Space-Based Solar Power: *Reaching New Heights in Green Aviation*

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Assisted by Faculty:
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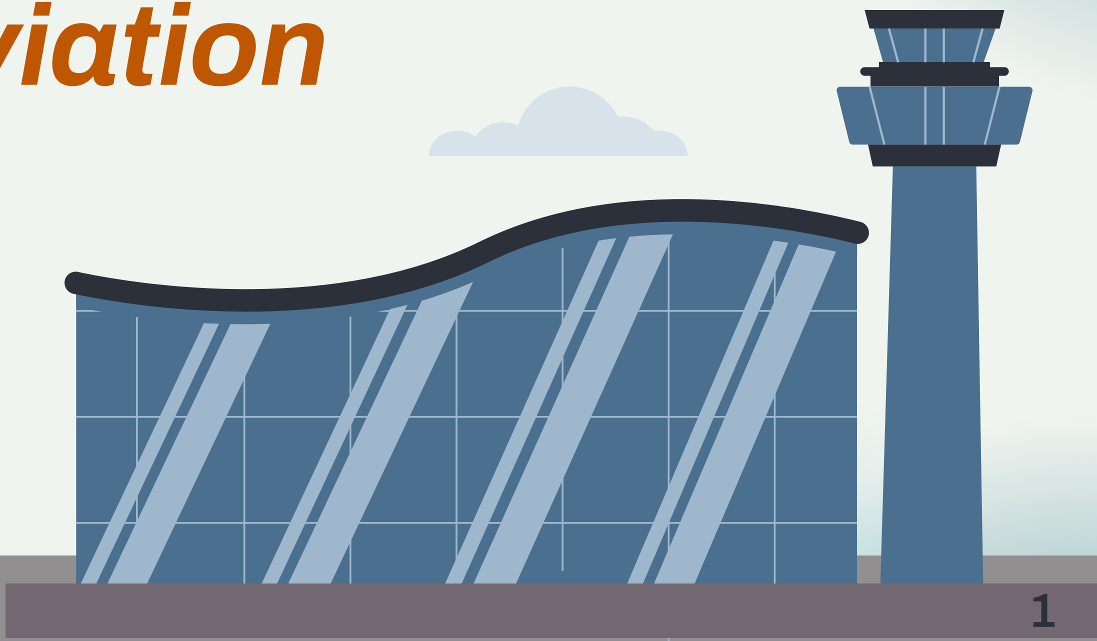
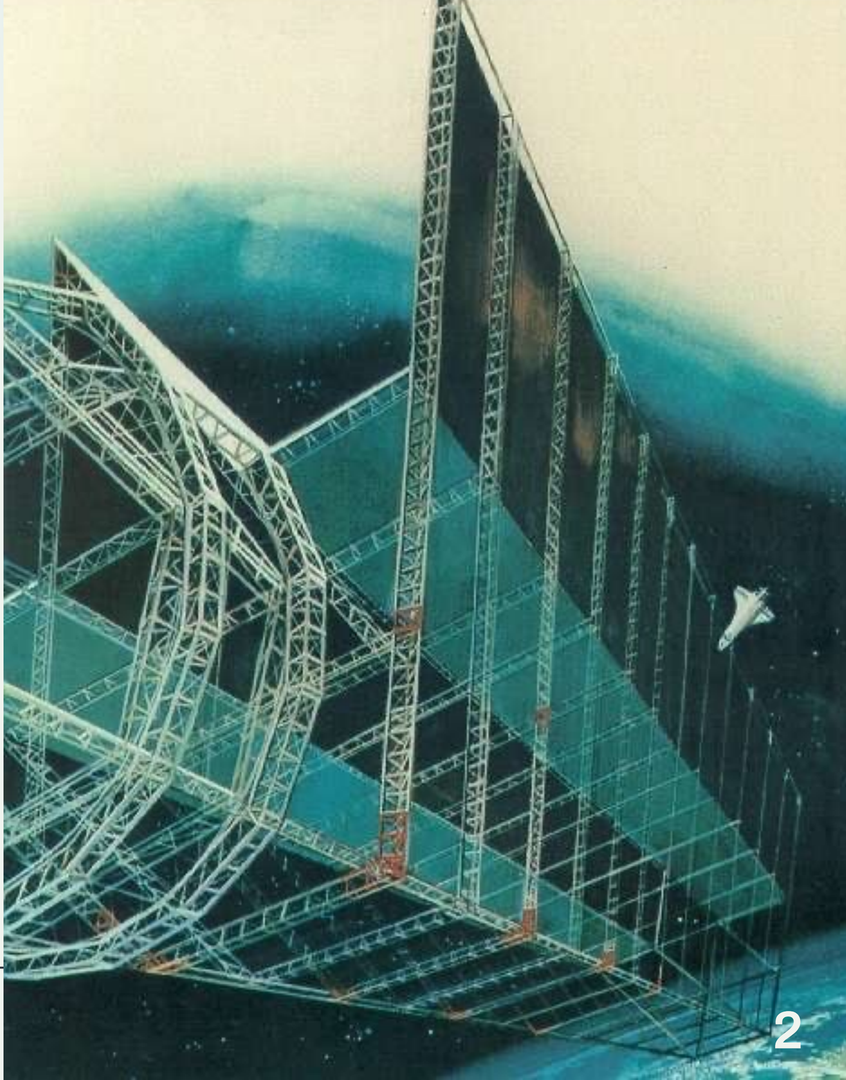


SBSP concepts have been around for *a long time.*

From its conceptualization in 1968, SBSP faces issues we hope to address by 2050: **Utilization, economics, & security**.



