VIRTUS SOLIS

Our Path to Space Based Solar Power

Dr. Edward Tate
CTO
ed@virtussolis.space

GM Executive Alumni Luncheon

May 8, 2024

VIRTUS SOLIS

Looking Back 40 years

September 1975, Popular Science

Image from https://books.google.com/books?id=RwEAAAAAMBAJ&printsec=frontcover#v=onepage&q&f=false

Coming–

Energy from space

for use on earth?

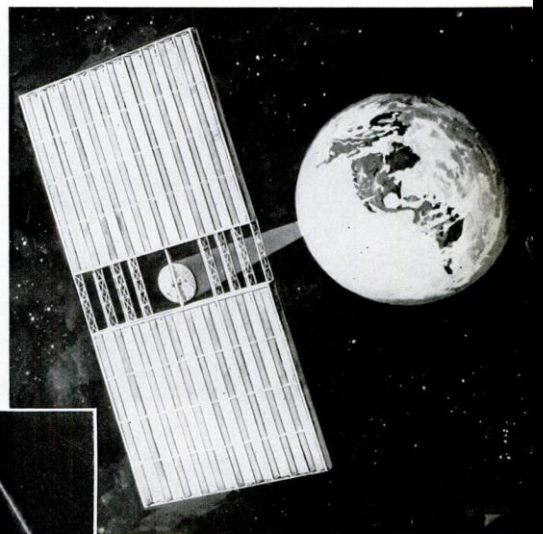
Microwave beams point the way to solar-power stations in orbit—and satellites to relay energy around the globe

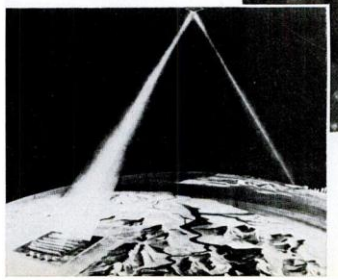
By **WERNHER von BRAUN**
PS Consulting Editor, Space

This summer, blazing lights on a hillside at Goldstone, Calif., were expected to signal the transmission of tens of kilowatts of electric power for a mile by a microwave beam. It would be the furthest step yet toward novel and imaginative proposals to supply earth dwellers with energy from space.

One such concept envisions an orbiting solar-power station that would beam energy to earth by microwaves. An alternate concept: a power-relay satellite that would deliver energy across continents or oceans from a solar or nuclear sta-

Continued





Gigantic solar-power satellite beaming energy to earth, proposed by Dr. Peter Glaser, is visualized in Grumman picture above from Arthur D. Little, Inc. It spans seven miles the longest way and would be assembled in geosynchronous orbit. Antenna between solar arrays transmits their electric power by microwave beam to a receiving station on earth. Alternate energy-via-space concept of Dr. Krafft Ehricke, pictured at left, uses satellite to relay power from a remote solar or nuclear plant on earth to a receiving station serving a populated region. Ground installation in foreground is transmitter of microwave-power beam.

tion at a remote place on earth.

Can we find help in space for the energy shortage? For the long haul the answer is an emphatic yes—though a close look at the two principal proposals so far shows that the haul may be long indeed.

Transmitting electric power from outer space to earth calls for starting with direct current provided, say, by a vast orbiting array of solar cells; converting it to a microwave beam; intercepting the beam with a receiving antenna on earth; and rectifying the energy to direct current for distribution to users. The rectifying units could be coupled to the receiving antenna, or built into it—a combination now called a rectenna.

The solar-power satellite

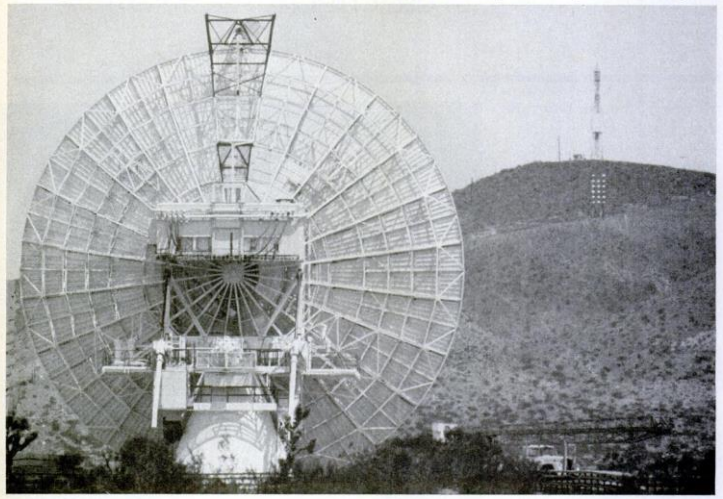
An orbiting solar-power station is the concept of Dr. Peter E. Glaser of Arthur D. Little, Inc., who heads a study team of specialists from his own company, Grumman, Raytheon, and Textron.

It would be placed in a geosynchronous orbit, 23,000 miles high, where it would hover over a fixed spot on earth, to deliver energy to a ground station. This concept has a lot of things going for it:

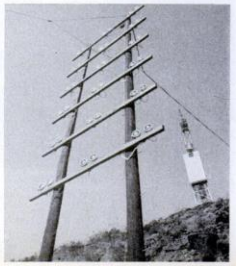
Outer space has no clouds, and no day-and-night cycle. The satellite's infall of sunshine would be interrupted only around the time of the equinoxes when the earth briefly shadowed it—for 72 minutes daily or less. The amount of energy it could collect would be limited only by the size of its solar arrays.

The proposed capacity of a Glas-

Hurling tens of kilowatts a mile without wires will be a step toward power from space



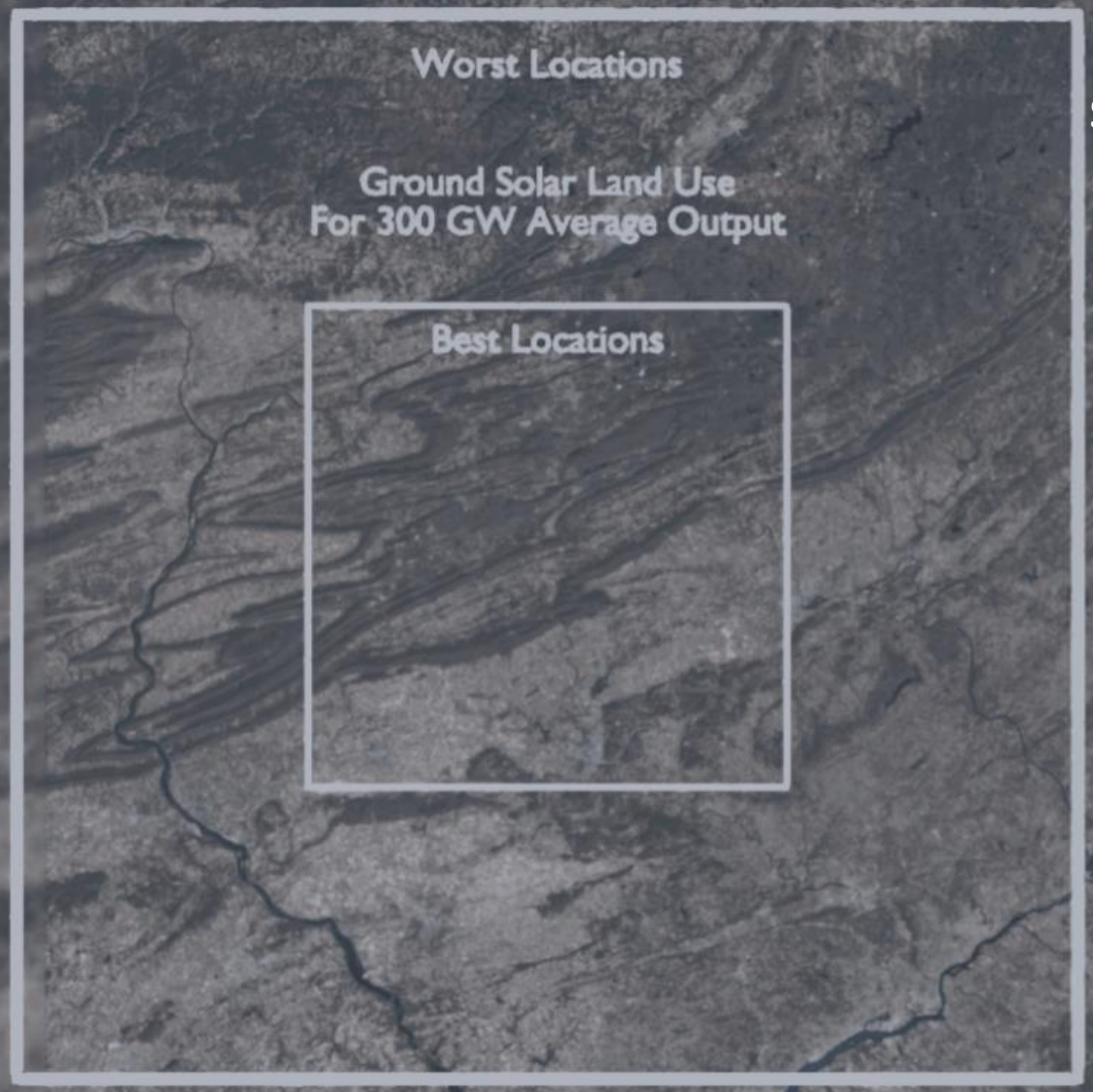
Big-scale demonstration of wireless power transmission by microwaves, scheduled for July and August 1975 by NASA's Jet Propulsion Laboratory and Raytheon, is readied at Goldstone, Calif. Dish antenna 85 feet in diameter (left foreground in photo above) will radiate 300 to 400 kilowatts toward a 12-by-14-foot receiver ("rectenna") a mile away on a hilltop tower, seen in right background of large photo and in close-up view at near right. It will recover sizable portion, expected to reach tens of kilowatts, of the beam. Pairs of high-intensity indicator lamps (far right) arranged in same pattern as rectenna's 17 elements, show which are energized as powerful beam sweeps across its target.



September 1975, Popular Science
Wernher von Braun

Image from https://books.google.com/books?id=RwEAAAAAMBAJ&printsec=frontcover#v=onepage&q&f=false

Ground Solar Land Requirements For 300 GW



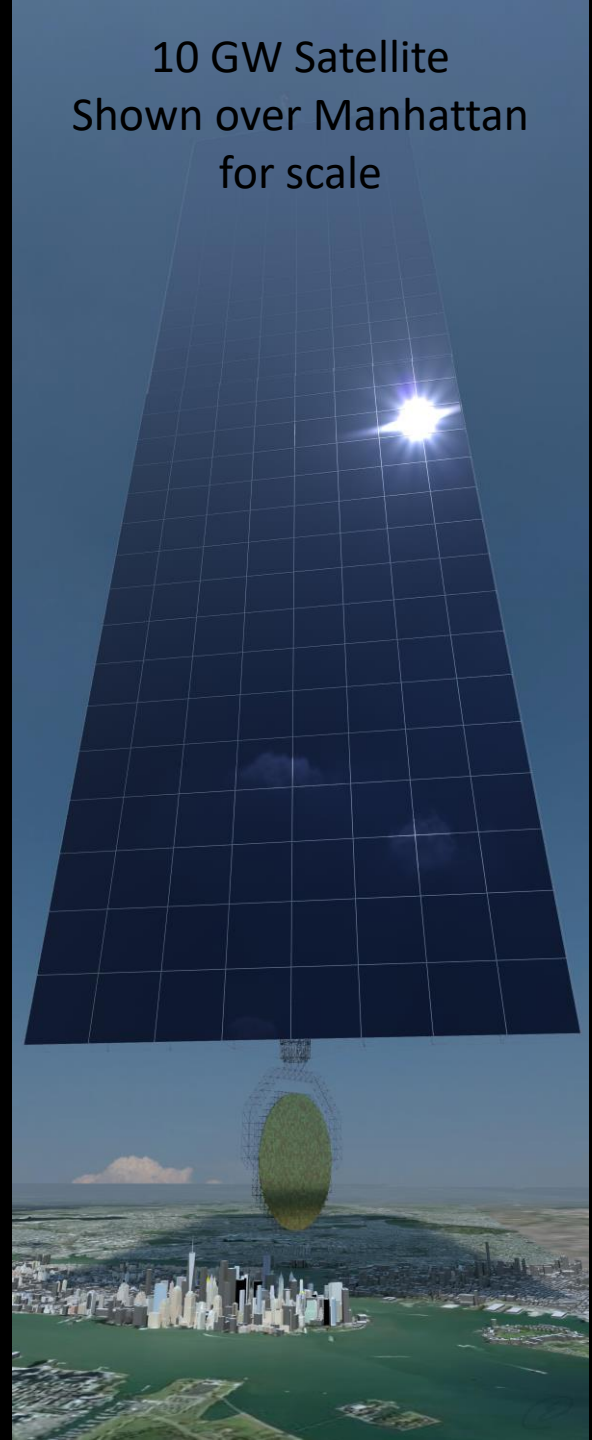
Satellite Area for 300 GW In Space

In 1979 Rockwell, Boeing, NASA & DoE
Proposed
Solar Power Satellites
to solve the energy crisis.

The engineering study cost
~$80M (2023 dollars)

In 1981, the program was shut down.

It was recommended to revisit in 40 years.



