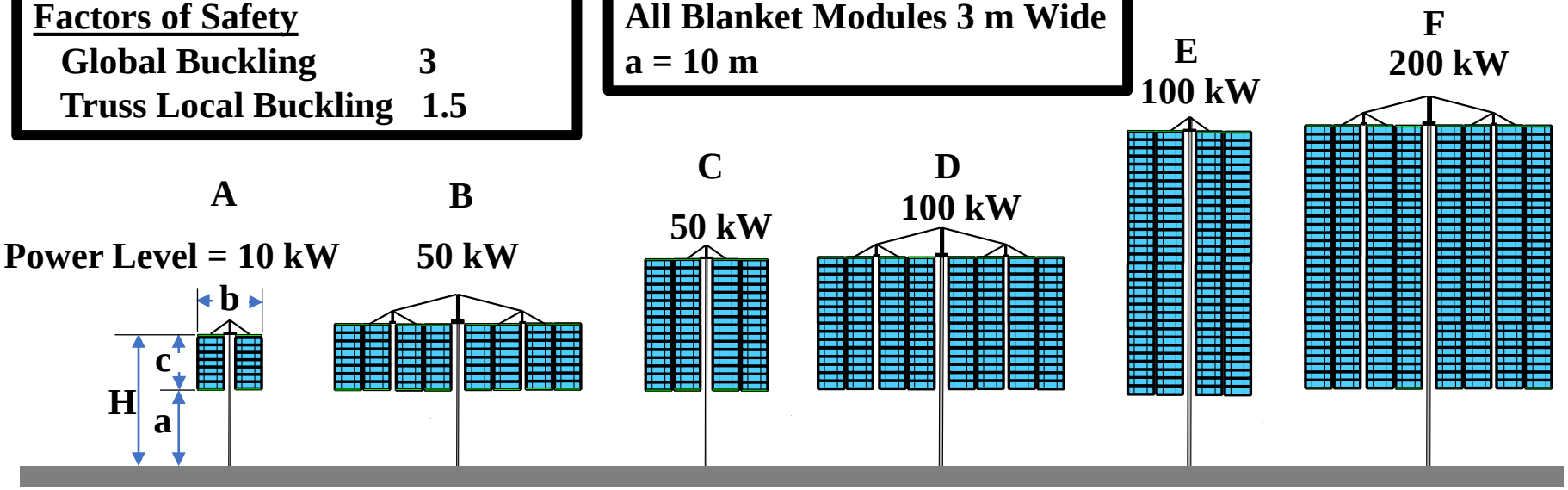
- **High Thermal Gradients**
- **1/6 Gravity**
- **No Wind**
- **No Ice**



Terrestrial Towers Subjected to Higher Environmental Loads Compared to Lunar Towers