Our *Agenda*

Context

How does it work?

Reasons why it failed in 1968, and how it has inspired our areas of focus

Our *Agenda*

Adaptability

What changes are necessary to make our system work in 2050...

... and how well they respond to environmental & economic demand

Our *Agenda*

Efficiency

Assessing the capacity of current and upcoming technology

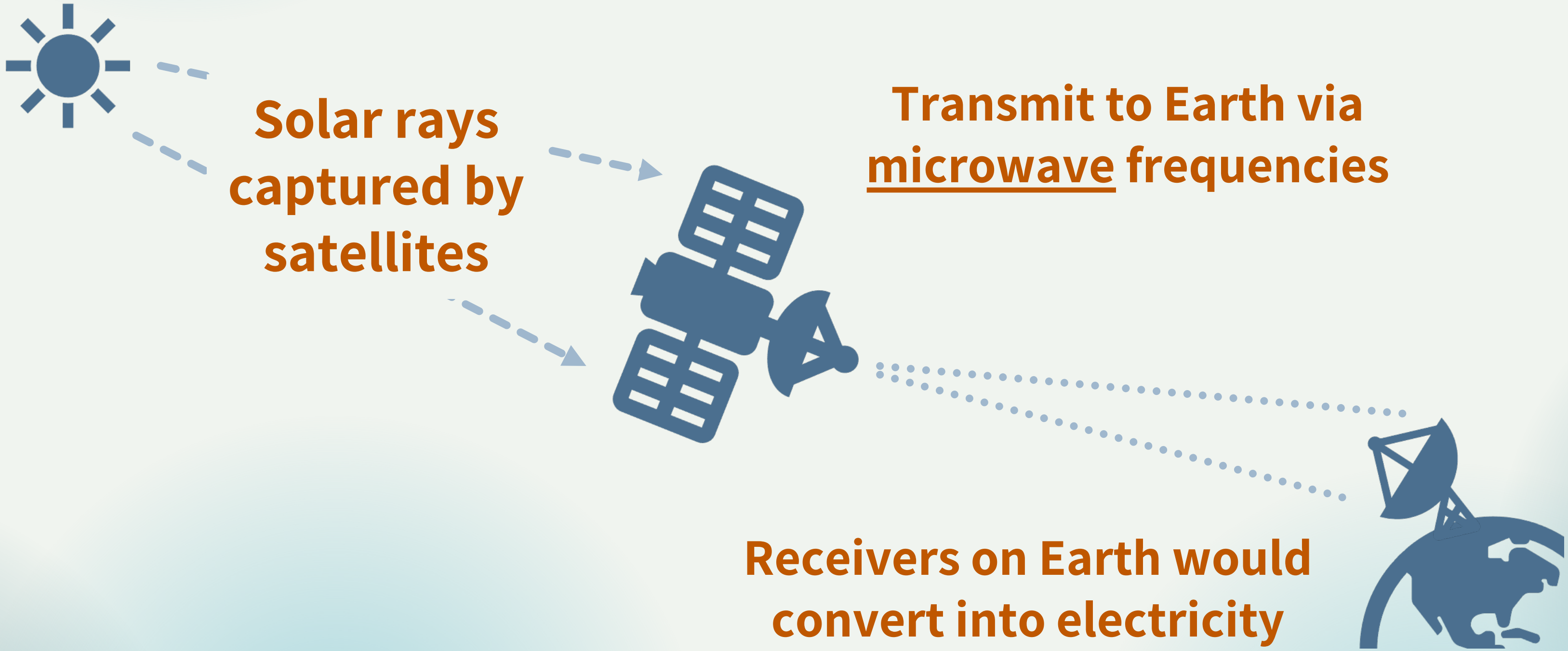
+ timeline of our phased implementation plan for the next 30 years

Our *Agenda*

Dependability

How seamlessly can SBSP blend into the future of the aviation landscape?

Peter Glaser’s idea in 1968:



Interest originally picks up...

Research trials began by 1974

Interest from DoE and ESA

Trials proved that launch costs made SBSP uneconomic

Concept loses traction

Success from Project Apollo shifts attention from SBSP

Cost of oil stabilized & encouraged deregulation

Defunding led to limited testing

Satellite Mega-constellations

1970 – 1980: GPS Systems

One of the **first applications** of satellite constellations on a global scope still used today