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VIRTUS SOLIS

WHO WE ARE

Founders

John Bucknell – CEO

Dr. Edward Tate – CTO

Seth Elliot – COO

Deeply Experienced Technical Team

CHANGE IS COMING

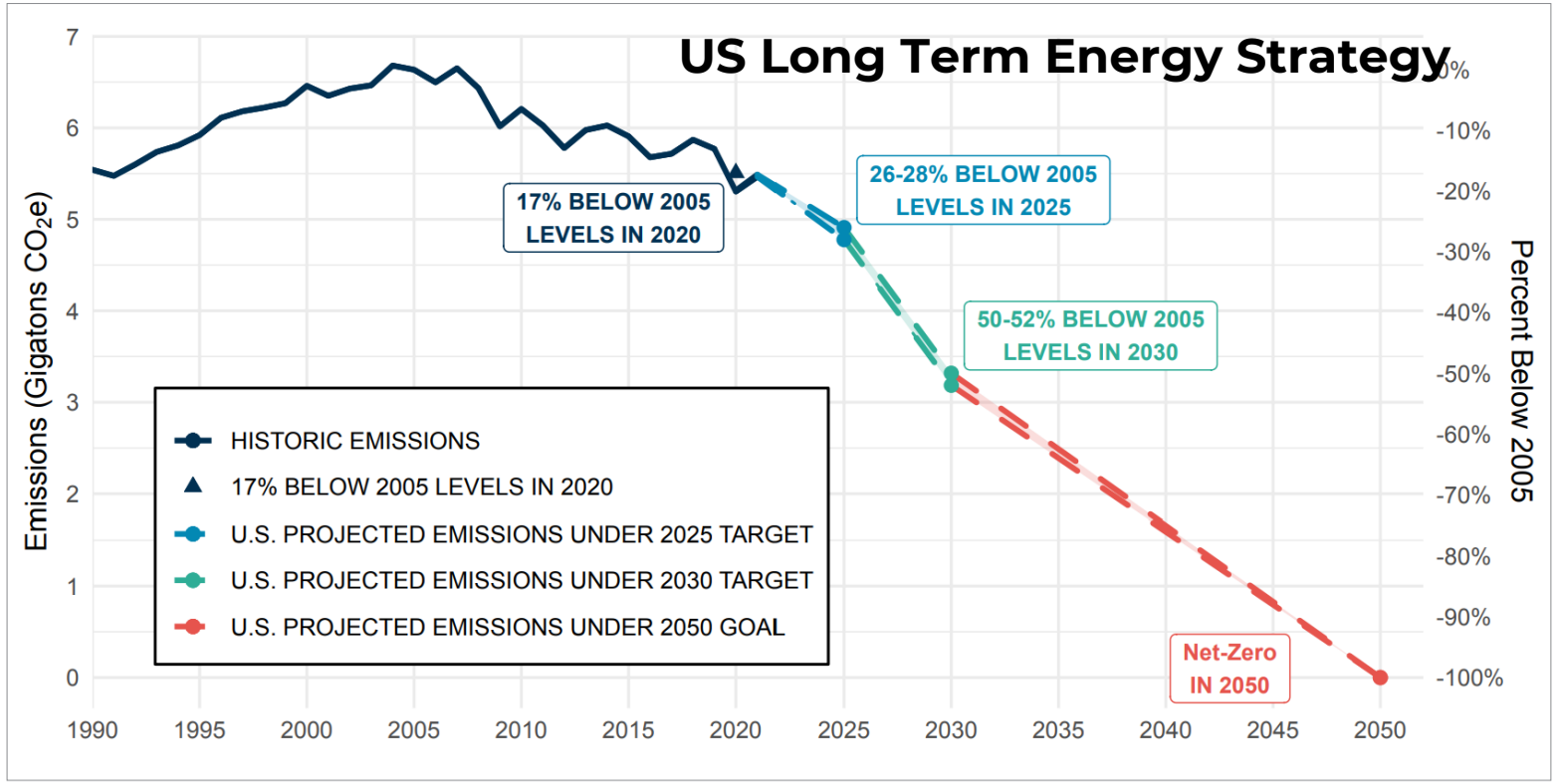
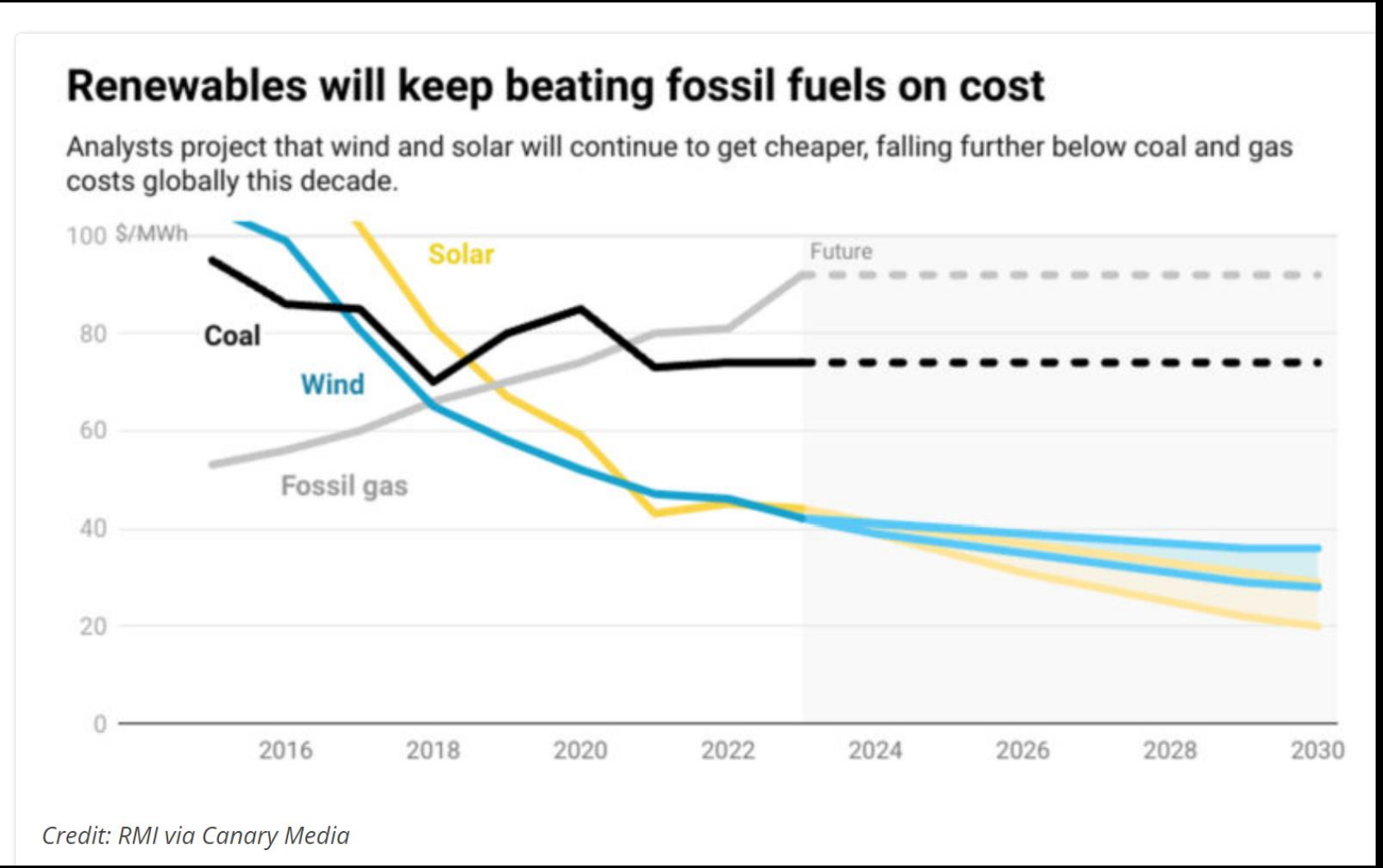


Figure 1: United States historic emissions and projected emissions under the 2050 goal for net-zero. This figure shows historical U.S. GHG emissions from 1990 to 2019, the projected pathway to the 2030 NDC of 50-52% below 2005 levels, and the 2050 net-zero goal. The United States has also set a goal for 100% clean electricity in 2035. That goal is not an economy-wide emissions goal so does not appear in this figure, but it will be critical to support decarbonization in the electricity sector, which will in turn help the U.S. reach its 2030 and 2050 goals.


Today’s path to a cleaner world ...
Solar Farms
Wind Farms
Grid Storage
Transmission lines
Distribution lines
Demand management

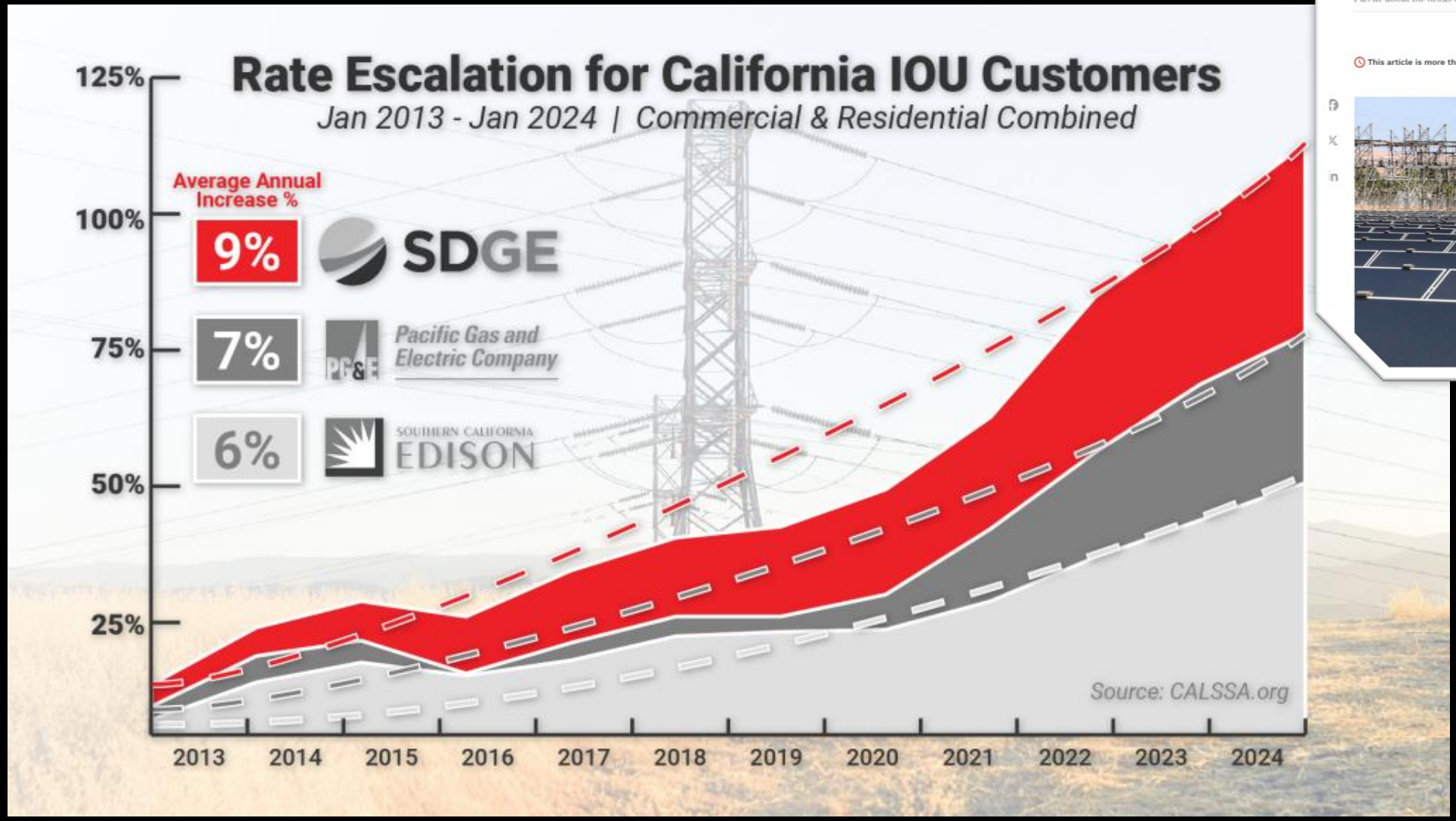
GENERATION COSTS DROPPING

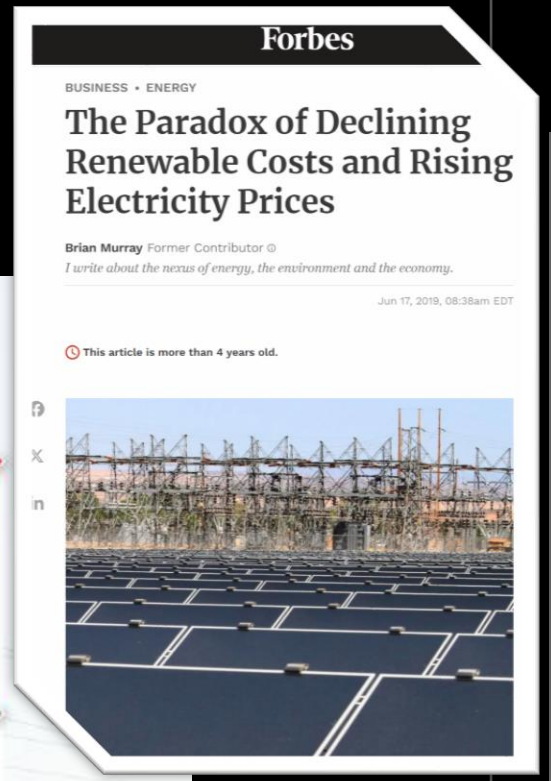


Credit: RMI via Canary Media

... YET

TOTAL ENERGY COSTS ARE RISING





Forbes

BUSINESS • ENERGY

The Paradox of Declining Renewable Costs and Rising Electricity Prices

Brian Murray Former Contributor

I write about the nexus of energy, the environment and the economy.

Jun 17, 2019, 08:38am EDT

This article is more than 4 years old.

https://revel-energy.com/2024-rising-electricity-rates-for-california-businesses/

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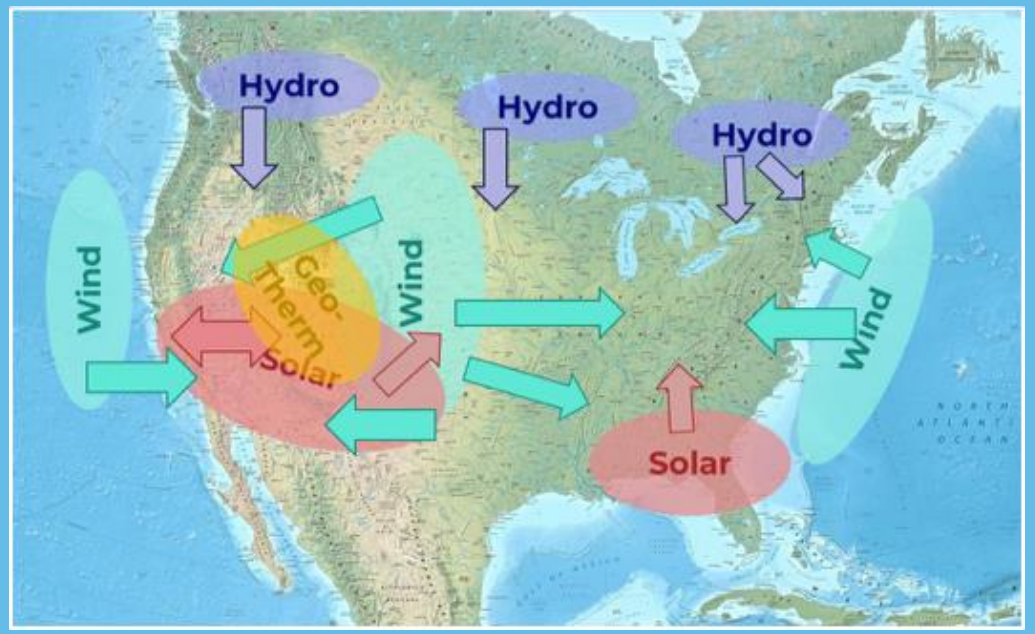
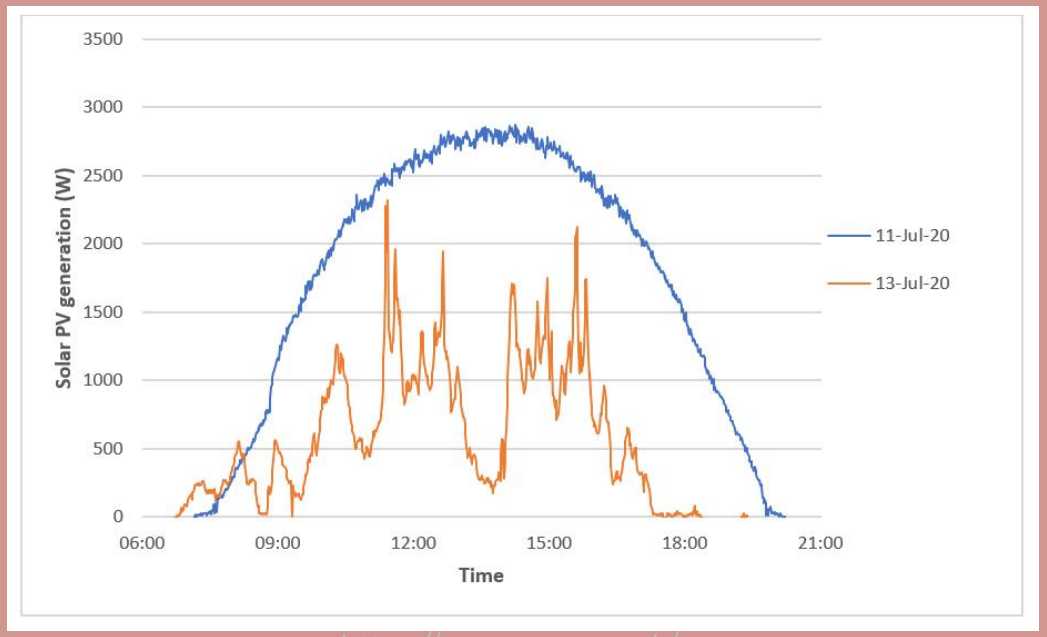
PROBLEM – VARIABLE RENEWABLES

Geographic Variation



Time Variation



https://www.nea.org.uk/

FIRMING IS STUPIDLY EXPENSIVE...

