VIRTUS SOLIS

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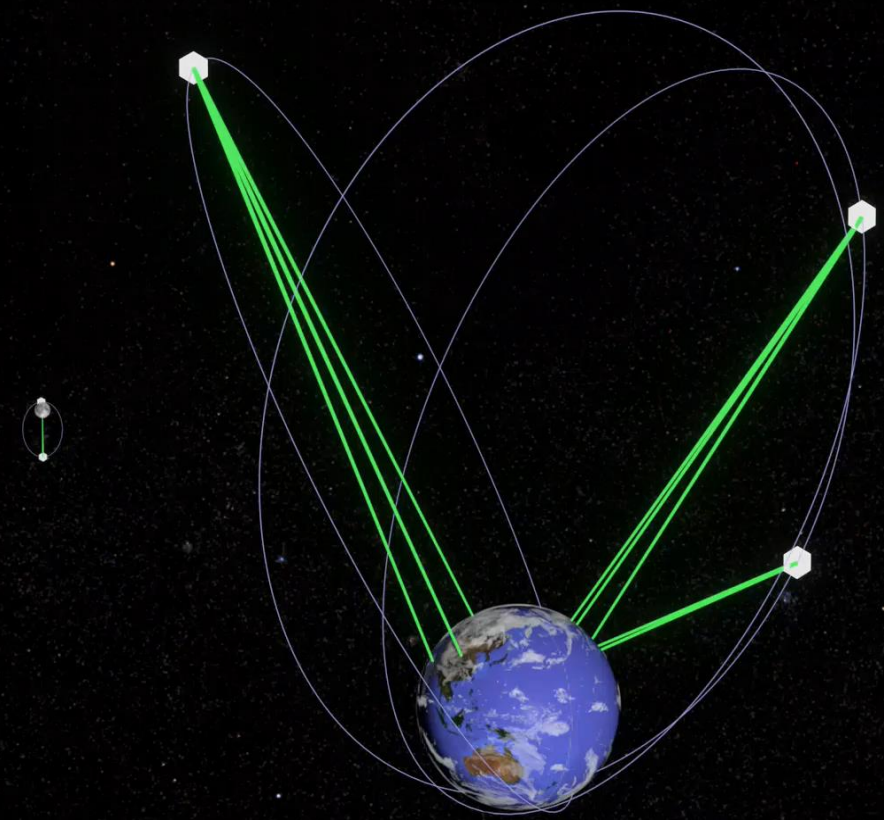
Low-cost, persistent **solar power** from space.

ISDC 2022
Space Solar Power Symposium
Arlington, VA
May 26, 2022

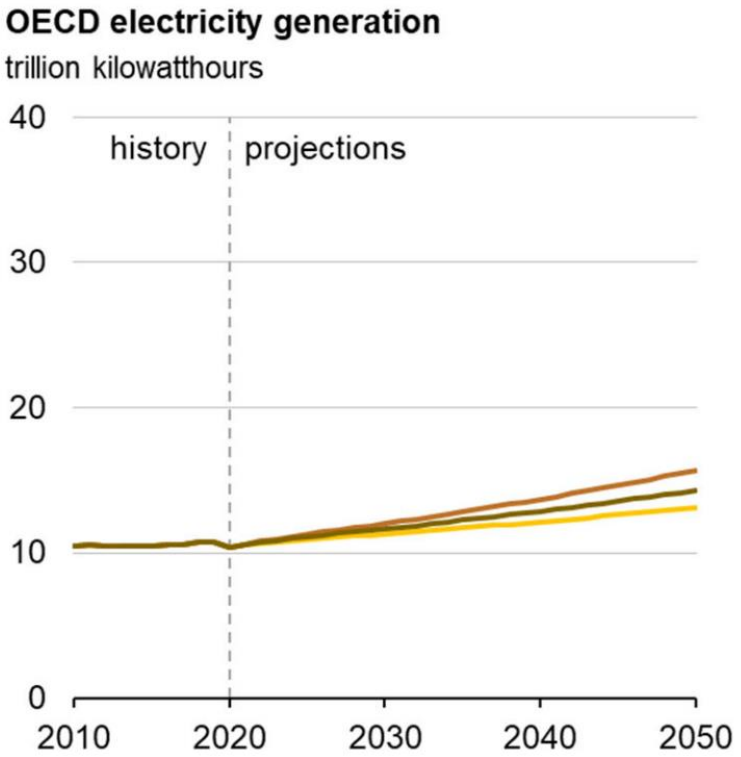
Dr. Edward Tate, CTO | Founder
John Bucknell, CEO | Founder

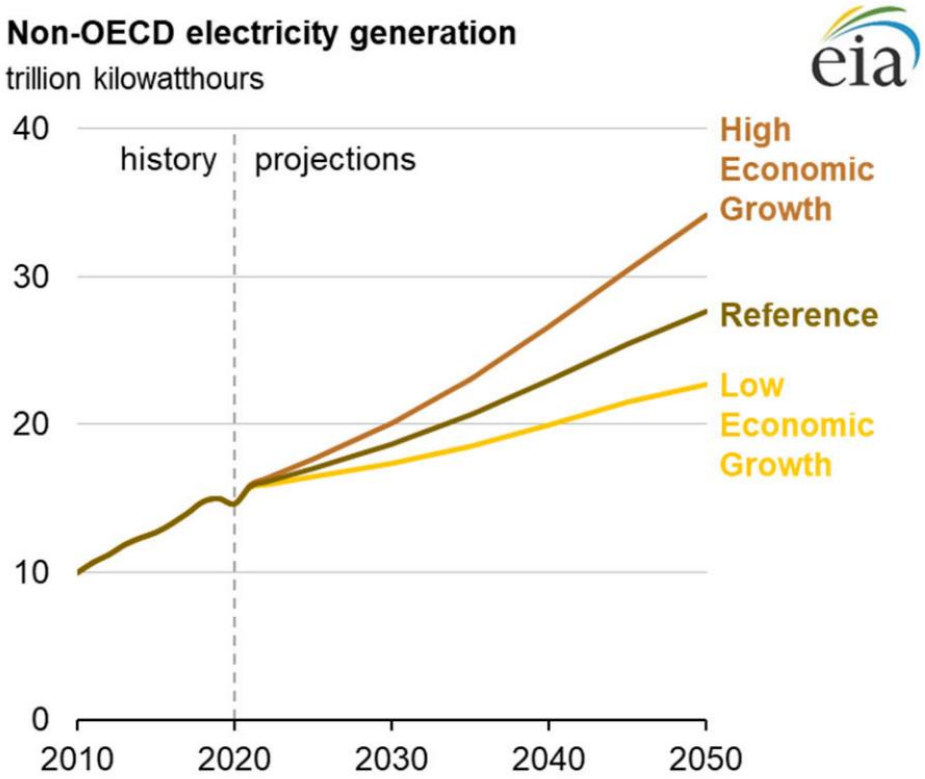
VIRTUS SOLIS

- Solar power in space, beamed to Earth.
- Targeting lowest levelized cost of electricity.
- Dedicated SSP WPT analysis toolsets
- Developing 3rd hardware generation.
- Founders have 15 production projects
  - passenger cars,
  - rockets and
  - simulation software.
- Partnership with Intersect Power



ELECTRICITY USAGE WILL CONTINUE INCREASING





Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

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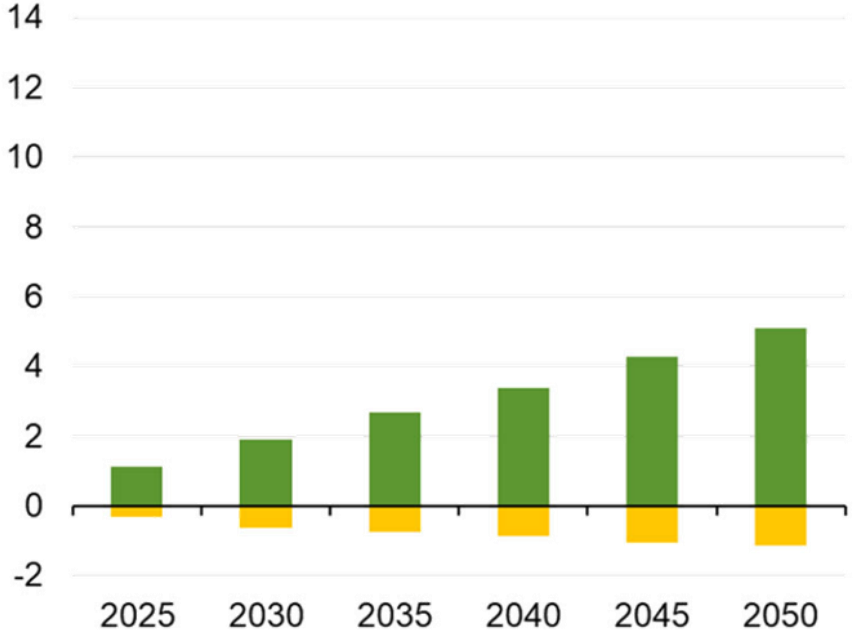
MORE RENEWABLES WILL BE USED