1990 – 2000: Iridium

Telecommunication satellites provide worldwide **cell coverage**

iridium® connected

2010 – 2020: Starlink

Satellites provide worldwide **Internet access**

STARLINK

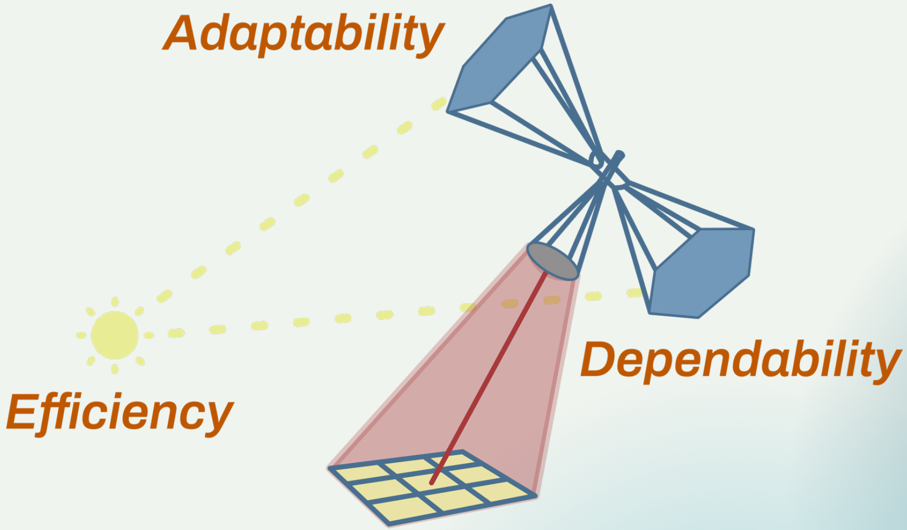
By 2030 – 2050:

As launches become more affordable, it becomes economically feasible to create constellations for SBSP

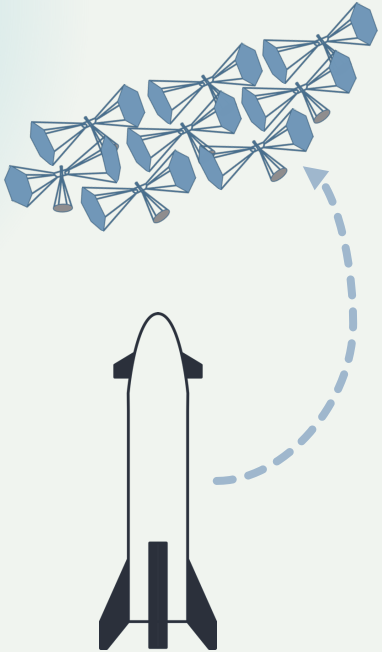
Our areas of focus

Prior concerns:

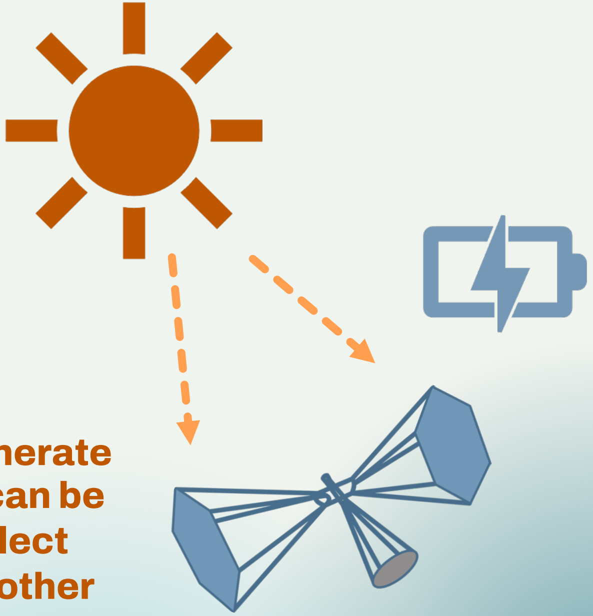
- Economic feasibility
- Technological optimization
- Security & skepticism



Outline of Our SBSP System

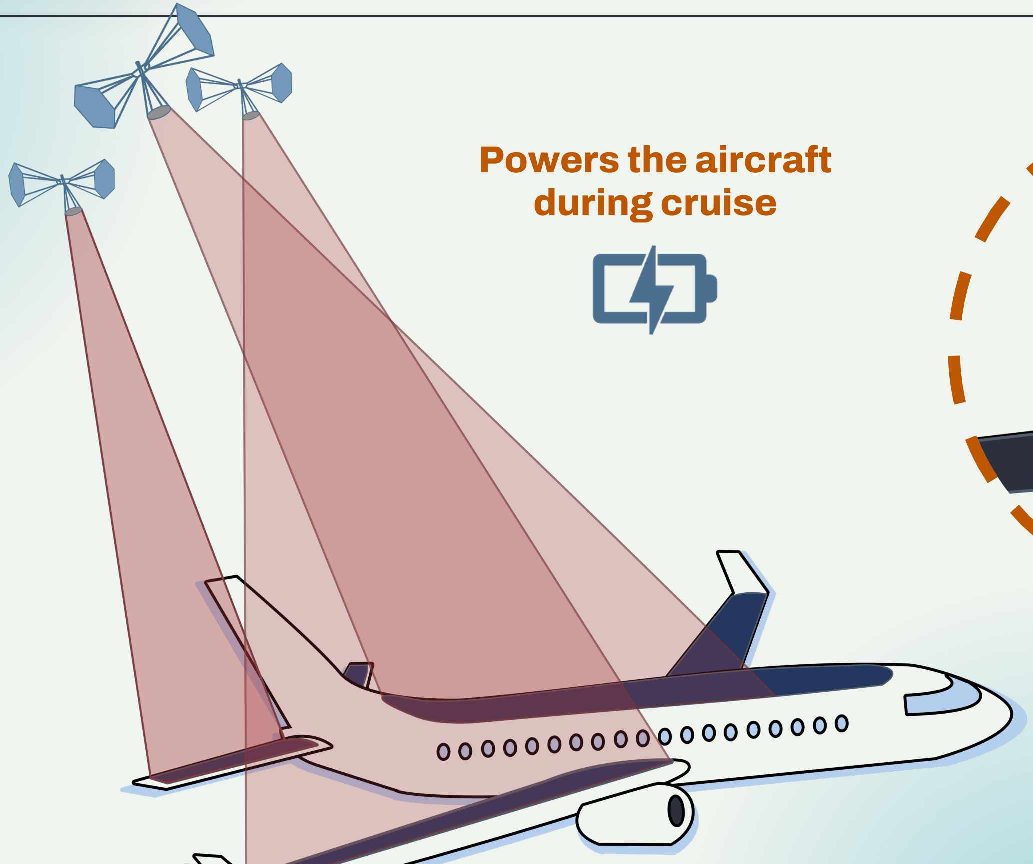


Deploy in Low Earth Orbit (1000 km altitude)