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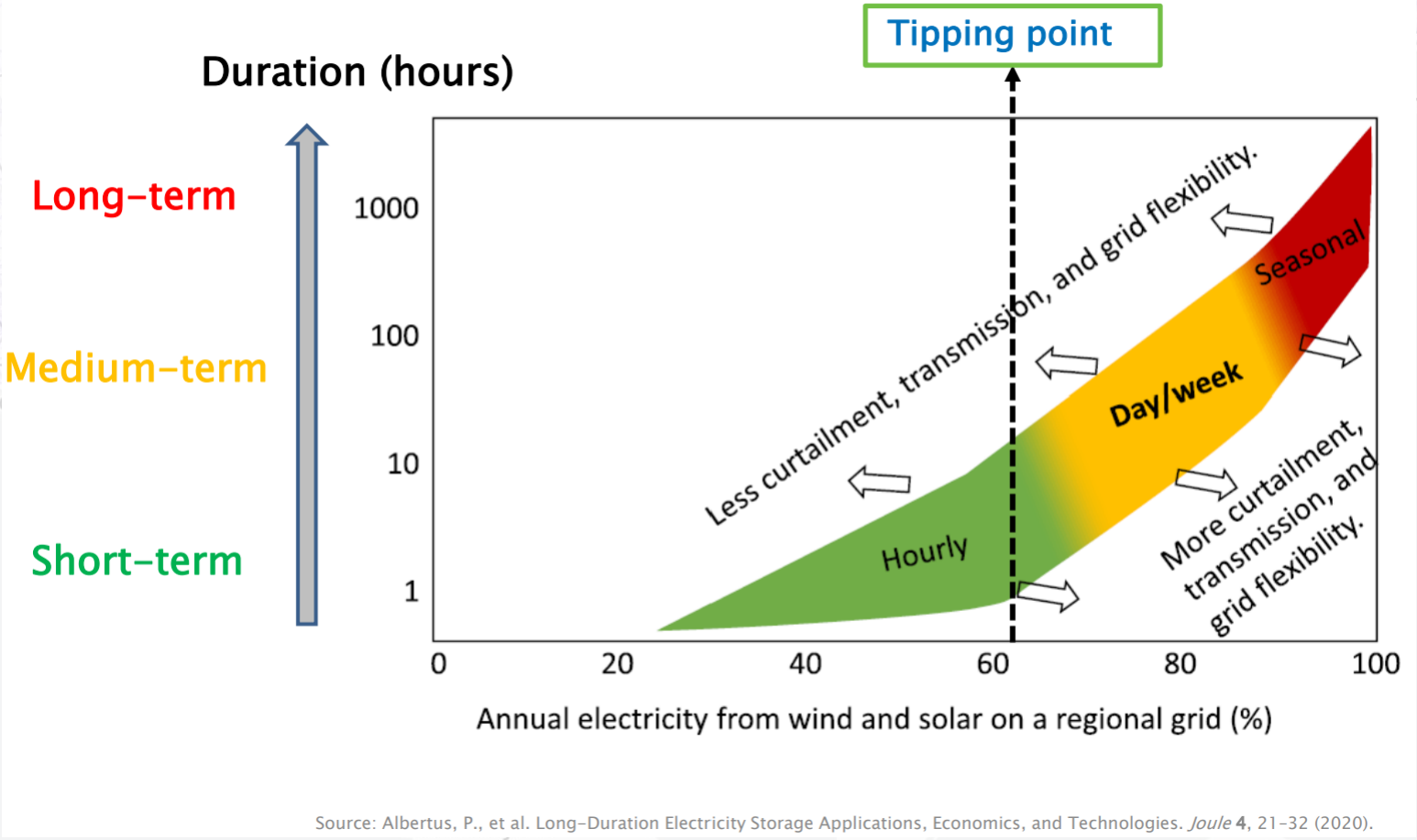
BATTERIES GET EXPONENTIALLY EXPENSIVE



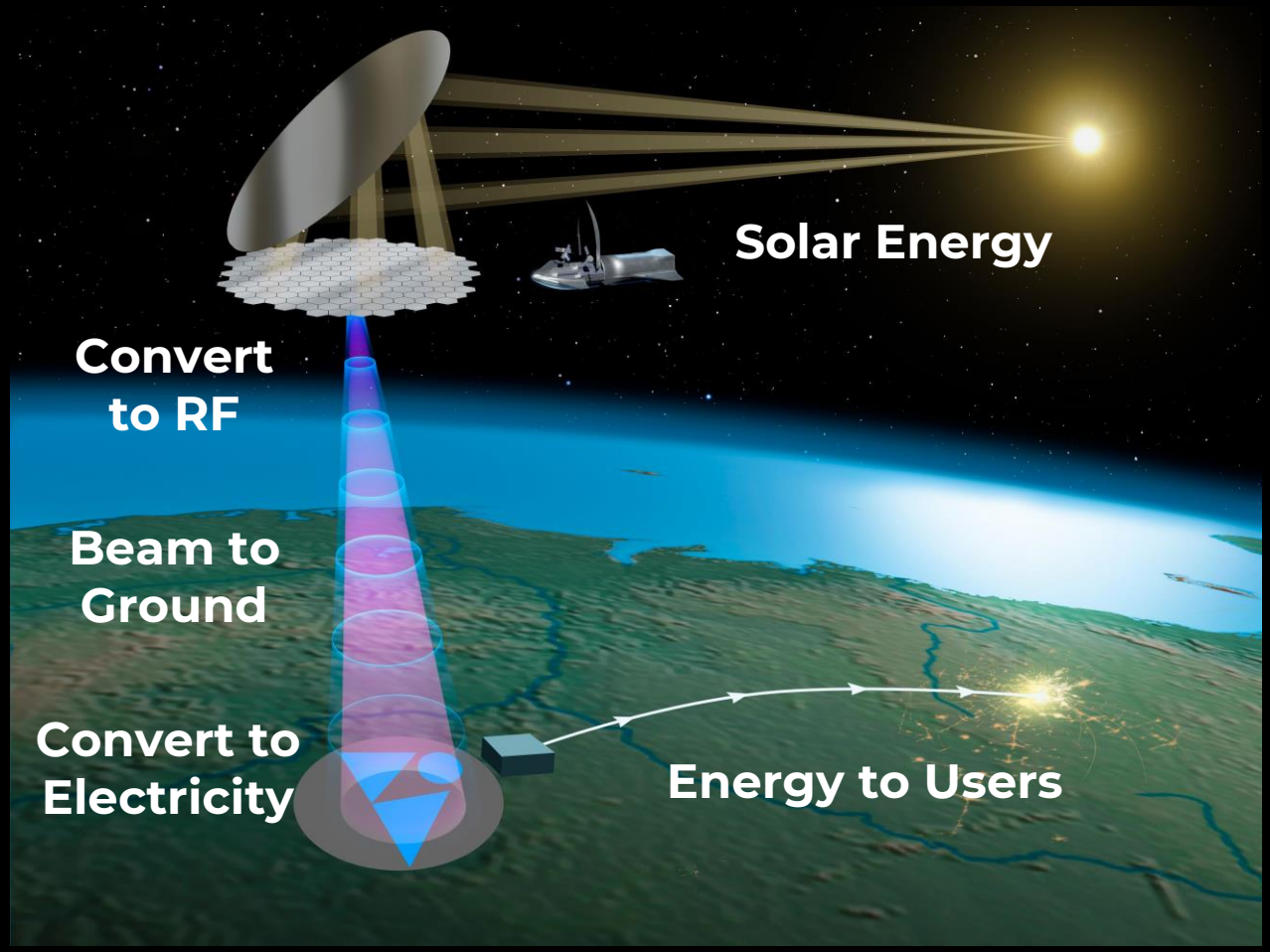
Source: Albertus, P., et al. Long-Duration Electricity Storage Applications, Economics, and Technologies. *Joule* **4**, 21-32 (2020).

Something Needs to Change

THE SOLUTION

Orbital power generation
- No night
- No clouds
- 24/7 Power

Beam power
- Through any weather
- Where needed
- When needed



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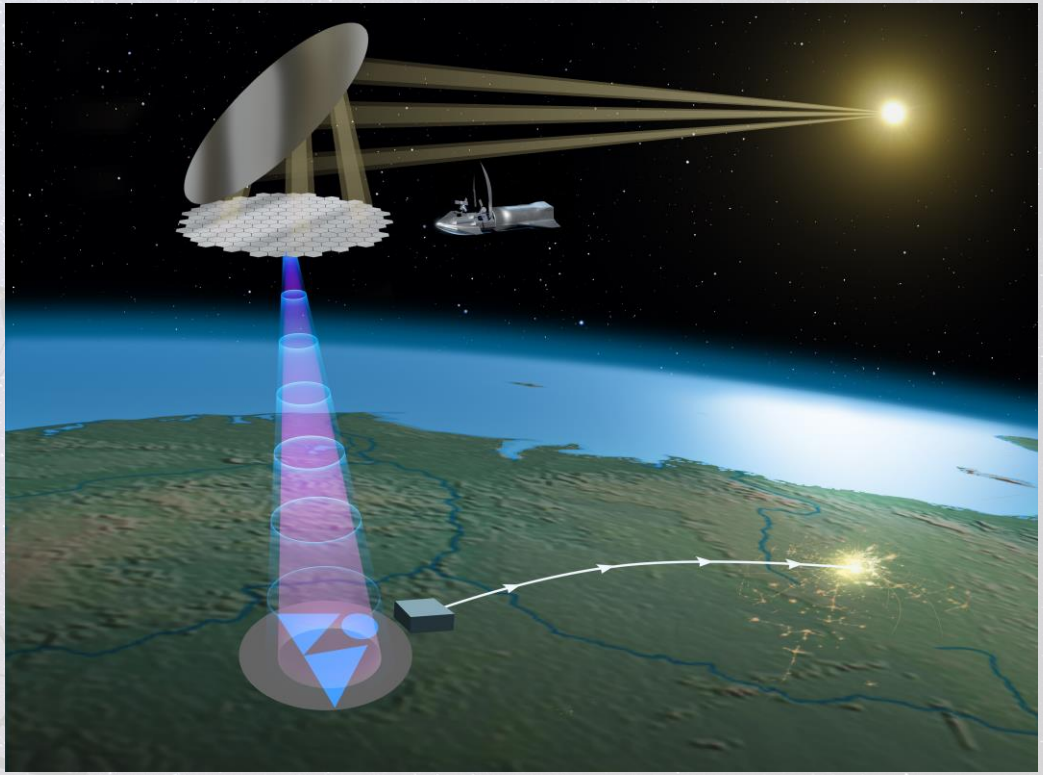
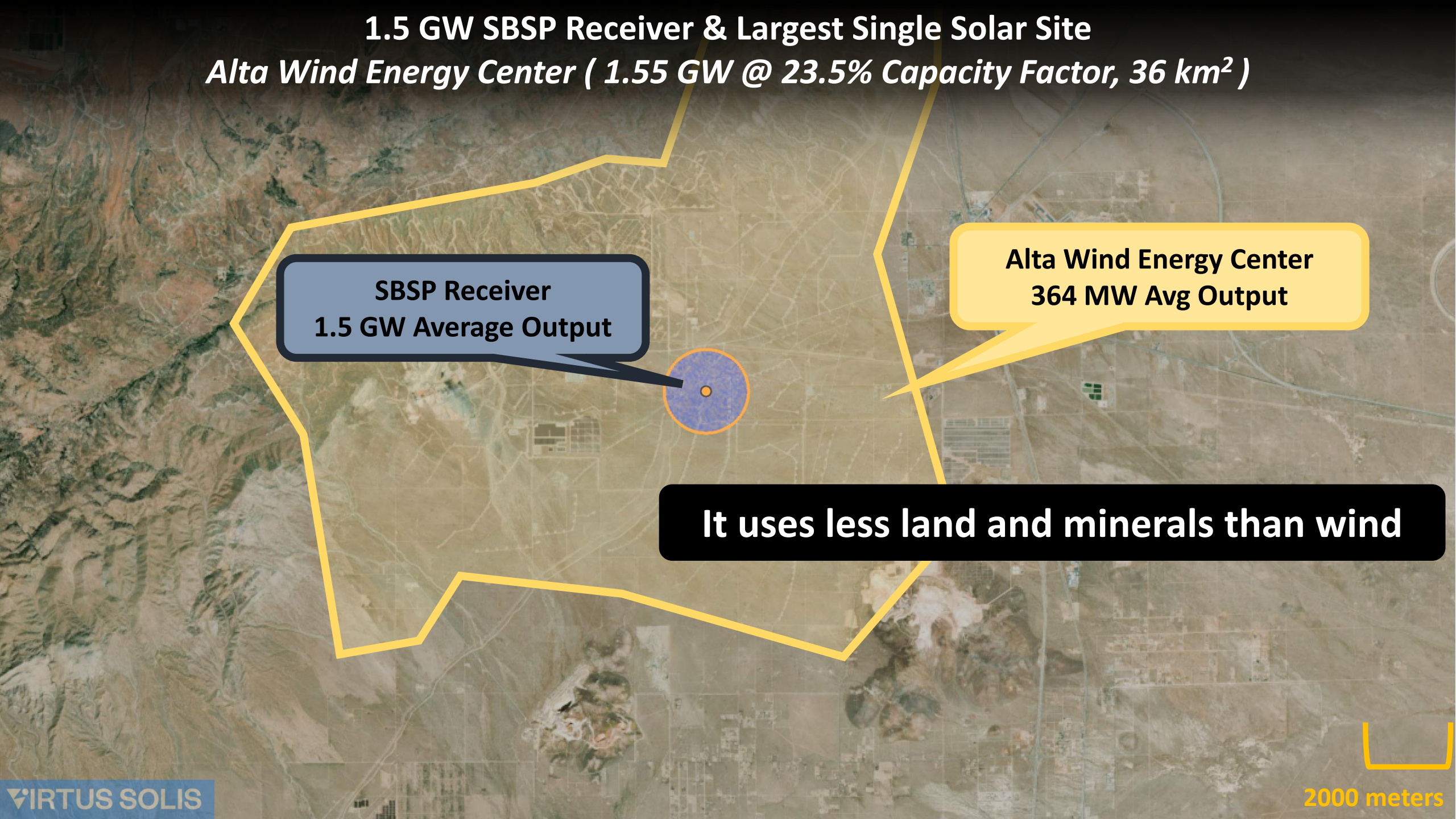
Video Available at
https://www.youtube.com/watch?v=SgS7BZIKuDQ

