SPACE SOLAR POWER DEVELOPMENT | GROUP

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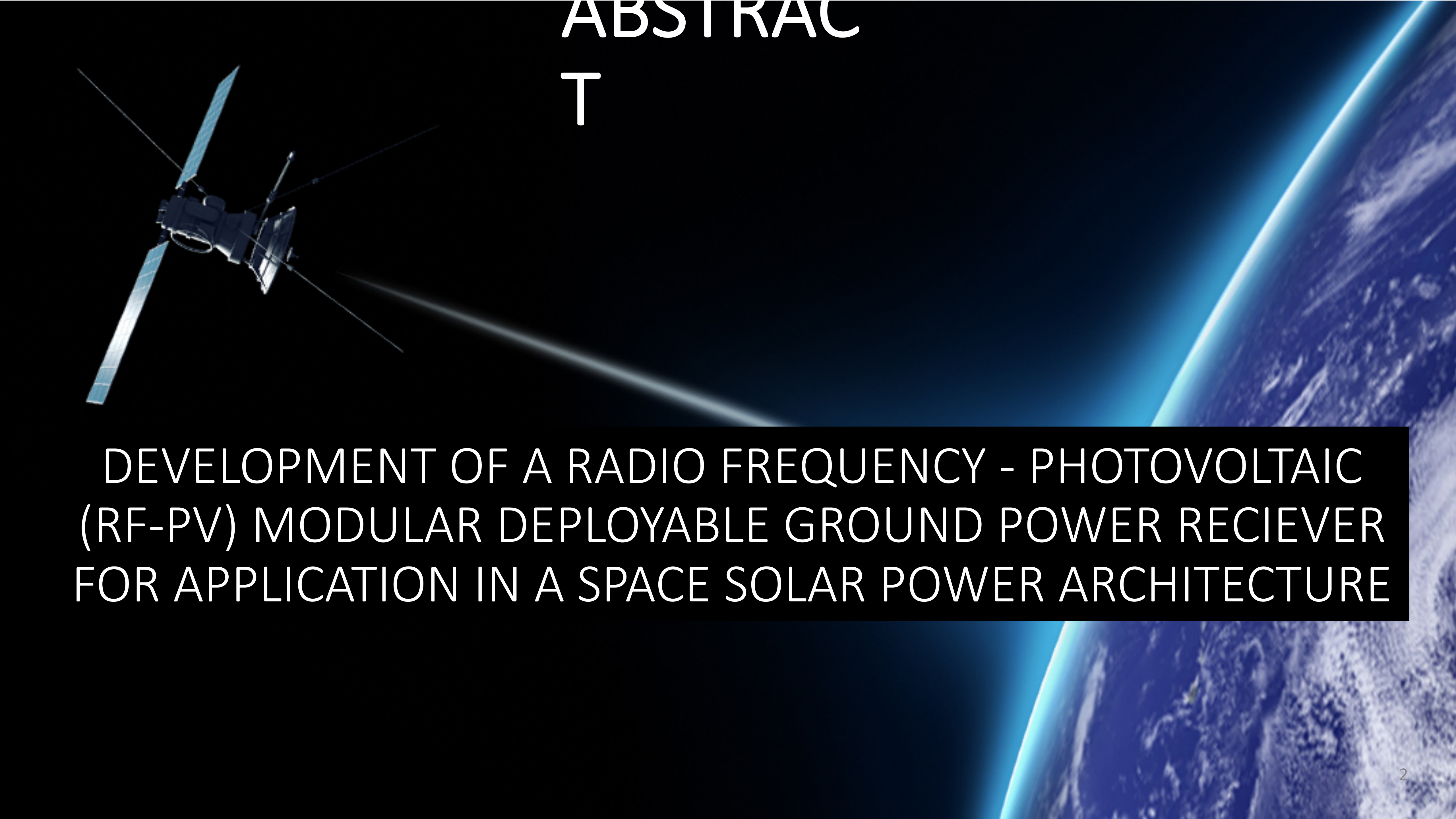
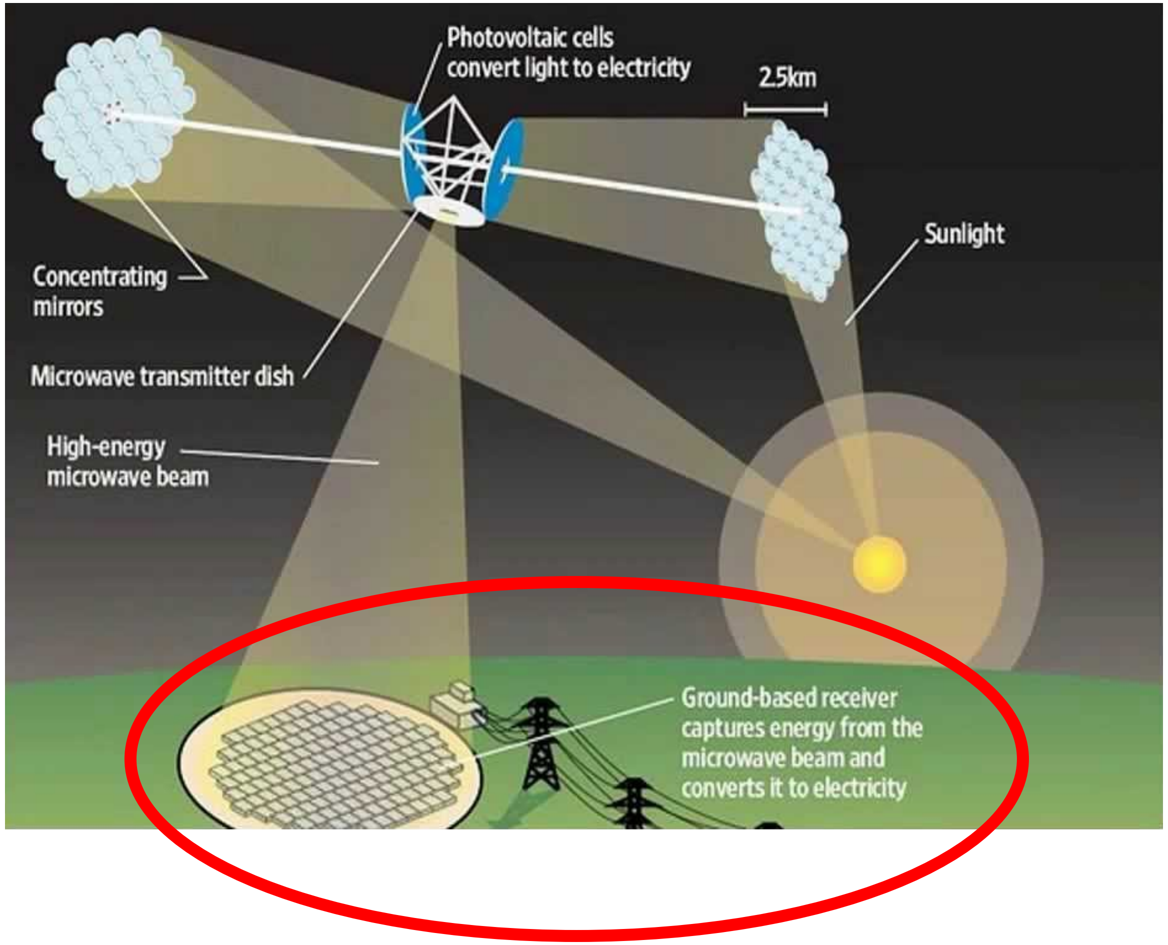
ABSTRACT



DEVELOPMENT OF A RADIO FREQUENCY - PHOTOVOLTAIC (RF-PV) MODULAR DEPLOYABLE GROUND POWER RECIEVER FOR APPLICATION IN A SPACE SOLAR POWER ARCHITECTURE



- With space solar, unfiltered, continuous sunlight is collected and converted into DC power through photovoltaics by large satellites in space.
- This power is then used to drive a power beaming system, transmitting a microwave beam to receivers on the Earth.
- Receivers then collect the beamed energy and convert it back to useable electricity for use on a grid.

