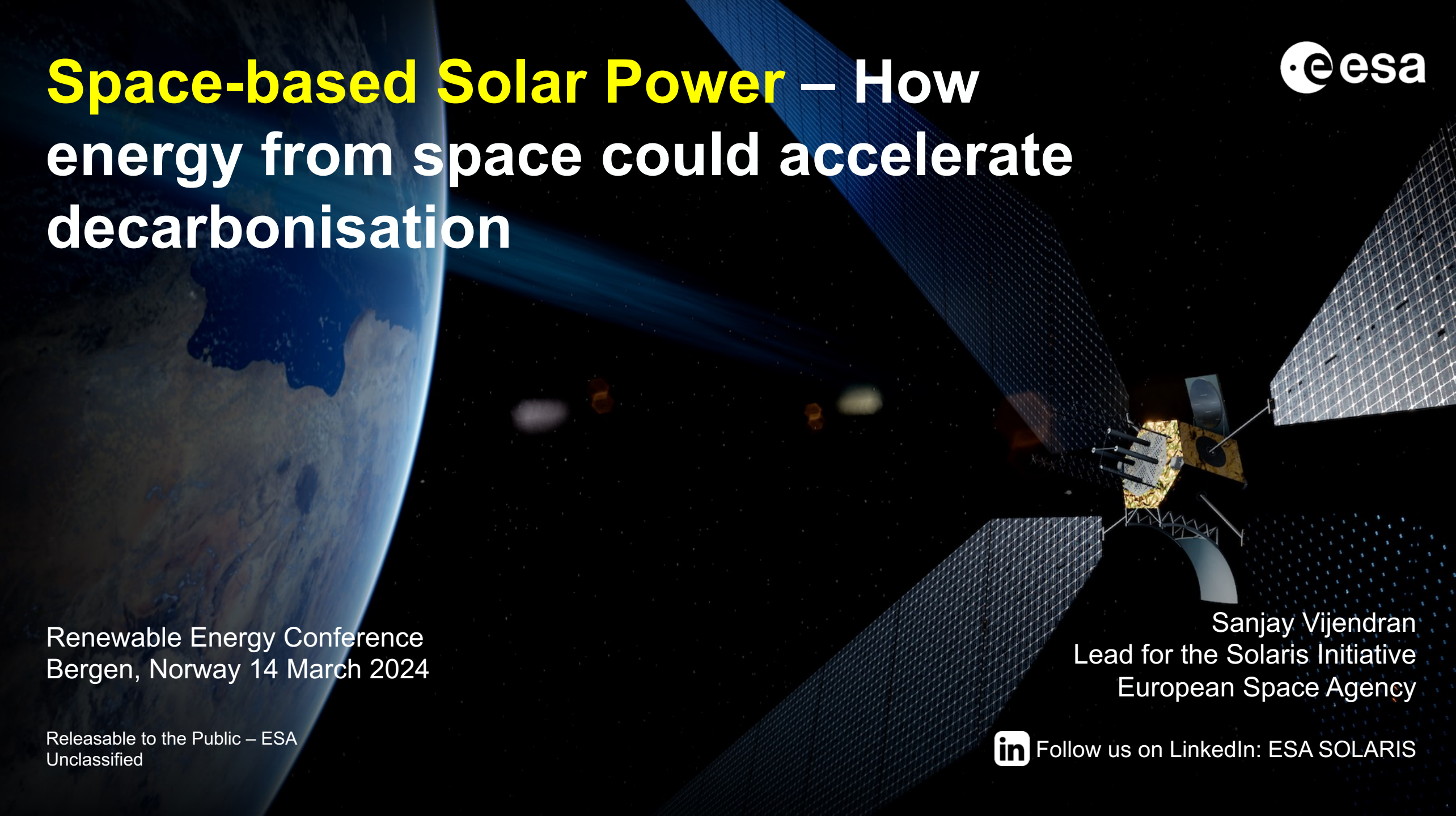
Space-based Solar Power – How energy from space could accelerate decarbonisation



Renewable Energy Conference
Bergen, Norway 14 March 2024

Sanjay Vijendran
Lead for the Solaris Initiative
European Space Agency

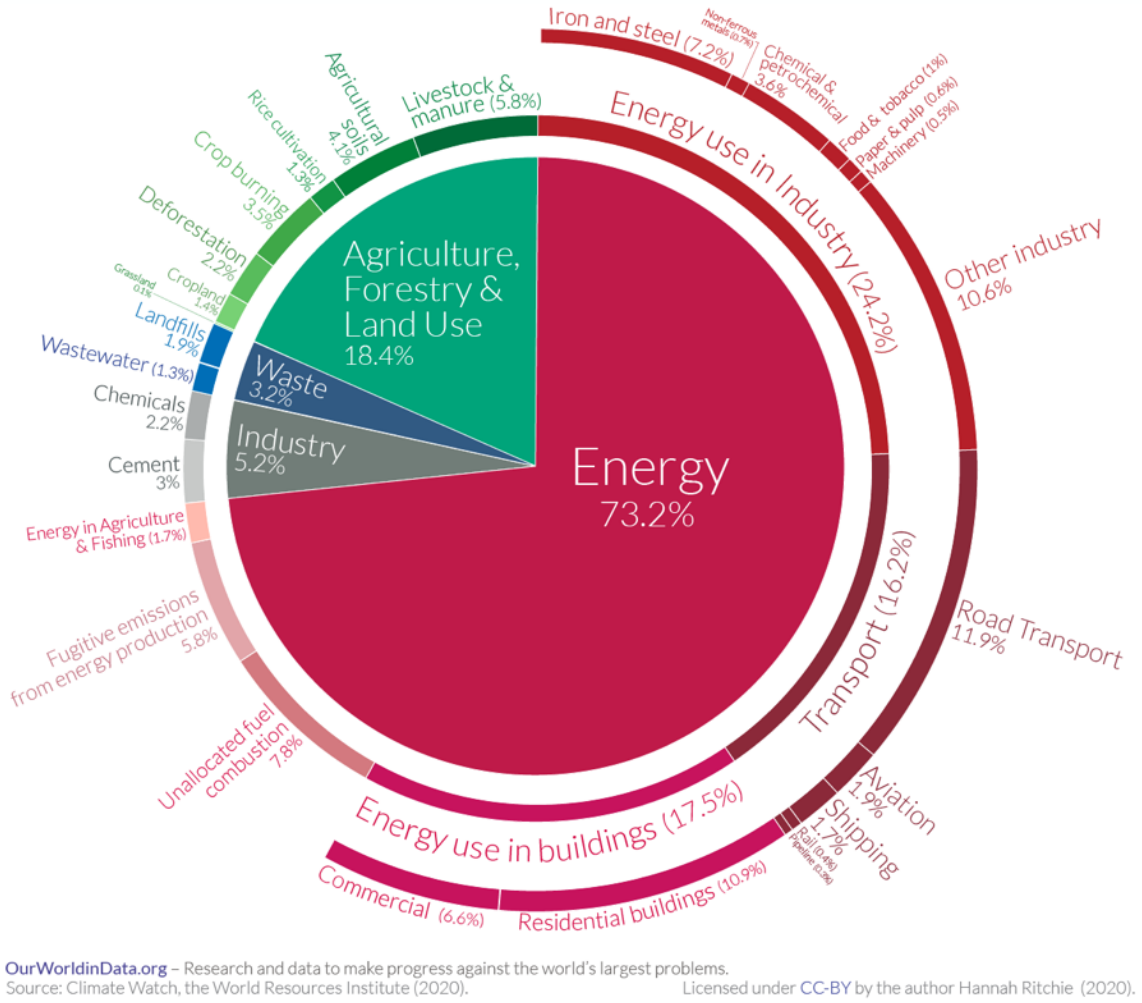
Follow us on LinkedIn: ESA SOLARIS


Link to ESA Solaris Video


esa
The Vision:
Energy is clean, abundant, affordable, secure and available to everyone


We have an
Urgent Energy
Problem
Climate Crisis
Energy Security

As the major source of global emissions, the **energy sector** holds the key to responding to the world's climate challenge.



[1]

[2]

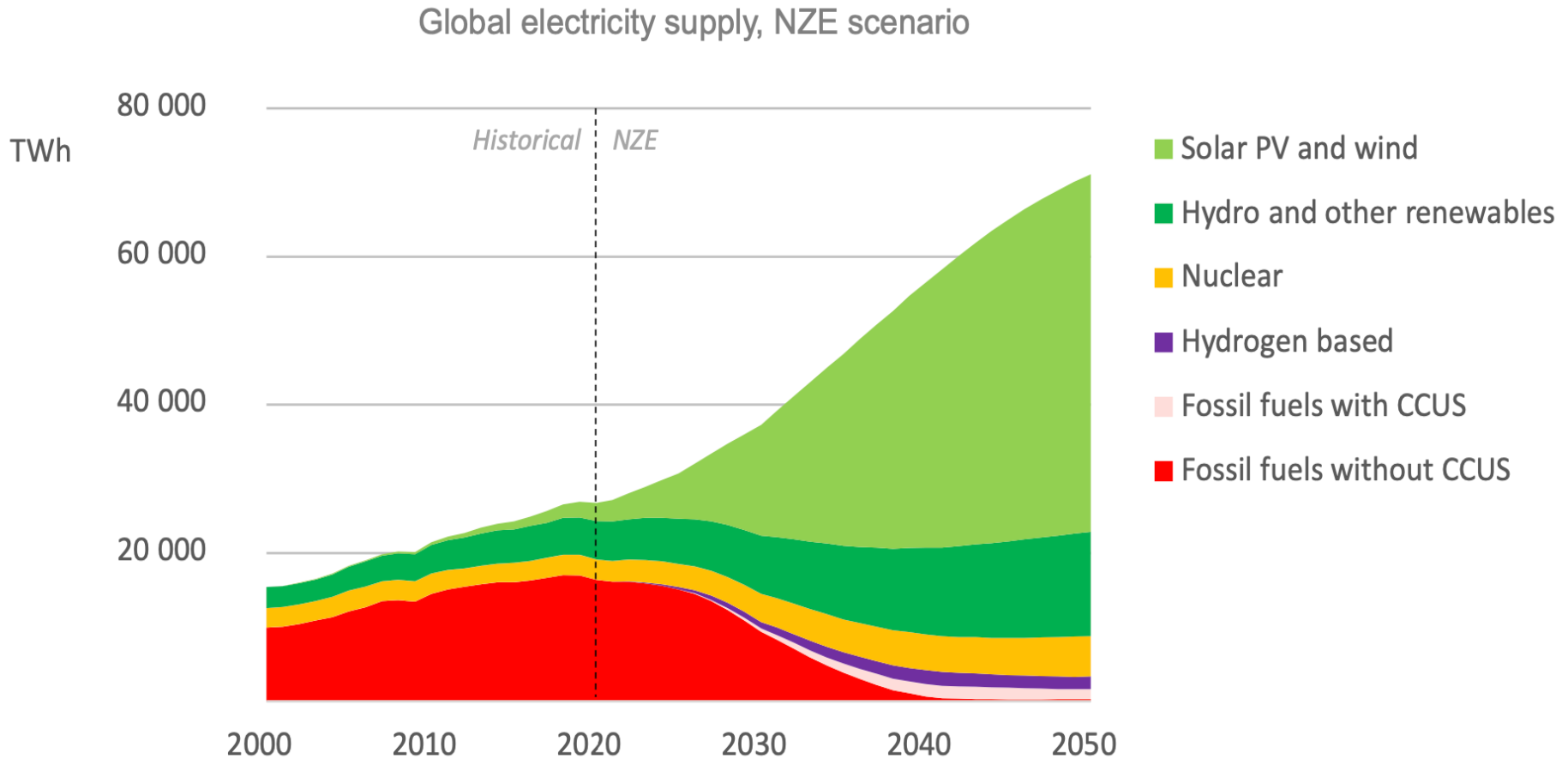
"Achieving net-zero emissions by 2050 will require nothing short of the complete transformation of the global energy system.", IEA