Space-Based Solar is Comparable to Uranium



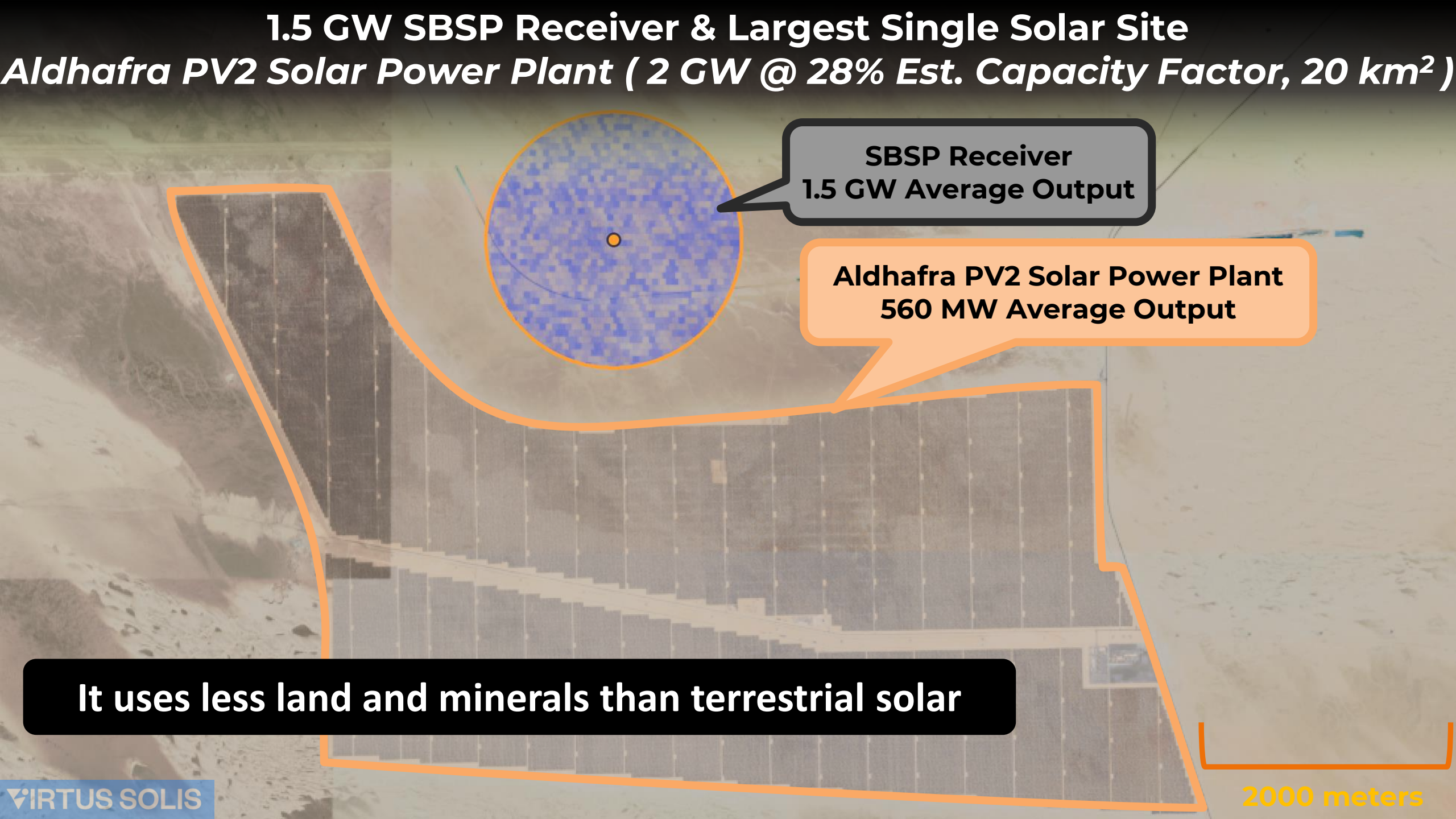
443,000 MJ/kg

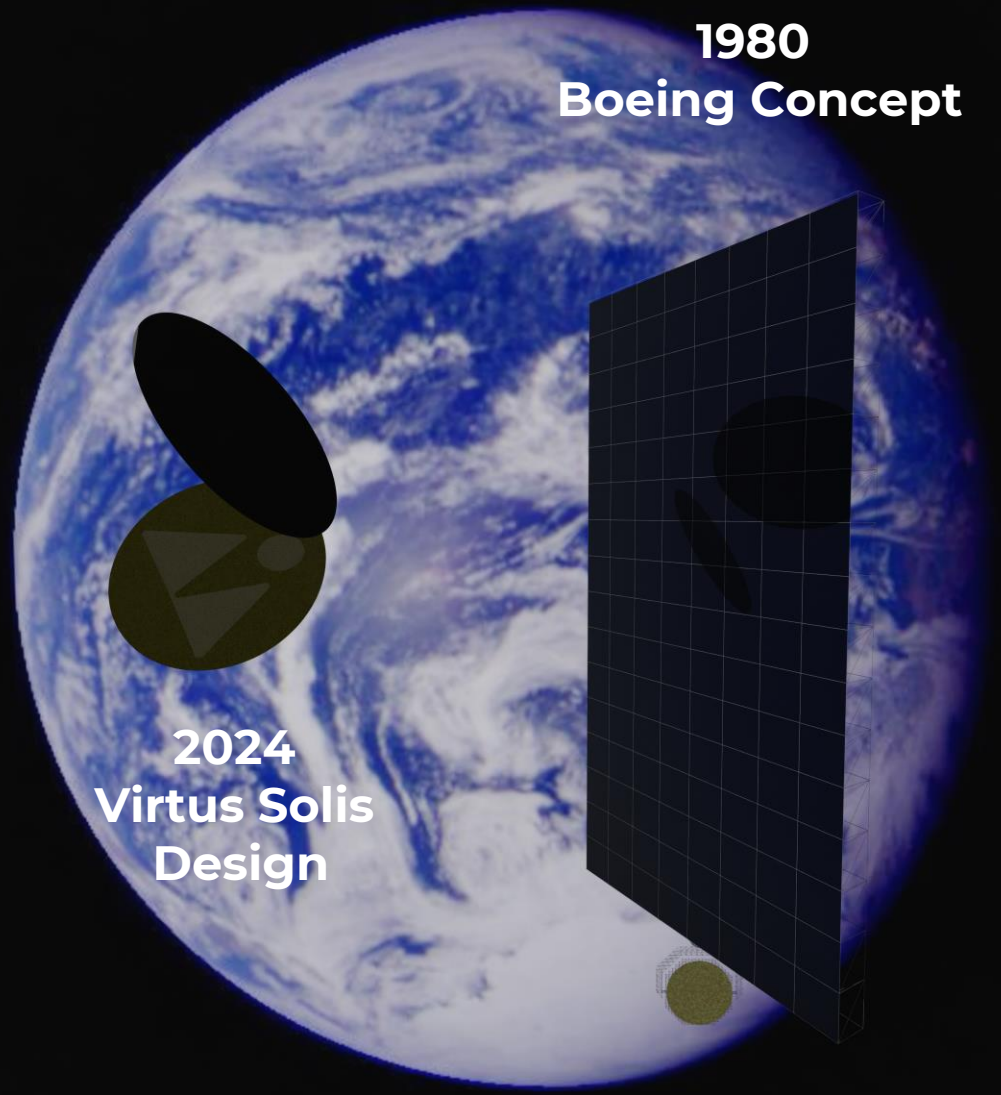
473,364 MJ/kg


1.5 GW SBSP Receiver & Largest Single Solar Site
Alta Wind Energy Center (1.55 GW @ 23.5% Capacity Factor, 36 km²)
SBSP Receiver
1.5 GW Average Output
Alta Wind Energy Center
364 MW Avg Output
It uses less land and minerals than wind
2000 meters
VIRTUS SOLIS

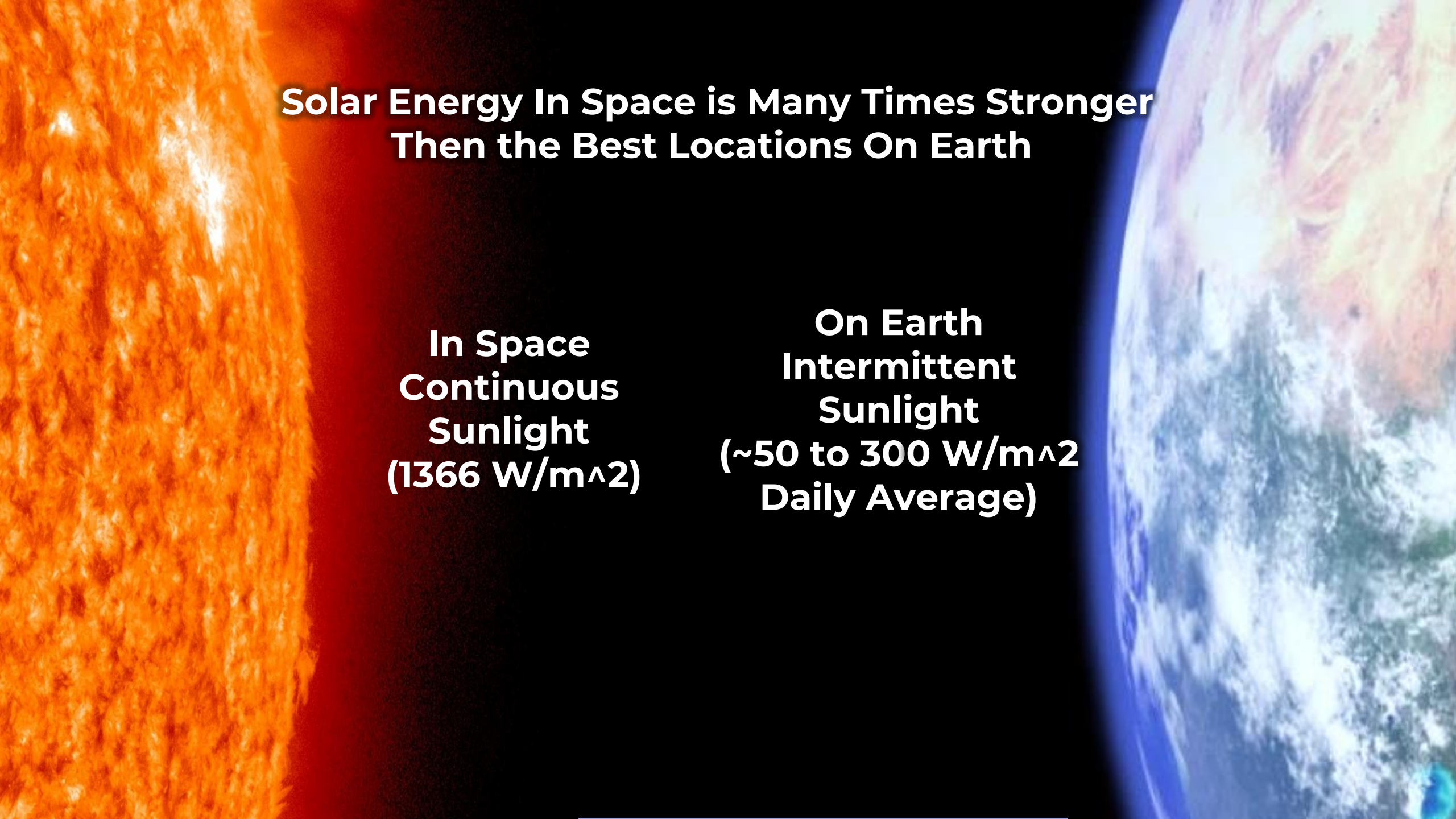
1.5 GW SBSP Receiver & Largest Single Solar Site

Aldhafra PV2 Solar Power Plant (2 GW @ 28% Est. Capacity Factor, 20 km²)