Space Solar System Architecture

Problem

Both defense and disaster recovery applications of space solar would almost certainly require the development of a tactically deployable power receiver to satisfy operational and transport requirements in theatre, no work has been done in this area to date.

Objective

In a novel approach to wireless power reception in a space solar power system, a modular deployable ground power receiver (MDGPR) will be developed, integrating both microwave energy (RF) and solar energy (PV) collection and conversion elements.

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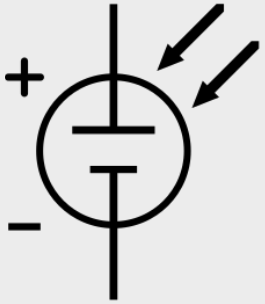
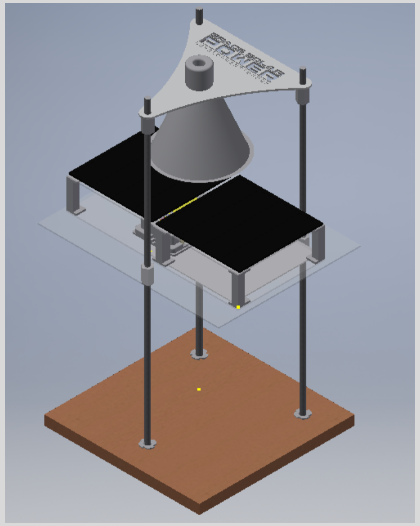
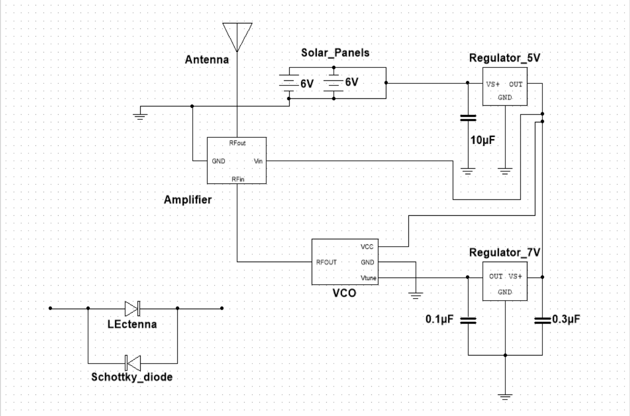
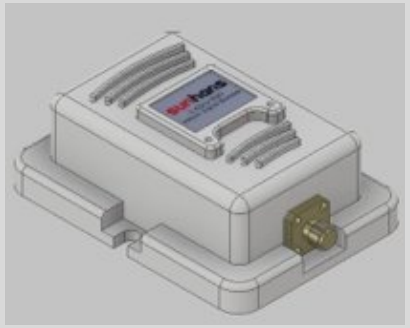


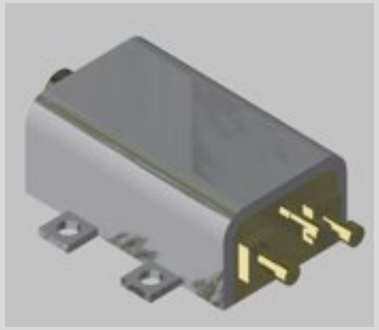
Wireless Power Transmission Demo

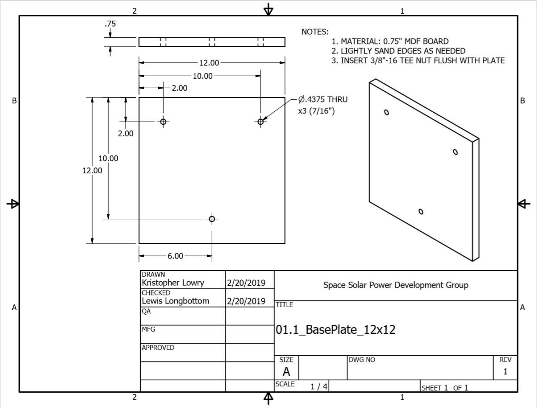
Purpose: A table-top demonstration of wireless power transmission and reception.











Why RF & PV?

- Our solution utilizes unused area within the satellite receiving aperture on top of containers
- The goal is to maximize to collection of available energy using multiple renewable sources to eliminate a single point of failure in power generation
- It’s a modular integrated solution that can grow with demand

Applications Considered

Defense and Energy Security

- The need to reduce logistics burdens and minimize energy resupply risks
- The transition to autonomous systems and crewless facilities
- The need to increase energy architecture flexibility

Disaster Response and Recovery

- Quickly restore electricity to critical infrastructure and recovery operations.
- Resilient, reliable power distribution day or night in any weather condition.
- Deployable and scalable power output to bring increasing power restoration during a period of need.

Requirements Summary

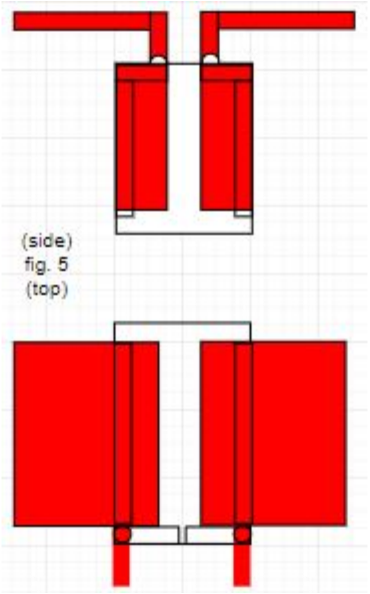
- Stakeholder (Defense Logistics Agency, DoD, Red Cross)
  - System setup deployment by no more than 5 personnel
  - Receiver shall operate in remote desert/tropical environment as well as mitigate obstacles and changes in elevation.
  - Modules shall be maneuvered by military helicopter, forklift, and flatbed loader
  - System shall have a protected perimeter with access control
- Project (MDGPR)
  - Convert RF energy at 5.8GHz and solar energy to DC power at 60Hz
  - Store the power within the module (container) for 12-hrs usage at 50% normal load
  - Output power of building block system (10 containers) shall be no less than 200kW (100 person – small forward operating base)
  - Each module shall be packaged in a standard 20-ft ISO shipping container
  - Receiver shall self-package without human intervention (self-retract)

Design Criteria

- Modularity
- Complexity
- Deployability
- Cost
- Stability/ Mechanical Safety
- Temperature Control
- PV Panel Integration

Selected Concept

- “Gullwing” container w/front and no rear door



Reasons:

- Maximum PV collection area
- Front door access allows for access without the need for a large area
- Through container passive cooling
- Possible spin-off applications

Structural Modifications Needed:

- Roof frame
- Gullwing door
- Gullwing door PV sub-frame
- Integrated battery pack mounts

Assumptions

- Rectenna PCB panel is flexible and can be spooled on a 6” diameter shaft
- Average intercepted power density of $50W/m^2$
- Each container has a receiver area of 4m x 100m ($400m^2$)
- 20,000W power output per container ($50W/m^2$)
  - 10 Containers = 200-kW
- IEEE Std C95.1 – 2005; 3 GHz to 300GHz
  - Controlled area: 100 W/m^2