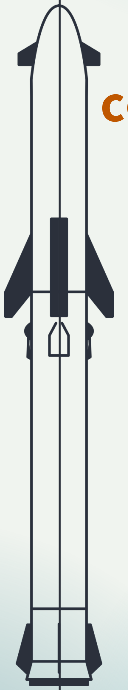
Satellites generate power (and can be used to reflect power from other satellites)

Outline of Our SBSP System



Powers the aircraft
during cruise

Rocket Deployment: *Starship*



Lower costs make it economically feasible to launch large constellations of heavy satellites, such as those from SpaceX's Starship.

Payload

17 satellites per launch by 2050

Recent Advancements

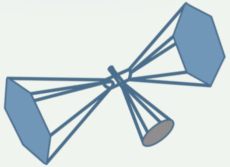
Successful April 2023 launch proves feasibility of Starships for SBSP use

Reusability

Multiple deployments reduces space debris

This rocket is based off SpaceX's Starship and is not indicative of reusable rockets that may be in use by 2050

Our Process Involves...

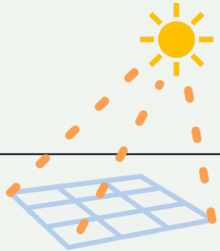


Satellites

- **Mass**: 8000kg/satellite
- Carbon Emissions for manufacturing: 393 tons

Solar Panels

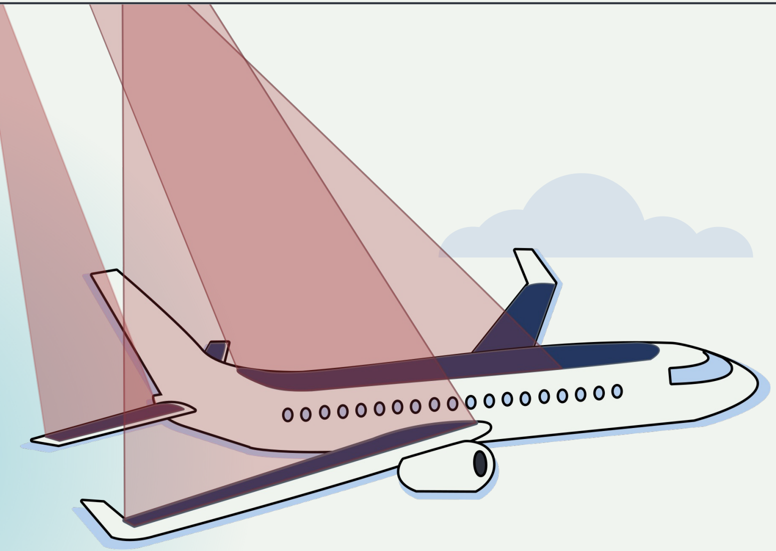
- **Gallium arsenide**: expected to reach up to 47%
- **Silicon**: expected to reach up to 25%
- 2620 m^2 /satellite = 933.33



Laser-based Power Transmission

- Infrared Optical Transmission Efficiency of 68.9%
- Power of 50Kw each
- Laser power beaming in space is currently investigated by the Pentagon (March 2023)
- Laser power of UAVs (ground based) has been tested by the DoD and NASA