Factors of Safety
Global Buckling 3
Truss Local Buckling 1.5

All Blanket Modules 3 m Wide
a = 10 m

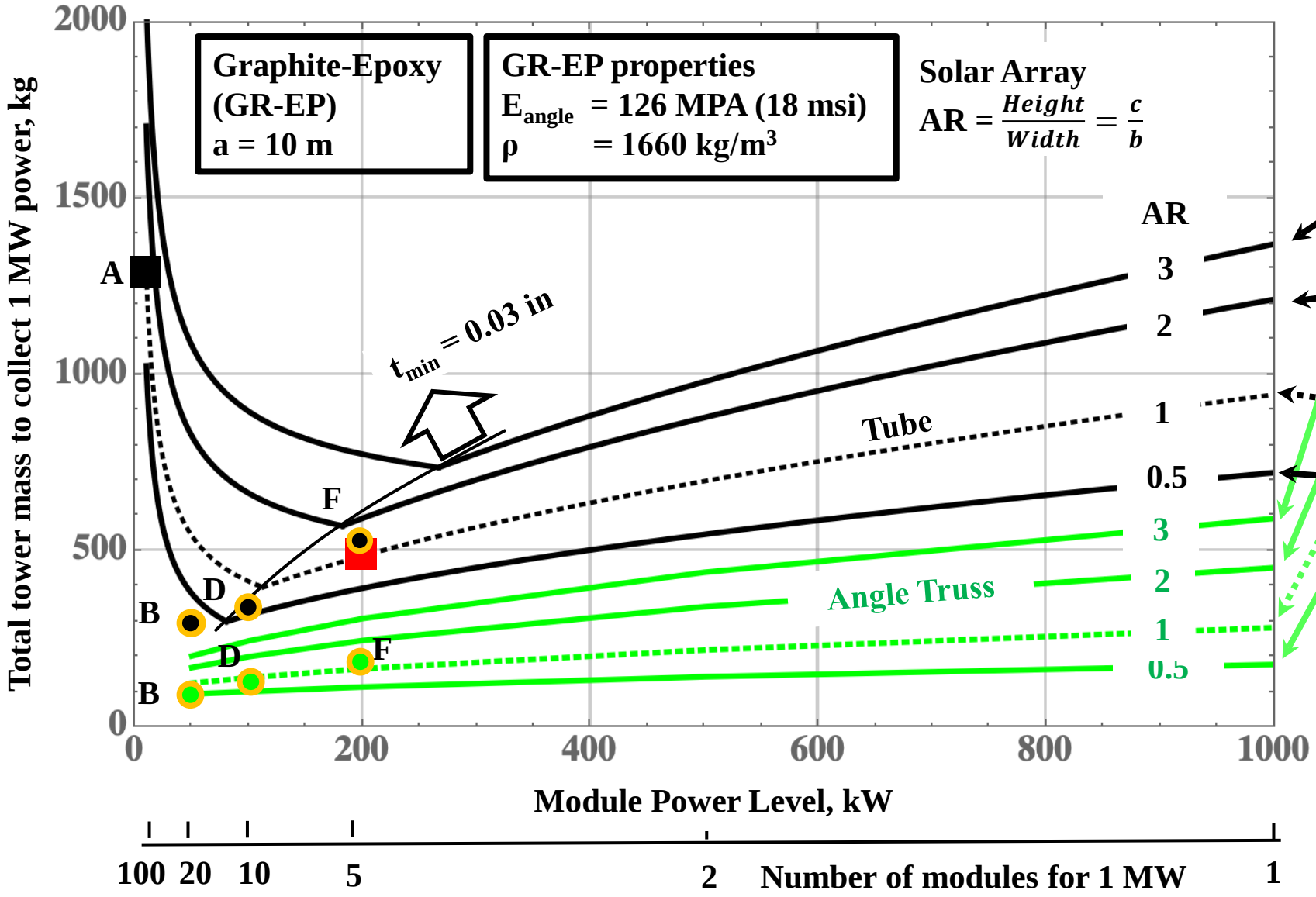


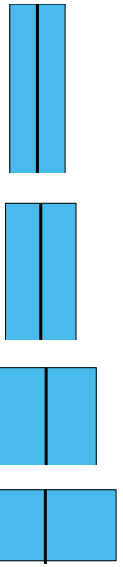
Power Modules to Achieve 1 MW

Height, H, m	16	17.5	25	25	40	40
No. of cells, N	100	20	20	10	10	5
Aspect Ratio, c/b	1	0.3125	1.25	0.625	2.5	1.25
Total Tower Mass, kg	1285	306, 78	617, 141	336, 112	780, 245	519, 194
Total Tower Volume, m^3	7.6	1.8, 0.07	3.6, 0.13	1.8, 0.1	4.6, 0.2	2.3, 0.17

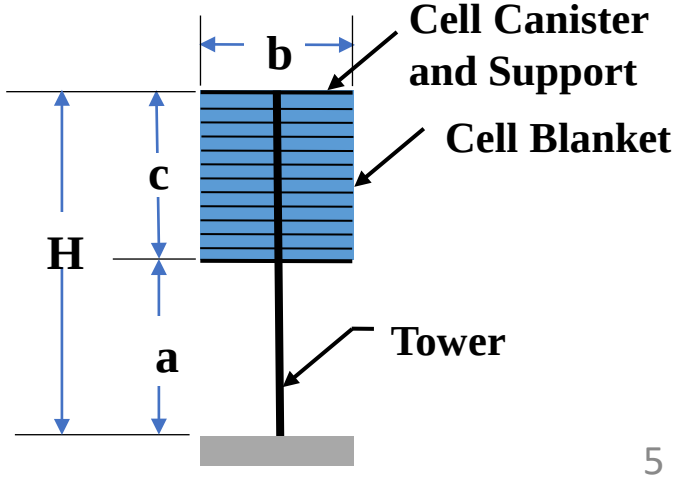
(Tube Mass and Volume Values in Black) **(Angled Truss Mass and Volume Values in Green)**