[1]

Existing energy options have **major challenges**

Scalability? **Availability?** **Land Use?**

IEA Net Zero Electricity Sources in 2050



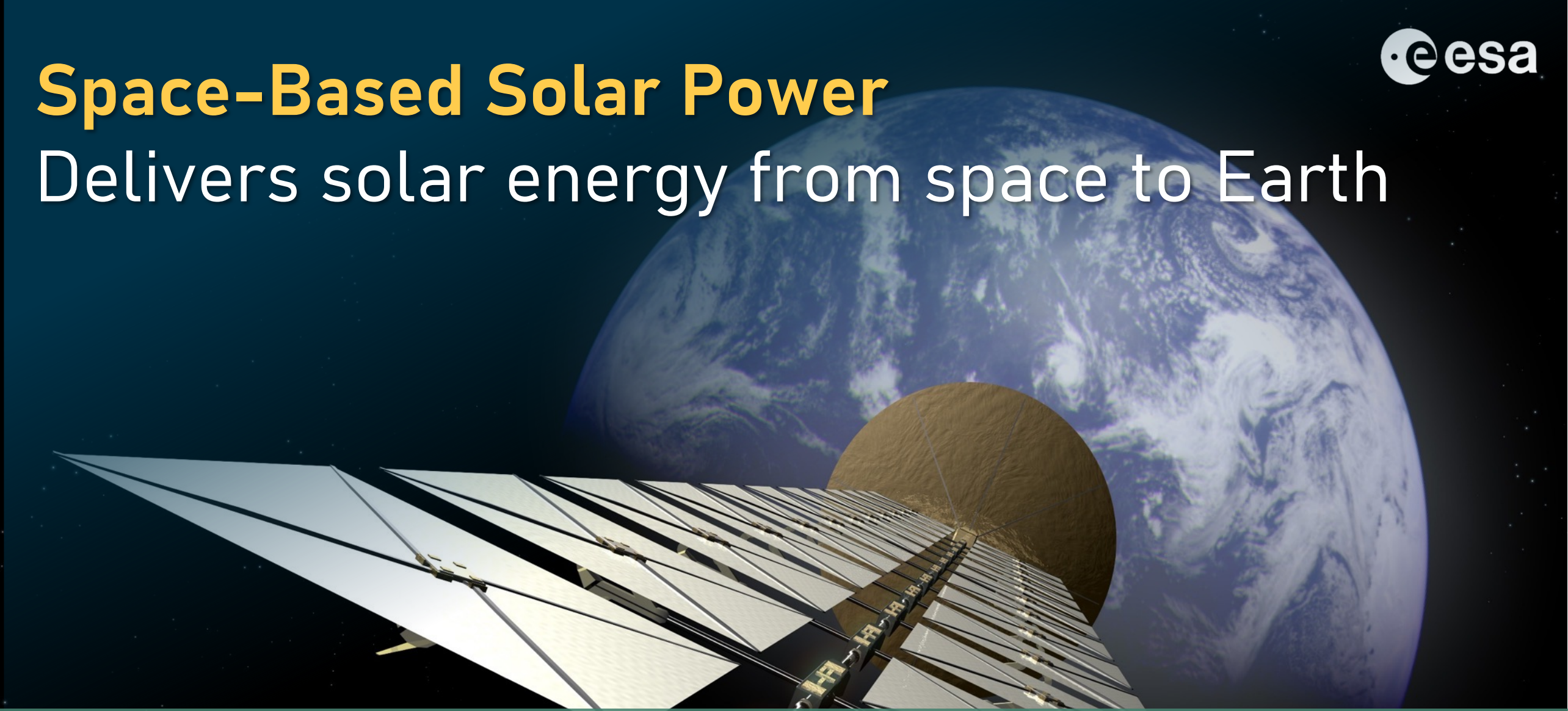
In our net zero pathway, renewables make up nearly 90% of electricity generation in 2050, propelled largely by solar PV and wind

"The rise in electricity demand also calls for extensive efforts to ensure the stability and flexibility of electricity supply through ***demand-side management****, the* ***operation of flexible low-emissions sources*** *of generation including hydropower and bioenergy, and* ***battery storage."****, IEA NZE by 2050 Roadmap*

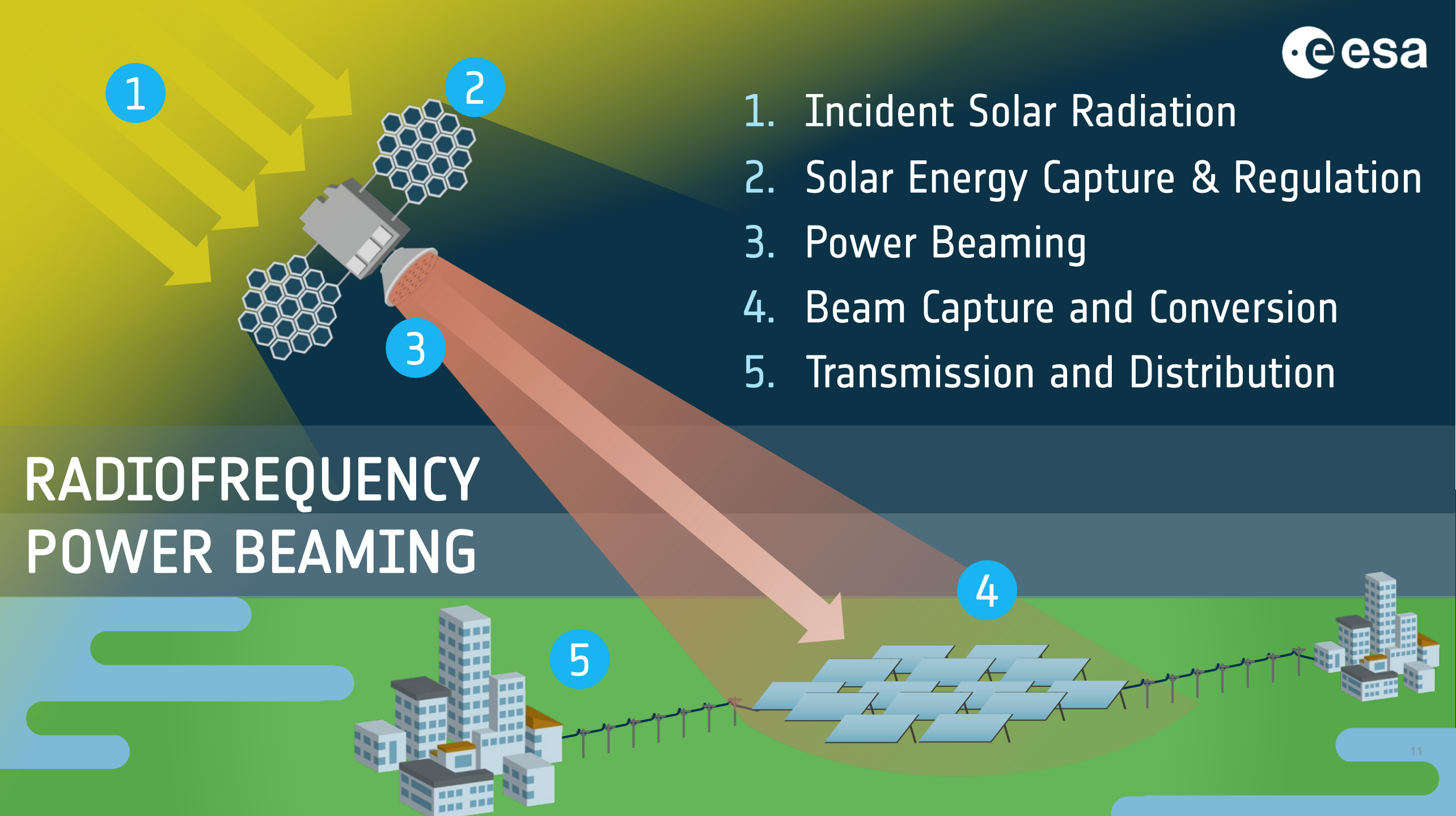
Could **space** help plug the gap in clean energy the world needs?