Powering the *Plane*



Power

15 satellites ≈ 14 MW

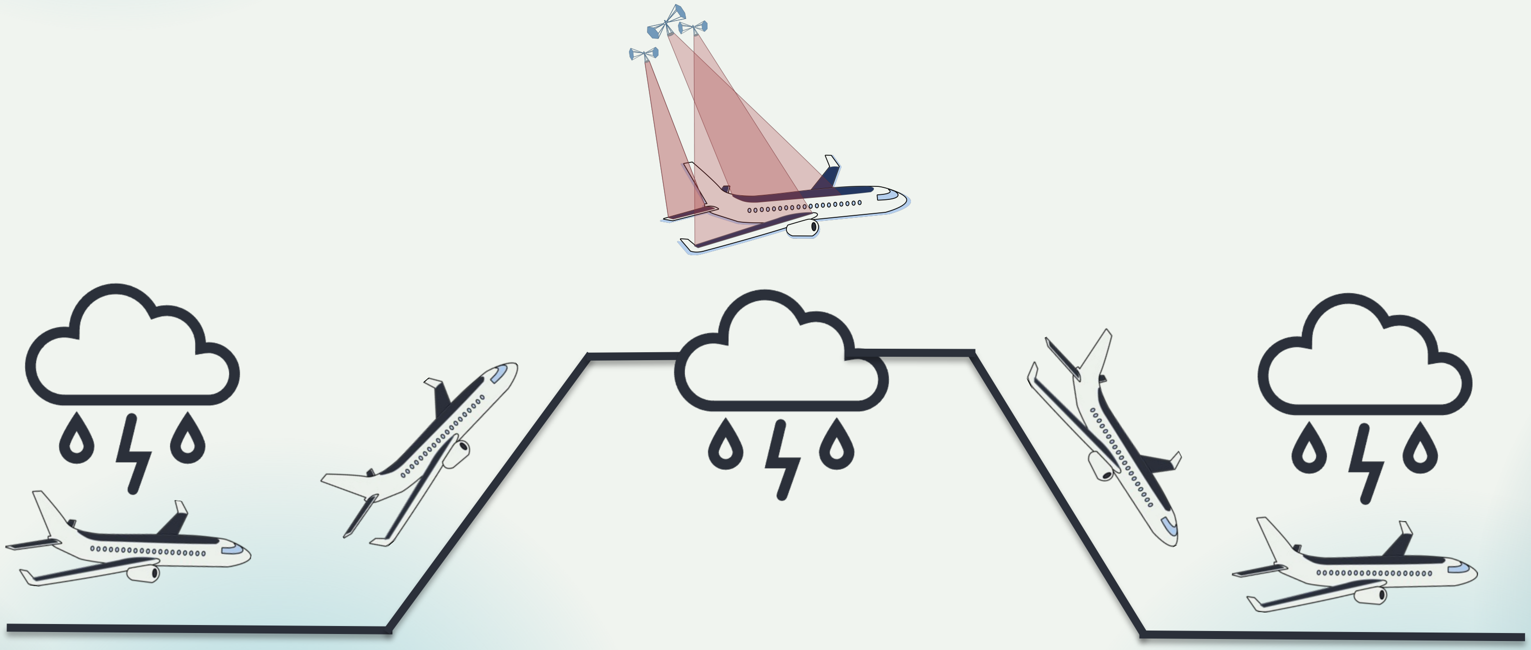
Li-ion Batteries

Support taxi, takeoff, and landing

Cruising Altitude

- Transmitted during **regulated flight**
- Optimizes transmission of energy & limit CO_2 emissions

Energy Conservation *During Flight*

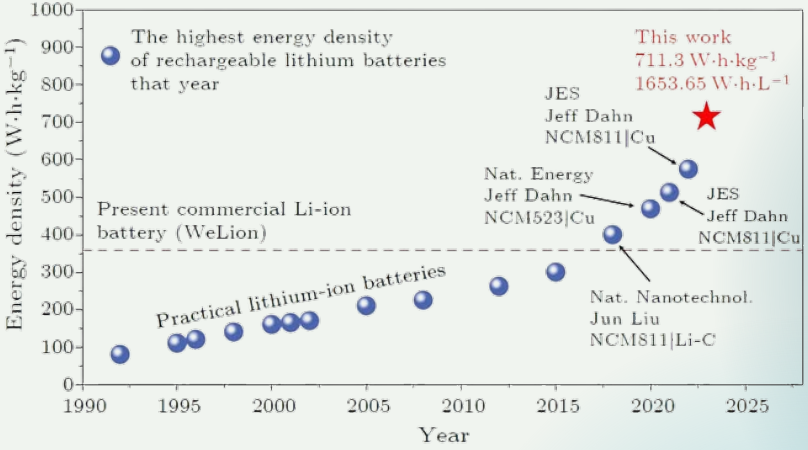


Lithium Batteries

Used for Taxi, Lift-off, Climb, Descent, Approach Flight-phases

- **Buffer for fluctuations in laser-beamed power**
- **Emergency back-up power** (ex. for loitering at low altitude)
- **Better energy densities are expected in the future**

Lithium Batteries Timeline



Xiqian Yu and Hong Li of the Institute of Physics, Chinese Academy of Sciences in Beijing, March 2023

Manufacturing Materials

Carbon Fiber

Energy-intensive to produce, carbon offers a

20% ***reduction in weight***

when used in airplanes

Gallium Arsenide

Allows for solar panels to reach

47%

efficiency by 2050

Lithium

Allows for an energy density of

300 **W-h /kg**

compared to 50–100 W-h/kg for lead acid batteries

Complete System Using Gallium Arsenide

Initial Concept: **Power 5,400 U.S. planes**

Full scope of implementation:

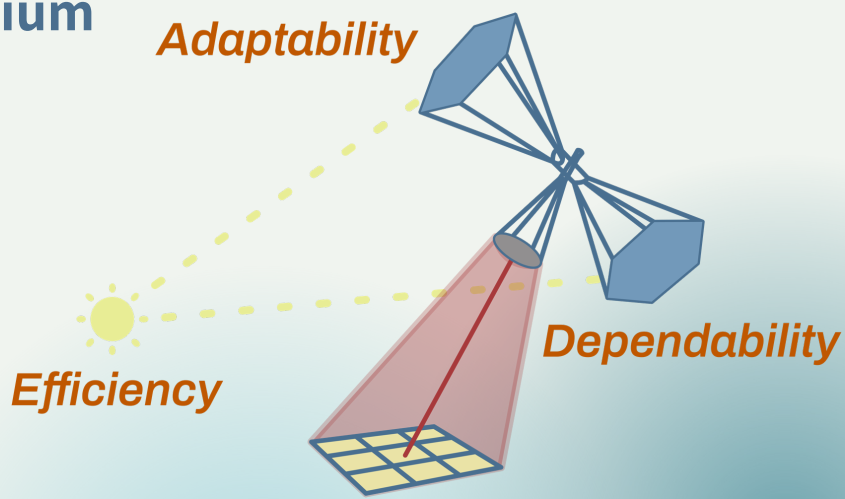
- 3-5 Starship launches per day
- 696,320 Satellites in Orbit
- **324,948 MW of Global Power;** **enough to power the entire NY state for four months.**