Tower Mass to Collect 1 MW

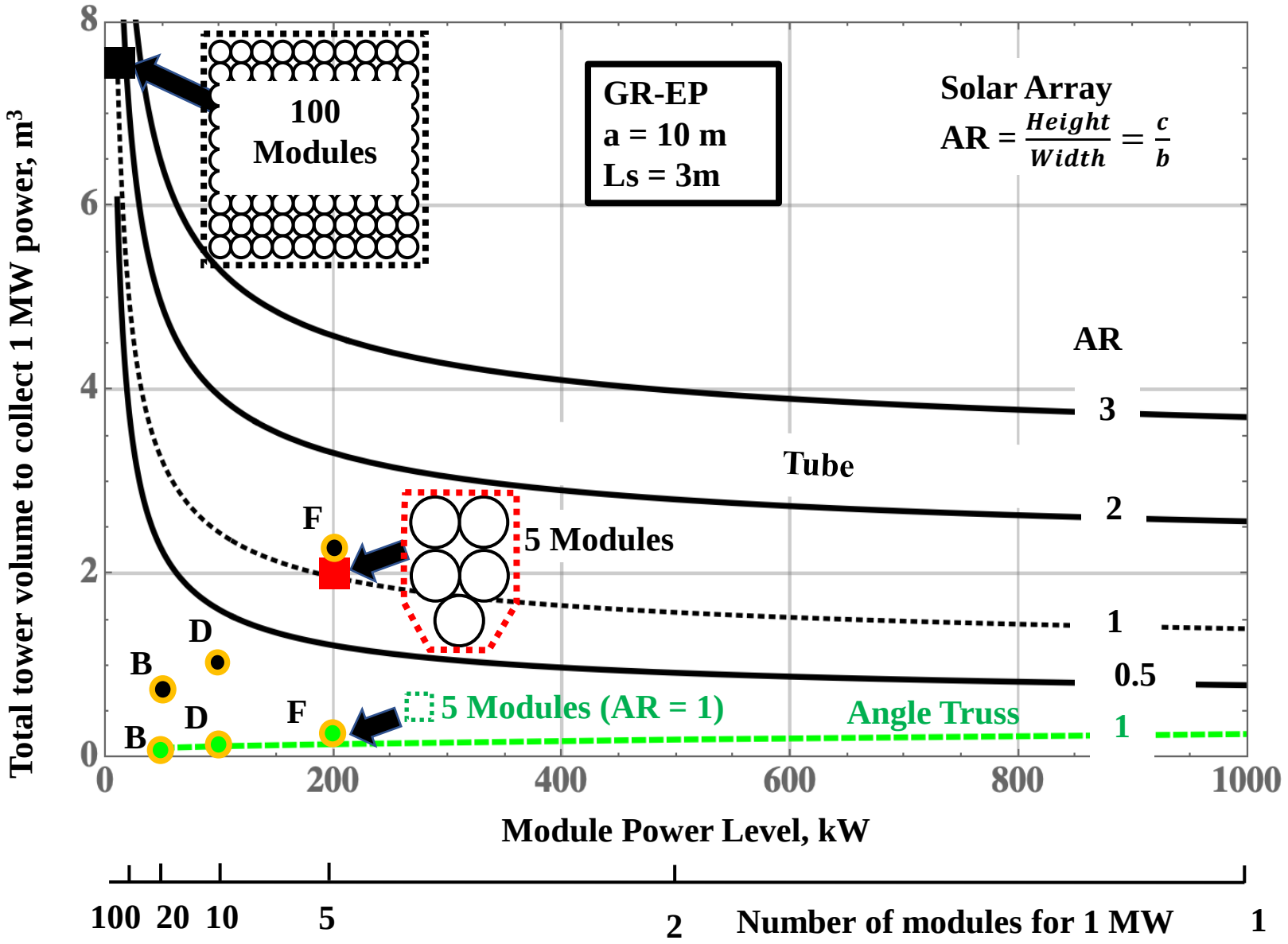




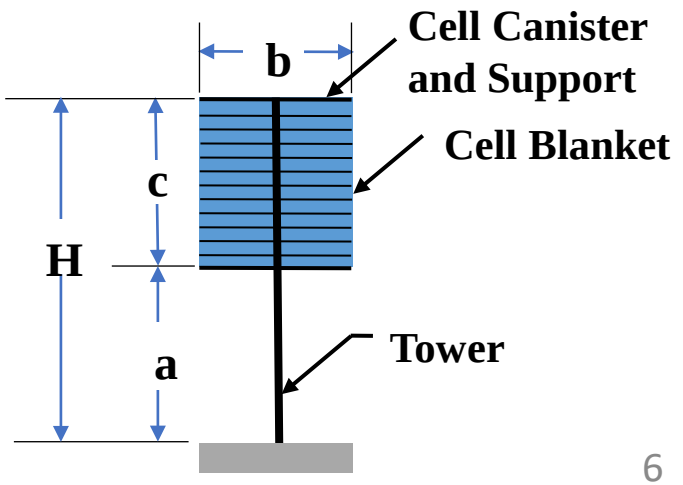
- Above 50 kW Truss Towers are a less Massive Alternative to Tube Towers
- Truss Towers for Power Modules are 1/2 to 1/3rd the Mass of Tube Tower