Space-Based Solar Power

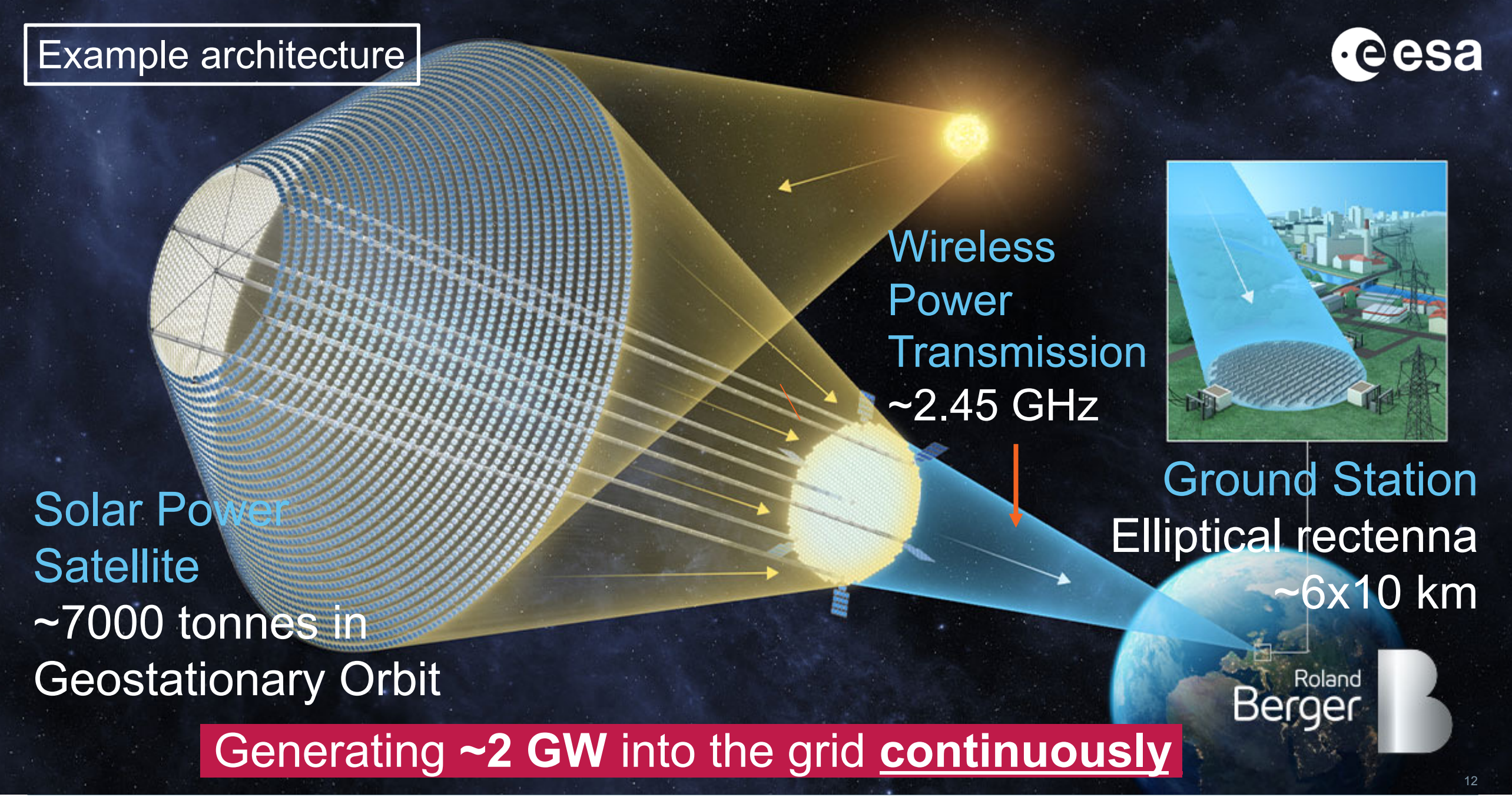
Delivers solar energy from space to Earth



Green, 24/7, affordable, scalable, secure and **available to everyone**


1
2
3
4
5
1. Incident Solar Radiation
2. Solar Energy Capture & Regulation
3. Power Beaming
4. Beam Capture and Conversion
5. Transmission and Distribution
RADIOFREQUENCY
POWER BEAMING

Example architecture

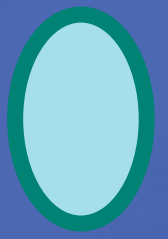


Generating **~2 GW** into the grid **continuously**

Ground receiver for radiofrequency power reception

~130 km²
~600 MW
Nameplate capacity

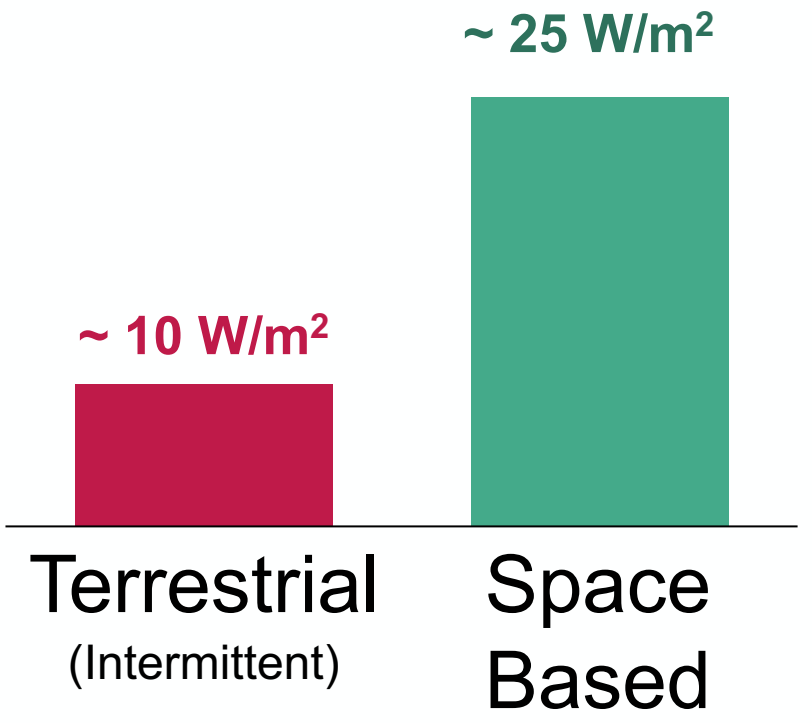
~75 km²
~2 GW
Continuous

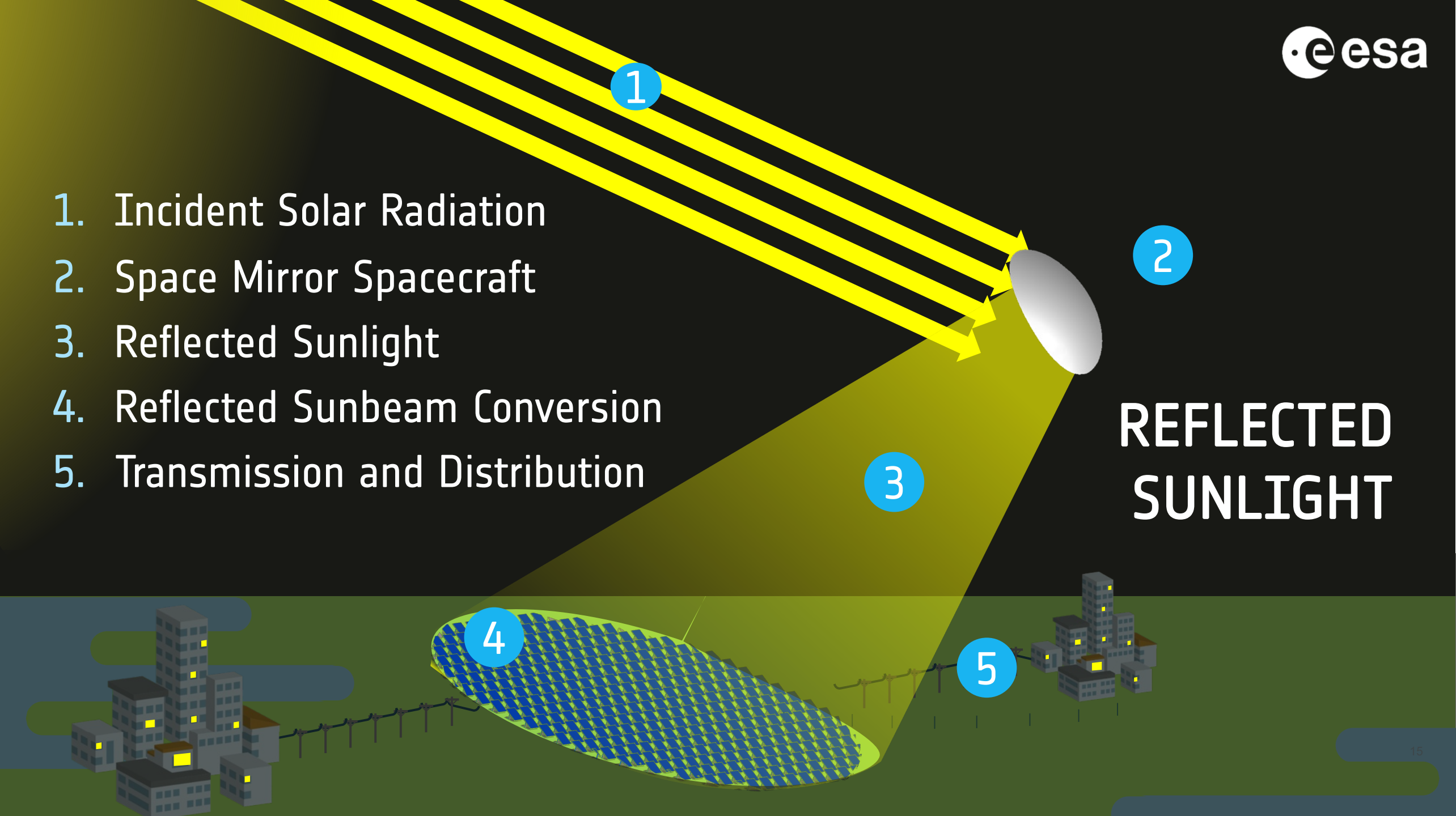


SBSP Ground Rectenna

Avg. Solar Power into Grid for land used on Earth

1,365 W/m² in space translates to…




1. Incident Solar Radiation
2. Space Mirror Spacecraft
3. Reflected Sunlight
4. Reflected Sunbeam Conversion
5. Transmission and Distribution
1
2
3
4
5
REFLECTED SUNLIGHT