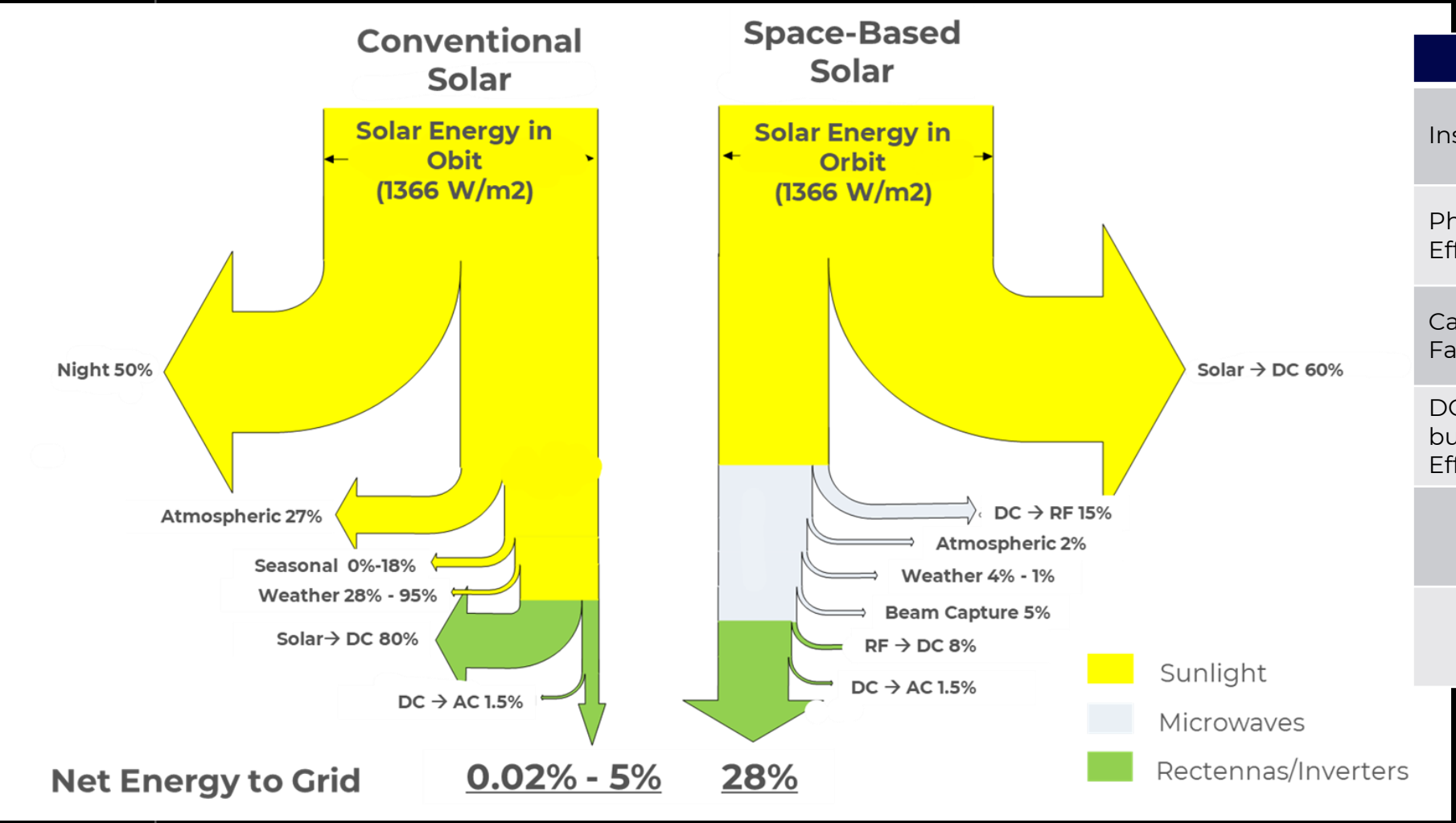




Recent SBSP designs are smaller & simpler than early concepts

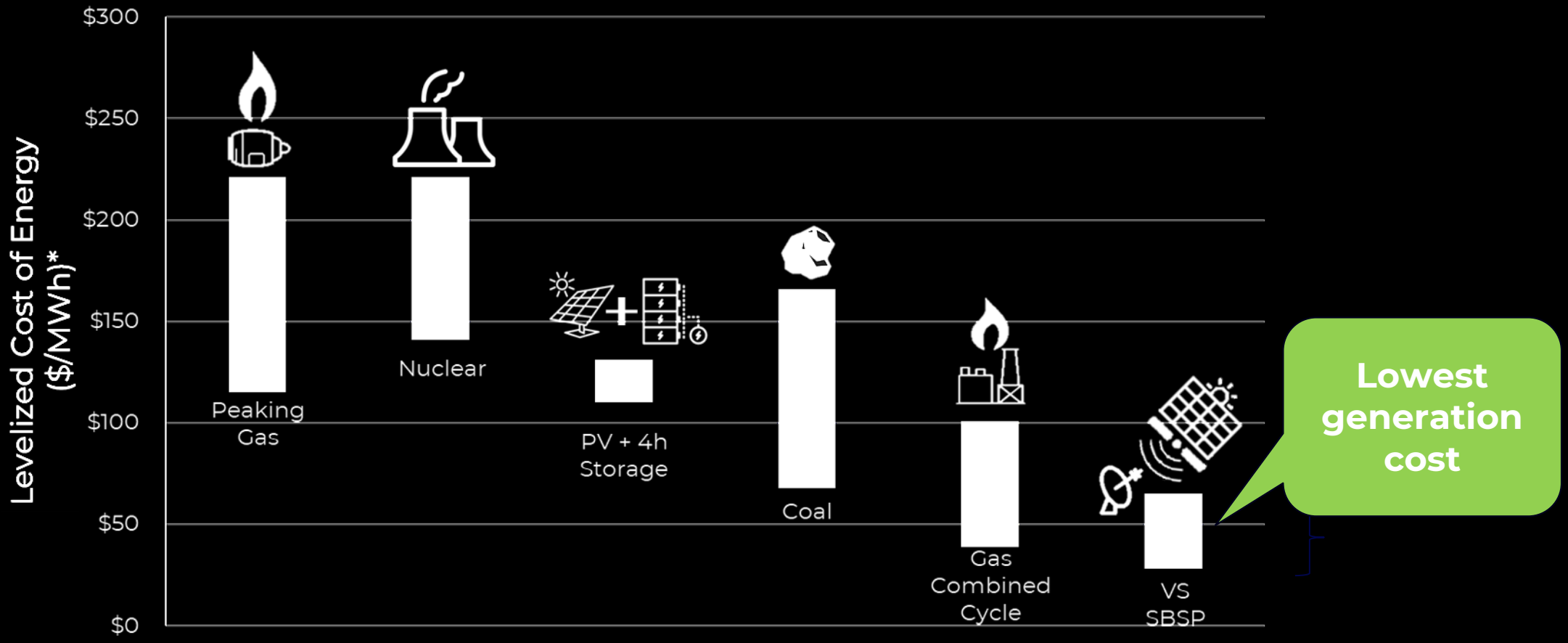

Solar Energy In Space is Many Times Stronger
Then the Best Locations On Earth
In Space
Continuous
Sunlight
(1366 W/m^2)
On Earth
Intermittent
Sunlight
(~50 to 300 W/m^2
Daily Average)

THE >6X BENEFIT OF COLLECTING POWER IN SPACE



	Terrestrial	Space
Insolation	1000 W/m^2	1366 W/m^2
Photovoltaic Efficiency	20%	40%
Capacity Factor	30%	90% (2 ground stations)
DC bus to AC bus Efficiency	98.5%	85%*98%*99%* 95%*92%*98.5% = 71%
Net	59.1 W/m^2	349 W/m^2
Delta		**>6x Better**

COMPARABLES



*Technology Data from Lazard's Levelized Cost of Energy Version 16 (unsubsidized costs)

**UK Net Zero by 2050 / European Space Agency Studies 2021/2022

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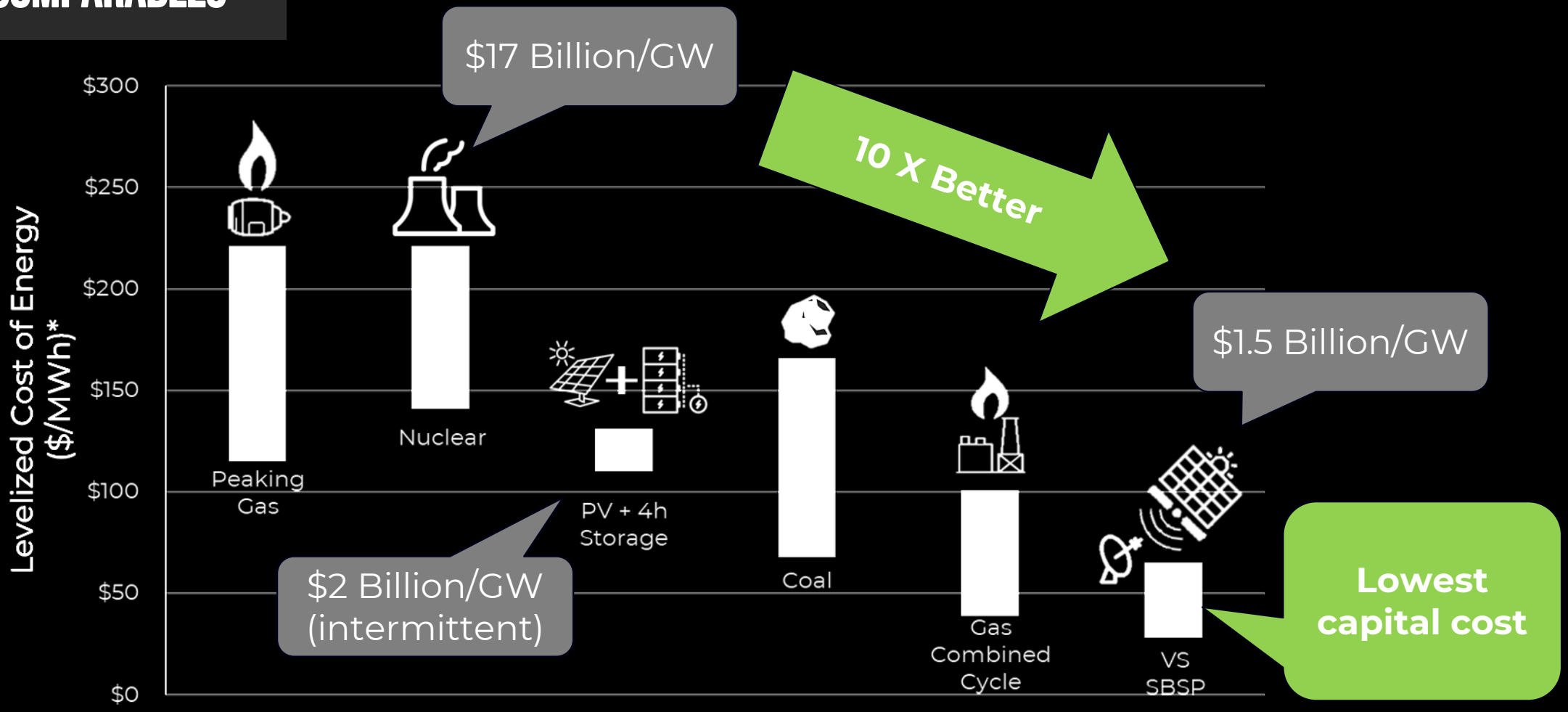
COMPARABLES



*Technology Data from Lazard's Levelized Cost of Energy Version 16 (unsubsidized costs)

**UK Net Zero by 2050 / European Space Agency Studies 2021/2022

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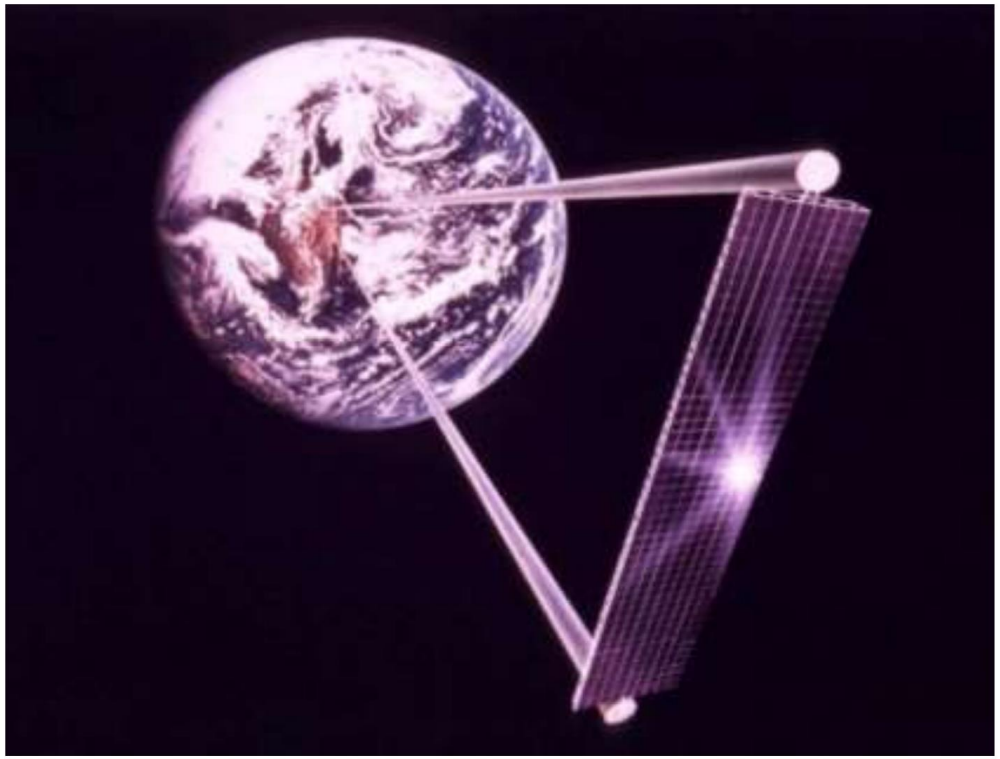
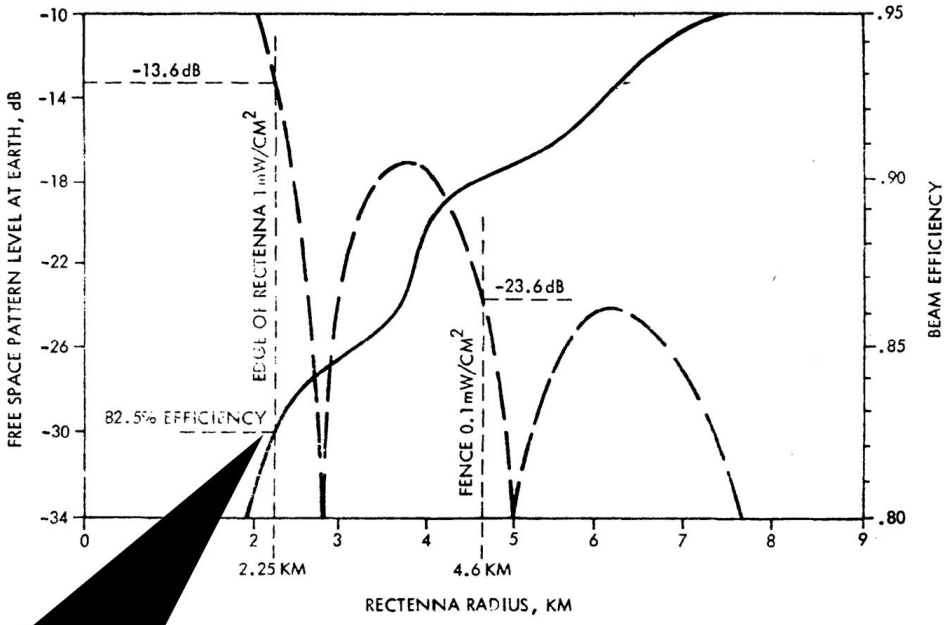
This Is How Its Done

POWER BEAMING IS KEY PIECE



Analyses from NASA 1980 Study



B-12

Figure B-6 Rectenna Size Vs Beam Efficiency - Uniform Illumination

82.5% efficiency
w/ 4.5km diameter receiver using 1970's technology

2024 technology can approach 100% with 2km receivers

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FIRST STEPS - 2023

Caltech

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In a First, Caltech's Space Solar Power Demonstrator Wirelessly Transmits Power in Space

June 01, 2023

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PHASED ARRAYS ARE WELL-ESTABLISHED TECHNOLOGY

Phased Arrays have been successfully used in radar for **60 years**.