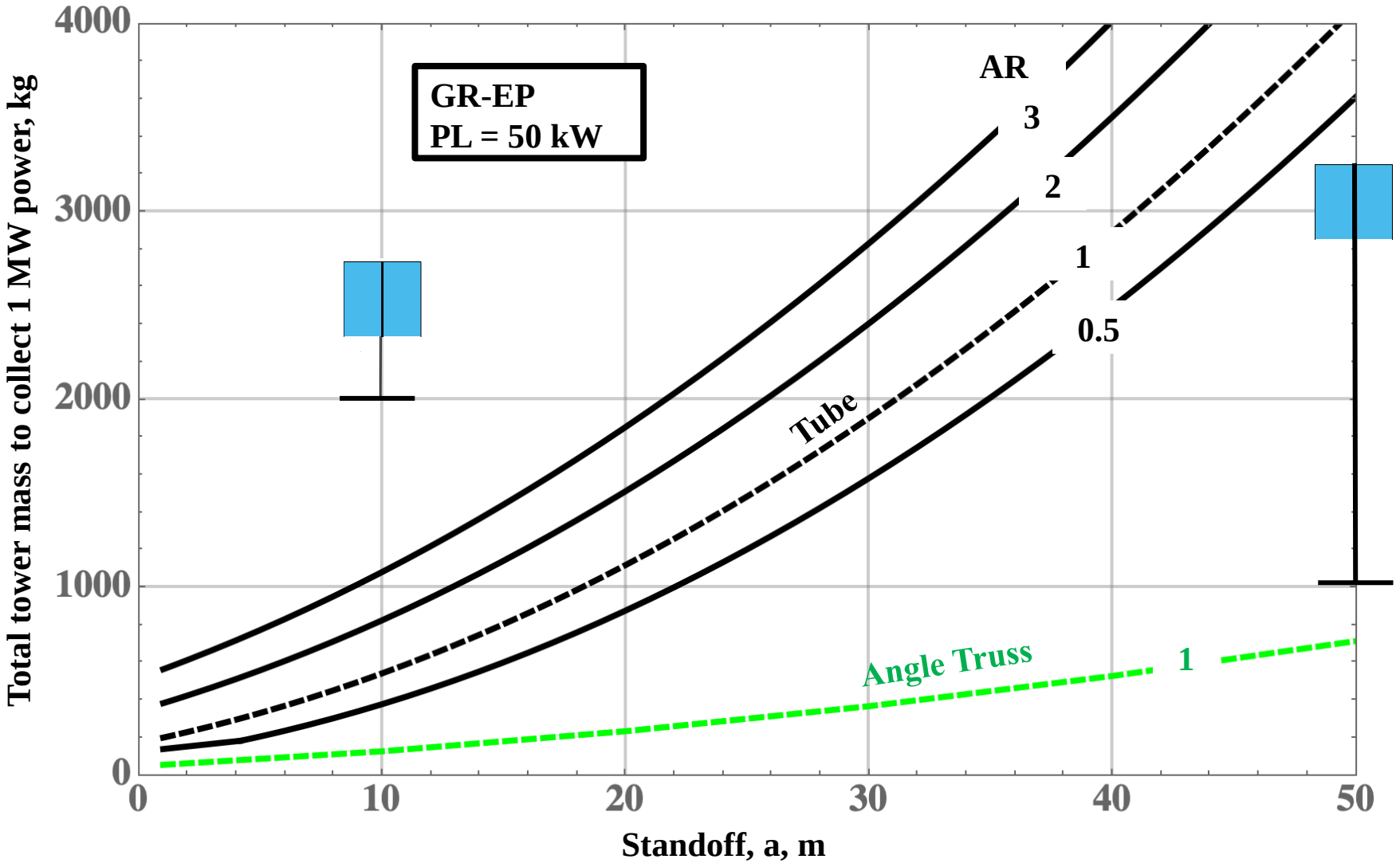
Tower Volume to Collect 1 MW



- **Truss Tower for Power Modules in the 50 kW to 200 kW Range Package into 1/25th to 1/14th the Volume of Tube Tower Decreasing to 1/6th for a 1 MW Power Module**