Initial Concerns with SBSP

- ~~Questionable trade-off due to high-cost launches~~
- Risky security for using SBSP lasers
- ~~Technological mismatch~~
- Fear and skepticism of using lasers
- ~~Manufacturing resources is unsustainable~~
- Casualty to the green premium

Current Concerns with SBSP

- ❑ Risky security for using SBSP lasers
- ❑ Fear and skepticism of using lasers
- ❑ Casualty to the green premium



Risk Factors

Li-Ion Batteries

Design allows for fire hazards to be minimized

Space Debris

Satellites naturally decay over time

Laser Safety

Invisible and eye-safe lasers will be utilized

Mining

Recycling of the batteries will allow for a reduction in mining

Maintenance

Satellites will be reliable which allows for failure tolerance

Cyber Security & Politics

Weaponization

Equipped with systems to prevent hijacking and to identify threats

Political Viability

Operate under strict U. S. regulations similarly to nuclear

Social Acceptance

Weaker overall power output guarantees safety

Implementation Timeline

Begin design research of energy receptors for U. S. aircrafts

Starship rocket reusability allows for 3-5 rockets a day

Increase Li-ion battery efficiency for commercial use: 81%

Begin manufacturing enough planes to supply power for the entire U. S.

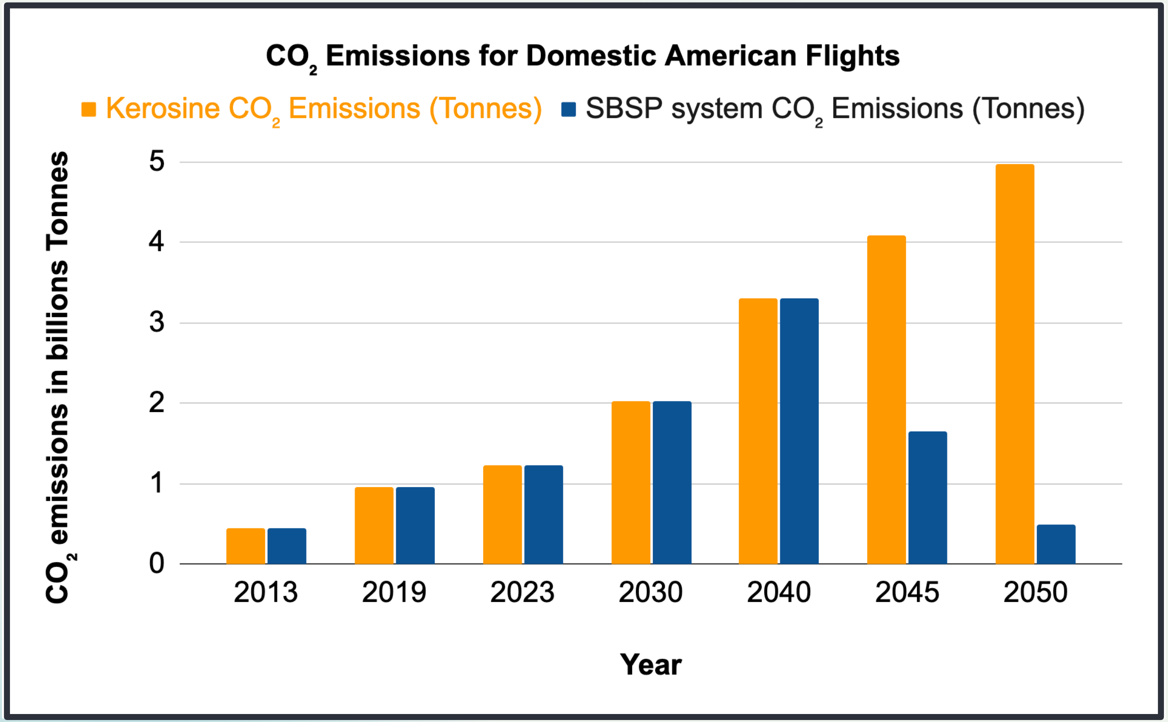
Roll out on-site gallium arsenide solar panels