Space Mirrors

Each 1 Km diameter in 1000km or higher orbits

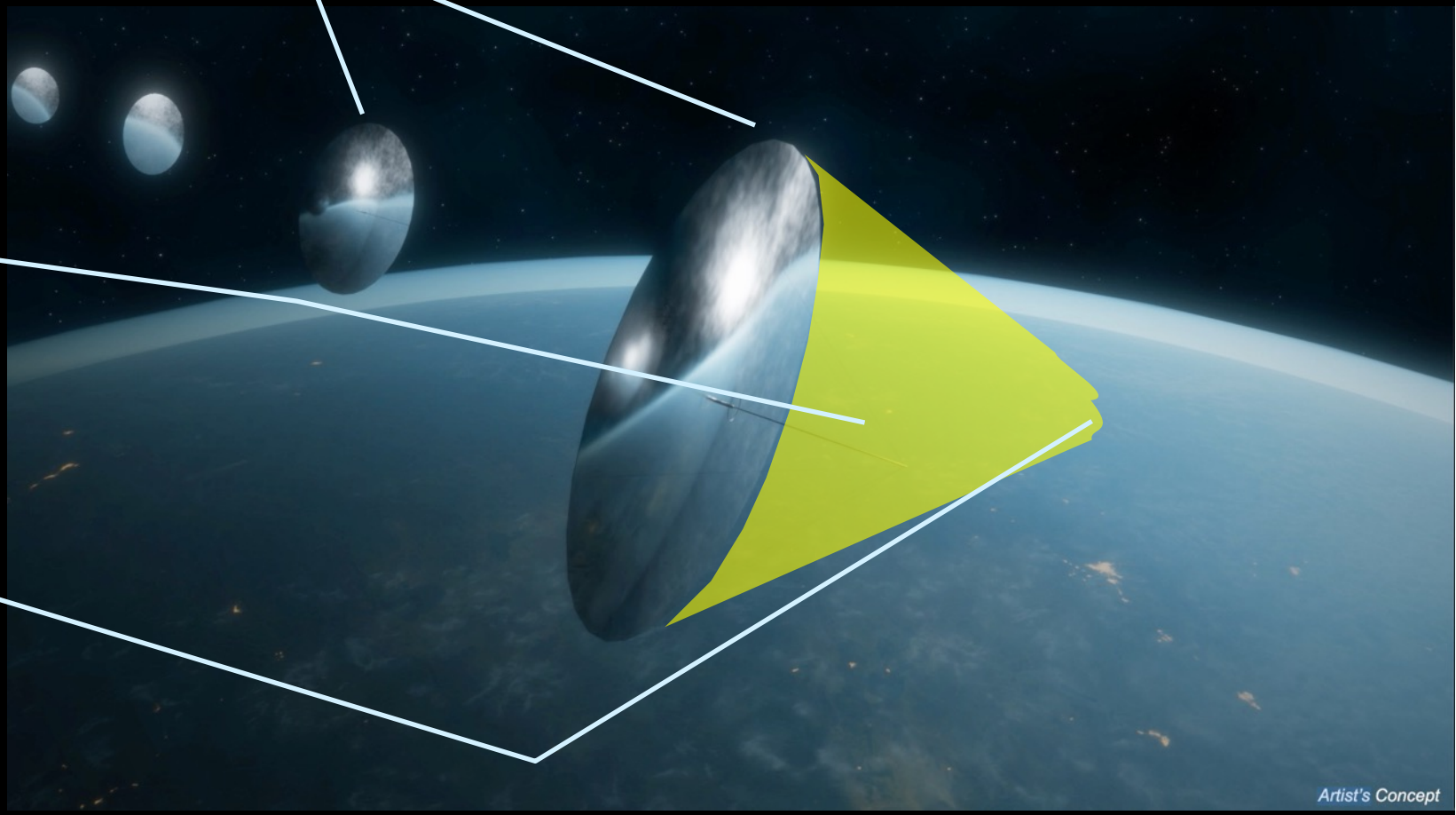
Reflected Sunlight

Up to same intensity as daylight 1000 W/m^2

Conventional Solar PV farm

~4 km diameter

SUNLIGHT REFLECTION



SOLAR FARMS RECEIVING REFLECTED SUNLIGHT

Up to 2 hours extra midday sun at dawn and dusk => ~60% additional electricity generation / year

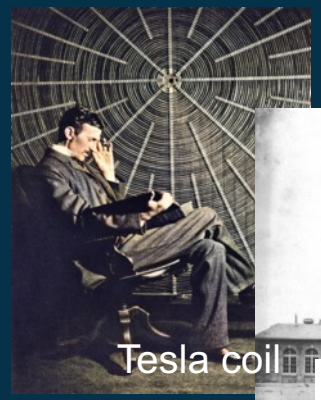
Link to video

This is not science fiction.

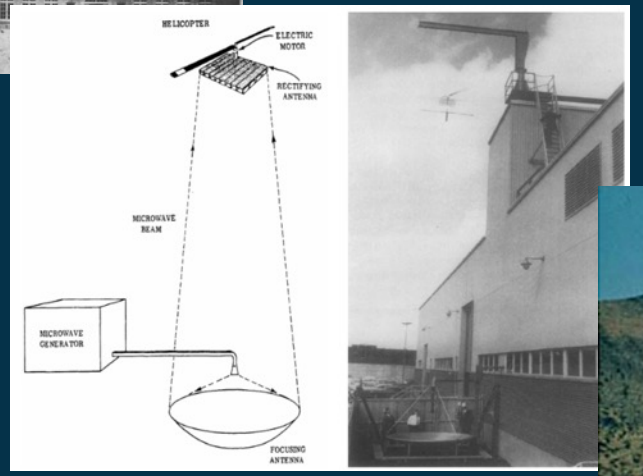
We should be taking this concept seriously

Wireless Power Transmission is a thing!

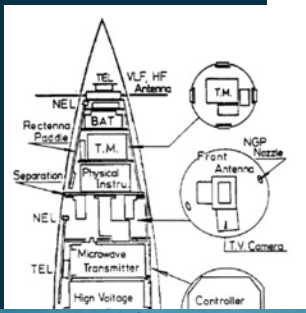
1900 1960's 1970's 1980's 2010's 2022

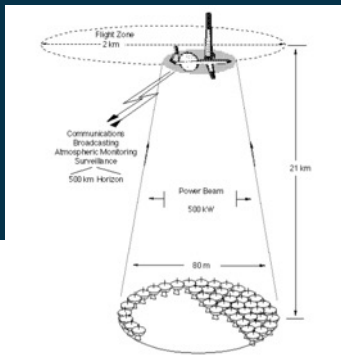


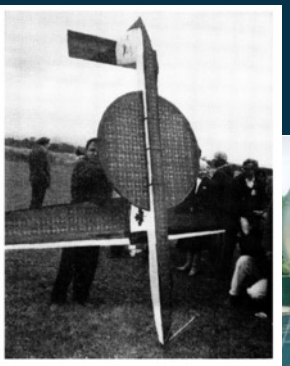
Tesla coil



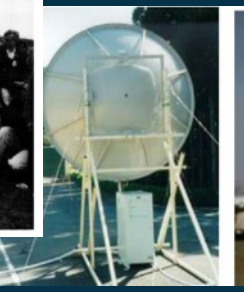
William Brown







Canada Communications Research Centre



JPL-Goldstone

US NRL

https://wpt.ieee.org/wpt-history/

Wireless Power Transmission is a thing!