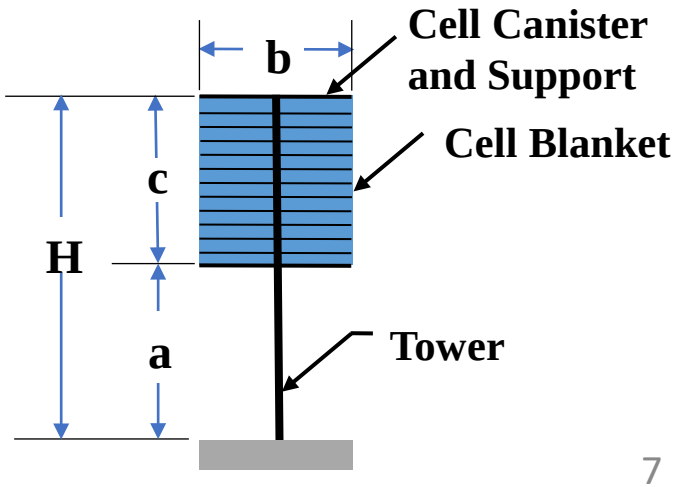


Tower Mass to Collect 1 MW as Standoff Increases

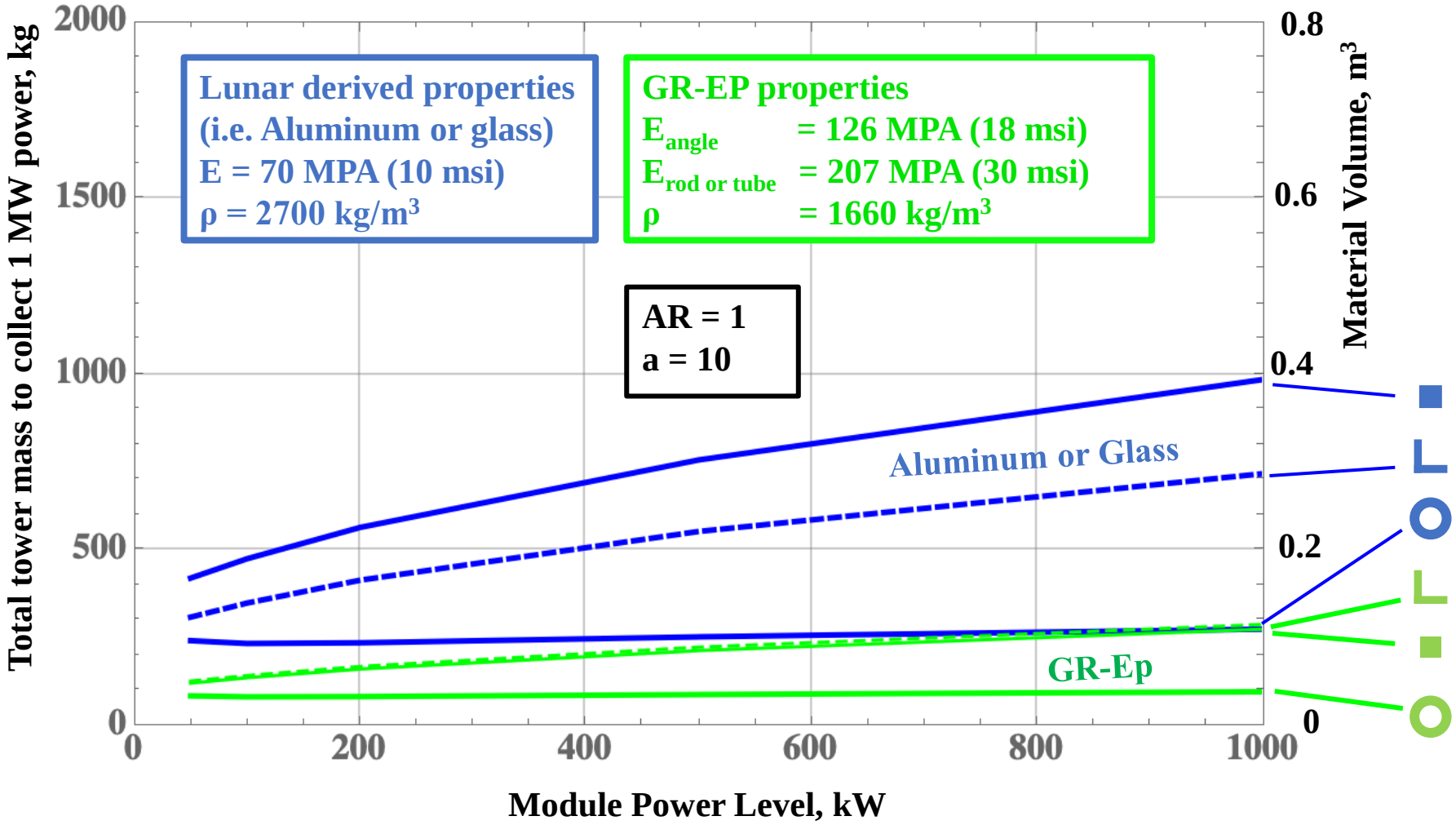


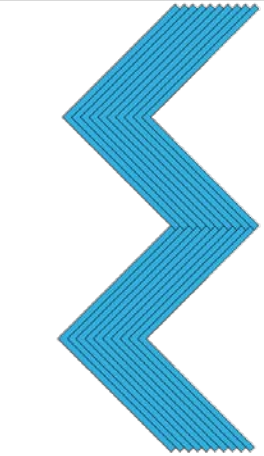
Solar Array

$$AR = \frac{Height}{Width} = \frac{c}{b}$$

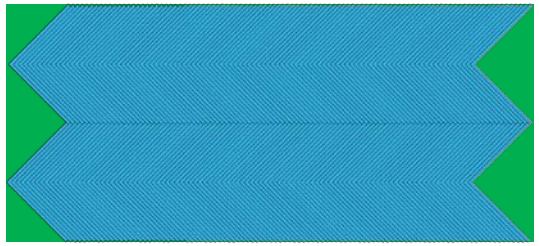


Truss Tower Mass to Collect 1 MW for Different Structural Member Geometries



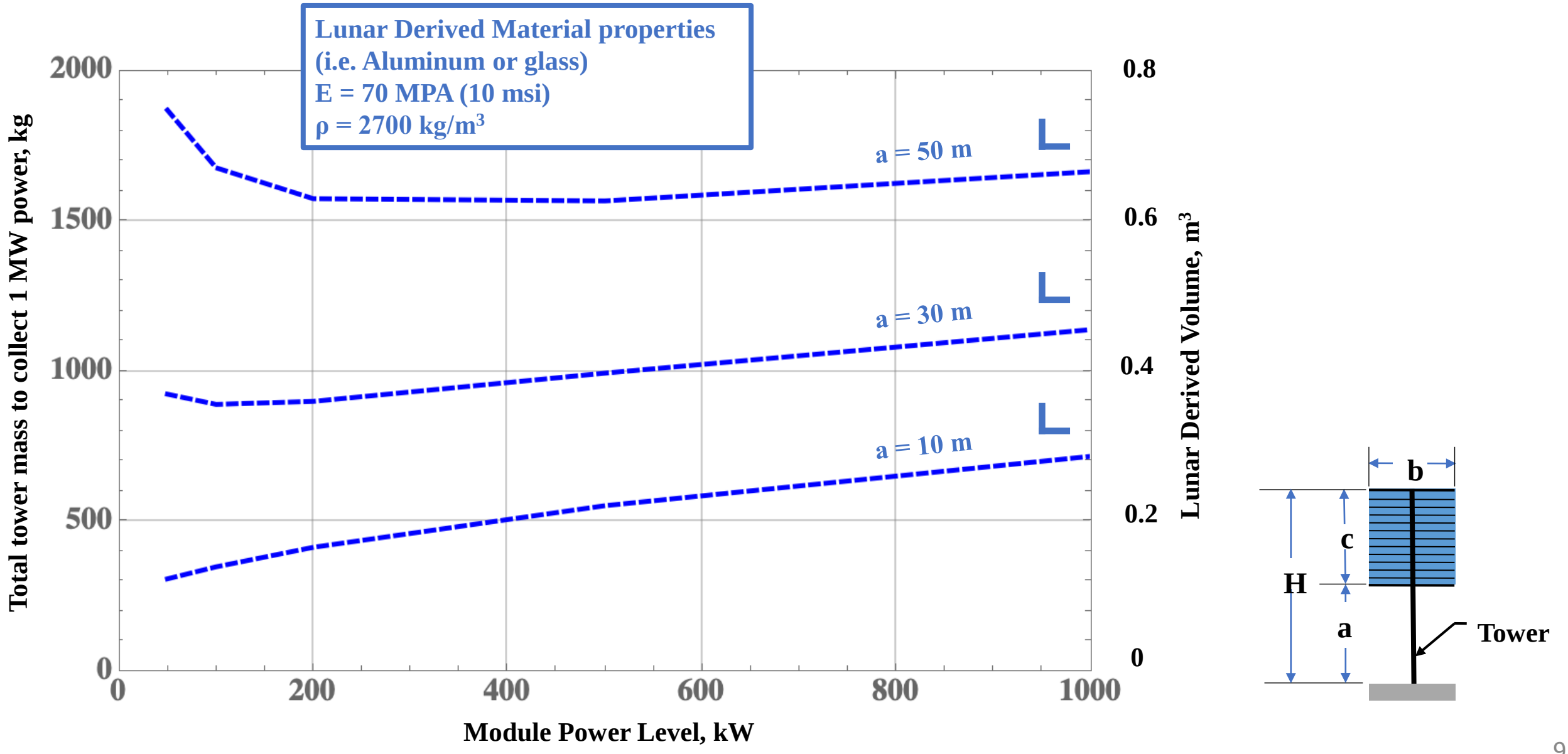


Angles Nest