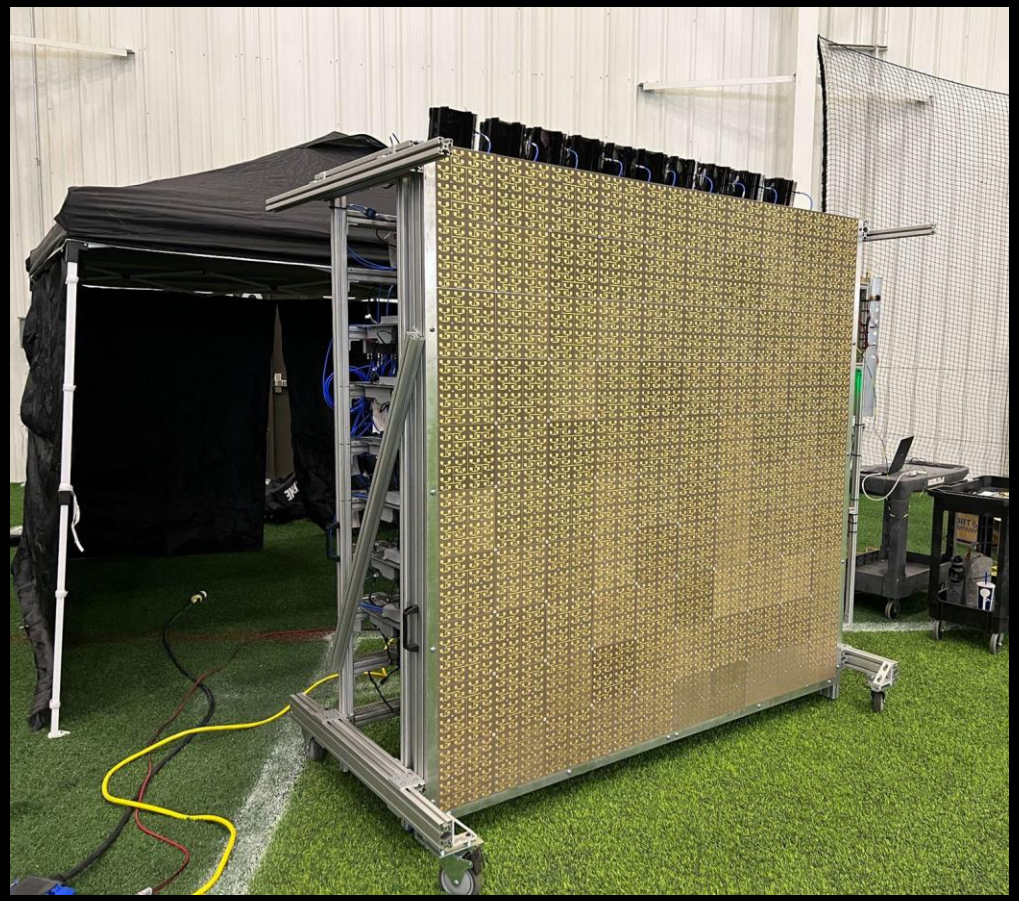
Many **individual antennas** combine to form a **narrow beam** that reaches **long distances.**

Cobra Dane radar is 120’ high and built in the 1970s. Range is over 2,000 miles.

VIRTUS SOLIS WORKING TRANSMITTER

6400 elements,

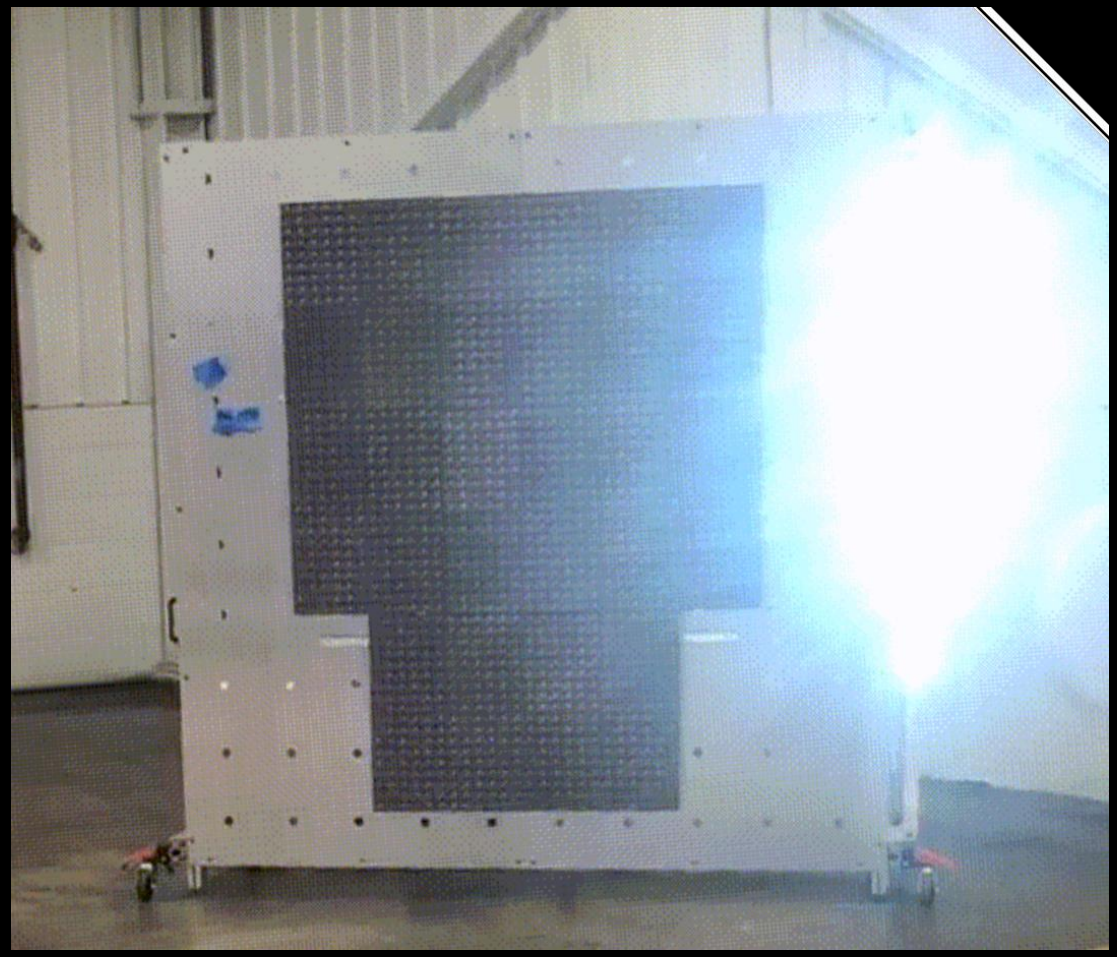
beams power **100 meters**



VIRTUS SOLIS WORKING RECEIVER

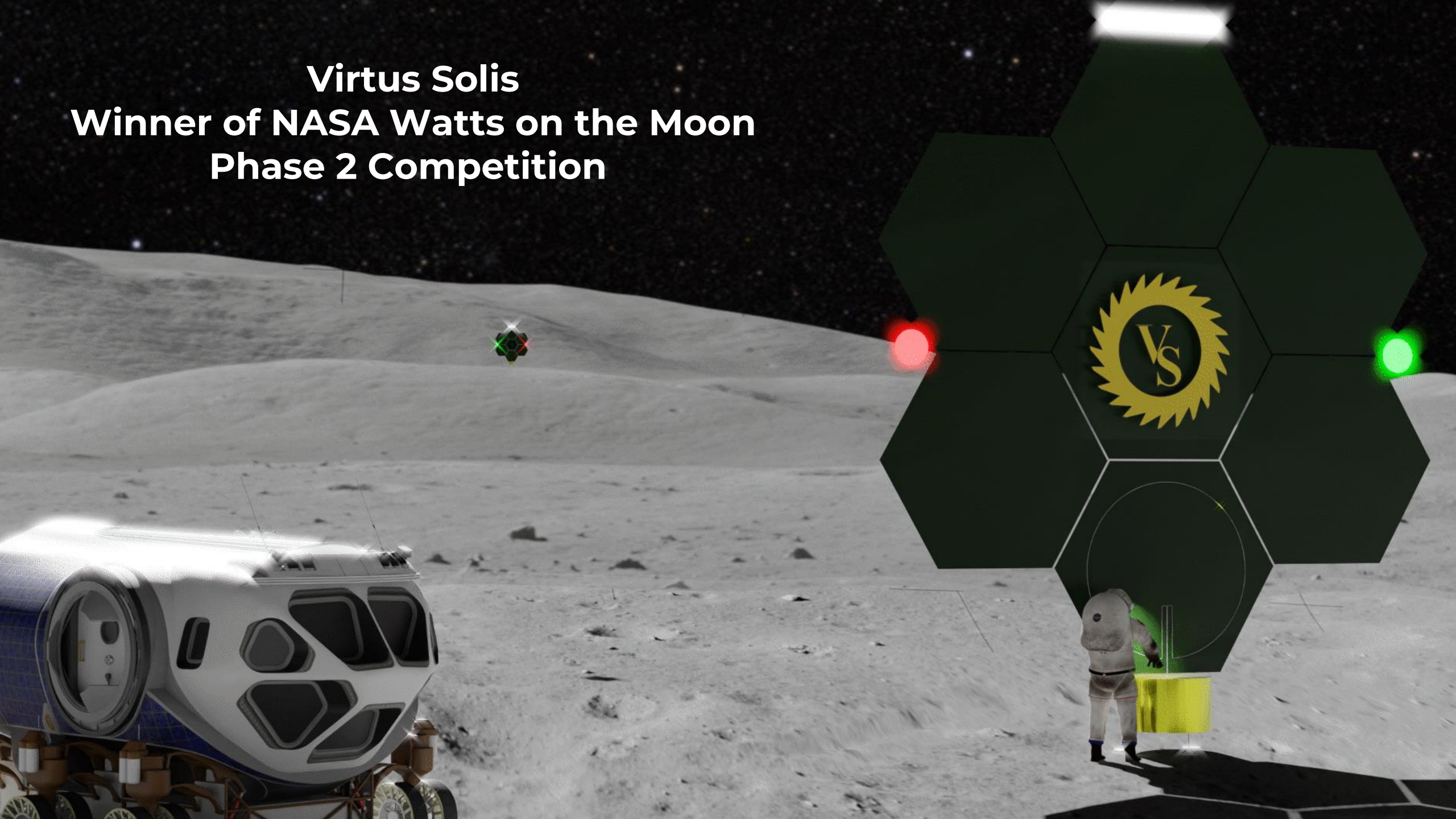
The receiver rectennas elements **convert 80% of incident power** into electricity.

We've demonstrated the core abilities to **send and receive** beamed power.

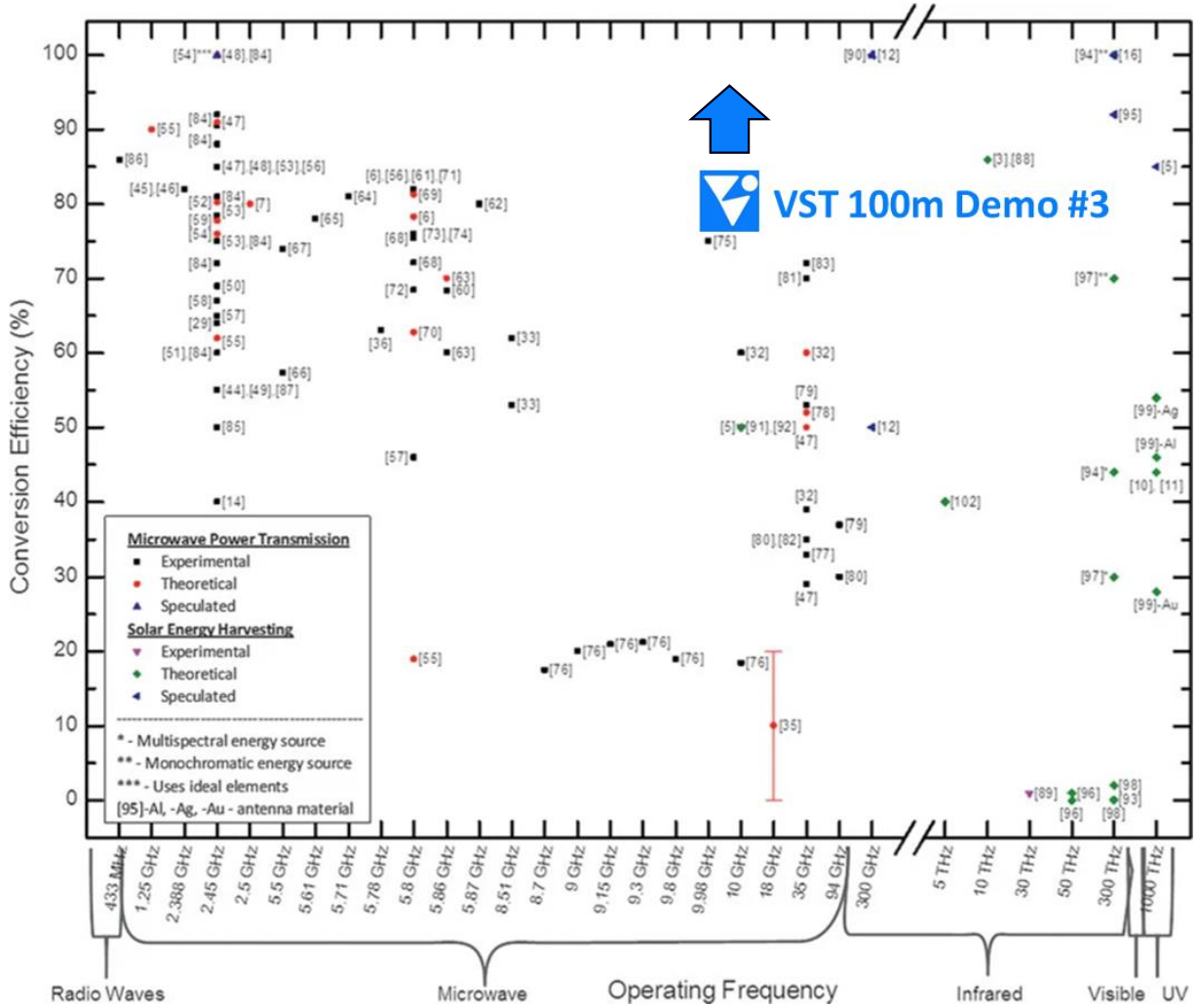


Rectenna array illuminating 30 bulbs at 100 meters

Virtus Solis
Winner of NASA Watts on the Moon Phase 2 Competition

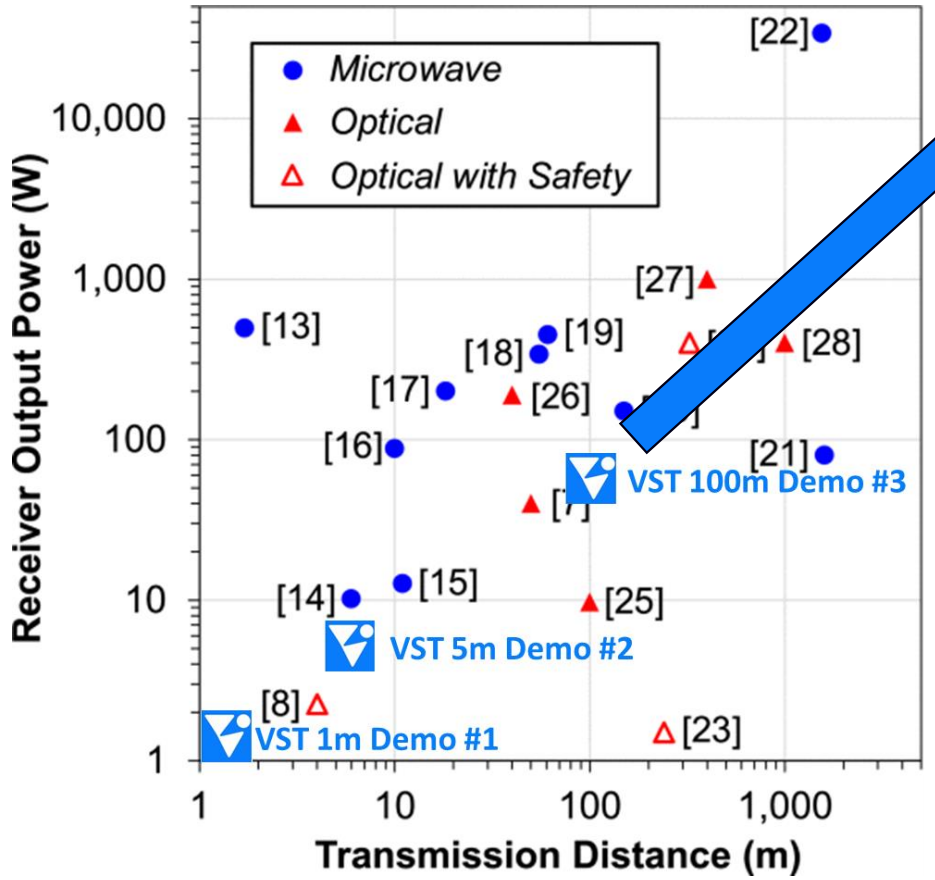


RECTENNA PERFORMANCE



Adapted fromDonchev, et. al., The Rectenna Device: From Theory to Practive (A review), MRS Energy & Sustainability, July 3, 2012. doi.org/10.1557/mre.2014.6