Link to demo video

2 kW beamed across 36 m

Airbus – ESA power beaming demo, Ottobrun, Germany
27 September 2022

POWER BEAMING MARKET OPPORTUNITIES

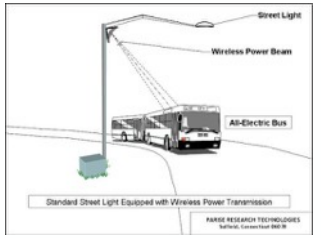
Wired => Wireless

Connect generation and consumption

Connect offshore to grid

Power cellular towers

Mobility / Maritime



Charge cars/buses

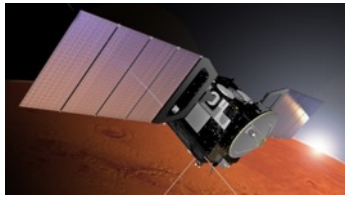
Charge ships/boats/ferries

Aviation

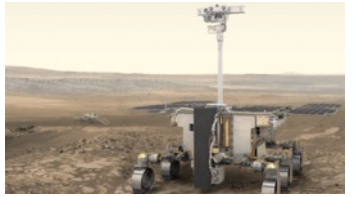
Charge drones

Charge airplanes

In-space



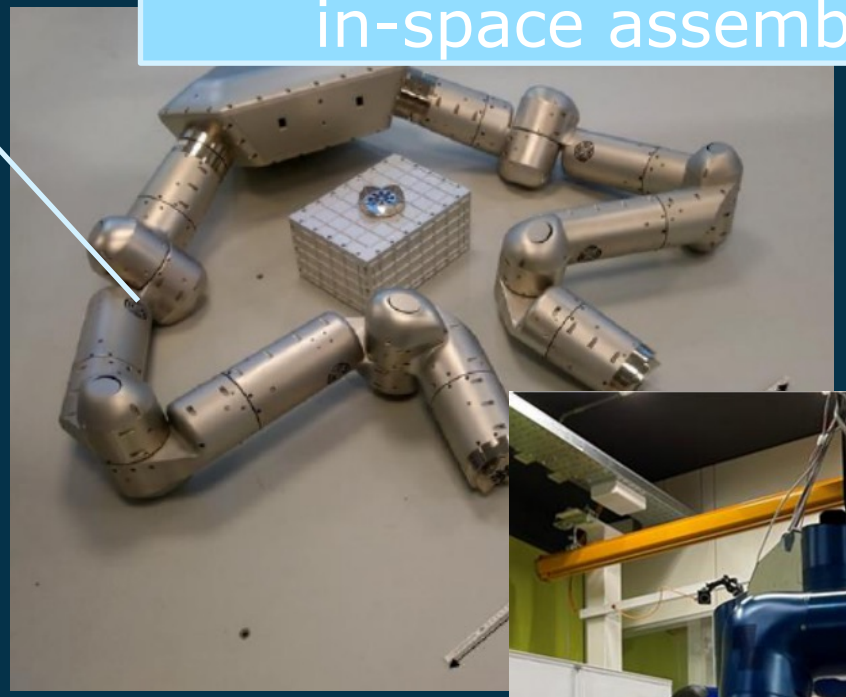
Charge satellites

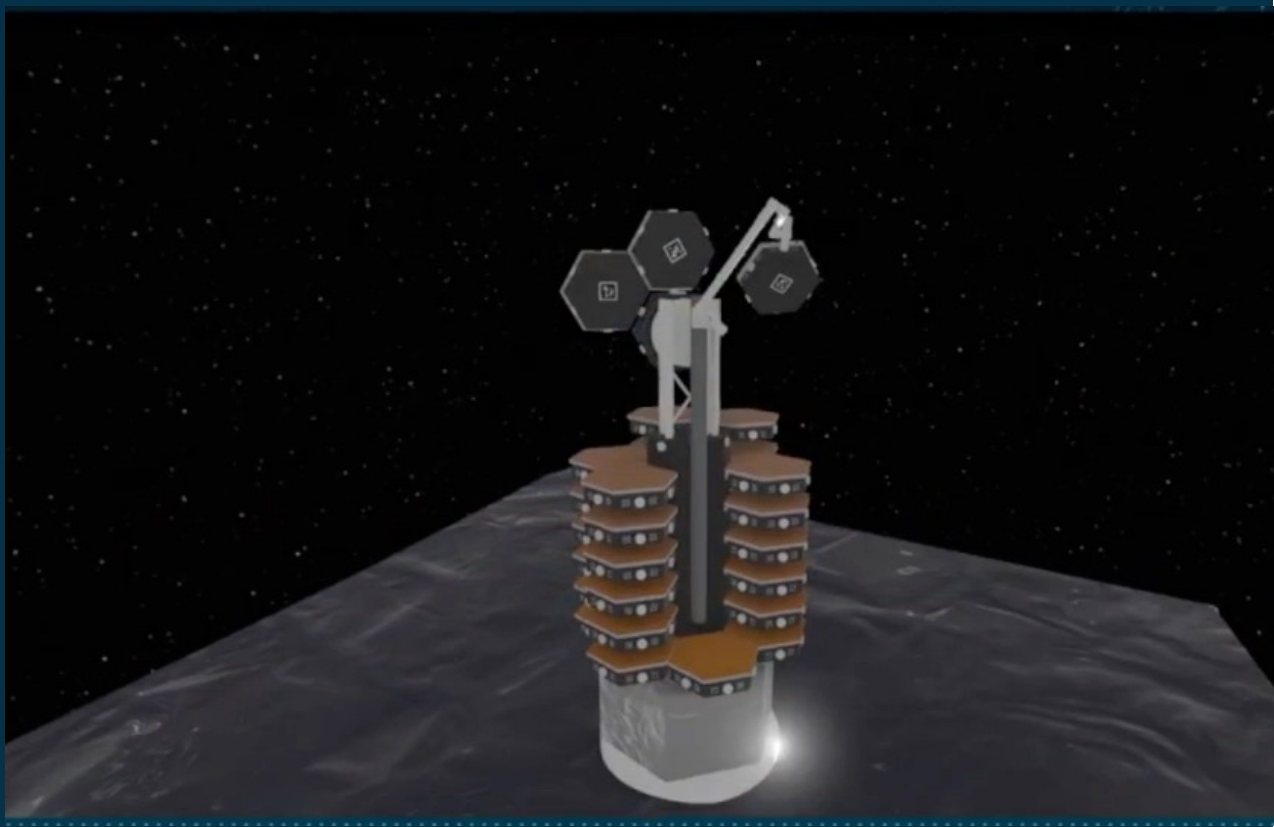


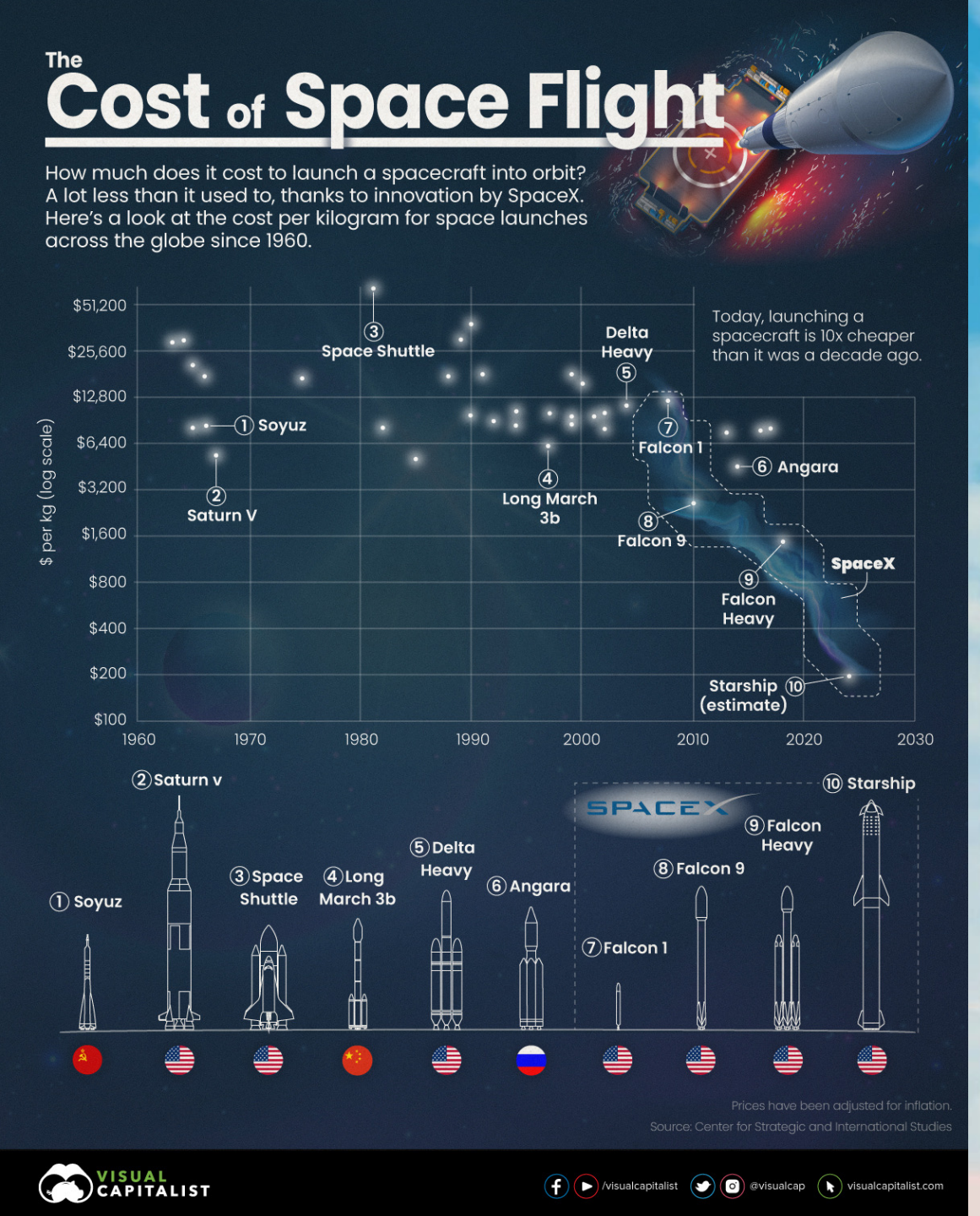
Charge vehicles on Moon & Mars

Large Scale Robotic On-orbit assembly is coming

MIRROR orbital robots for in-space assembly



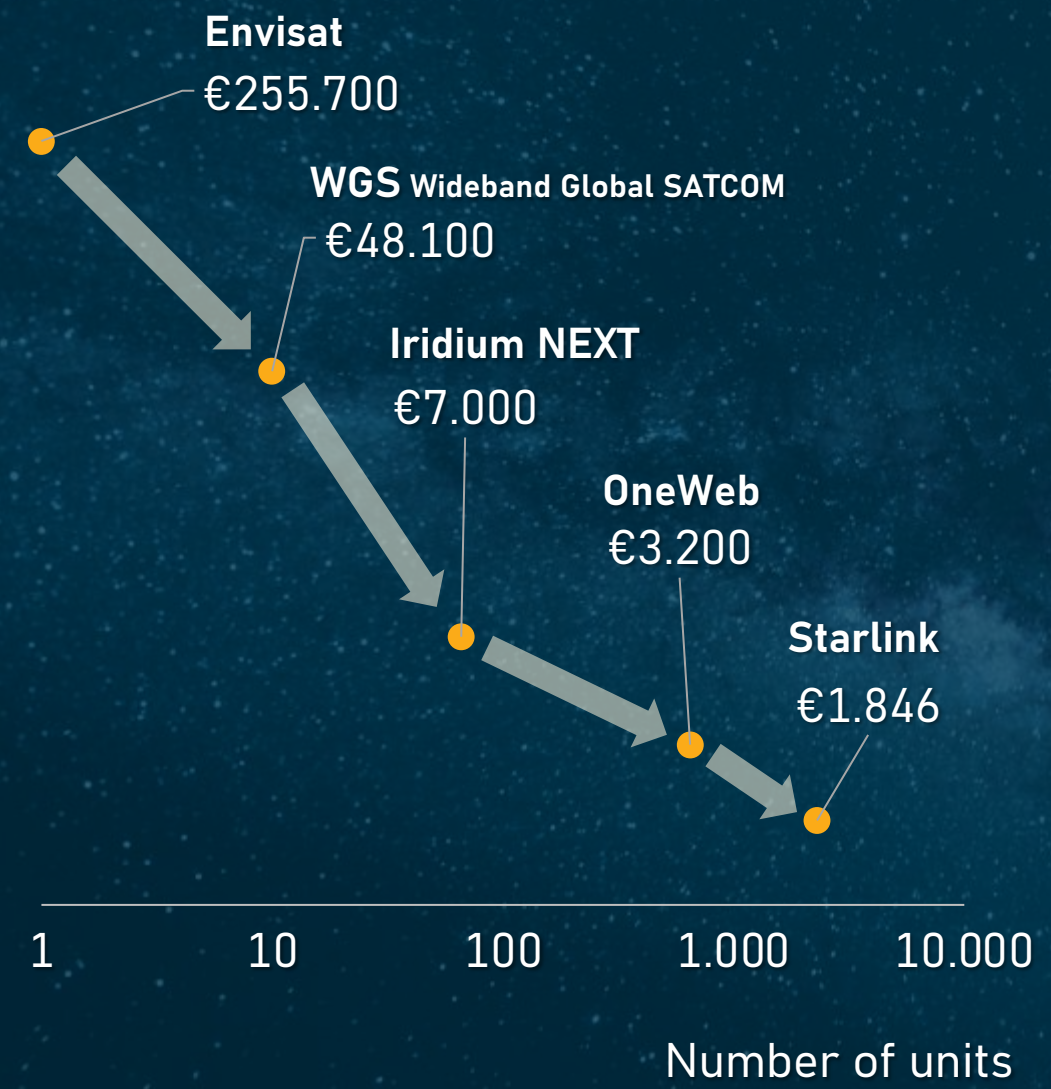




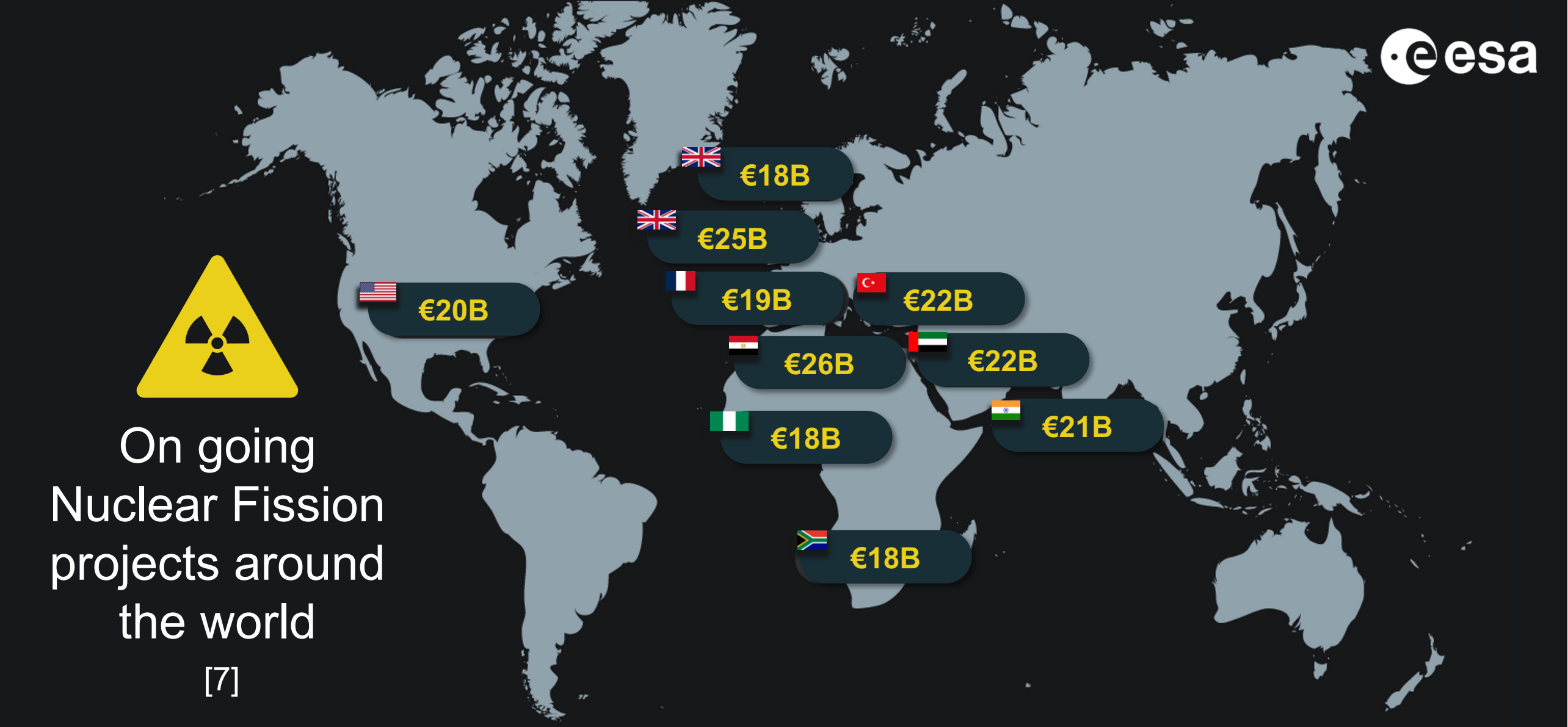
esa

Finally a "Killer App" for low-cost, re-useable European launch capabilities?