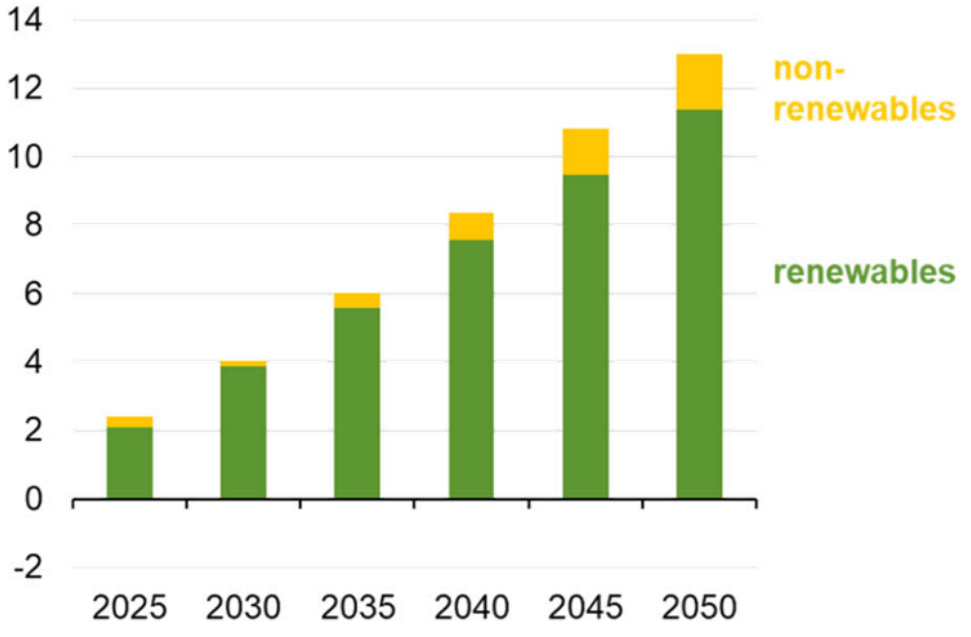
OECD electricity generation change from 2020, by type

trillion kilowatthours



Non-OECD electricity generation change from 2020, by type

trillion kilowatthours



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

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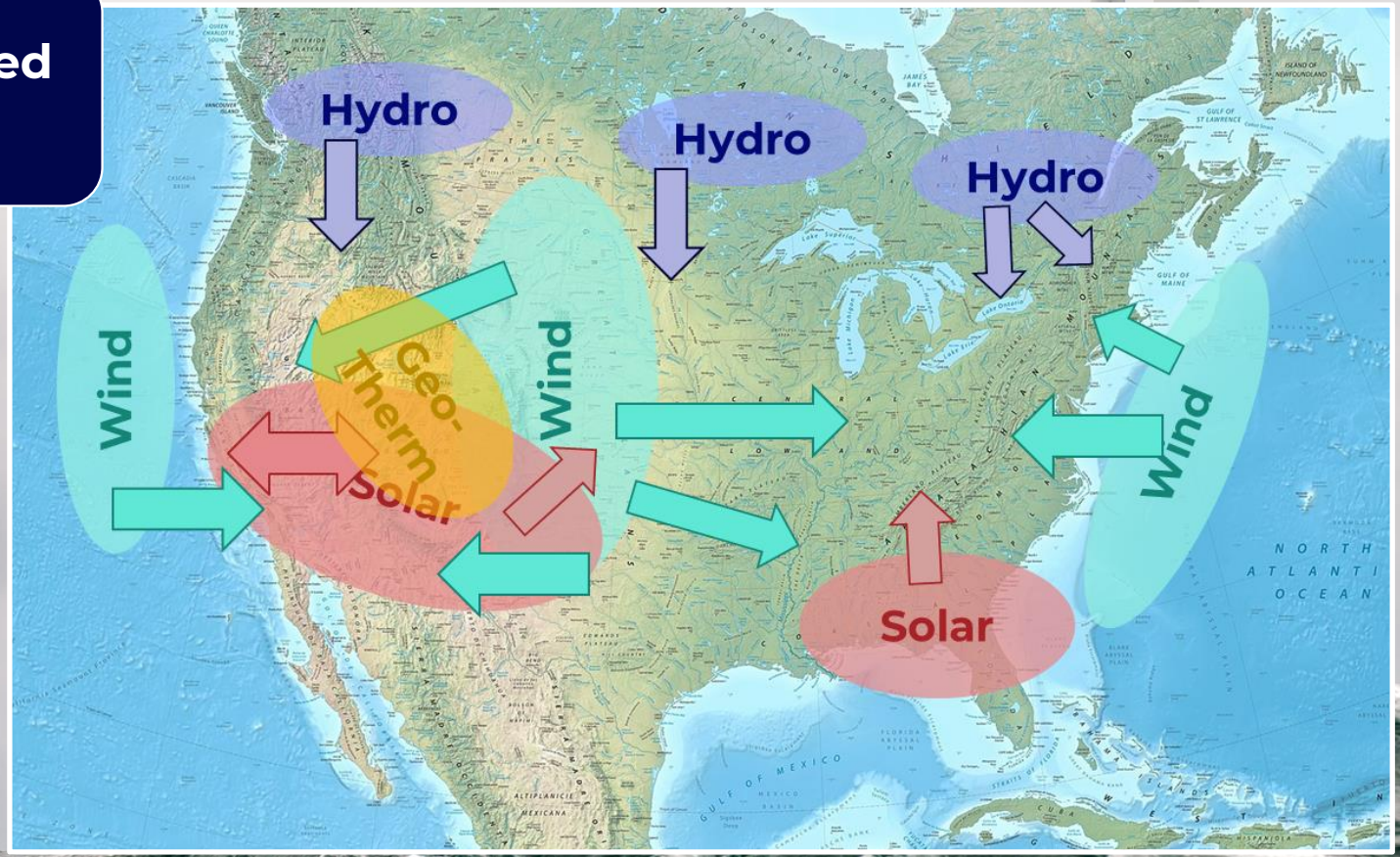
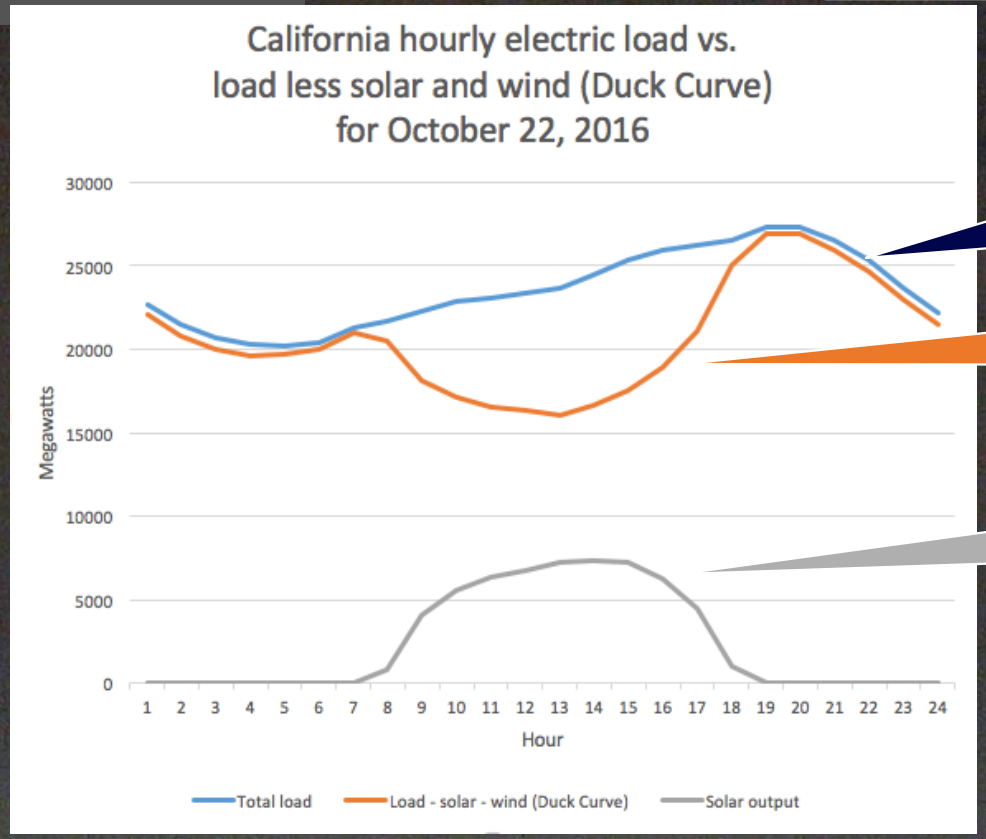
BUT THERE ARE 3 PROBLEMS

1 - Renewables are not located where power is needed.



BUT THERE ARE 3 PROBLEMS

2 - Renewables not available when needed.



Electric Demand

Demand not met by wind & solar

Solar generation

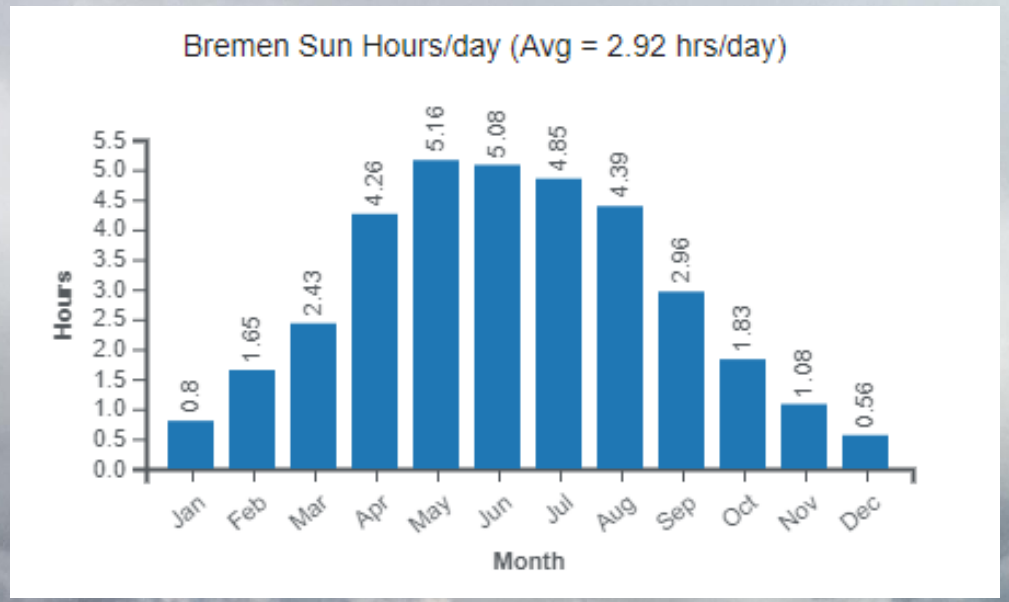
The “Duck Curve” in CA shows increasing electrical demand in the evening.