Strengthened electric infrastructure to support SBSP

Satellites reach operational power at a global scale

2023 2030 2040 2050

Carbon Reductions *through SBSP*



5 billion Tonnes of CO_2 in 2050 = **192 Billion trees**

10:1 Ratio **Reduction**

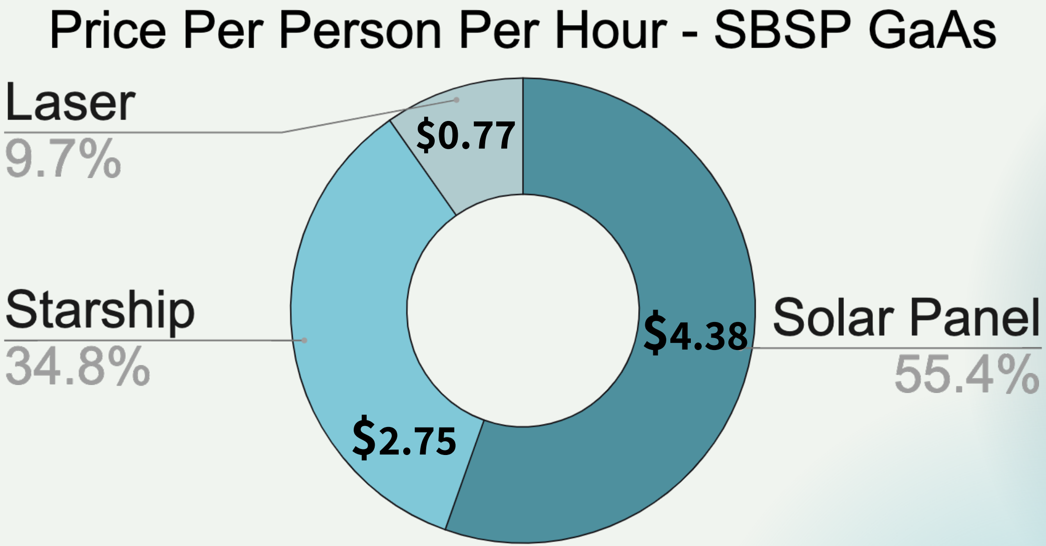
Calculations derived from utilizing 17% of global CO_2 emissions, as the U. S. contributes to 17% of all global air traffic.
Exact calculations may be shown in the report or in the Q&A

Economic Feasibility

~$11.00 cost per passenger hour for **Jet fuel** scenario

~$8.00 cost per passenger hour for **SBSP** scenario

28% reduction in cost



Electric Cars: *Economic Case Study*

Electric cars have been around since the 1970’s, but the technology hadn’t been culturally integrated as a “safe” vehicle until the 2010’s.

Similar concerns can be drawn between electric cars & SBSP technology, notably with public distrust and skepticism

Performance mismatch

Questionable functionality

Green premium

Market Size *Similarities*

Electric cars became integrated by:

- Vertical market integration
- Consumer appeal
- Long-range innovation

Parallels that will reflect SBSP's impact:

- Market changes allow for greater environmental funding
- Electrification allows for more eV support

Supporting Our Future

[illegible]

Mateo Renaud
Mechanical Engineering

Mariana Ponce R.
Civil Engineering

Tiffany Huang
Sustainability Studies, Advertising

Talia Elkhatib
Environmental Engineering

Enrique Loredo
Chemical Engineering

Dafhne Salvador
Mechanical Engineering

Special thanks to our advisor Christian Claudel and the Cockrell School of Engineering

Calculating Carbon Emissions

Boeing 737-Max-8

SBSP:

6,000 Tonnes CO_2 + 4,400 Tonnes CO_2 = 10400 Tonnes of CO_2

Current:

10 hr * 365 days * 10 year * 2 Tonnes CO_2/hr * 3.16 kg CO_2 = 230,000 Tonnes of CO_2

Price Passenger Hour: Jet Fuel

Boeing 737-Max-8: holds 162-189 passengers

Average Jet Fuel A Cost: $2.45/ gal 1

Fuel Consumption Rate: 800 gallons/hr

800 gallons/hr * 1 hr flight * $2.45/gal / 175.5 passengers = **$11.16 cost per passenger for Jet fuel scenario**

US jet fuel spot price passes $5.00 per gallon at end of April. PlaneStats. (n.d.). https://planestats.com/usfc_2022mar

Price Per Passenger Hour: SBSP

Boeing 737-Max-8: holds 162-189 ~ 175.5 passengers

Solar Panels Cost = ($.3/W)* (200W/ 1m^2) *2620m^2 *k = 3.70
Starship Cost = $2000000 [I] /17 satellites* 1.78 ratio*k =$4.90
Laser Cost = $326,335,100[II]/ 9919[II] lasers*k = .77

k=1/ (15 Satellites/ 175.5 passengers/ 365 days/1hr flight/ 10 years)

$9.37 cost per passenger for SBSP scenario Silicon

I) II) references on Citation Slide

Price Passenger Hour: SBSP

Boeing 737-Max-8: holds 162-189 ~ 175.5 passengers

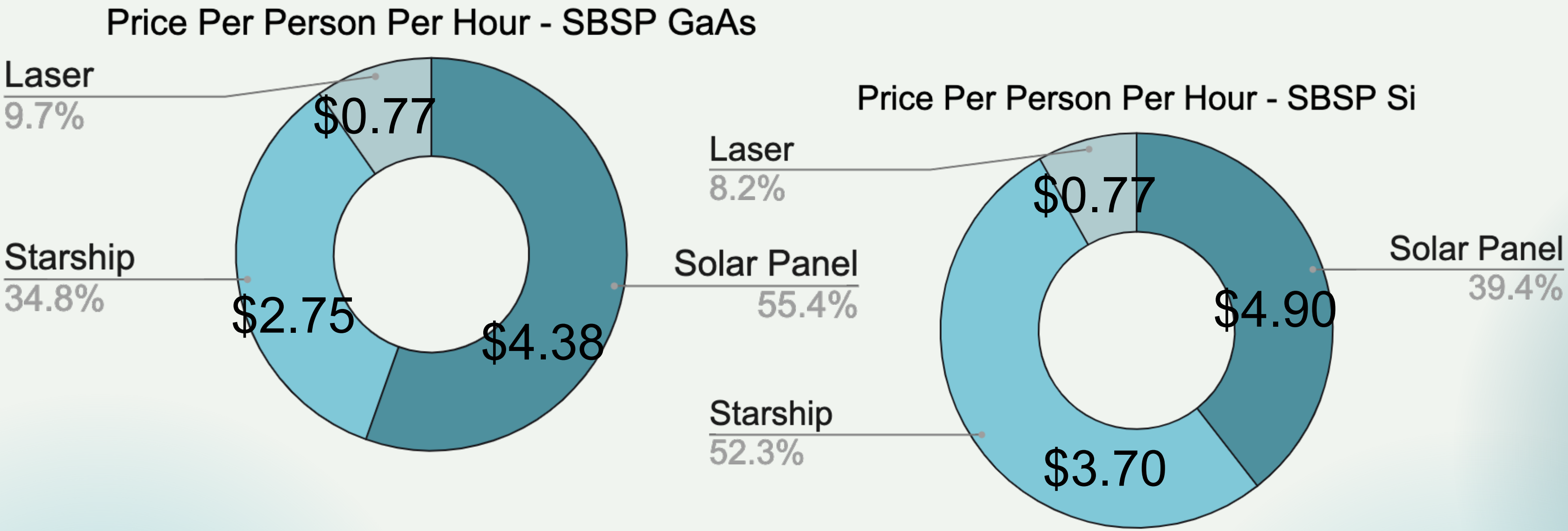
Solar Panels Cost = ($.3/W)* (356W/ 1m^2) *2620m^2 *k = 4.38
Starship Cost = $2000000[I] /17 satellites *k = 2.75
Laser Cost = $326,335,100[II]/ 9919[II] lasers*k = .77