Hardware cost per kilogram



Mass production of spacecraft units has proven to **reduce the cost of hardware**.



On going Nuclear Fission projects around the world

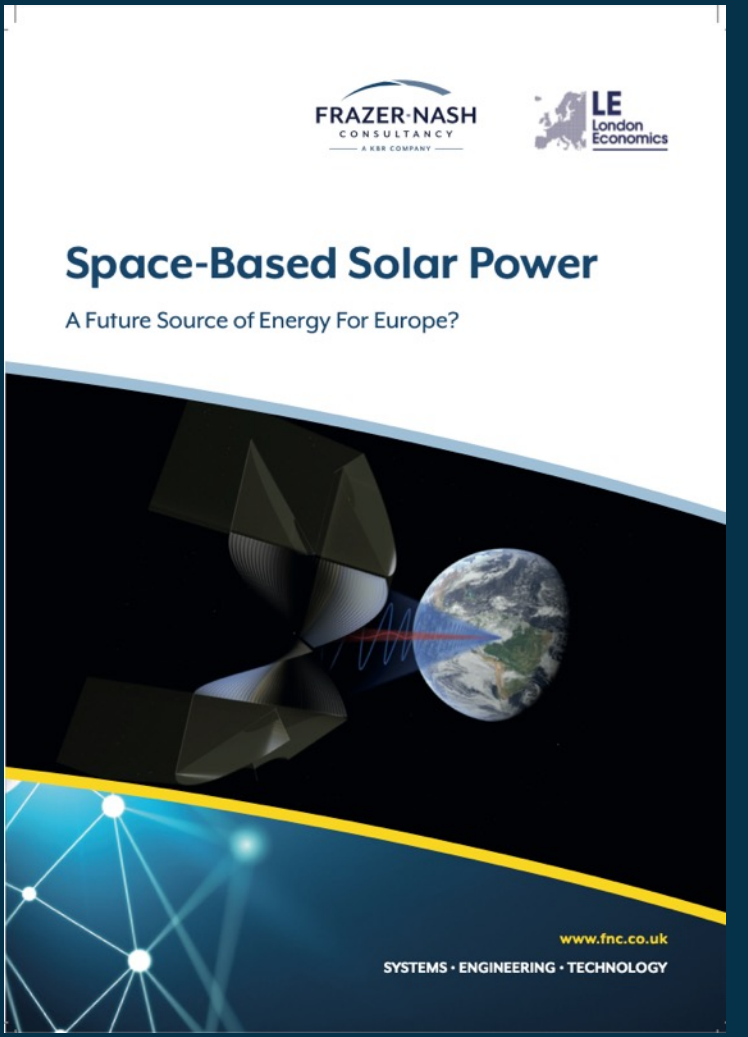
[7]

→ First GW-scale Solar Power Satellite ~ €20B

[3]

How could it contribute to mitigating the climate crisis?

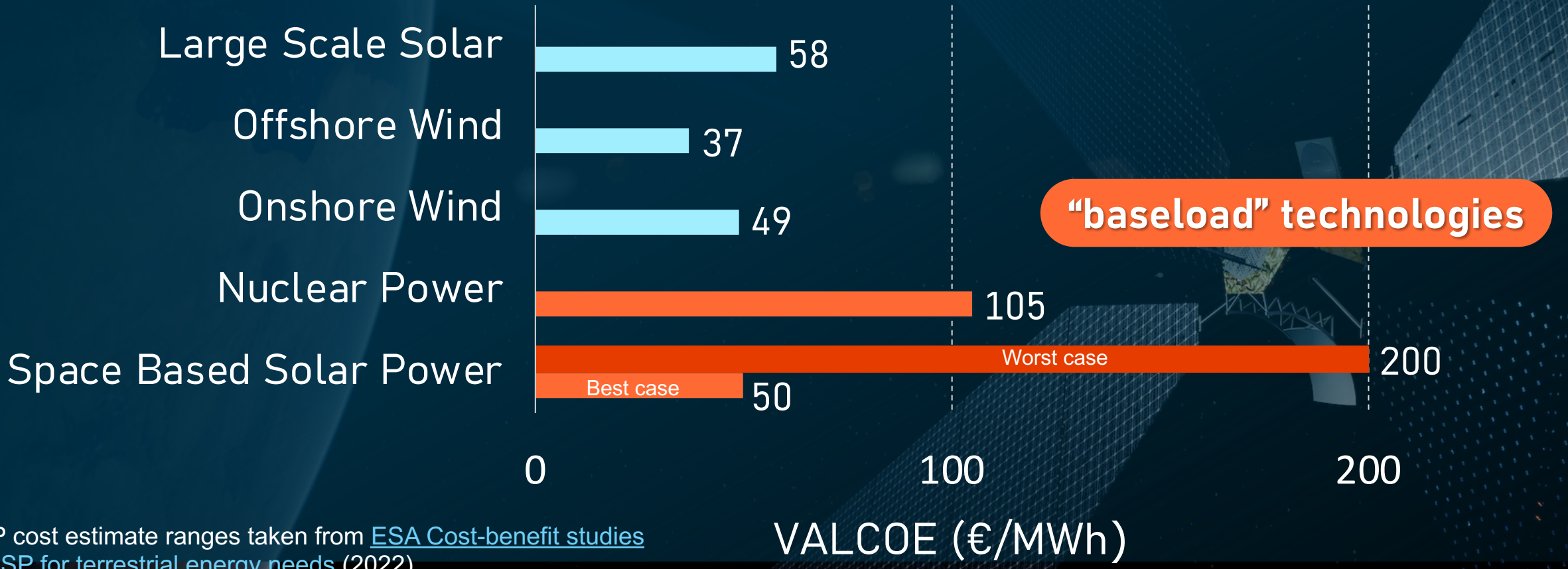
ESA Cost-benefit Study of SBSP for terrestrial energy needs (Feb '22 – Aug '22)



Study results available at: www.esa.int/solaris

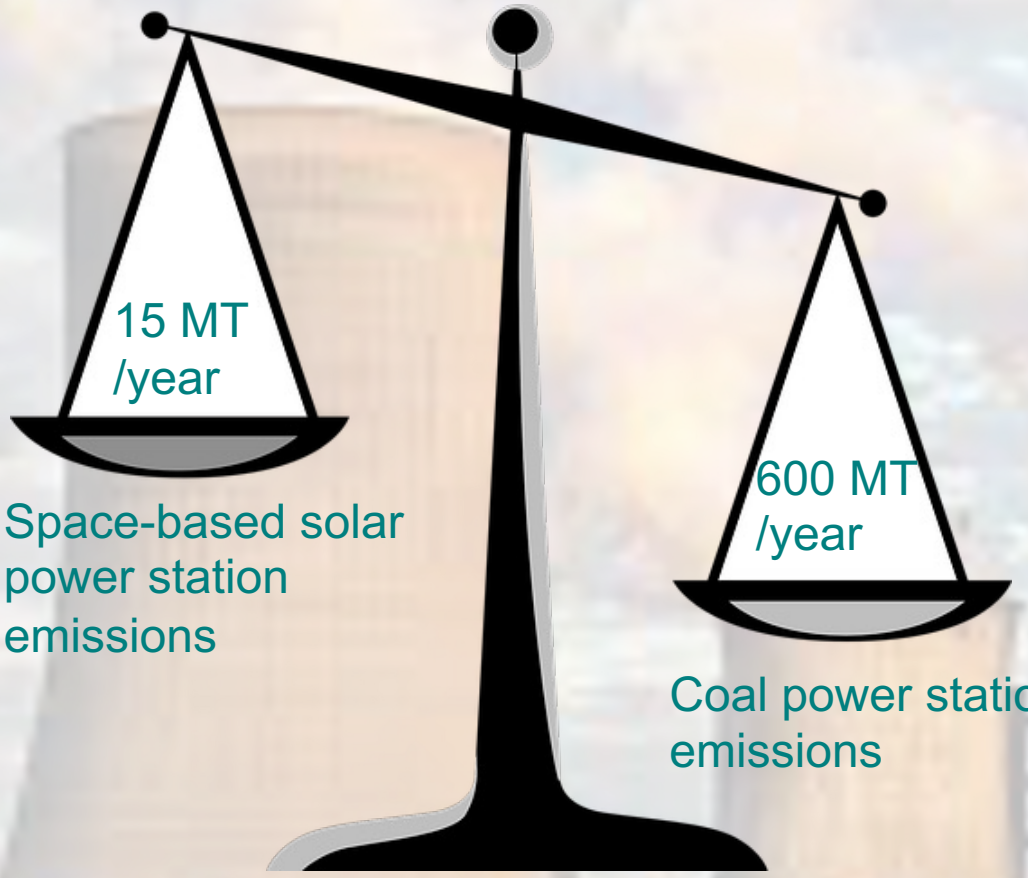
How much will the electricity cost?