Case Study: COP Hanson

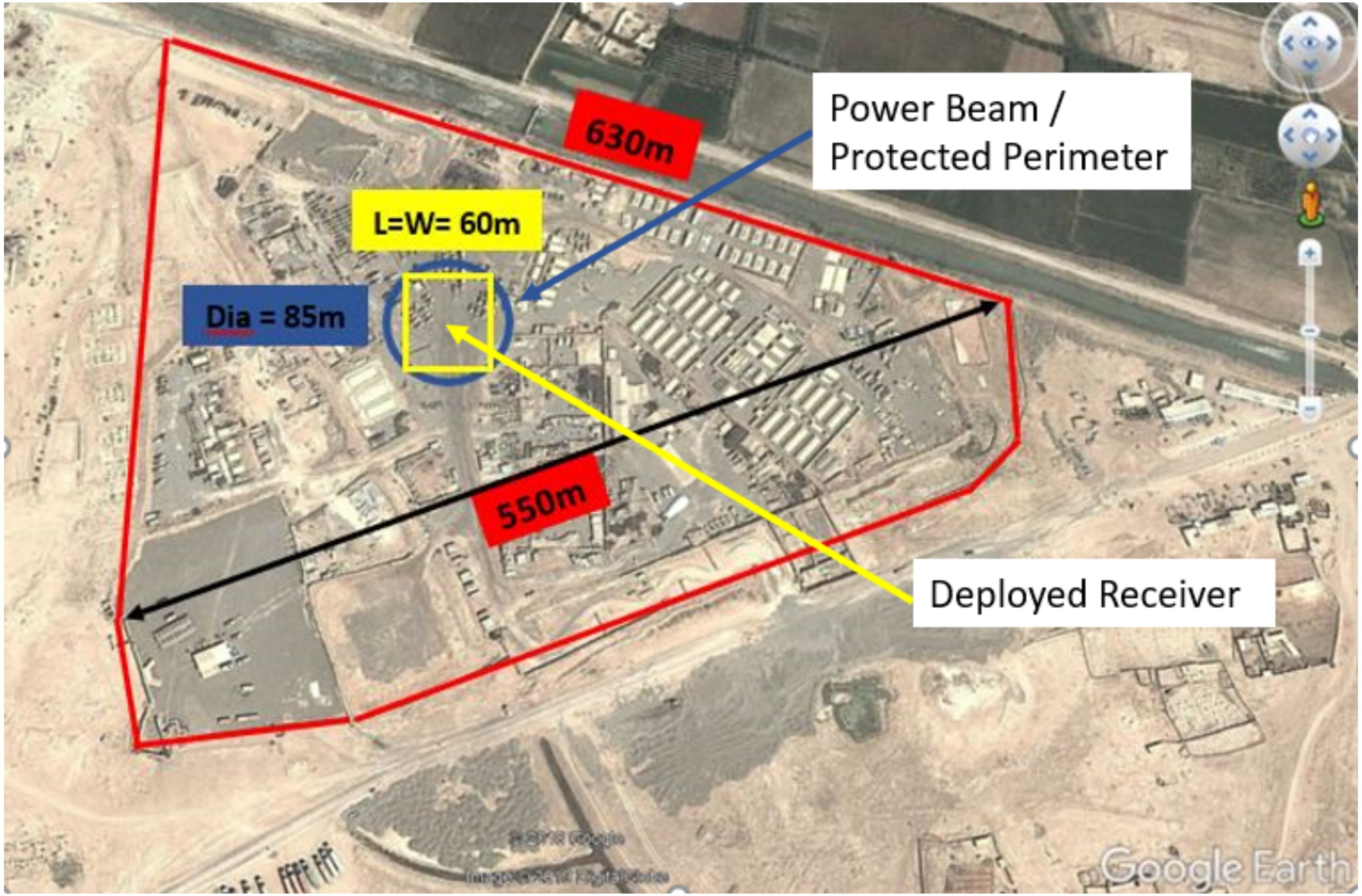
Avg power density: **50 W/m²** (assumption)

Number of Containers: **10**

Deployed Receiver (ea container)
- Length: **60m**
- Width: **4m**

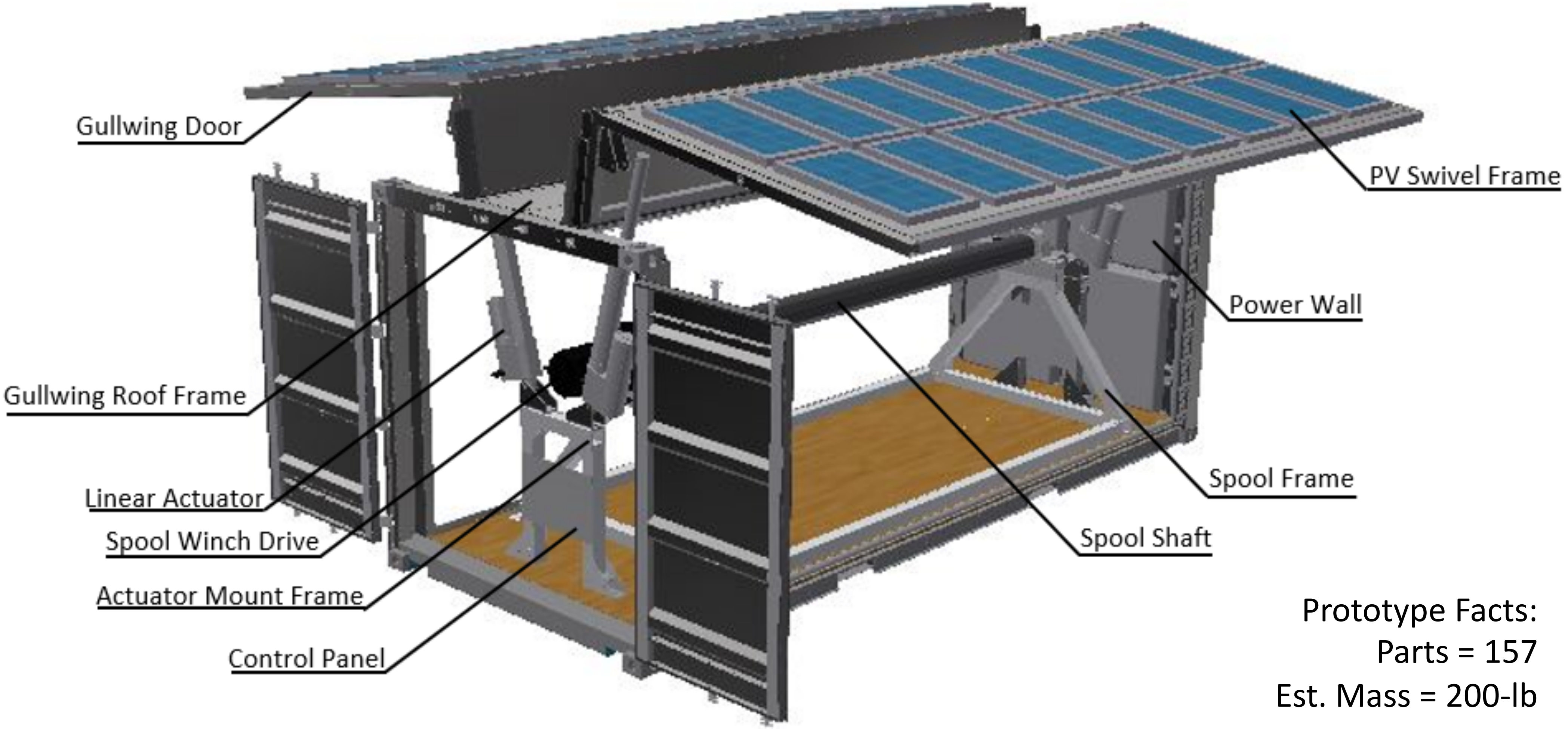
Power available: **12,000 W** (per container)