POWER BEAMING DEMOS



Commercial Power

Orbital Demo

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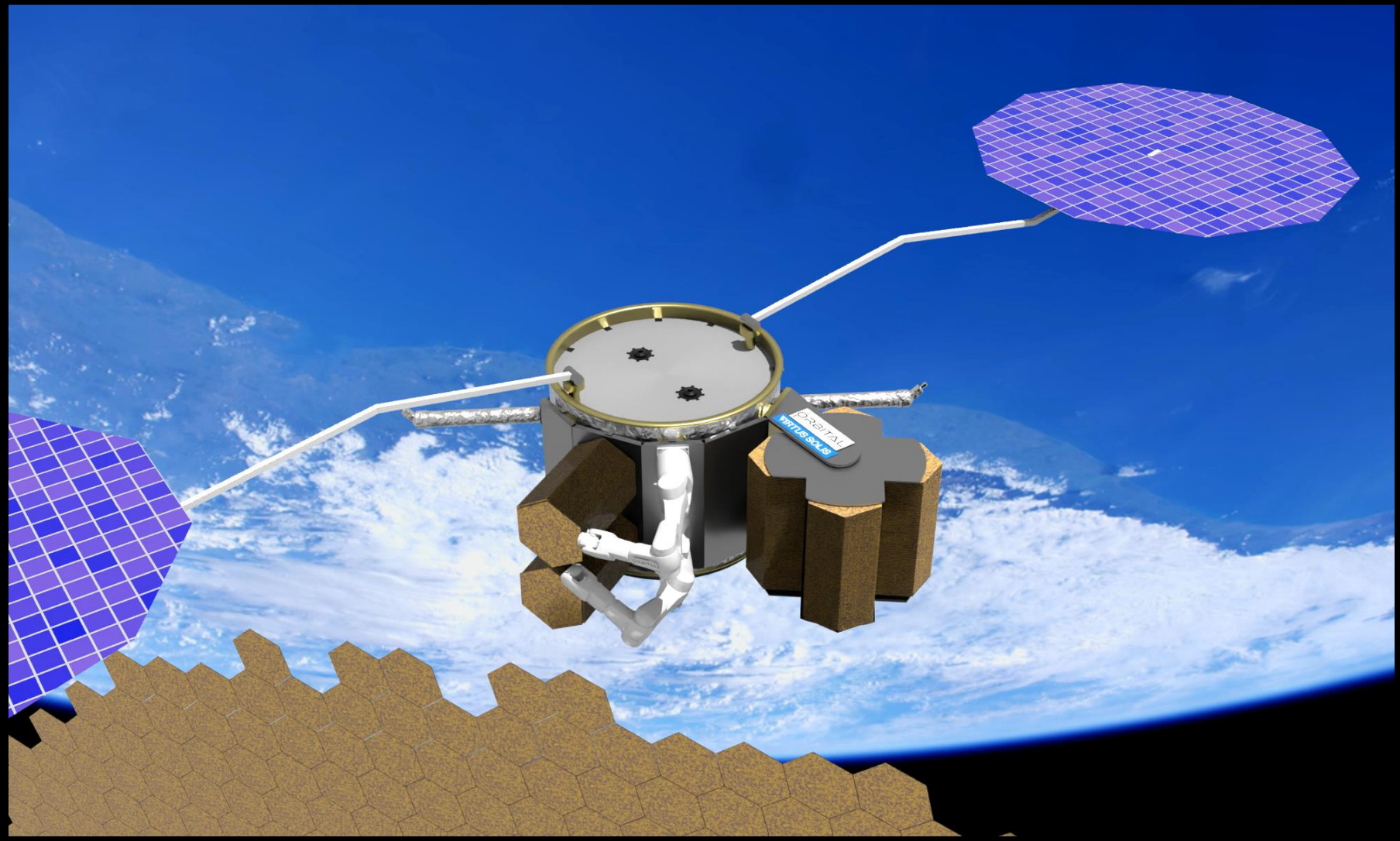
Adapted from Rodenbeck, et. al., "Microwave and Millimeter Wave Power Beaming", IEEE Journal of Microwaves, Jan 7, 2021. DOI 10.1109/JMW.2020.3033992

2027 ORBITAL DEMO



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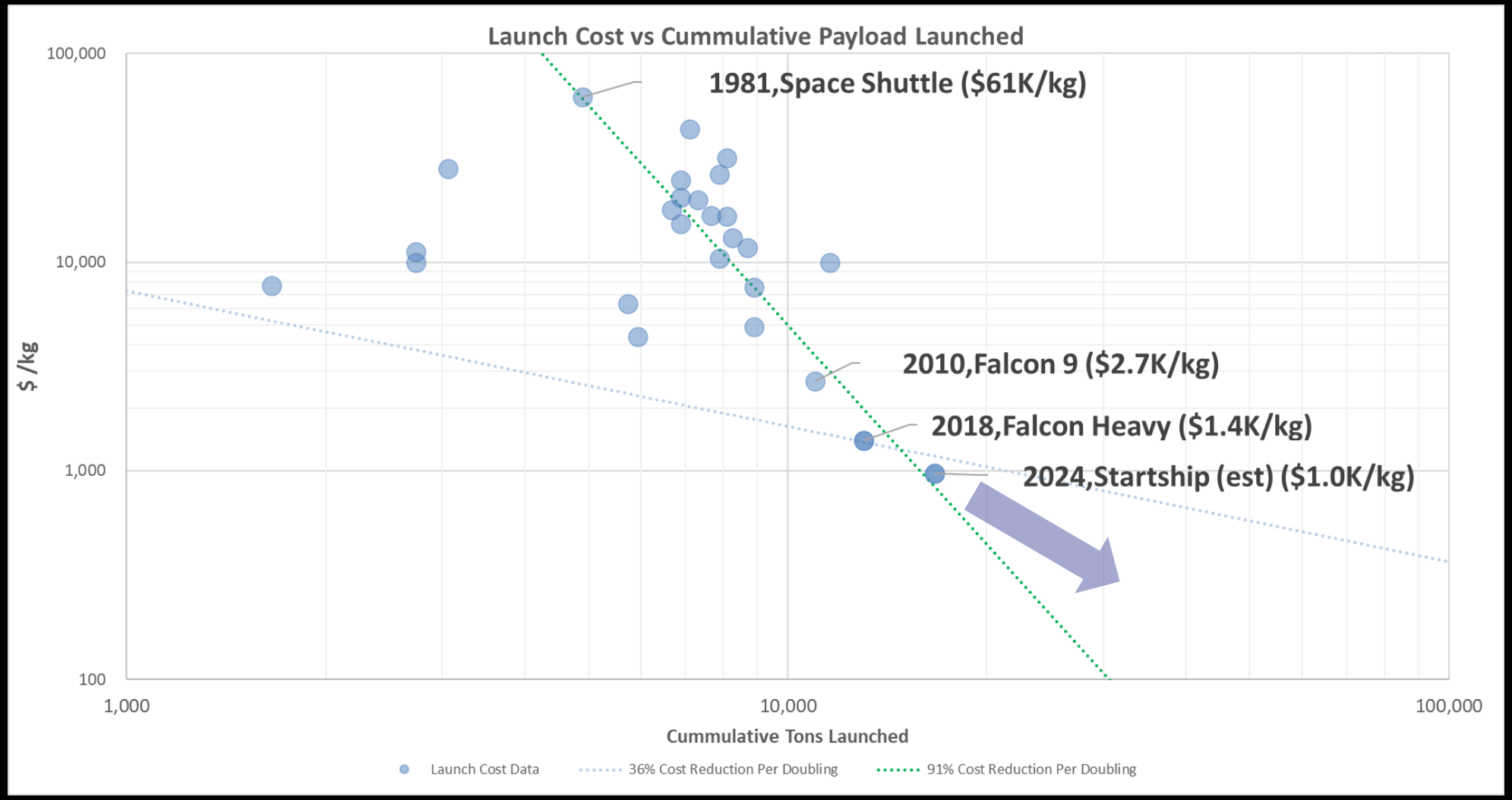
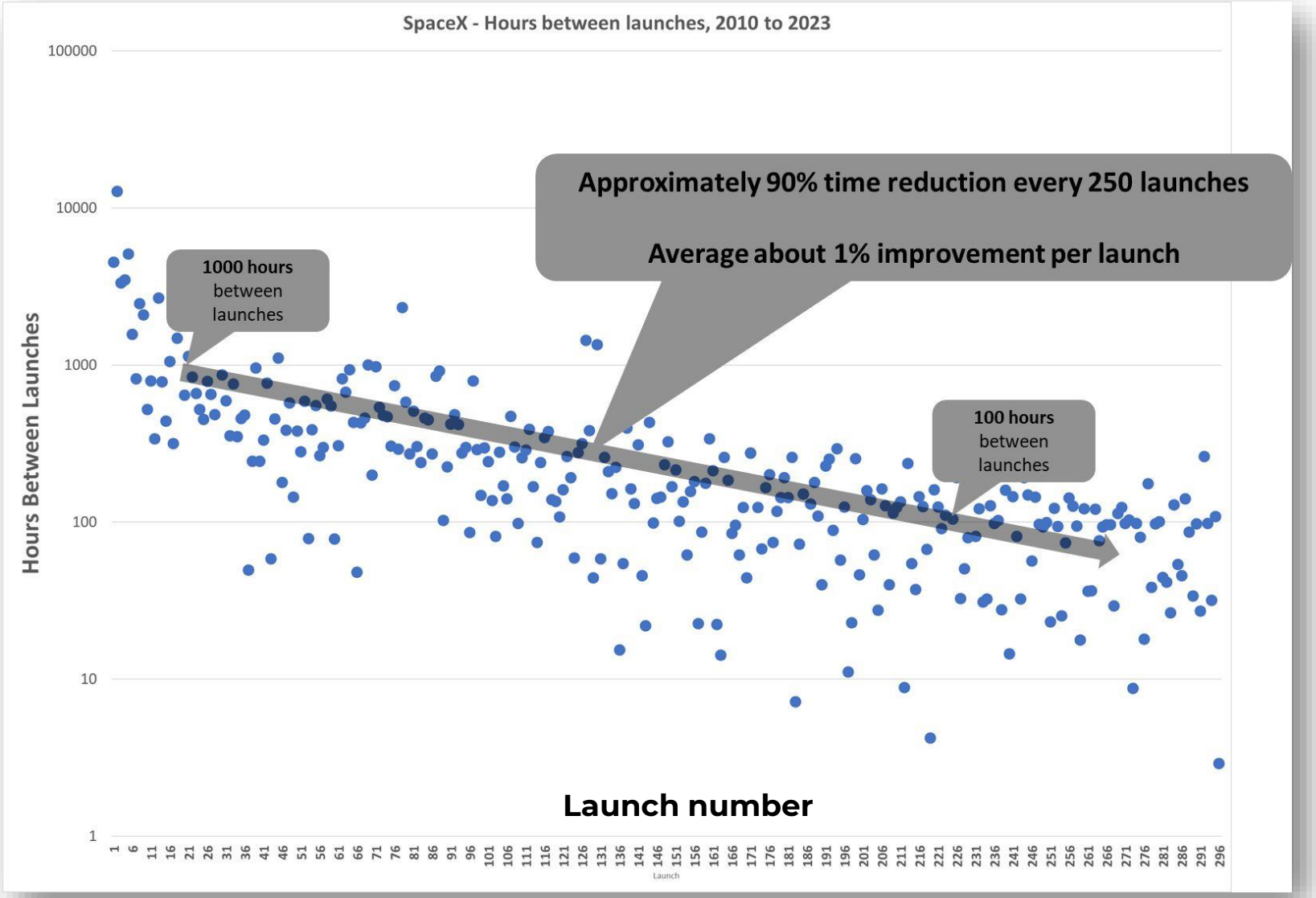
Trends Enabling SBSP

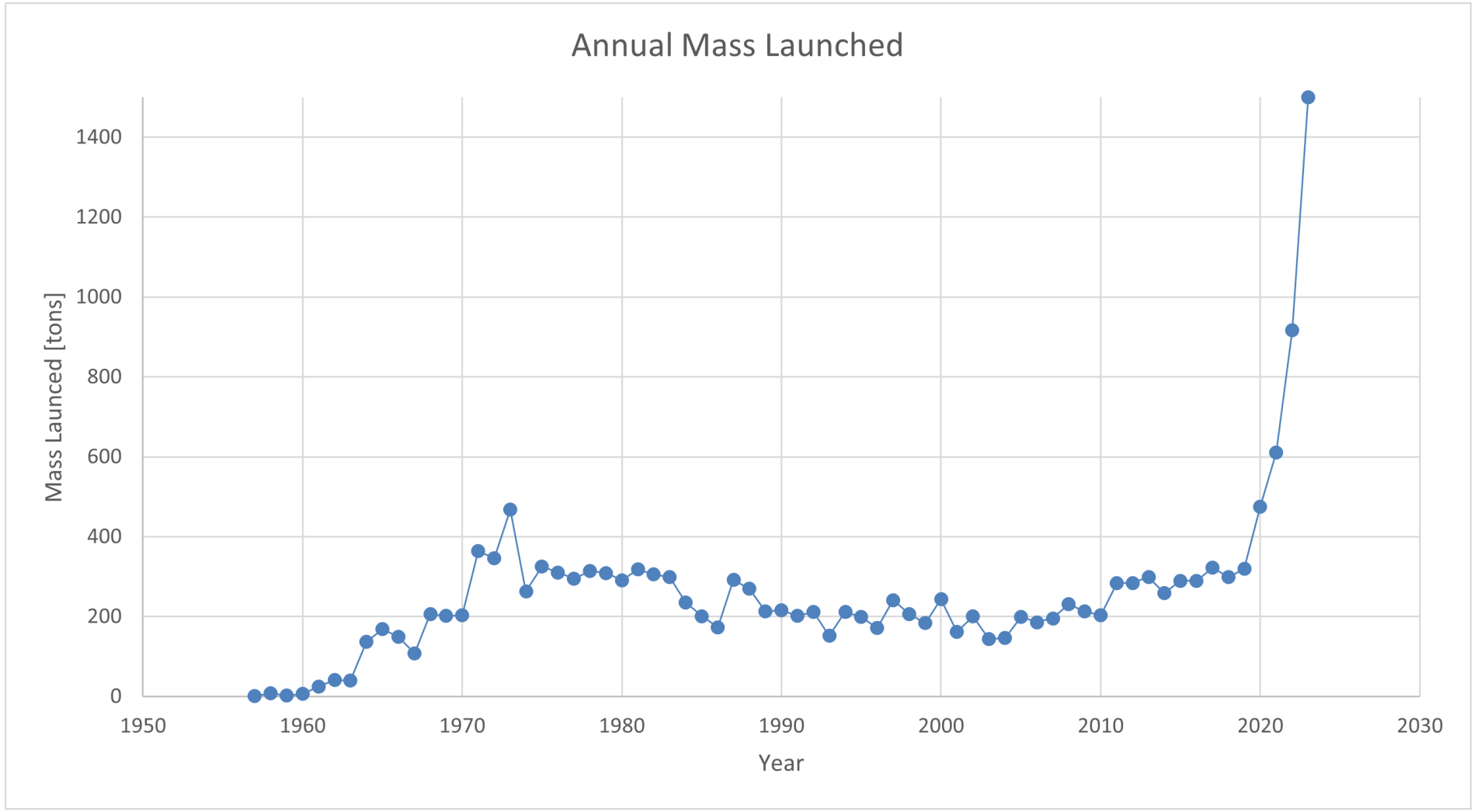
Now is the time because launch costs continue dropping