Projected Value adjusted Cost of Energy (VALCOE) in 2050 for Low Carbon Energy Generation (10th of a Kind SPS)



SBSP cost estimate ranges taken from ESA Cost-benefit studies of SBSP for terrestrial energy needs (2022)

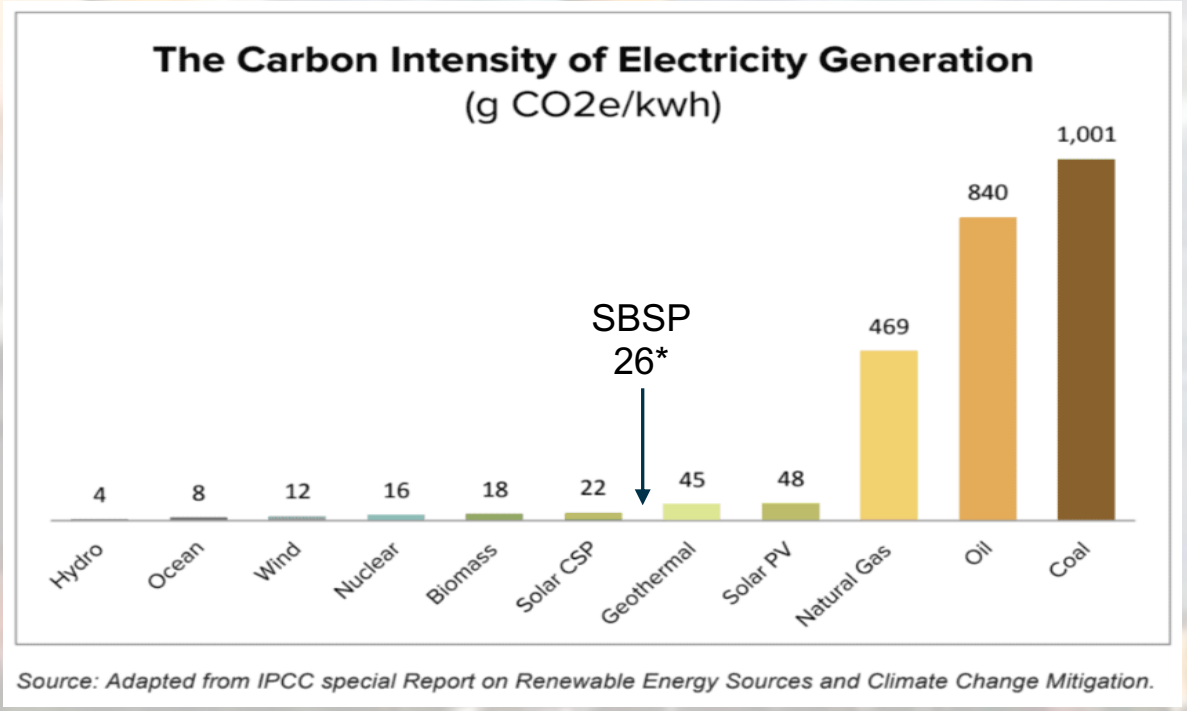
Potential scale of impact on Europe's emissions



54 x 1.44GW SBSP systems in place of coal by 2050

With 54 SPSs by 2050, each producing 1.44GW, total generation = ~ 600 TWh per year†

Assuming SBSP displaced coal generation, **CO2e savings by 2050 would be = 585 MT per year**



Source: Adapted from IPCC special Report on Renewable Energy Sources and Climate Change Mitigation.

†based on the 2022 Frazer-Nash study for ESA on Cost-benefit study on SBSP for terrestrial needs.

*based on 2GW Cassiopeia SPS, Wilson, A. R., Vasile, M., & Oqab, H. B. (2022). Life cycle assessment of the UK Space Energy Initiative technology roadmap.

ESA COST-BENEFIT STUDIES - CONCLUSIONS

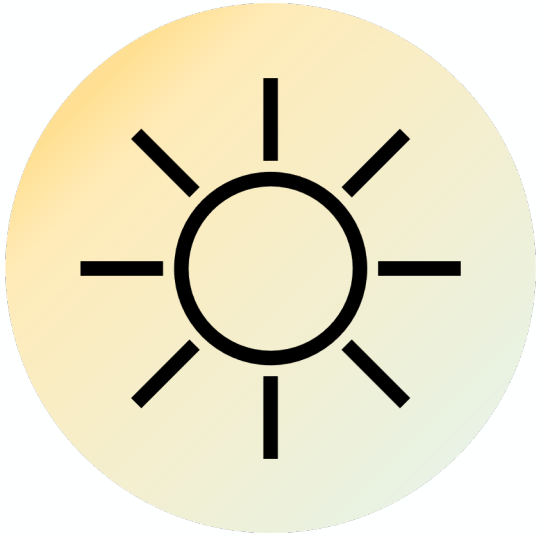
SBSP could provide competitively-priced electricity to European homes and businesses by 2040, displacing fossil-fuels and some nuclear, while complementing renewables like solar PV and wind, reducing the need for large-scale storage solutions.

When deployed at scale (25-50 SPSs by 2050 providing 10-15% of Europe's electricity needs), SBSP would provide substantial environmental, economic, and strategic benefits for Europe, including energy security.

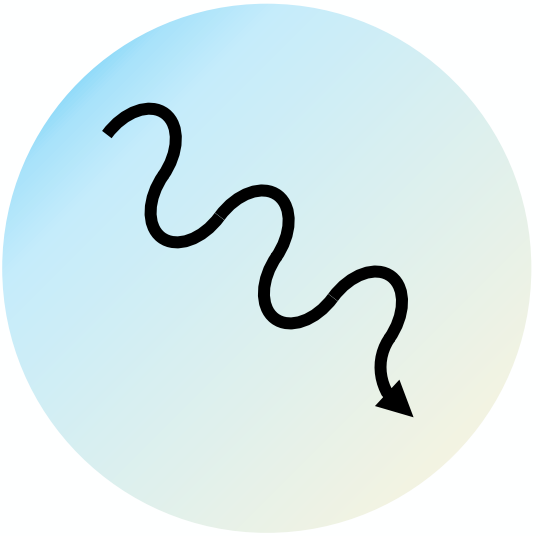
A lot of challenging technology developments are needed to be matured and these will have widespread applications both on Earth and in space.

Awareness raising, especially amongst the energy sector and public authorities, and further investments in technology R&D, are needed now.

Is SBSP safe?



Power density (10-230 W/m^2) on ground is ¼ that of full summer sun



Wavelength (5-15 cm) of received beam is non-ionizing (similar frequency to wi-fi and cell phones)

Encrypted retrodirective pilot beam used as off-switch for off-rectenna pointing

There are many risks….

Political

Technological

Economic

Legal

Social

Environmental and safety

[3]

….but no showstoppers.

This is important to pursue now

Urgency to decarbonise global energy supply

Falling cost of launch increases viability

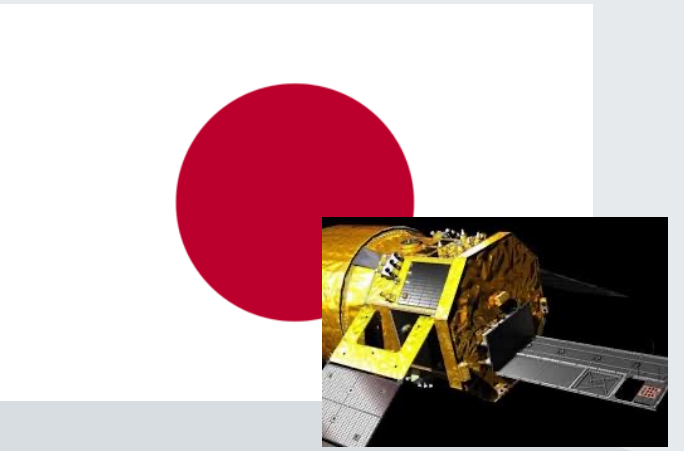
Increased technology maturity relative to historic efforts

Strategic potential to secure European leadership

SBSP is already being developed around the world

- US Navy did space tests (2020) and Air Force planning space-ground tests in 2025
- 100 M$ private donation to Caltech. Techno demos launched in Jan 2023

- Space-ground demo planned for 2028
- MW-level early 2030's
- GW commercial plant by 2050
- SBSP ground station & test facilities already being developed



- Long-term technology programme in JAXA (Basic Space Policy)
- SBSP demo mission planned for launch in 2025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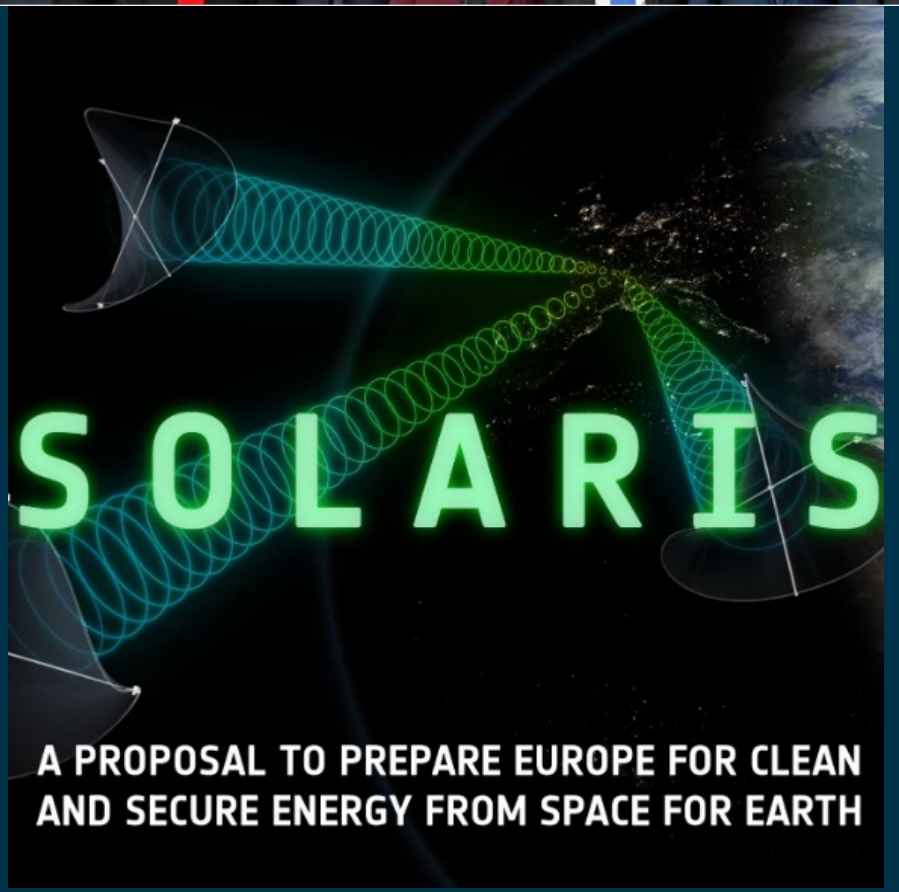
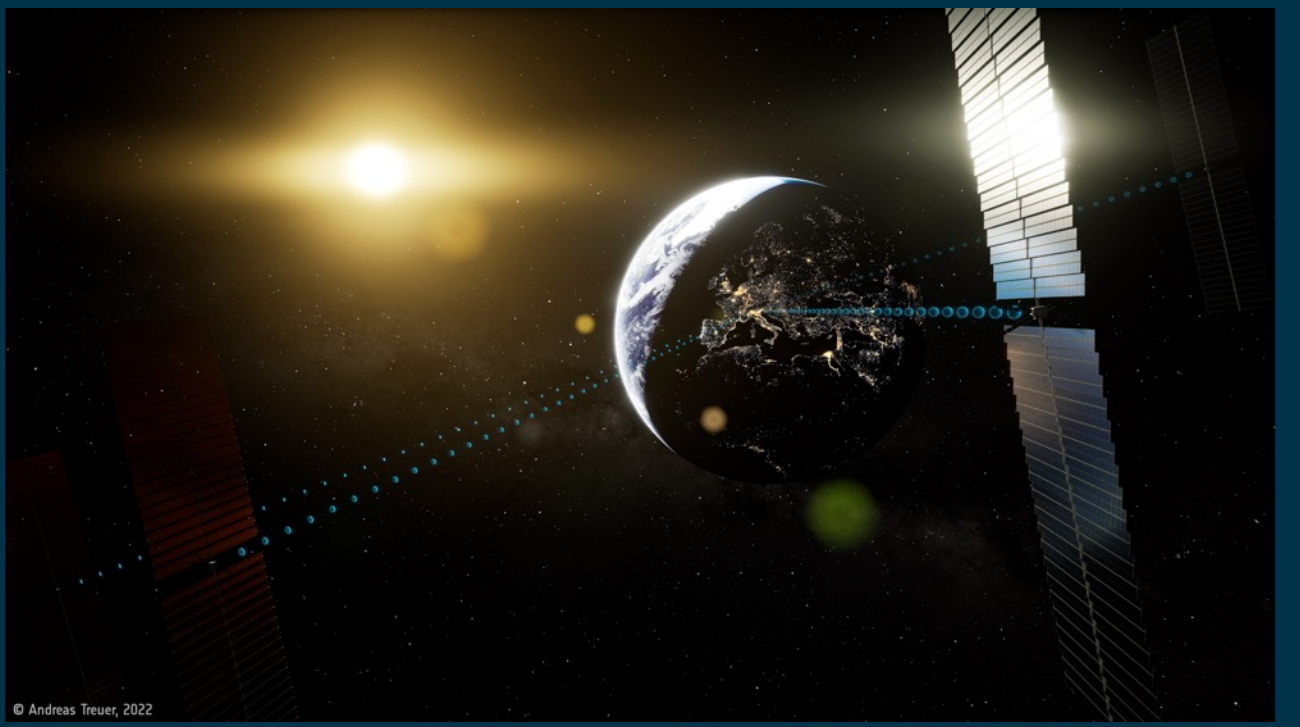
AMBITION
Council Meeting at Ministerial Level
Paris, 22-23 November 2022
esa