Power available: **120,000 W** (case study)
**not including PV integration



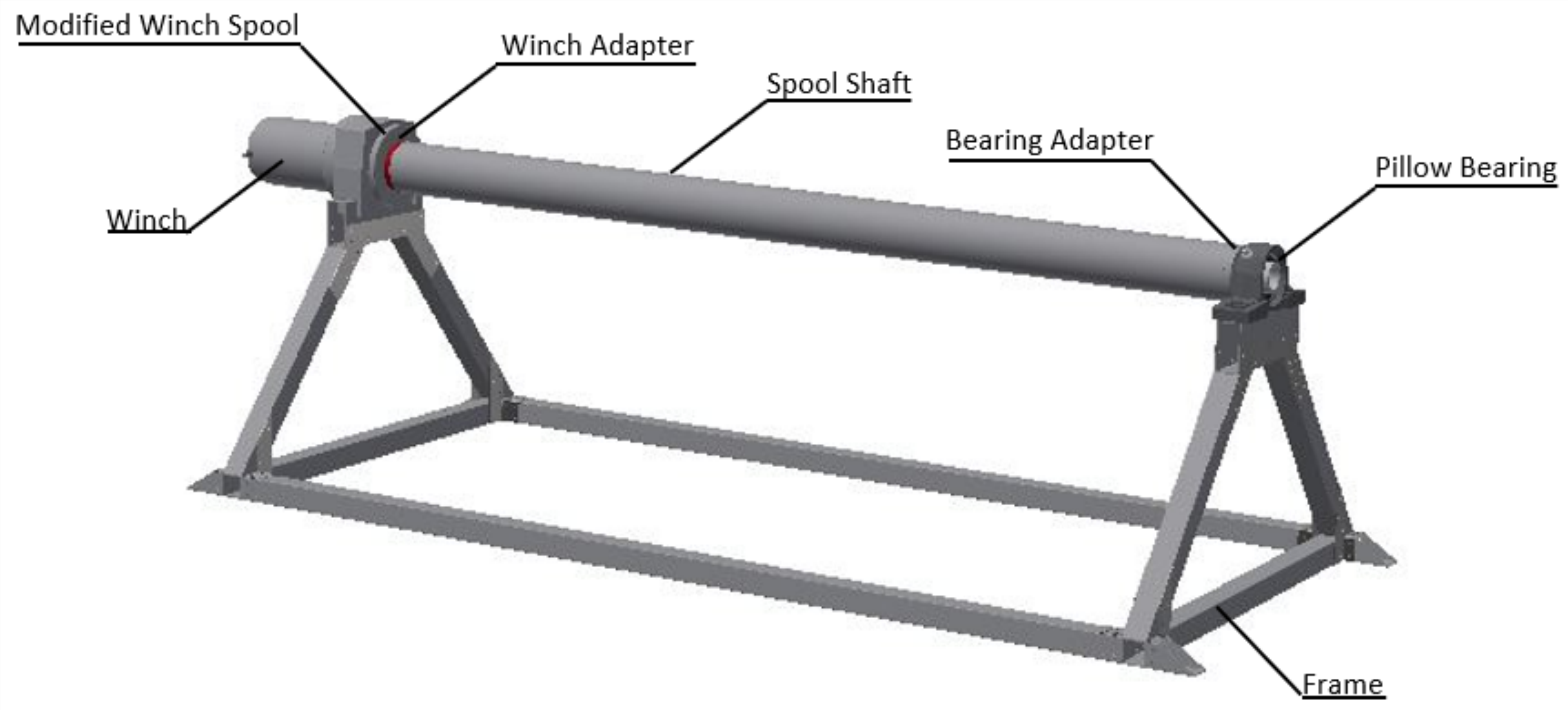
Publicly Available Information, Decommissioned Base