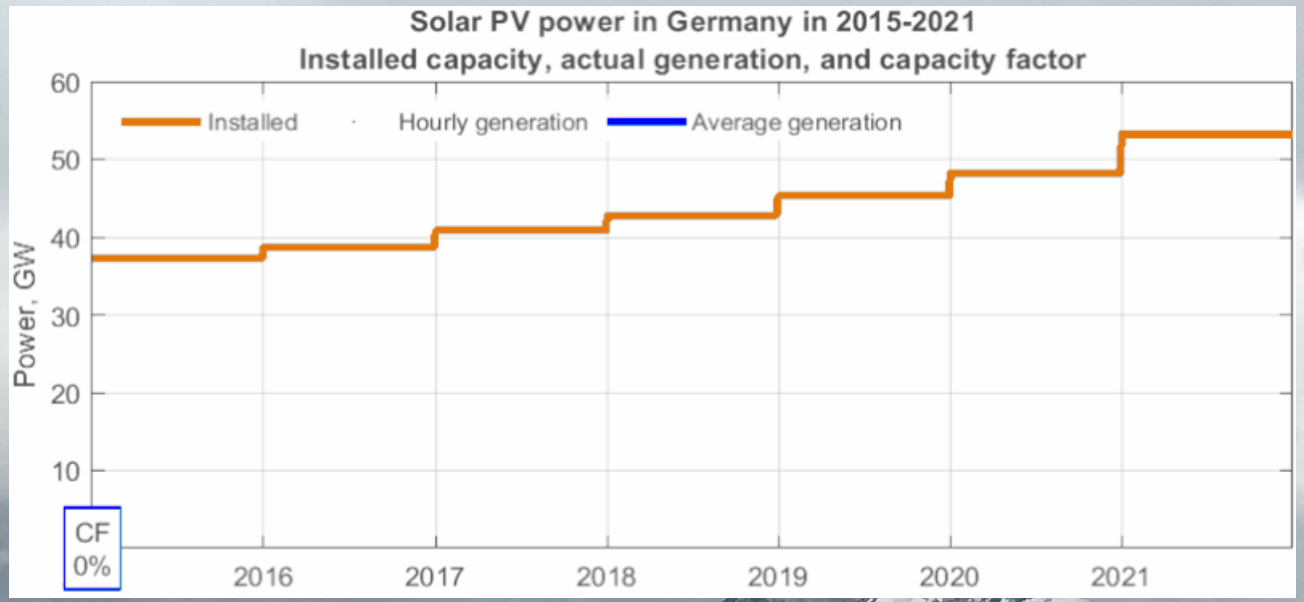
Solar & wind are not available to meet the demand

Duck Curve from https://en.wikipedia.org/wiki/Duck_curve#/media/File:Duck_Curve_CA-ISO_2016-10-22.agr.png, Arnold Reinhard

BUT THERE ARE 3 PROBLEMS

3 – Capacity factors can be extremely low



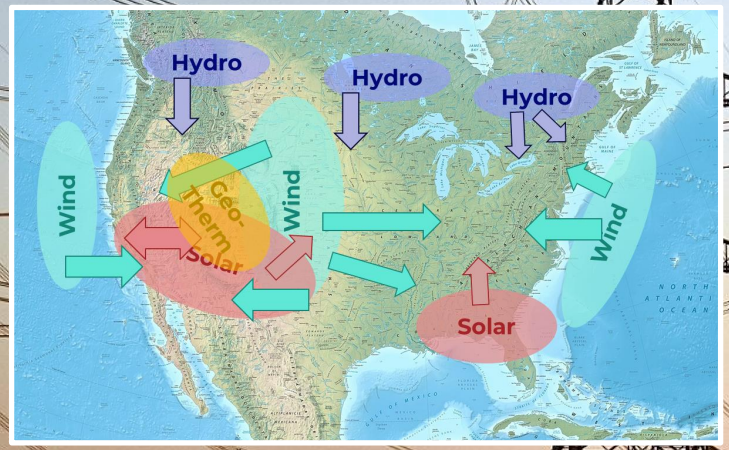


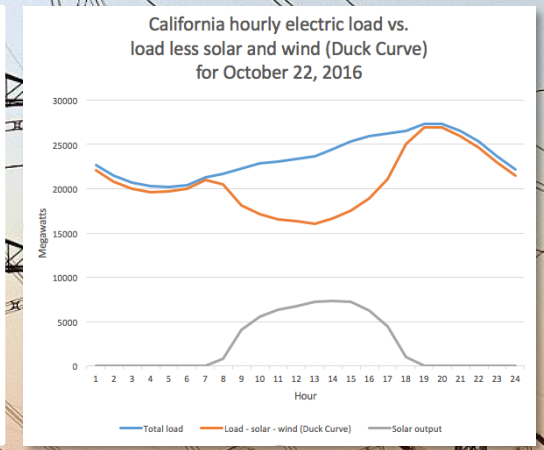
In Germany solar power runs at a 1-3% capacity factor in the winter.

Large scale solar is nearly useless in the months when electrical demand is greatest.

THE PROPOSED FIXES – MORE THEN $1TRILLION OVER 20 YEARS

Even if renewables were free...