SOLARIS
A PROPOSAL TO PREPARE EUROPE FOR CLEAN
AND SECURE ENERGY FROM SPACE FOR EARTH


© Andreas Treuer, 2022

SOLARIS initiative objectives 2023-25

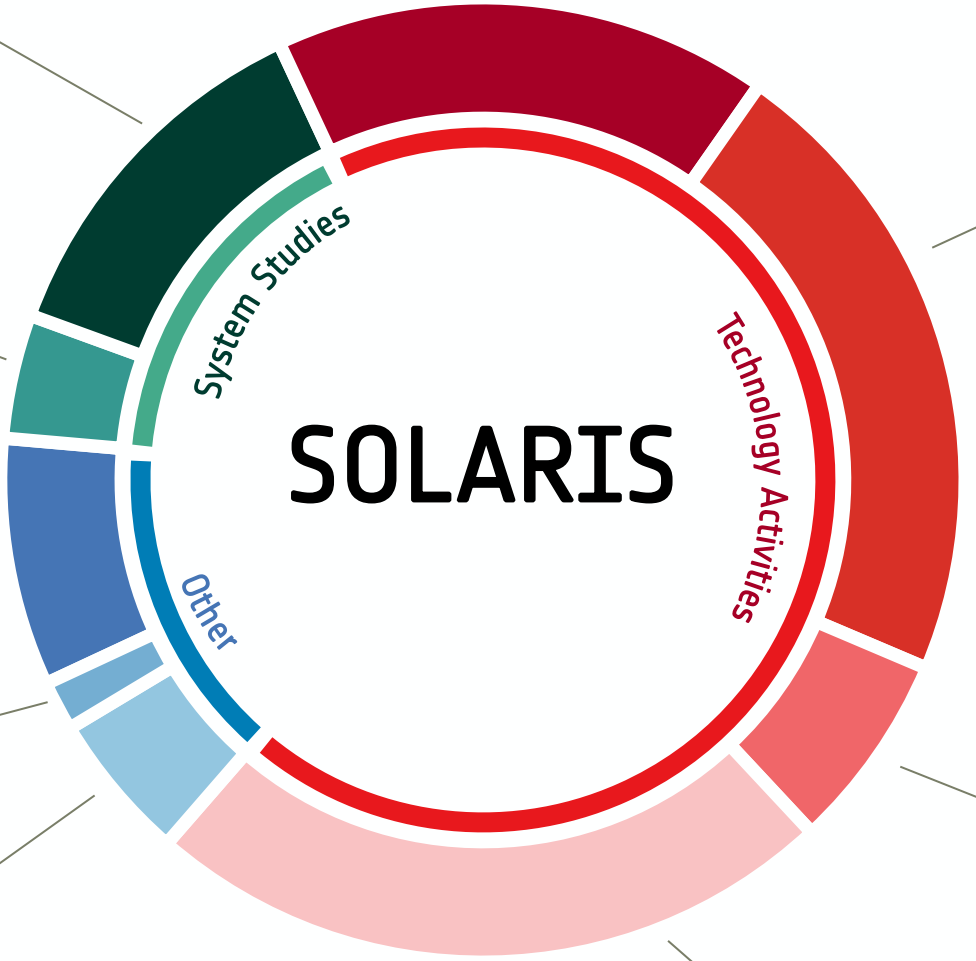
Determine **benefits, technical feasibility, costs** and **risk**

Raise awareness of SBSP amongst key stakeholders

Establish opportunities for international cooperation

Prepare **proposal for a development programme**

Position Europe as a **serious player in SBSP**



Prep. Studies for SPS Demonstrator (Phases 0/A/B1)

Prep. Studies for Commercial-Scale SPS (Phase 0)

Ground / Aerial Power Beaming Demonstration

Stakeholder Engagement, Regulation and Outreach

Environmental, Health & Safety Studies

Highly mass and cost-efficient photovoltaic systems

Highly efficient RF generation and beam forming

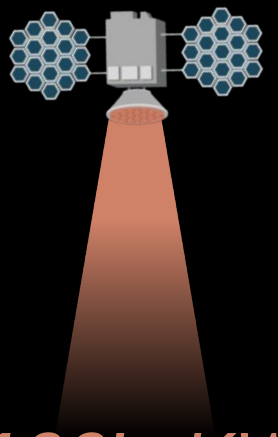
High power management and distribution

Large structure deployment, in-space manufacturing, robotic assembly

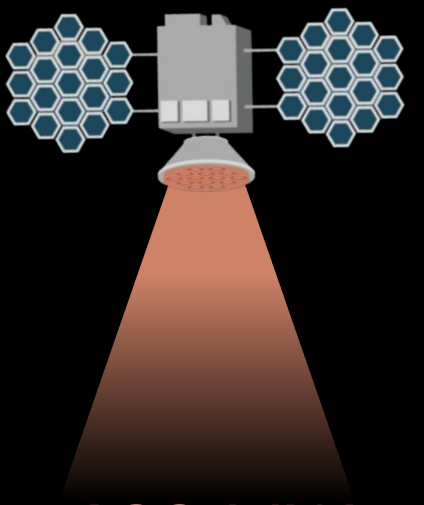
Notional European SBSP Roadmap

Future phases still to be confirmed

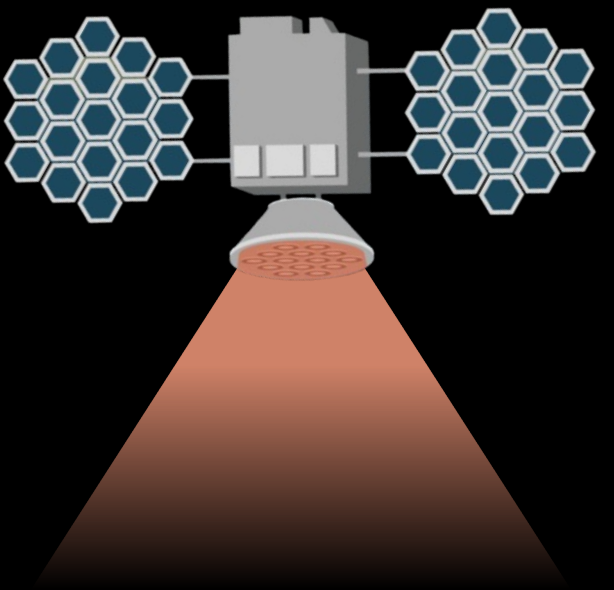
Ground Demos



100's KW



100 MW



Multi-GW

2023-2025

SOLARIS R&D initiative

2026-2030

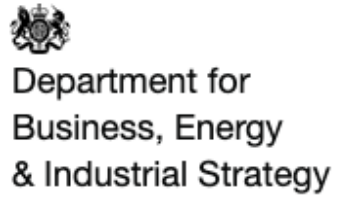
Sub-Scale Space-Based Demonstrator

2031-2035

Pilot Space-Based Power Station

2036-2040

Operational Space-Based Power Station


Bilaterals since Dec 2021

40+ different entities

50+ bilateral meetings

Takeaways:

- Value and Urgency of SBSP benefits recognized
- High Investment potential in case of institutional backing

The future of SBSP – Sustainability

Greater Earth Lunar Power Station

– Using Lunar resources for powering the Earth

A visionary study for ESA by Astrostrom GmbH, completed April 2023.

Link to Video

Take-home messages

1. The challenge of achieving a clean energy-rich, Net Zero Europe and world by 2050 is extremely great

2. Recent ESA studies have shown that the **energy transition could be accelerated** by introduction of a new source of green baseload power from space => "**Space-Based Solar Power**", displacing fossil fuel generation plants and thereby contributing to mitigating global warming

3. The are many challenges remaining to realise its potential; some limited R&D efforts are now on-going globally including ESA's SOLARIS initiative, **but more investments are needed now**

The window of opportunity to help solve the energy crisis and contribute to saving the planet is short.

SOLARIS

Towards a world of Clean and Secure Energy

www.esa.int/solaris

Solaris in the news

Solaris video

Follow us on LinkedIn: ESA SOLARIS

References

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7. The most expensive nuclear energy projects around the world - Future Power Technology | Special Issue | November 2018 (nridigital.com)
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