The Container Module

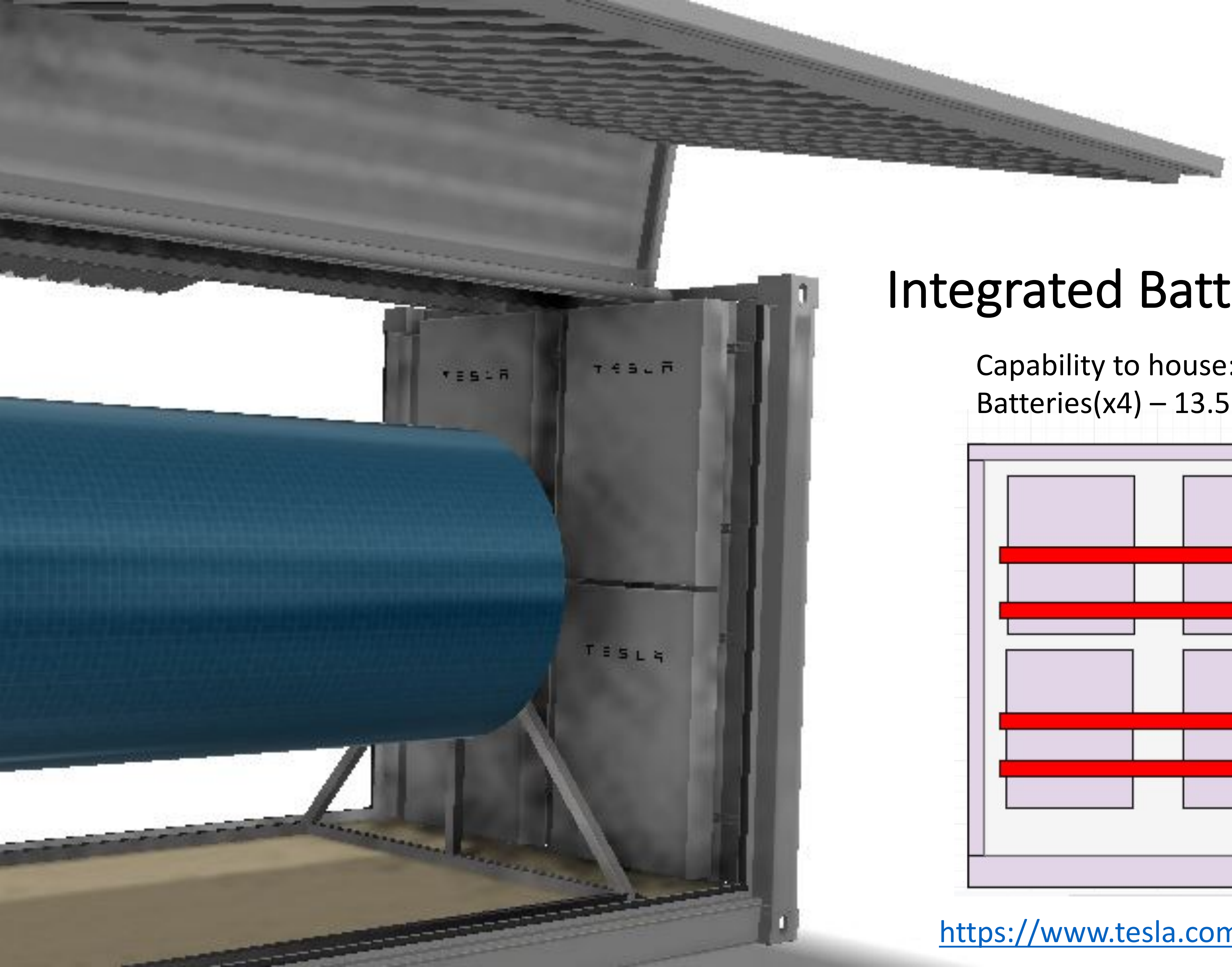


Prototype Facts:
Parts = 157
Est. Mass = 200-lb

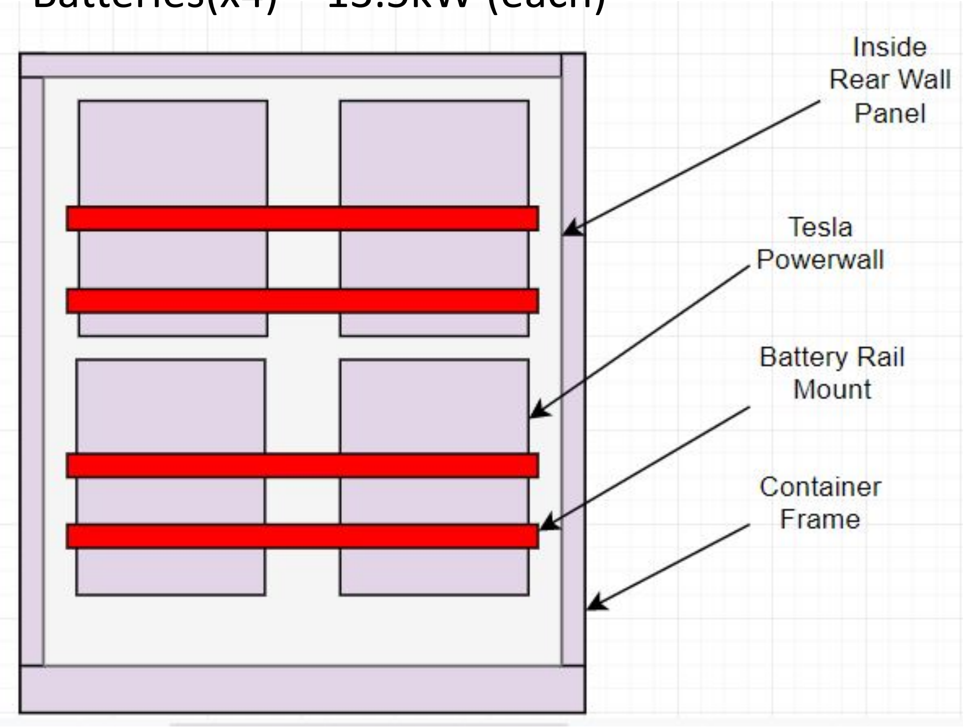
The Rectenna Spool



Integrated Battery Power Storage

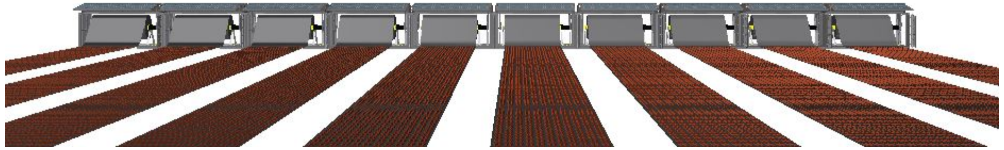


Capability to house:
Batteries(x4) – 13.5kW (each)