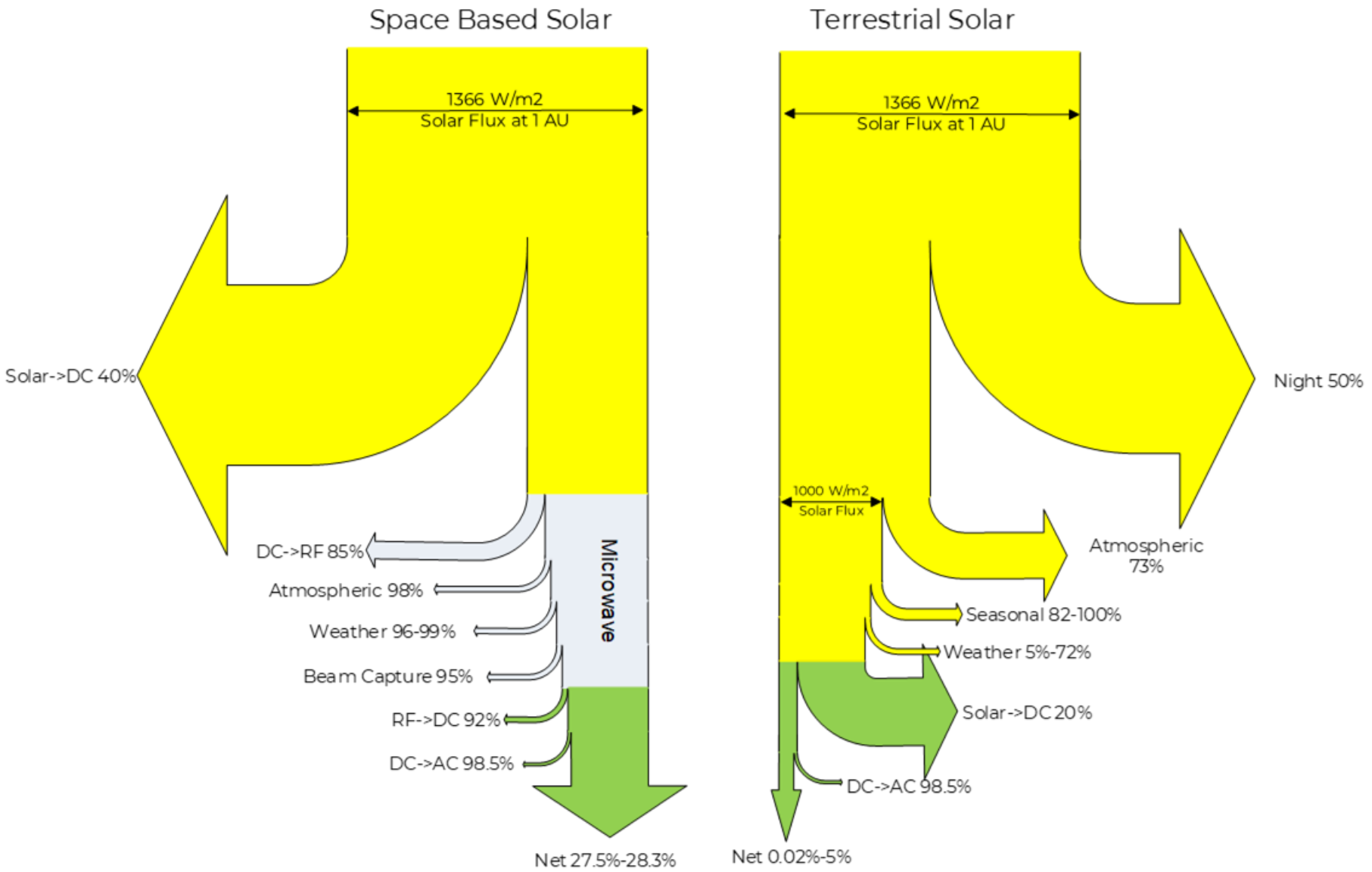


Storage (globally)
$620B thru 2040

Smart Grid
$200B thru 2040

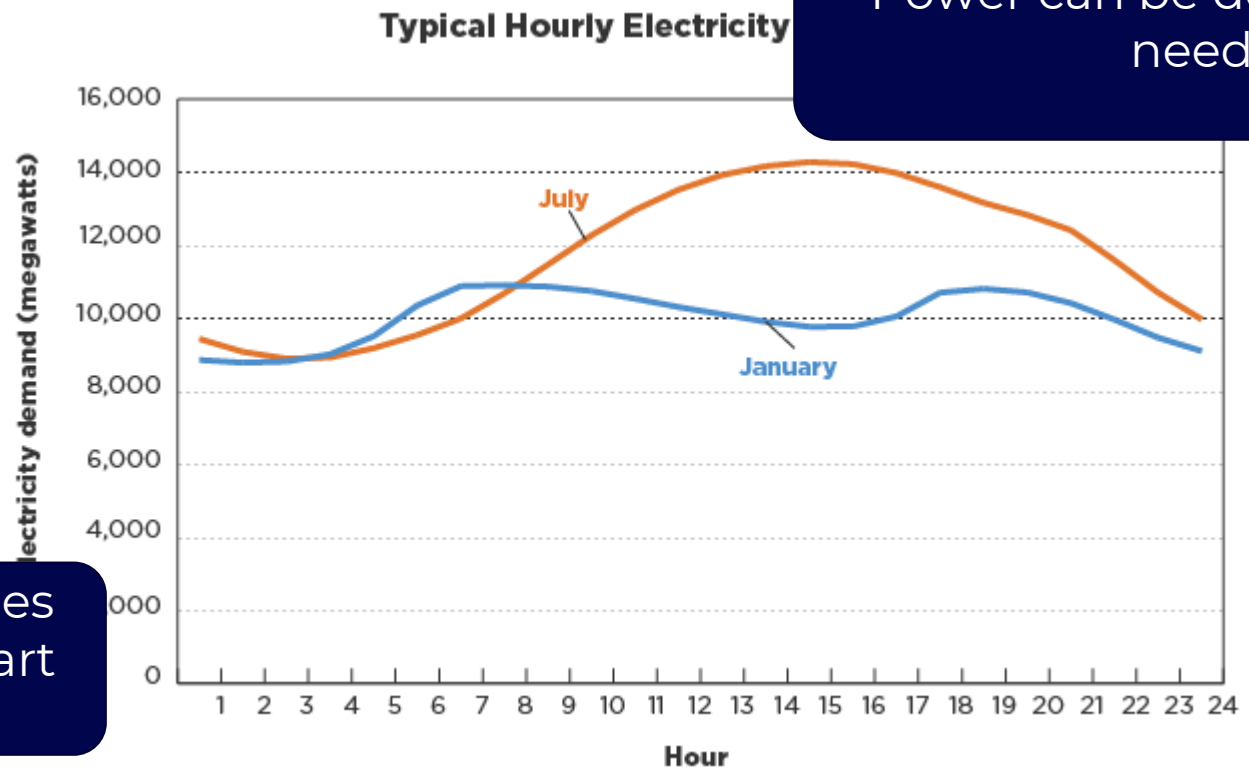
USA National Energy Grid
Upgrades for renewables & interconnect $500B Thru 2040

SOLAR POWER CAPTURE IN SPACE AND ON EARTH



AN ALTERNATIVE – DISPATCHABLE SPACE SOLAR POWER

Power can be delivered when needed.



Space Solar Power reduces need for storage and smart grid.

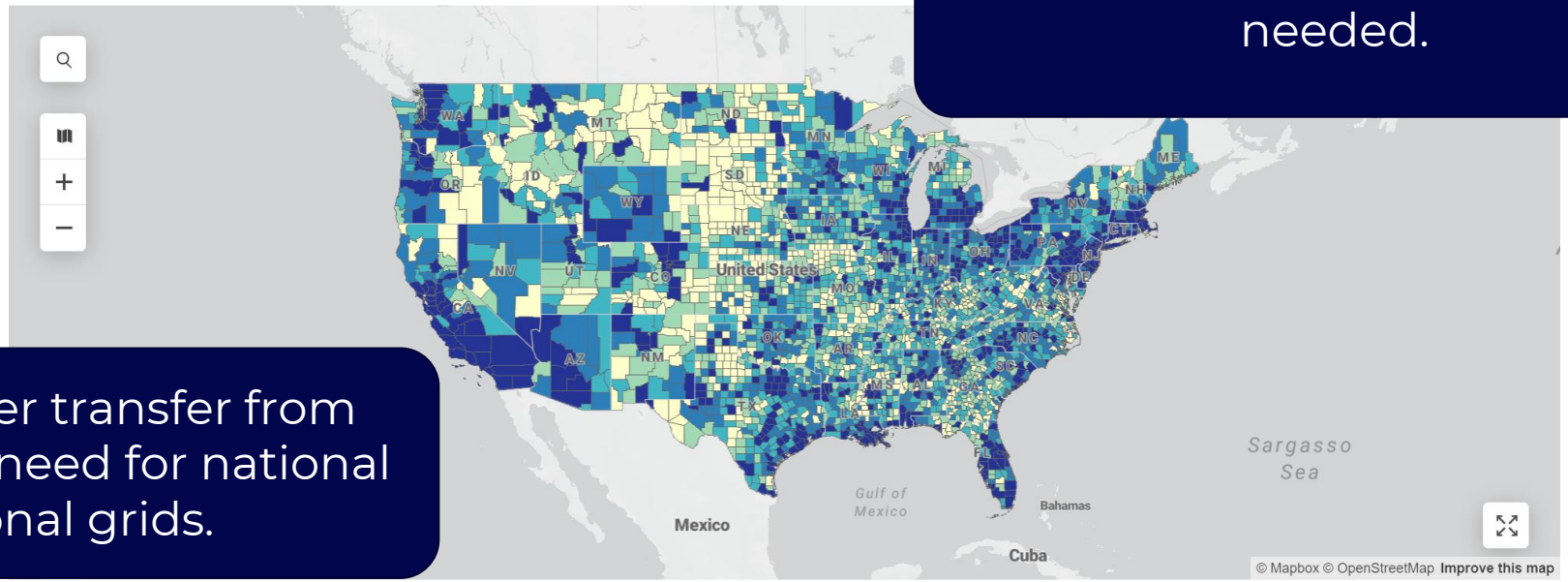
https://www.epa.gov/energy/electricity-delivery-and-its-environmental-impacts

AN ALTERNATIVE – DISPATCHABLE SPACE SOLAR POWER

Power can be delivered where needed.

Wireless power transfer from space reduces need for national or regional grids.

Aggregate Electricity & Natural Gas Consumption by County



Map Legend
(MMBtu)

- 10,350,000+ MMBtu
- 4,168,000 - 10,350,000 MMBtu
- 1,857,000 - 4,168,000 MMBtu
- 721,000 - 1,857,000 MMBtu
- 0 - 721,000 MMBtu

National Renewable Energy Laboratory. "Net Electricity and Natural Gas Consumption," *State and Local Planning for Energy*, accessed 5/21/2022, https://maps.nrel.gov/slope.

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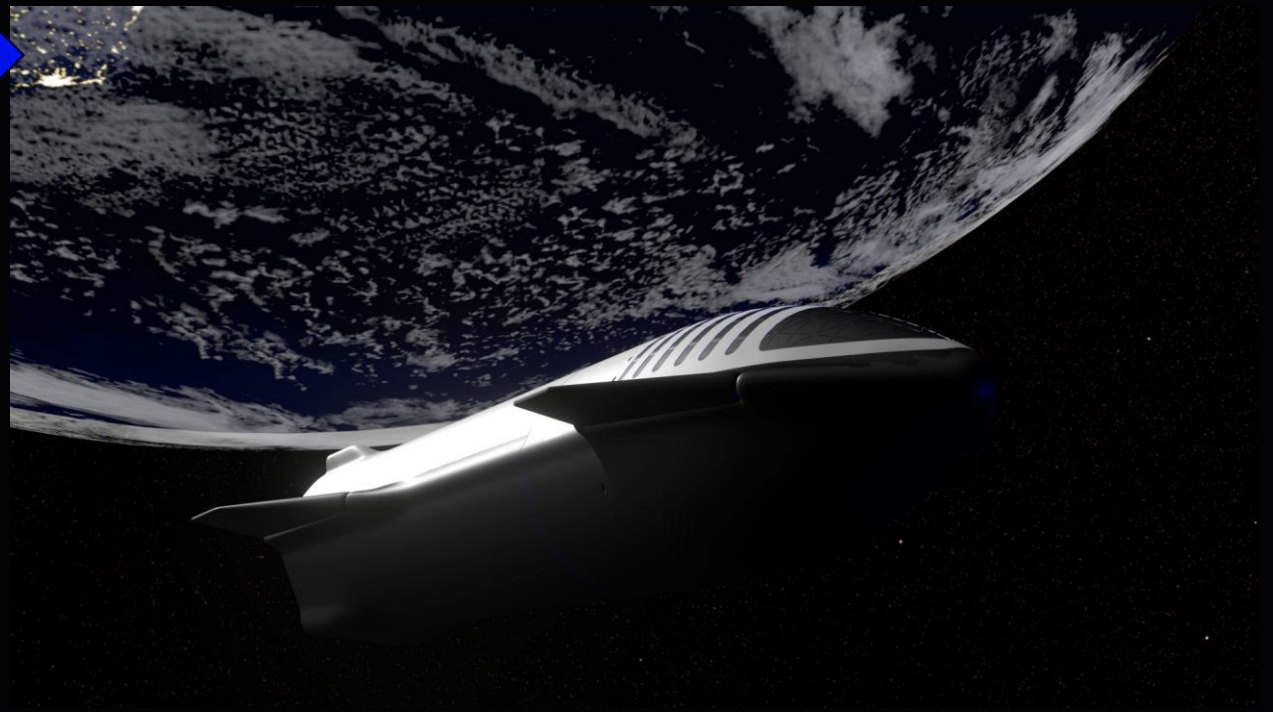
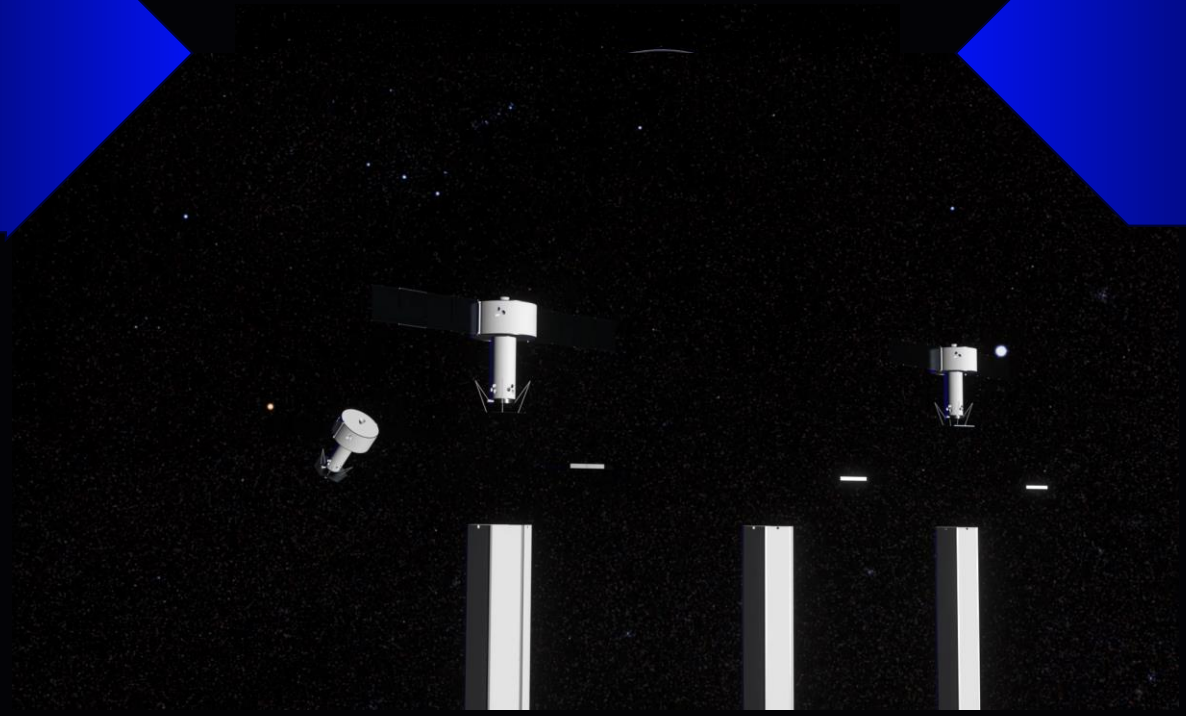
SPACE SOLAR POWER ENABLERS