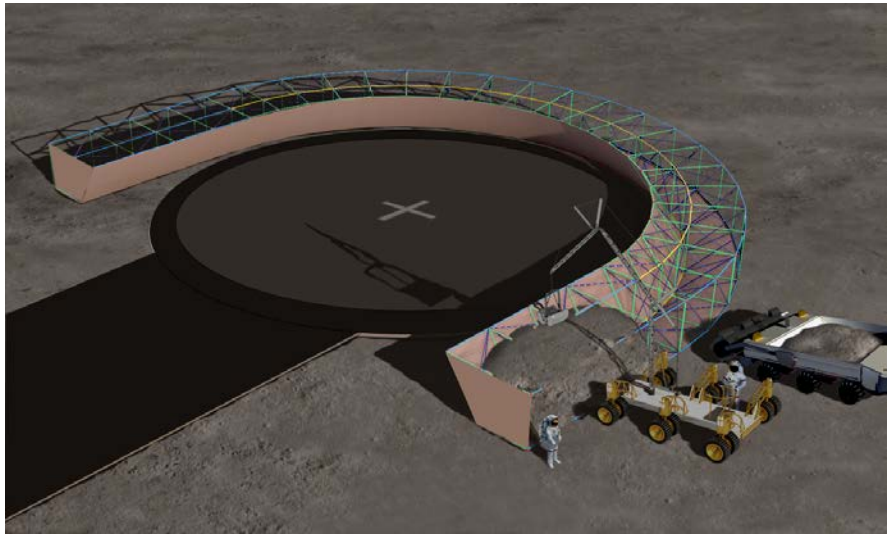
Angles Package Efficiently

Truss Tower Mass to Collect 1 MW Using Lunar Derived Truss

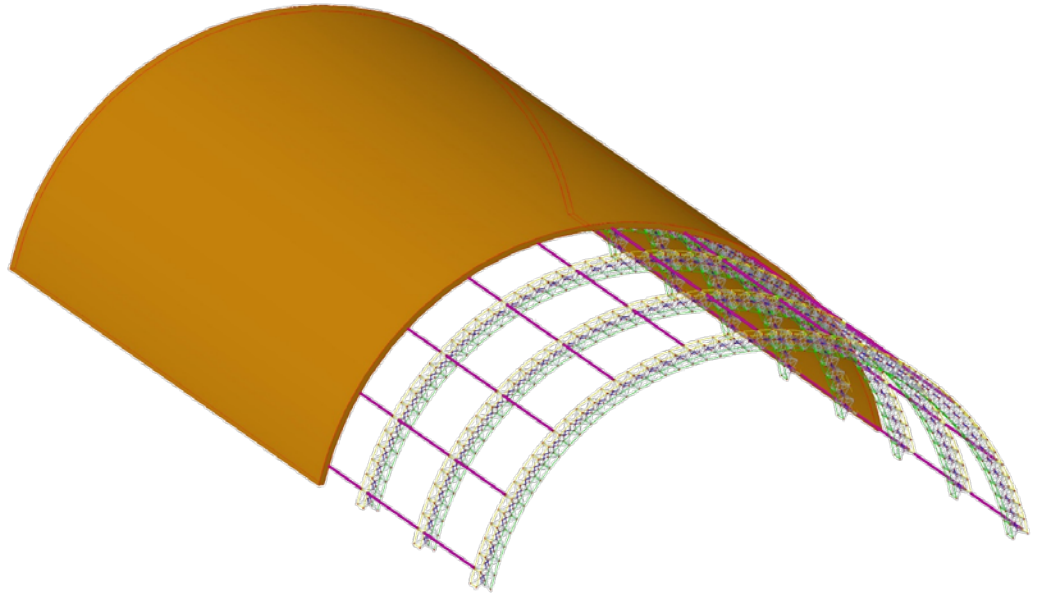


Closing Comments

- **Above 50 kW Truss Towers are a Less Massive Alternative to Tube Towers. Typically, Truss Towers for Power Modules are 1/2 to 1/3rd the Mass of Tube Tower**
- **Truss Towers for Power Modules in the 50 to 200 kW Range Package into 1/25th to 1/14th the Volume of Tube Tower Decreasing to 1/6th for 1 MW Power Modules**
- **Truss Towers Provide a Direct Path to Towers Derived from Lunar Materials as Lunar Manufactured Structural Members from Regolith Become Available**
- **Automated Assembly Technology for Truss Towers Extends Directly to other Applications such as a Rocket Blast Containment Structures and Arches for Shelters**