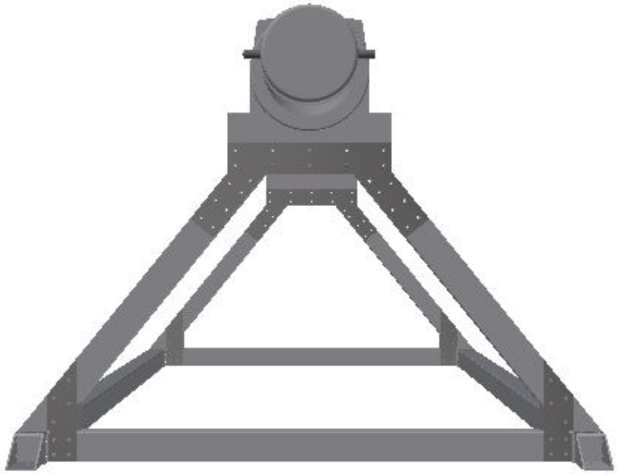
https://www.tesla.com/powerwall

Spool Frame Side View



Set of 10 MDGPR's

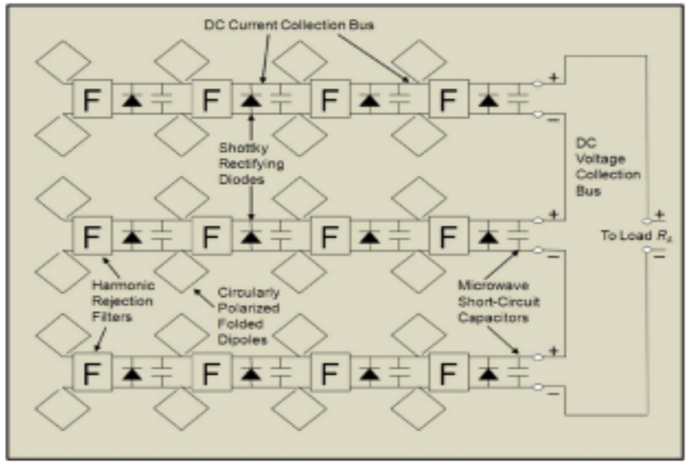
View of MDGPR

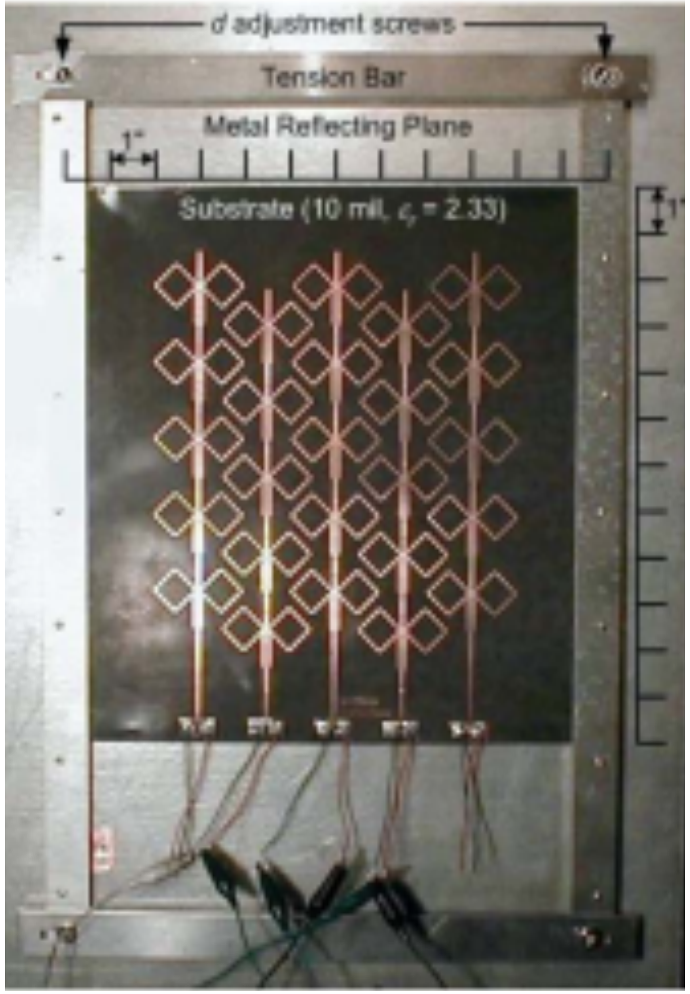


Spool Frame Left

Printed Rectenna Array

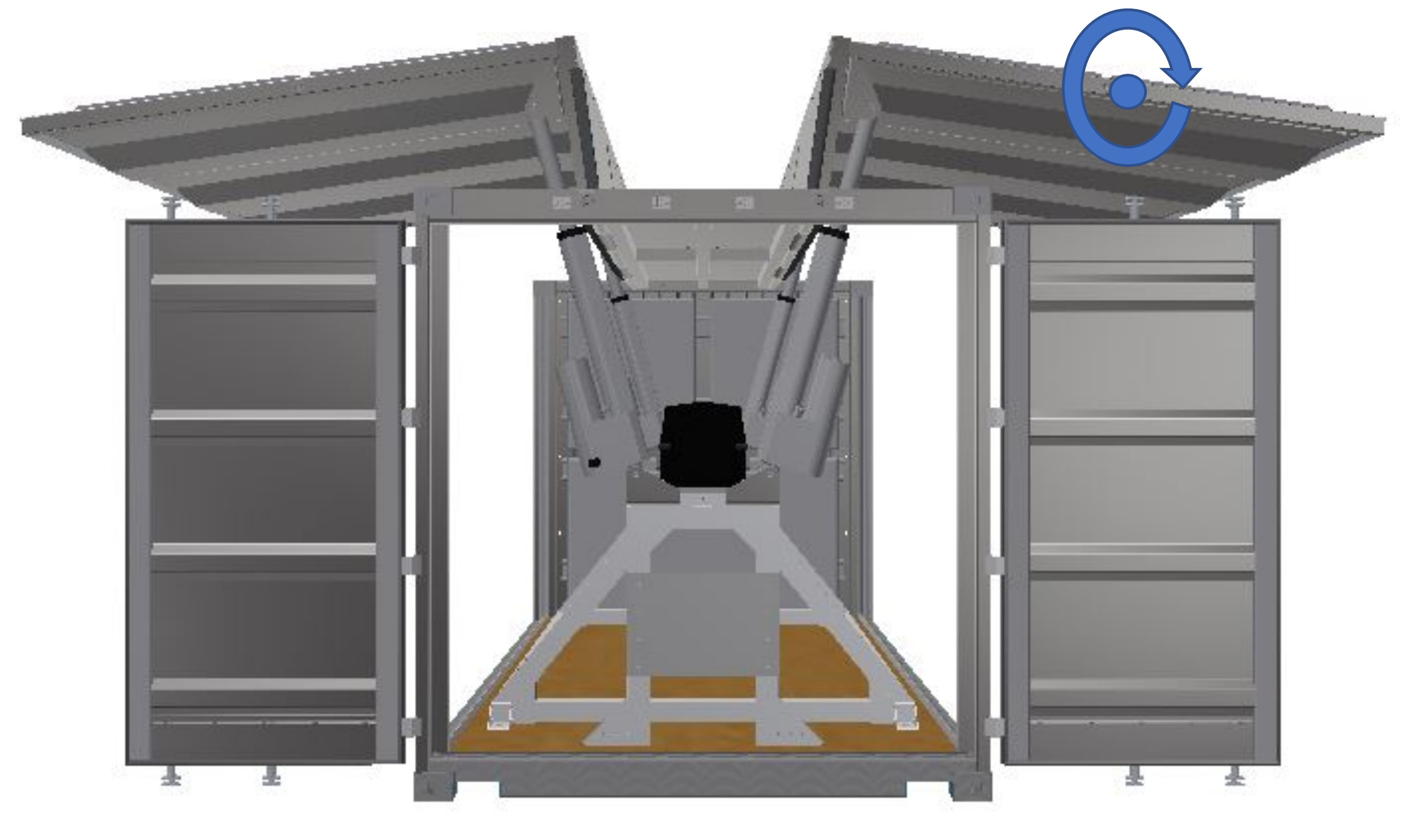
- Use of circularly polarized (CP) folded dipoles.
- Circular polarity is necessary as the source of transmission will be orbiting overhead.
- Requires half of the number of rectifying antennas in a given area verses that of a linearly polarized (LP) array.
- A flexible, printed array will make up the spooled receiver panel.





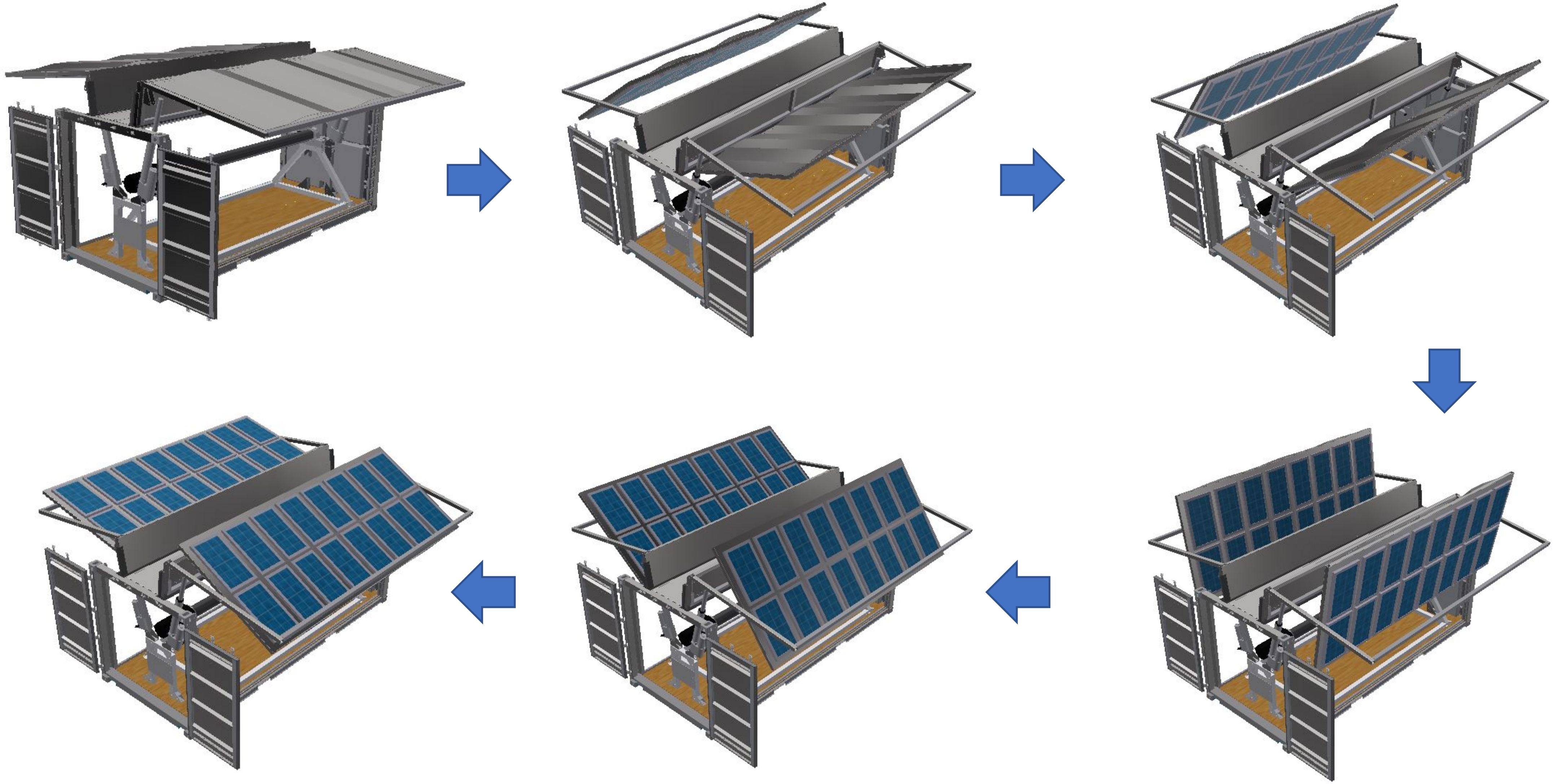
Tested rectenna array by Strassner and Chang