Commercial Launch Costs



ENABLERS

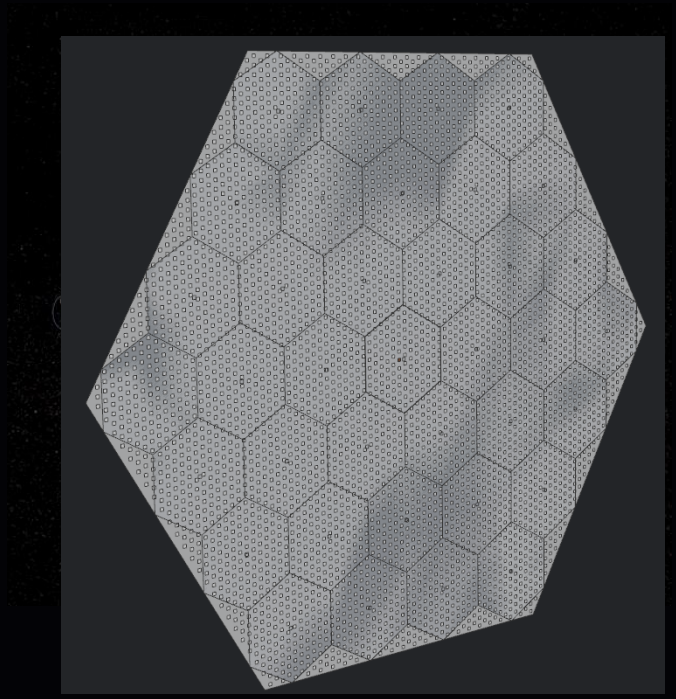
Commercial Launch Costs



Automated assembly

ENABLERS

Commercial Launch Costs



Automated assembly

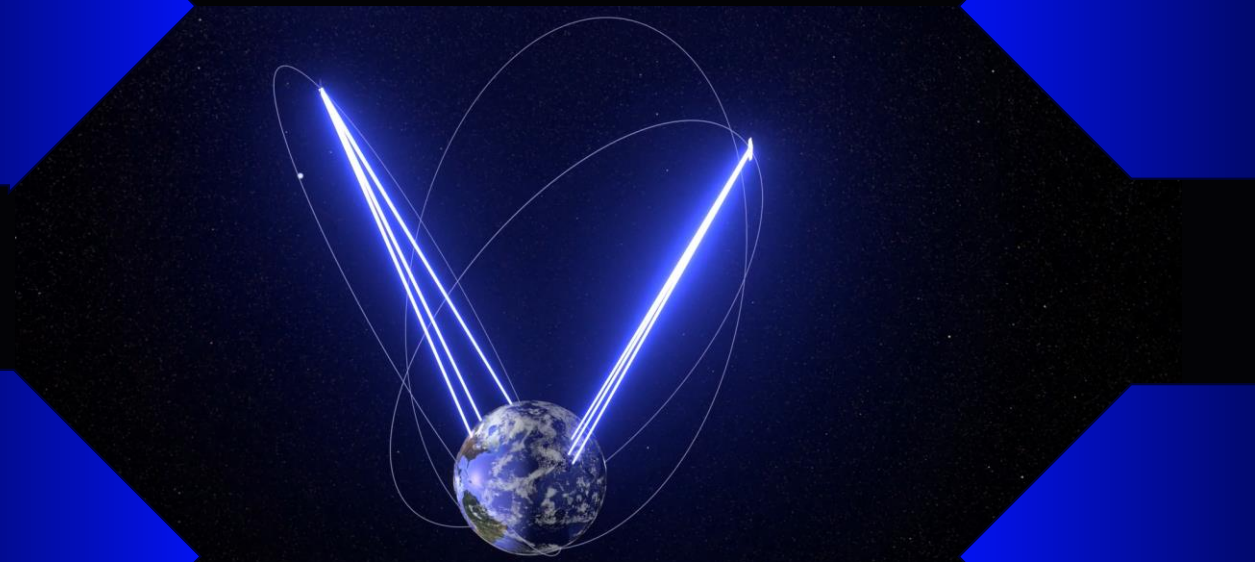
High volume manufacturing

Millions of standardized sub-sats

ENABLERS

Commerical Launch Costs

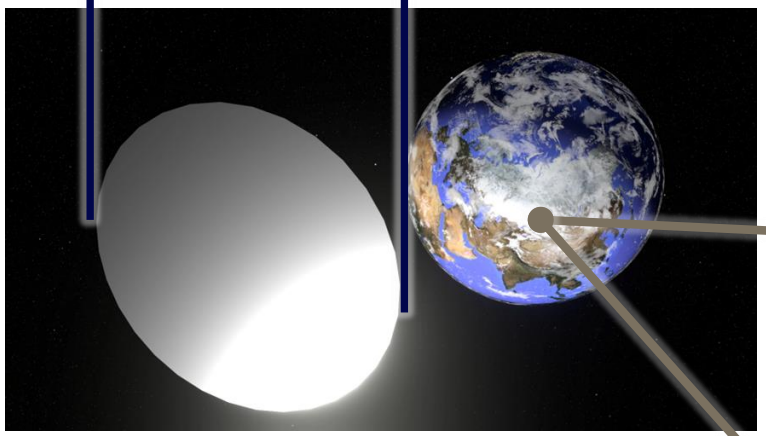
Automated assembly

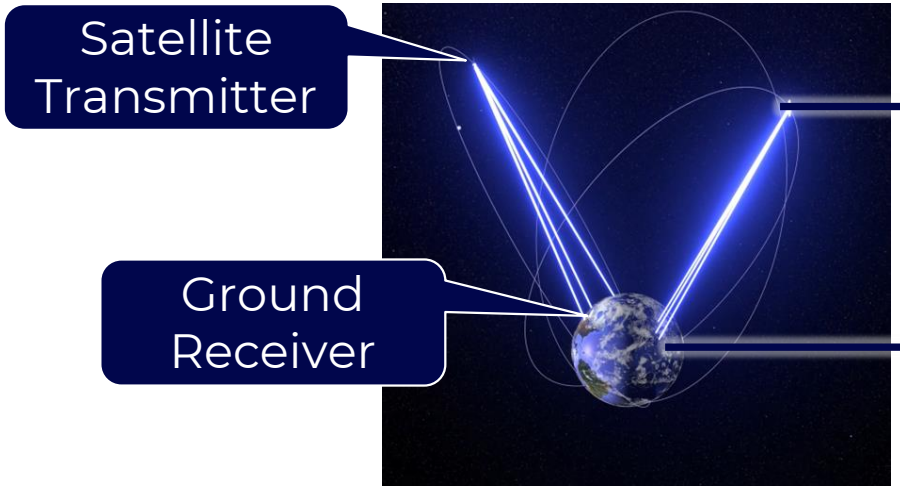


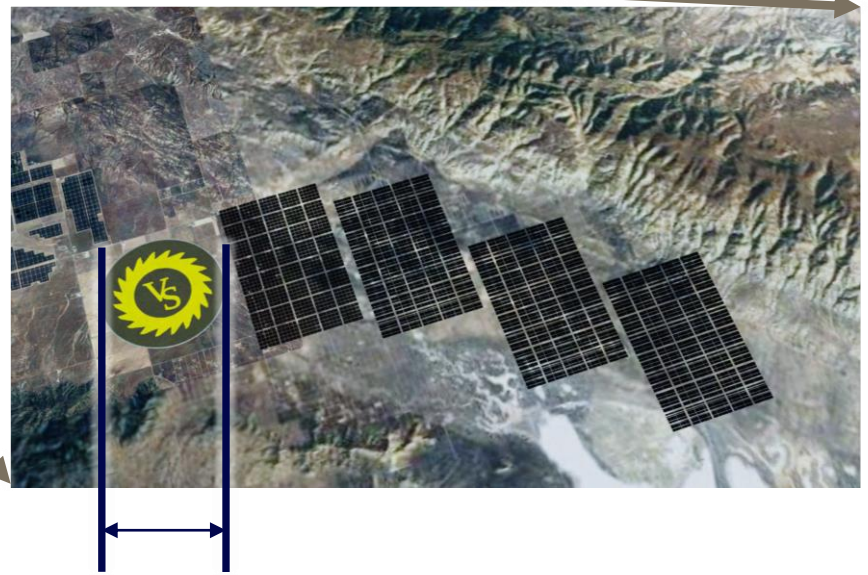
Long-distance wireless power transfer

High volume manufacturing

WIRELESS POWER TRANSMISSION







SPACE SOLAR IS BEST USE CASE FOR LONG DISTANCE WIRELESS POWER TRANSFER

Typical SBSP Tx Rule of Thumb