k=1/ (15 Satellites/ 175.5 passengers/ 365 days/1hr flight/ 10 years)

$7.91 cost per passenger for SBSP scenario Gallium Arsenide

I) II) references on Citation Slide

Comparing Price Per Passenger Hour



Calculations for the 96.4% Reduction – Global reduction/Max efficiency

The limiting factor is the satellite's lifetime (87,600 total hours for 10 years):

- For jet fuel – 2000 kg/hour of CO2 released x 24 hours/day x 365 days x 10 years x 3.16kg/hour = 553,632,000 CO2 released in total for 10 years
- For SBSP (30 satellites) – 20,800 Tons x 1000kg/Tons = 20,800,000
- 96.4% reduction rate

Expected to reach up to 99% when including the rise of technology and efficiency

Satellites & Power Calculation

Satellite Number Calculation:

Calculated using a ratio of the number of satellites required to power all U.S. planes in flight at peak travel season (≈ 5400 planes) and the area of the contiguous U.S. compared to a ratio of total satellites in the world and the area if the contiguous U.S. wrapped around the Earth.

Area of contiguous U.S. wrapped around Earth

Power Calculation:

933.33 kW of usable energy generated per satellite. Assuming only half are in sun at any point. 696,320 / 2 satellites.
933.33kW x 348,160 x 1 kW / 1000 MW =
324,948 MW

Calculating Power for NY

Half of satellites at any time generates: 324,948 MW

Estimate of NY energy usage in 2021: 3541.1 trillion Btu

3541100000000000 Btu / 365 days / 24 hrs = 404235159817 Btu/h

404235159817 Btu/h = 118469.63089 MWh

118469.63089 / 324,948 = 0.3645 year or around 4 months

IV) referenced on Citation Slide

Safety Precautions with the Laser

There are 19 lasers that are 50 kW lasers per satellite. Each laser covers a larger area when reaching the plane. This distributes the energy intensity.

Infrared Laser does not impair vision of bystanders, or plane passengers.

Manufacturing Emissions

Carbon Fiber

20 tons of CO2 emitted per 1 ton of carbon fiber

Solar Panels

- 50g of CO2 per kWh for silicon or gallium solar panels

  Comparable to

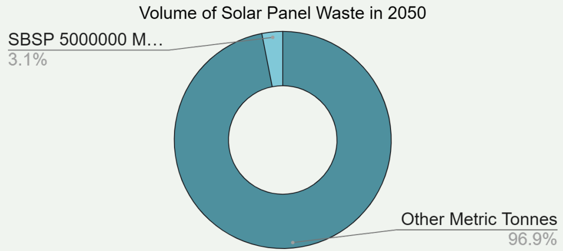
- 181g of CO2 per kWh for natural gas
- 247g of CO2 per kWh for petroleum
- 309g of CO2 per kWh for coal

Lithium

150 kg of CO2 emitted for every kWh of battery capacity

Space Debris

- Satellites will be planned to naturally decay and deorbit to Earth after about 10 years – a very large surface area will allow control to decay faster (orientation of the satellite).



- 3% of the relative total solar panel waste by 2050 – With a large number of solar panels being launched, about 450 tons a day if we launch 3 starships a day, 450 tons x 365 days = 160,000 tons a year. "By the 2050s, the volume of solar panel waste will rise to at least 5 million metric tons a year, the agency said."

- Plans to clean up space debris – "In 2018, scientists on the International Space Station tested the Remove Debris satellite. In this picture, robotic arms push the device into space. It measures about three feet on each side. It uses a 3D camera. This tracks the location and speed of floating debris. The satellite fires a net to capture the junk. Then the junk falls and burns up in the Earth's atmosphere."

Thermal Impact

Solar Panel Coverage

Satellites would block <0.00001% of the incoming solar flux, which has a negligible impact on climate.

Starship Impact

A Starship releases significantly less emissions than a single long distance flight's contrails. And there will be a magnitudes less launches than flights currently.

Our SBSP system will have negligible thermal impact on the Earth.

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