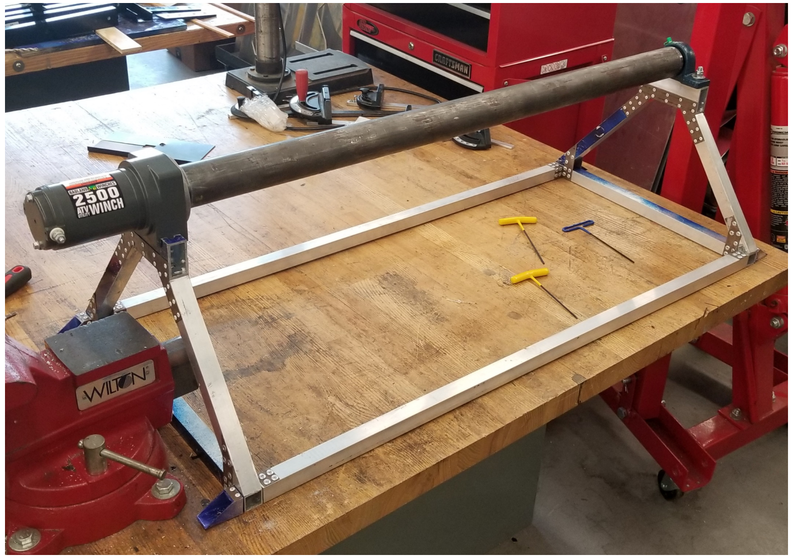
The PV Swivel Panel

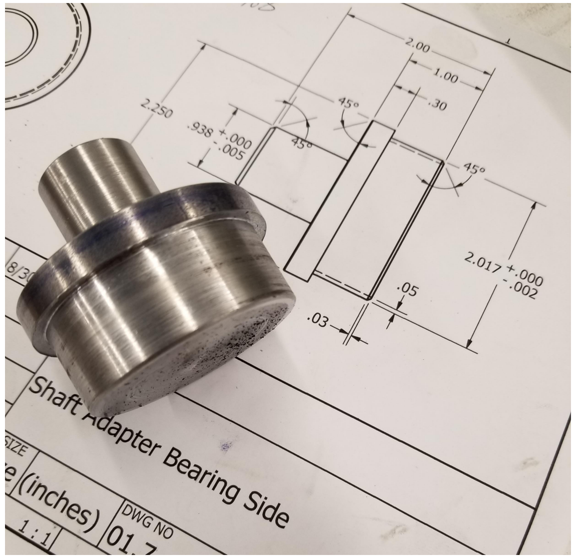


Approximately 2000-W of Power Generation Per Door
(x2) Doors = 4-kW Per Container
10 Containers = **40-kW Added Power To System**

PV Panel Deployment




2500
WINCH


2.00
1.00
.30
2.250
45°
.05
.03
Shaft Adapter Bearing Side
(inches)
DWG NO
1:1

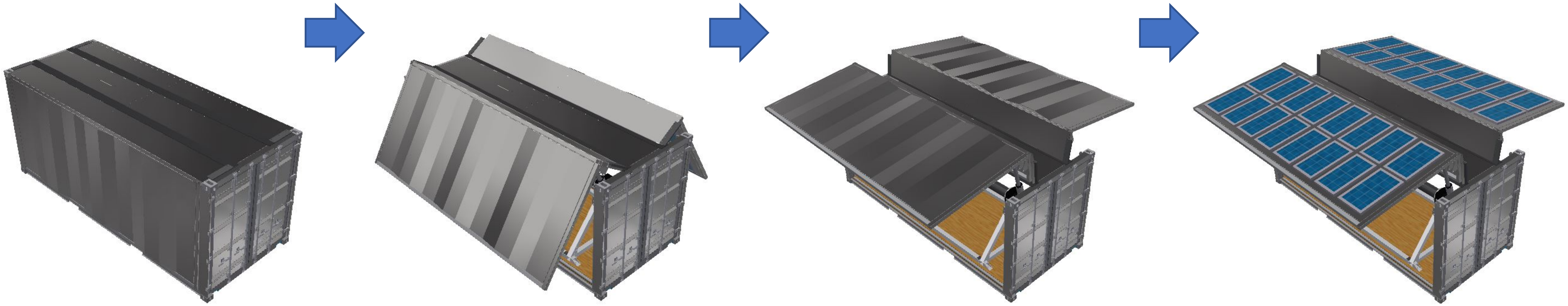
Container Cost Estimate

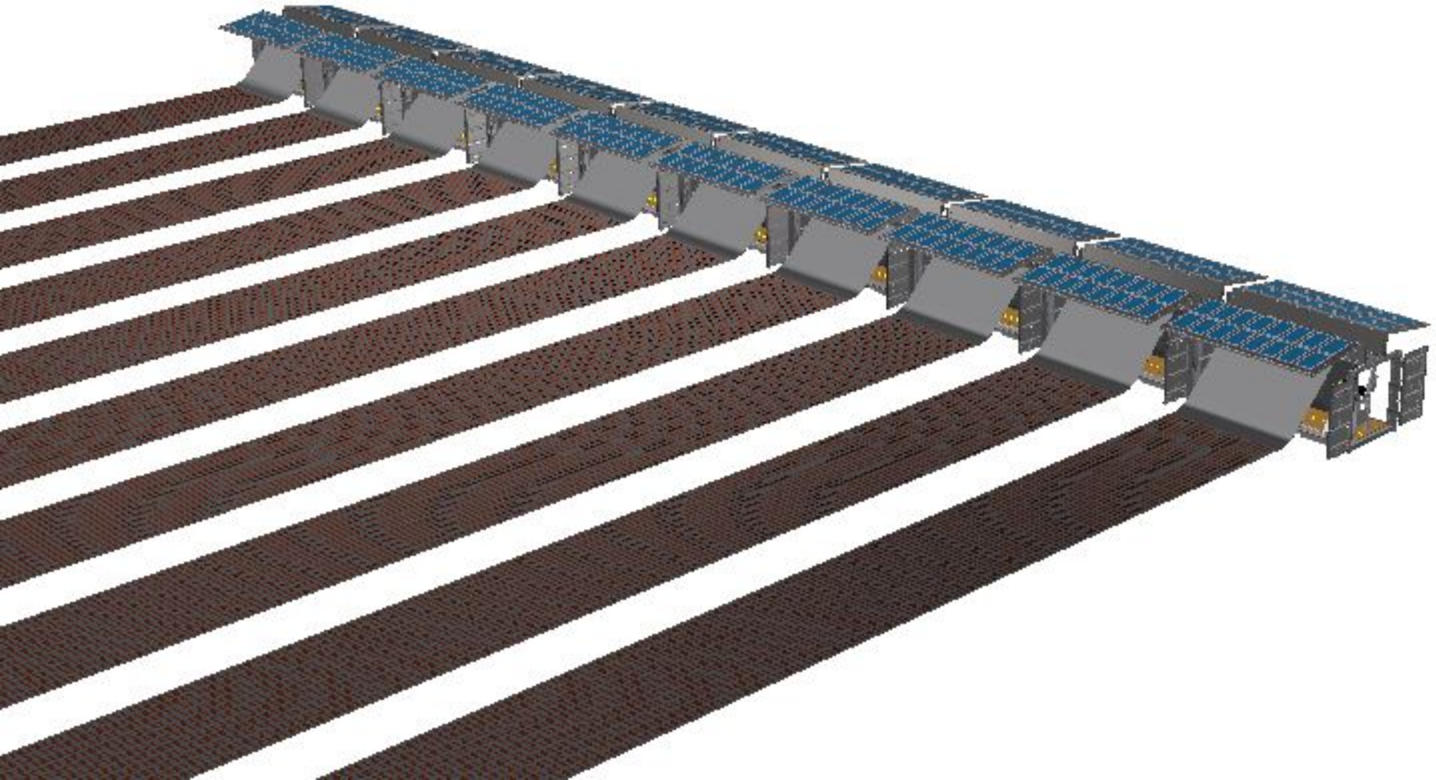
- Custom Container: $5,000 (base) + $5,000 (mods) = $10,000
- 4 Batteries: $15,000 each = $30,000
- Spool Frame: $5,000
- Spool Drive System: $2,000
- Total: $47,000
- 10 Container Cost: $470,000 – equivalent to ~94,000 gallons of fuel at $5/gallon

- **Rectenna cost not included

System Deployment

1. Deployment site is scanned by small UAS, and cleared of major debris
2. Containers are airlifted or unloaded to the pre-determined location
3. Gullwing doors are unlocked and opened
4. Manually rotate the PV panel sub-frame 180deg
5. Center of container is located and marked
6. A line 90 degrees to container side is marked out a pre-determined length
7. ATV hooks-up to the receiver and drives down the line
8. Retract the rectenna with remote control





Design Strengths

- Simple reliable structure to build in short time on a tight budget
- Easy to transport using existing methods
- A spool is a safe and reliable means of deployment
- Gullwing PV swivel door design is novel and could have spin-off applications

Future Work

- Design a small flexible thin-film rectenna
- Fabricate and integrate a ¼ scale rectenna on the spool
- Integrate sun sensor into Gullwing Door mechanism
- Install PV panels on swivel doors
- Build full-scale prototype

Challenges with Developing the Ground Component

- No significant development or manufacturing activity done to date
- Prototyping costs could be high
- System needs to flexible enough to satisfy many different applications to be viewed favorably amongst stakeholders
- Power demand varies significantly with application and may not be suitable for some

Any Questions?