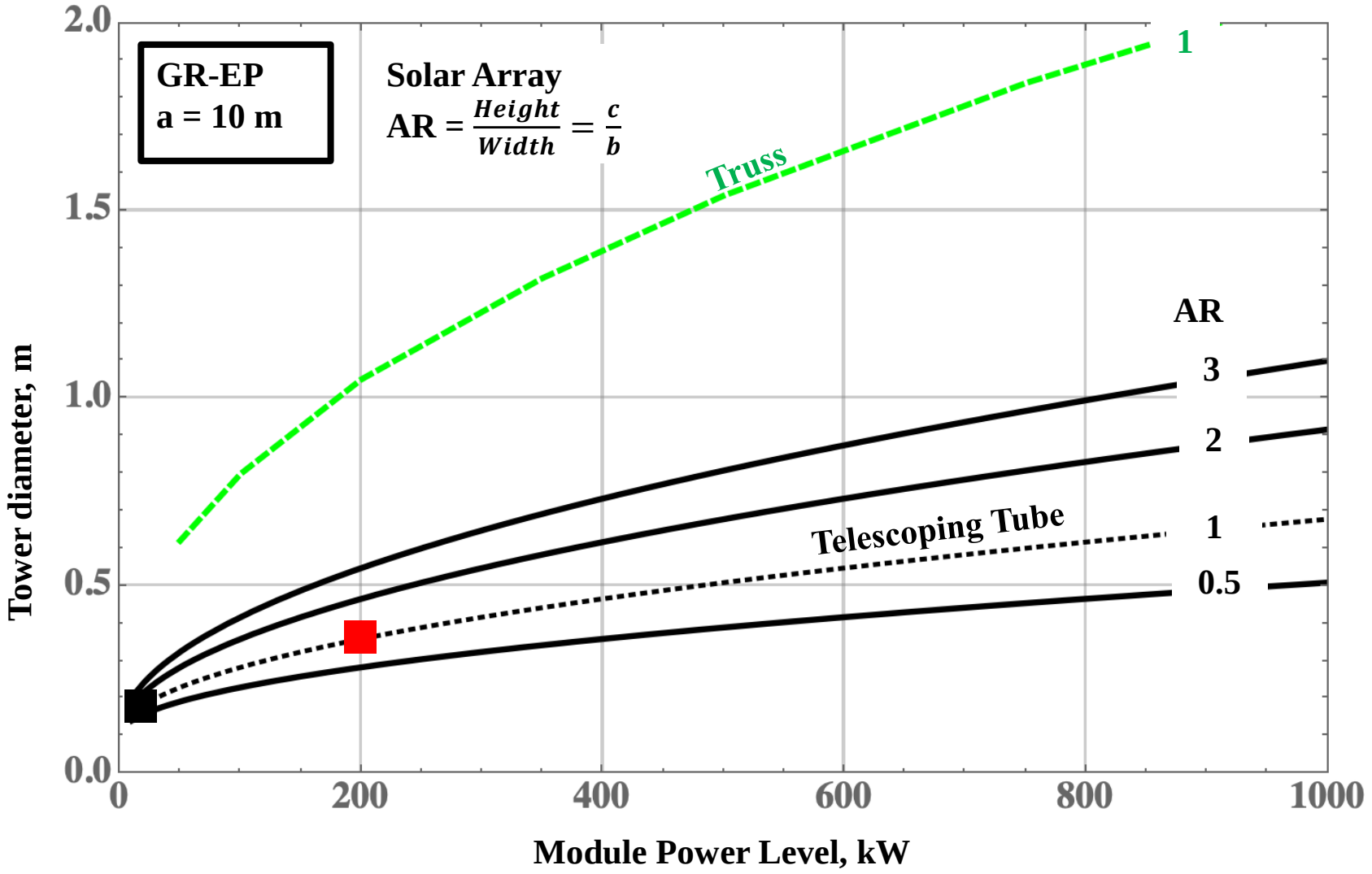


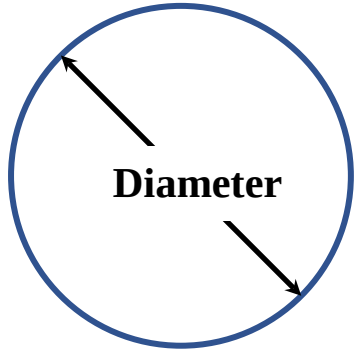
Rocket Blast Containment Shield Supported by Truss Structure



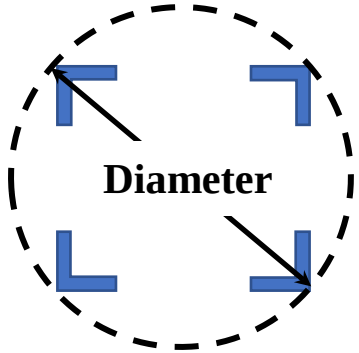
Shelter Formed using Curved Truss Arches

Backup: In Situ Tower Diameter to Achieve 1 MW





Bottom Tube



Truss

Backup: Parameter Values

Cell Blanket Design Parameters	Variable	Value	Unit
Power per unit area	Π	0.3	kW/m^2
Blanket thickness	tb	1.3 (0.05)	mm (in.)
Blanket width		3	m
Solar cell areal density	bd	1	kg/m^2
Resultant solar cell blanket power per unit volume	PPV [Π/tb]	230	kW/m^3
Resultant blanket power per unit mass	PPM [Π/bd]	0.3	kW/kg
Factor to account for horizontal structure supporting blanket	η	See paper	

Tower Structural Design Parameters	Variable	Value	Unit
Composite tube modulus	E	207 (30)	MPa (msi)
Composite angle modulus	E	126 (18)	MPa (msi)
Composite material density	ρ	1660 (0.06)	kg/m^3 (lb/in^3)
ISRU (aluminum or glass) modulus	E	70 (10)	MPa (msi)
ISRU (aluminum or glass) material density	ρ	2700 (0.1)	kg/m^3 (lb/in^3)
Slenderness ratio (Height/Diameter)	HovD	100	
Minimum thickness of structural members	t_{min}	0.76 (0.03(<1/32))	mm (in)
Penalty for joints	JF	1.3	
Factor of safety Euler for tower	FSE	3	
Factor of safety Euler for longeron	FSL	1.5	
Tower self-mass loading parameter	C1	0.3	
Gravitational constant	g	9.8	m/s^2
Ratio of Lunar gravity to Earth	gf	1/6	
Flange length to thickness ratio of angle	$\bar{L}$	10	
Length of telescoping tube section.	Ls	3	m
Batten and diagonal cross sectional area reduction	β	0.7	

Backup: Tall Lattice Towers

Rank	Name	Type	Year	Built in	City/location	Height m	Height ft	Cost	Weight	Remarks
1	Petronius Compliant Tower	Oil Platform, Compliant tower	2000	USA	Gulf of Mexico	640	2,100	$500 million	50,500[3]	Tallest lattice tower of any type. Supported by water
2	Tokyo Skytree	Lattice tower	2012	Japan	Sumida, Tokyo	634	2,080	$806 million[4]	36,000 tons[5]	Tallest free standing lattice tower
3	Baldpate Compliant Tower	Oil Platform, Compliant tower	1998	USA	Gulf of Mexico	581.5	1,908	$300 million	38,700 tons	Tallest structure in the world 1998–2000
4	Bullwinkle Platform	Oil Platform, Steel Truss	1989	USA	Gulf of Mexico	529	1,736	$500 million	72,000 tons	Tallest fixed/rigged structure built in water
5	Benguela-Belize Lobito-Tomboco Platform[6]	Oil Platform, Compliant tower	2008	USA	Congo basin	512	1,680	$820 million[7]	69,500 tons	
6	Pompano Platform	Oil Platform, Steel Truss	1994	USA	Gulf of Mexico	477	1,565		39,890 tons (not including platform)[8]	
7	Tombua Landana platform[9]	Oil Platform, Compliant tower	2009	USA	Congo basin	474	1,554	$200 million[10]	81,500 tons[10][11]	
8	Harmony Platform[12]	Oil Platform, Steel Truss	1992	South Korea[13]	California	366	1,200		44,100 (not including platform)[13]	height listed is only to water level, likely to be 1,500 ft or more in total height
9	Virgo Platform[12]	Oil Platform, Steel Truss	1999	USA	Gulf of Mexico	344	1,130			height listed is only to water level, likely to be 1,400 ft (430 m) or more in total height
10	Coelacanth Platform[14]	Oil Platform, Steel Truss	2016	USA	Gulf of Mexico	400	1,312			

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