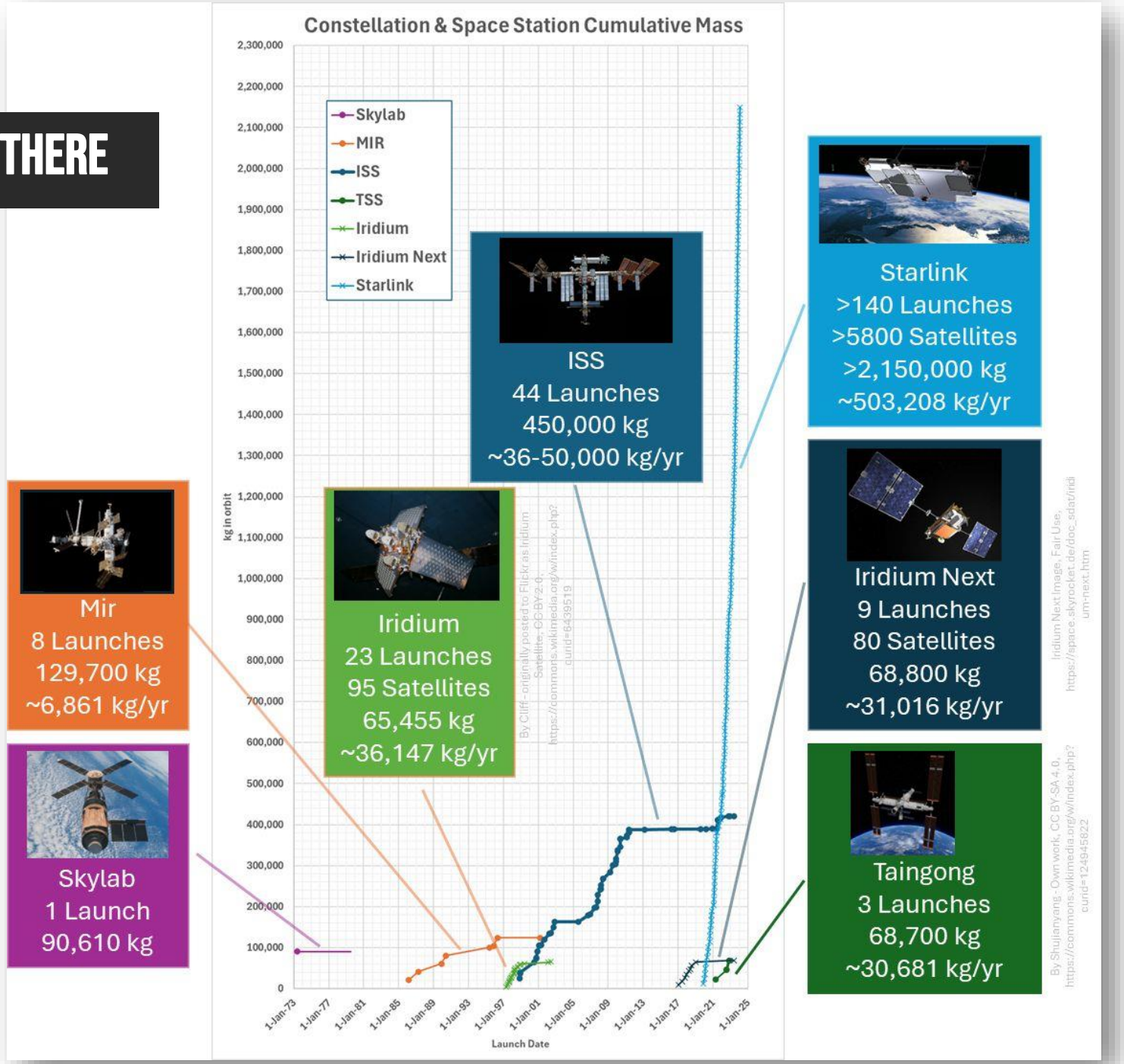
LAUNCH CADENCE WILL BE THERE



LAUNCH CAPACITY WILL BE THERE



IN-SPACE ASSEMBLY WILL BE THERE



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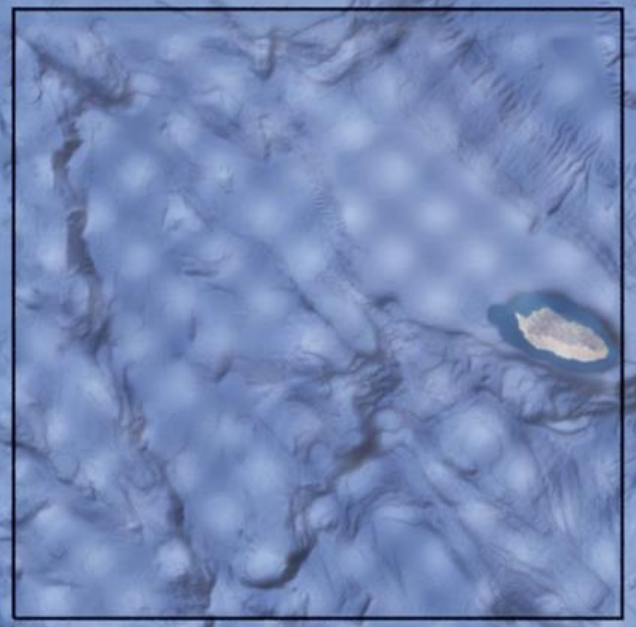
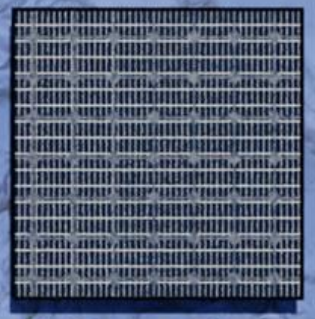
Global Annual Production - Surface Areas

GLOBAL HARDWARE PRODUCTION IS READY

Los Angeles– 1,302 square km



Sheet Glass – 11,200 square km



Solar Modules – 2,526 square km

Silicon Wafers – 10 square km

Sheet Steel – 43 square km

Circuit Boards – 290 square km

LCD Displays– 328 square km

COMPETITION IS GROWING

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- Capitalized
- Commercial
- Demonstrations
- Deployment by 2030

SPACE SOLAR
SOLAREN
SST SOLAR SPACE TECHNOLOGIES
ASTROSTROM
ALVIOR
SPACE POWER
EMROD
OVERVIEW ENERGY

SBSP Ecosystem
- Early Stage
- Concept

Space Energy Initiative
U.S. NAVAL RESEARCH LABORATORY
esa
MITSUBISHI
NEOM نيوم
CATAPULT Satellite Applications
JAXA
Caltech
NORTHROP GRUMMAN
ECL
AIRBUS

Adjacent
- Research Focused
- National Teams

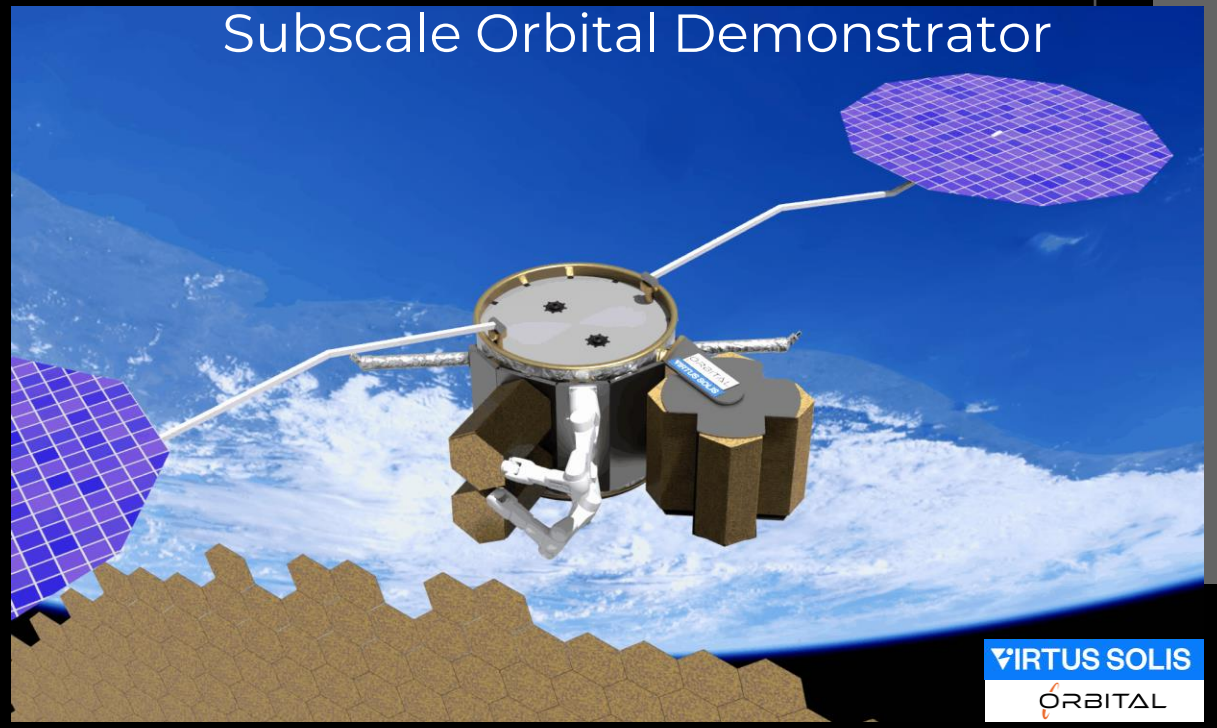
RAISING SEED FUNDS TO PUT FIRST SYSTEM IN ORBIT

Continuing to bring in small investors in preseed round

Raising $10M seed round

- **Expand the team**
- **Build 4th gen hardware**
- **Secure launch**

Warm intros are appreciated!



A PARTING THOUGHT

“Space based solar power is not rocket science, its electronics.”

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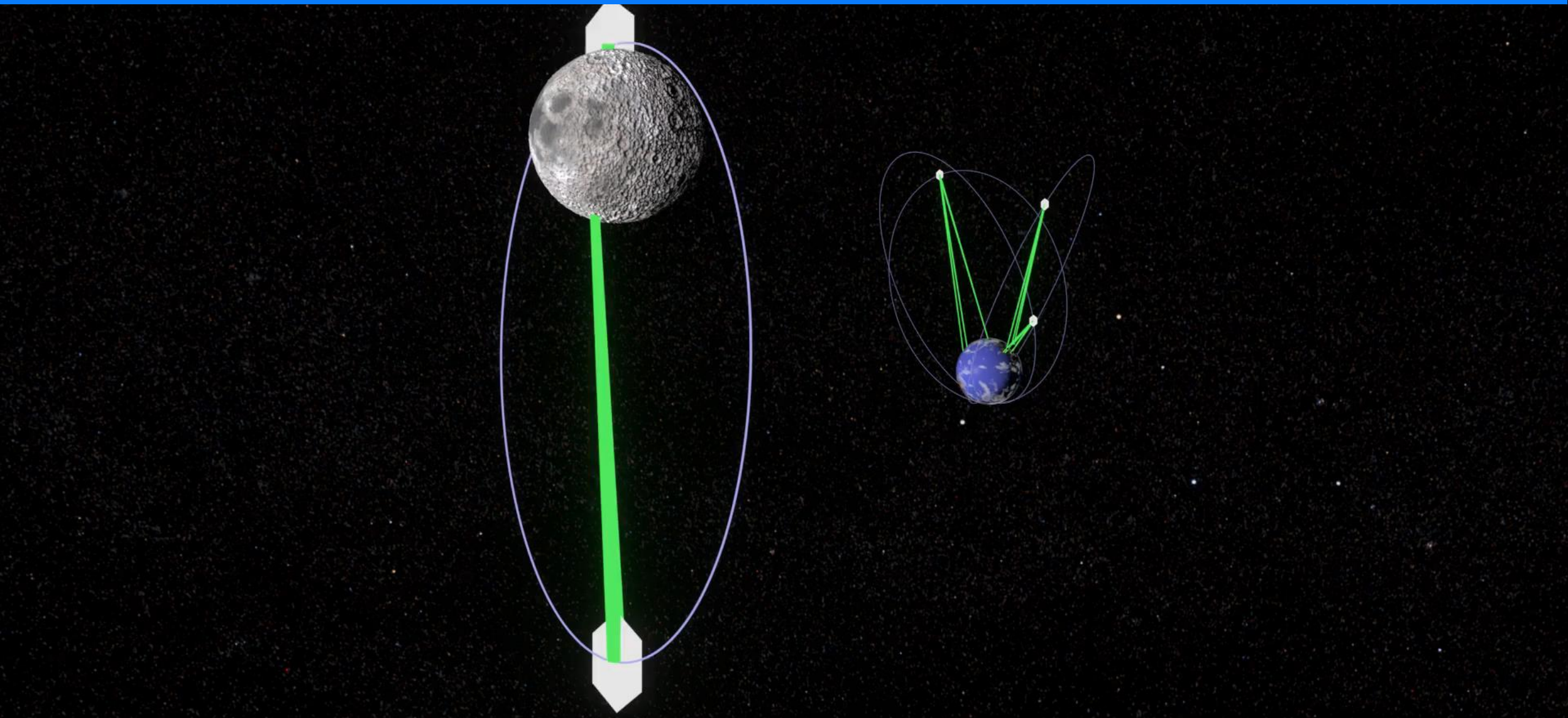

Clean, Firm, Renewable Power for Earth and Beyond