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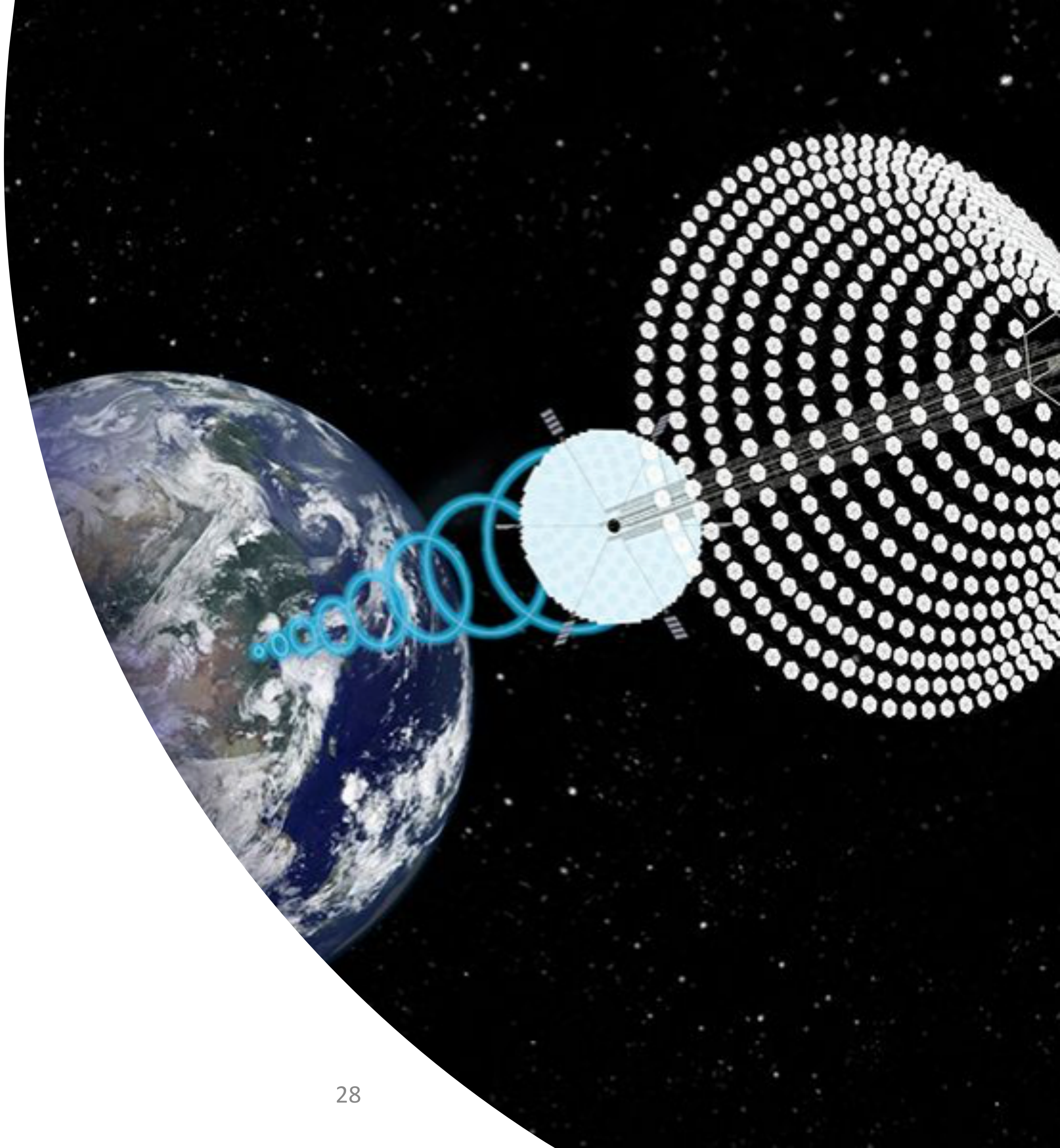

BACKUP

Useable Volume In Shipping Container For Reciever

	m	ft	in		m³	ft³	in³
Length	4.50	14.76	177.17	Volume	20.19	713.13	1,232,296
Width	2.01	6.58	78.95				
Height (avail)	2.24	7.34	88.10				

$$D_o = \sqrt{\frac{4Lt}{\pi} + D_i^2}$$

Input Diameter of Shaft and Deployed Length Desired

	m	ft	in	
Diameter (spool) D	2.24	7.35	88.19	*max available (height)
Diameter (shaft) D_i	0.10	0.33	4.00	*subject to change
Length (deployed) L	100	328.10	3937.20	*max 310

$$t = \frac{\pi(D_o^2 - D_i^2)}{4L}$$

	in	
Thickness (panel)	1.55	(max possible)

Input Desired Panel Thickness

	in	ft	m
Desired Panel Thickness	0.50	0.04	0.01

Panel Material Mass per m² (kg):

Total Mass or Reciever Panel:

Input Power Requirement

Power Received (Required)	Power Transmitted (Output)	Area of Transmitter	Wavelength	Far Field Distance	Area of Reciever	Diameter of Receiver	Diameter of Transmitter
P_r (GW)	P_t (GW)	A_t (km²)	λ (mm)	D (km)	A_r (km²)	d_r (km)	d_t (m)
0.0002	1.3	143.9	51.8	7066.7	1.44	0.04	428
P_r (kW)	P_t (kW)	A_t (m²)	λ (m)	D (m)	A_r (m²)	d_r (m)	
200	1,300,000	143872.4	0.0518	7066738.7	143.53	42.47	

	m2
Area Required	143.5

$$P_r = \frac{P_t A_t A_r}{\lambda^2 D^2} \quad where\ D > \frac{2d^2}{\lambda}$$

$$A_r = \frac{P_r \lambda^2 D^2}{P_t A_t} \quad where\ D > \frac{2d^2}{\lambda}$$

Summary of determined dimensions

	m	mm	ft	in
D_{rolled}	1.28	1,275.64	4.19	50.22
D_{shaft}	0.10	101.60	0.33	4.00
Panel	0.01	12.70	0.04	0.50
Deployed Panel Length	100.00	100,000.00	382.10	4,585.20
Deployed Area (m²) [per	m² 450.00		Power Density Selection 50	Output per Container: 22,500.00
Weight of Rectenna on Spool (kg) [2kg/m²]:	900.00		Power Desired (W)[see input power req table]:	200,000
Weight of Shipping Container (kg) [empty w/	4000		Required Number of Shipping	9
Gross Weight of Container w/Array (kg)[subj. to change]:	4900			

Image References

- Slide 23: https://www.tesla.com/powerwall
- Rectenna Array Design: https://images.app.goo.gl/VNuUbSv5RH4B1aU4A
- Paul Jaffe Presentation: https://www.youtube.com/watch?v=V5SMF9p-4Q0