At = ø 1000m
Ar = ø 5000m
λ = 0.03m
D = 40,000km

τ = 3.27
η = **100%**
Ω = 0.007deg

Goubau, 1970

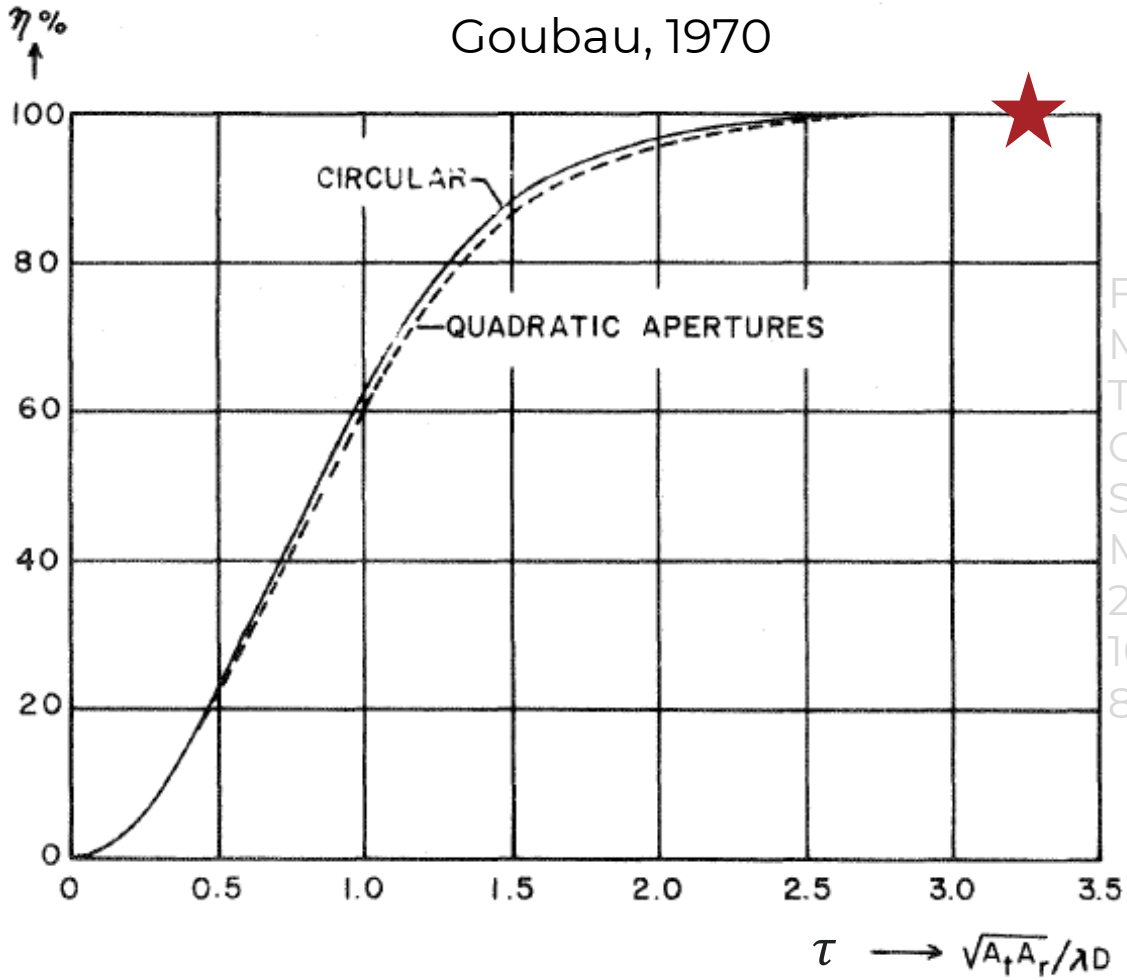
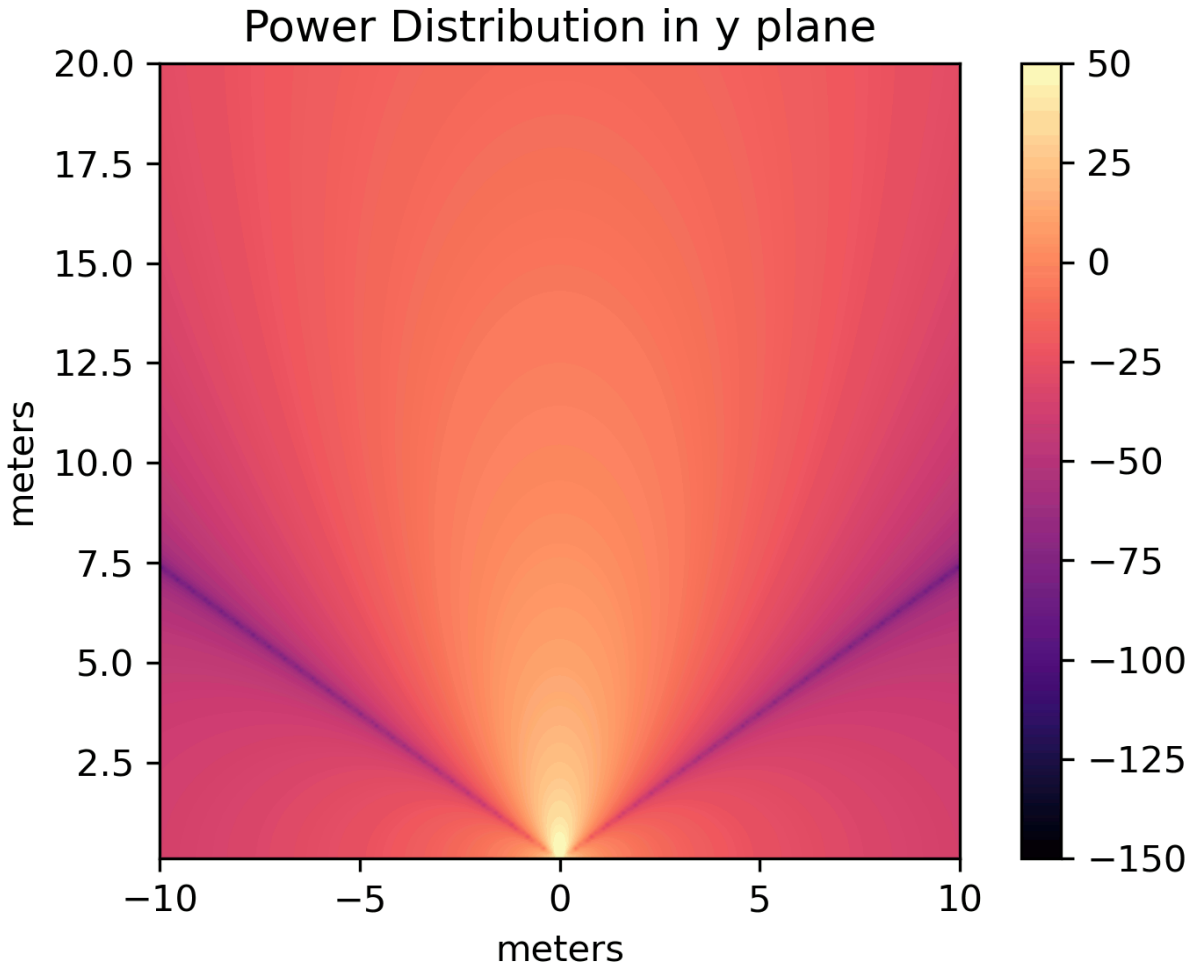


Fig. 2 Transmission efficiency for optimum field distribution in the beam.

From G. Goubau (1970) Microwave Power Transmission from an Orbiting Solar Power Station, Journal of Microwave Power, 5:4, 224-231, DOI: 10.1080/00222739.1970.11688876

ILLUSTRATION OF APERTURE IMPACT ON BEAM

- LARGER TRANSMITTER = SMALLER RECEIVER
- KEY DESIGN PARAMETER



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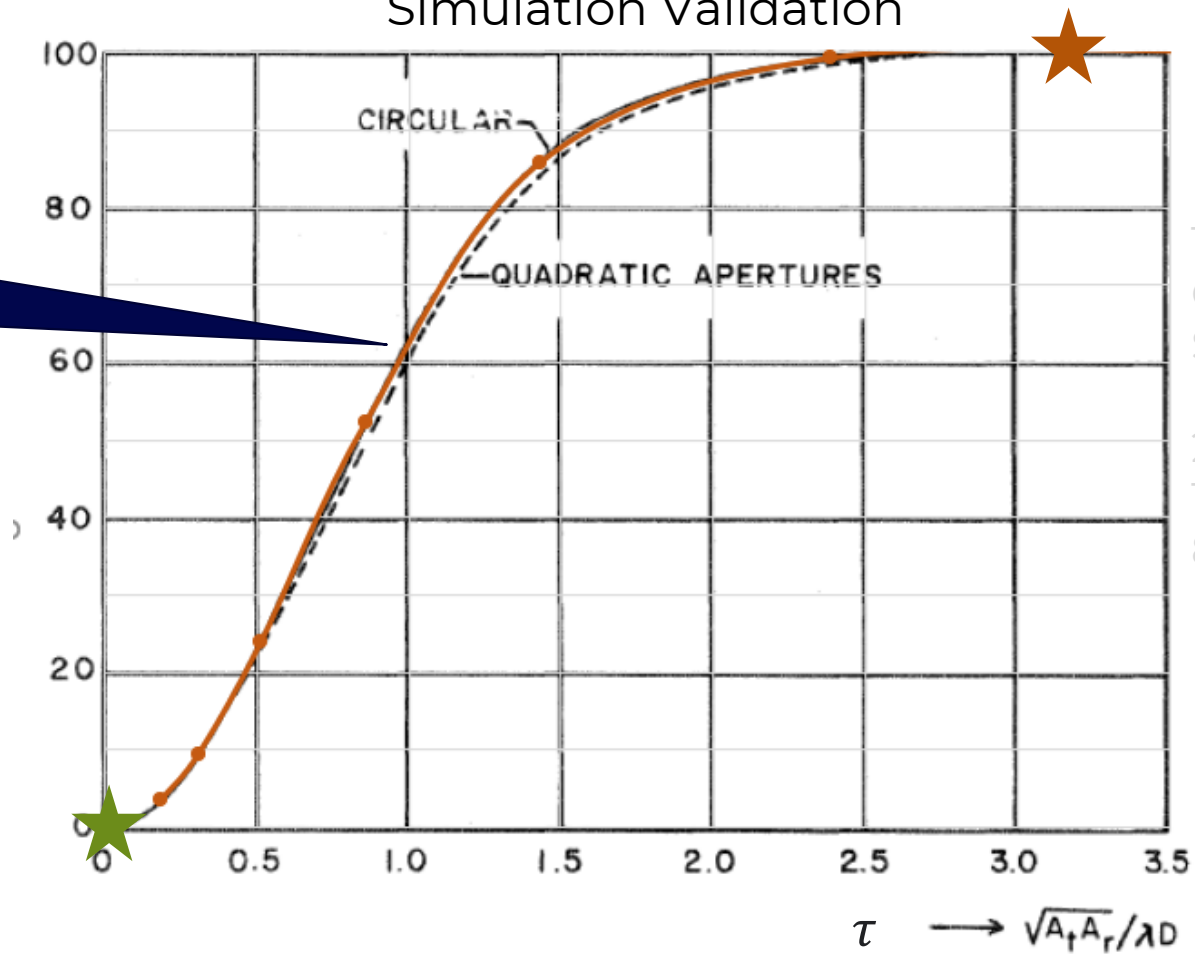
VALIDATION FOR PHASED ARRAYS

Efficiency predicted by detailed simulation

Simulation Validation



From G. Goubau (1970) Microwave Power Transmission from an Orbiting Solar Power Station, Journal of Microwave Power, 5:4, 224-231, DOI: 10.1080/00222739.1970.1168876

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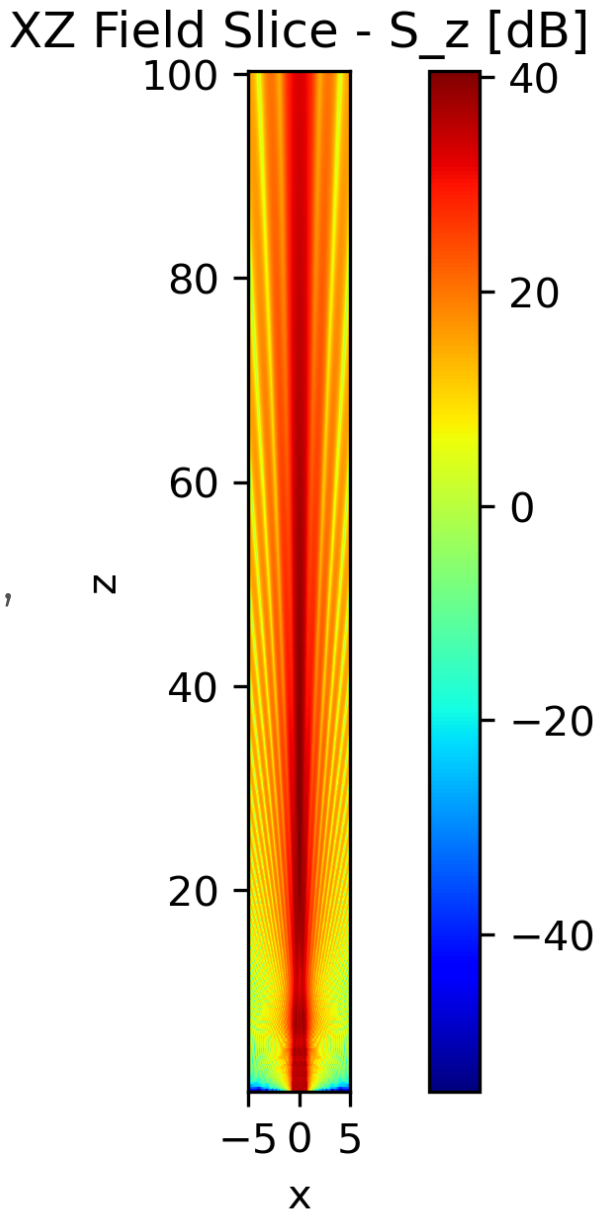
TOOL CHAIN CONSIDERATIONS

- Large phased arrays require large computational effort
- 40,000km distance requires kilometer-scale Tx aperture, therefore >1B (10^9) elements @ 10GHz
- Commercial codes can't simulate more than ~6M (6x10^6) antennas
- VS developed in-house code due to above



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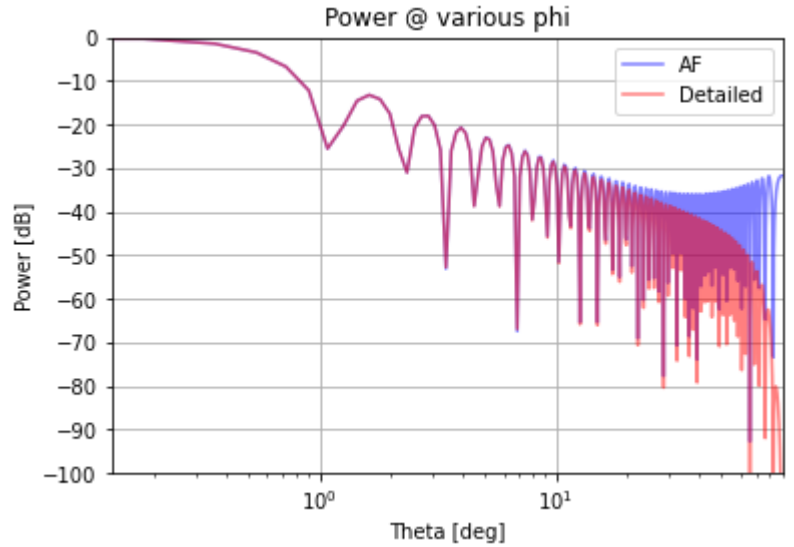
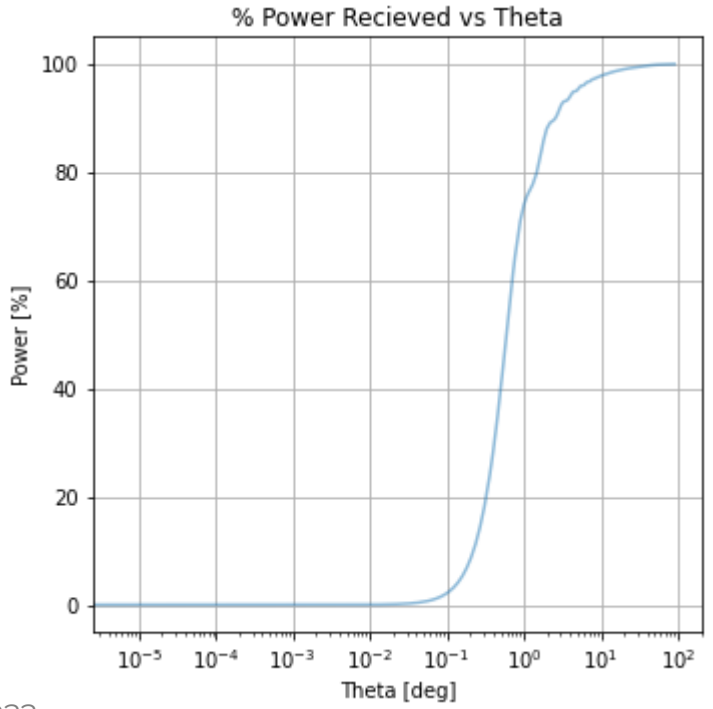
MATHEMATICS

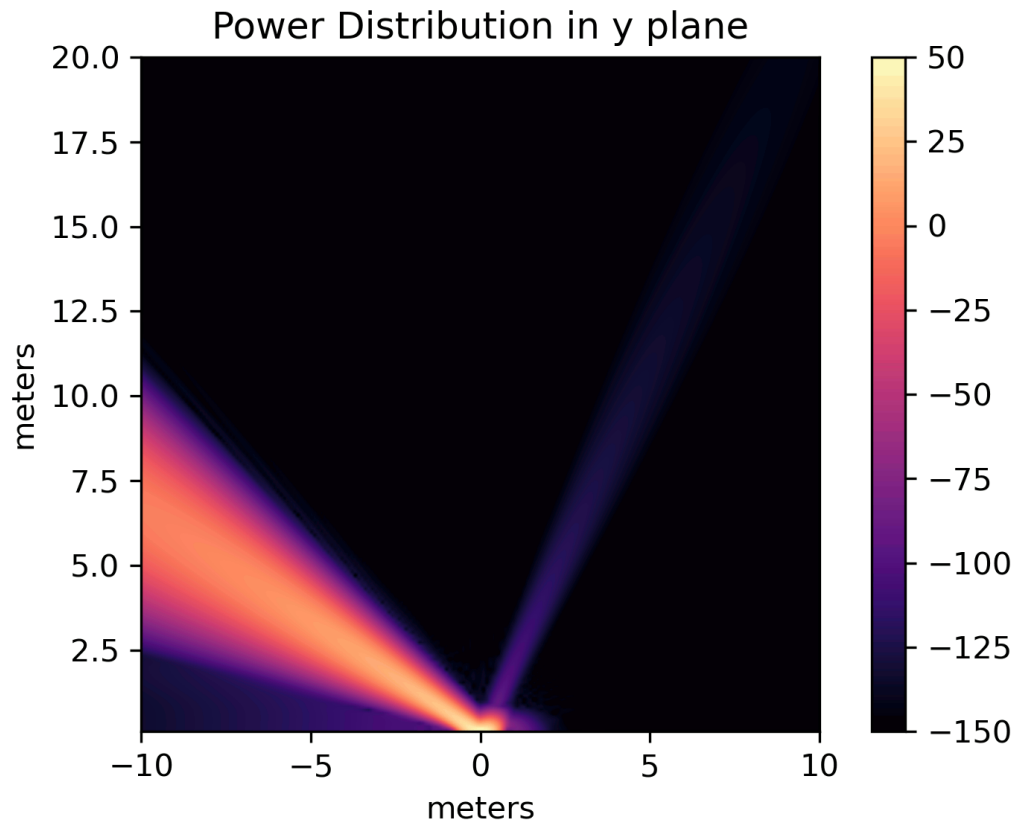
- Intersection of Optics and RF
- Array factor (AF) vs detailed simulation
- Polarization effects included
- Extending for atmospheric effects
- Key output is beam efficiency





ADDITIONAL CAPABILITIES

- Beam Steering
- Side lobes
- Sensitivity
- Failure Effects
- …



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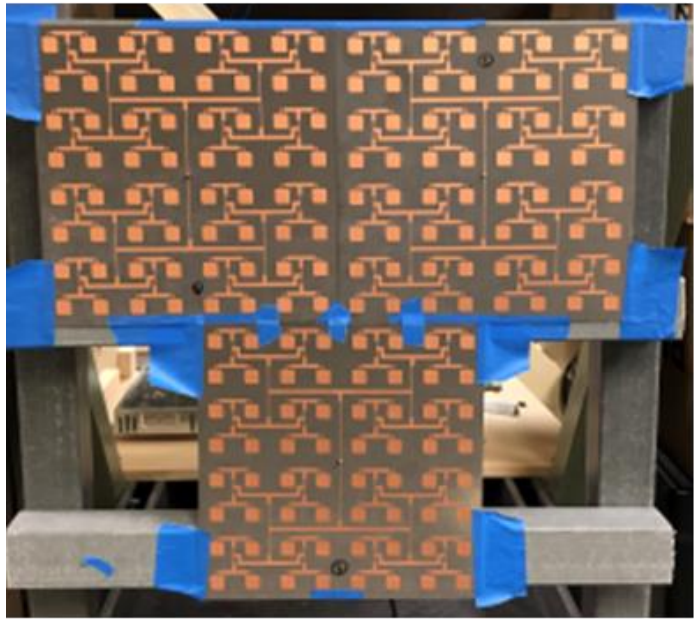
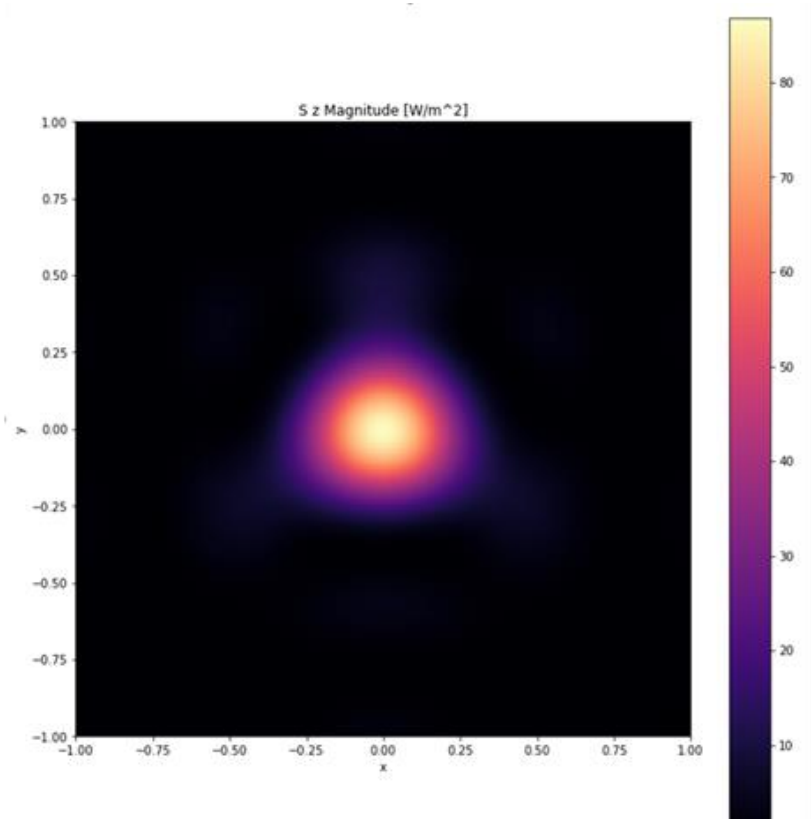
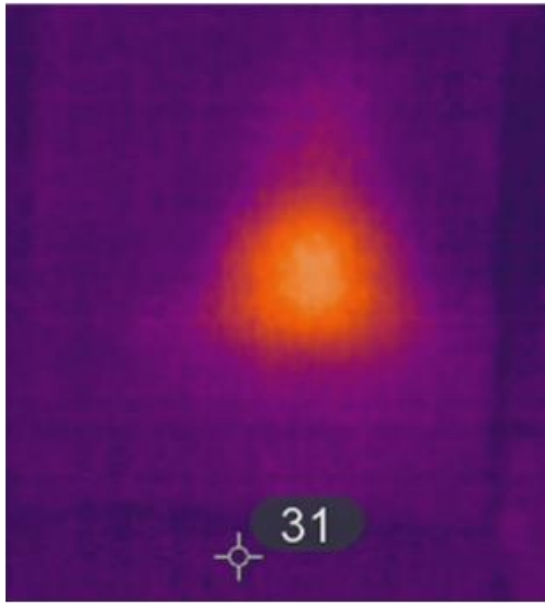
VALIDATION WITH PHYSICAL TESTING



Patch Antenna Transmitters



Intensity map



Thermal image of RF-Absorbing Foam

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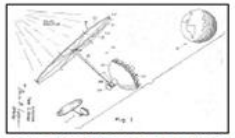
SPACE SOLAR POWER IS THE ANSWER

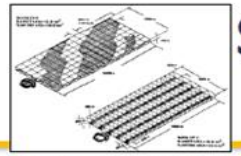
- Dispatchable – any time, any location
  - Works with existing infrastructure
- Simplifies terrestrial renewables
  - No seasonal storage
  - No overbuild
  - No smart grid
- The time is now.

VIRTUS SOLIS IS DESIGNED TO DECARBONIZE THE WORLD

U.S. NAVAL RESEARCH LABORATORY

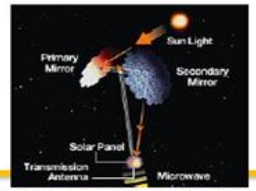
Some proposed implementations


Peter Glaser GEO concept, circa 1968

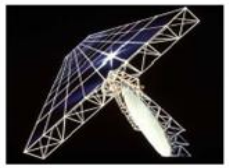

NASA/DOE SPS Reference System, circa 1978

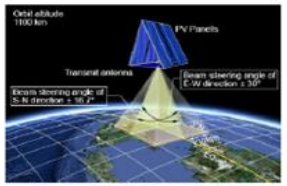
Perpendicular to Orbital Plane, circa 1973


Krafft Ehricke Soletta Space Mirrors, circa 1978

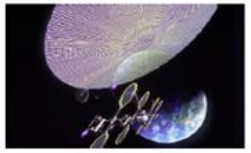


NASA/DOE Microwave sandwich concept, circa 1980

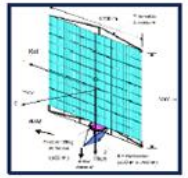

NASA Reference Design, circa 1981

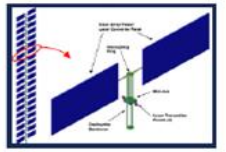


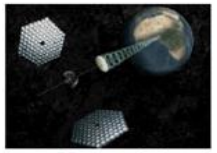
Japanese SPS-2000 LEO concept, circa 1994

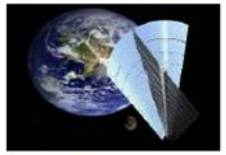

SolarDisc, circa 1997


SunTower, circa 1997

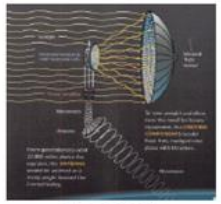

Abacus, circa 2001

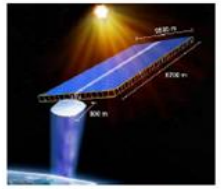

Aerospace Corp. Laser Concept, circa 2002

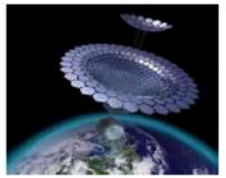

Modular Symmetrical Concentrator, circa 2007

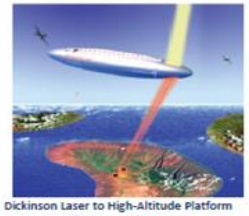

JAXA modular laser, circa 2008


EADS Astrium laser concept, circa 2011

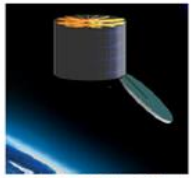

Solaren, circa 2010

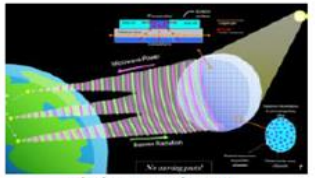

SolarHigh, circa 2012


SPS-ALPHA, circa 2013

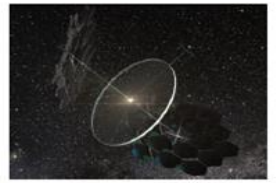

Dickinson Laser to High-Altitude Platform to Microwave, circa 2013

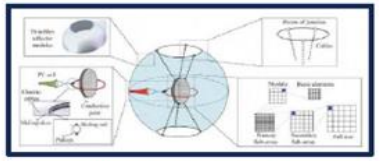

Sun Synchronous Orbit Concentrating PV, circa 2014

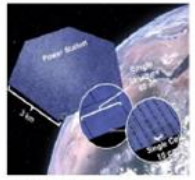

Tin Can SPS, circa 2014

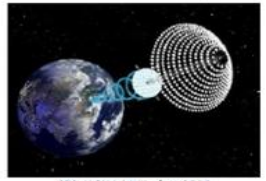

Hyland Power Star, circa 2014


China Academy of Space Technology (CAST) Multi-Rotary Joints SPS, circa 2015


Team Sunflower Thermal Power Satellite, circa 2015


SPS-OMEGA, Xidian University, circa 2014


Caltech/NG SSPI, circa 2015


SPS-ALPHA MKII, circa 2016


CASSIOPeiA, circa 2017

Etc....