POWER BEAMING TO ENERGY STORAGE AIRSHIPS

A Presentation for the

19th Annual Directed Energy Symposium

By

Les Johnson
and
Daniel O'Neil

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Airships Will Fill a Void in the Cargo Delivery Market

"We really do have a very large need for a better system of lifting bigger pieces and bigger sizes that you can't fit into an airplane door, into all kinds of places … A lot of places around the world are inaccessible."

- *Barry E. Prentice*, professor in the department of supply chain management at the University of Manitoba's I.H. Asper School of Business

Since trains, trucks, and cargo boats can't reach many parts of the world, Prentice predicts airships will come to fill that void. And he says it would happen even sooner if world economies were "more serious" about climate change.

https://www.inverse.com/article/14312-how-airships-like-the-airlander-10-could-replace-cargo-planes-in-just-years

Companies are Buying Airships

Lockheed Martin strikes $480M deal to sell airships
Wednesday, 30 Mar 2016 | 5:39 AM ET

Lockheed Martin has landed its first contract for the hybrid airship it created inside its top secret Skunk Works division. In a deal valued at $480 million, Straightline Aviation (SLA) has signed a letter of intent to purchase 12 of the heavier-than-air airships that measure nearly a football field long. First delivery is scheduled for 2018, with the final airship expected no later than 2021.

http://www.cnbc.com/2016/03/29/lockheed-has-liftoff-sells-new-airships-in-480m-deal.html

Cargo Delivery Air Ships *Are not your parents' blimp*

Hybrid Air Vehicle (HAV)

- Airlander 10 made its maiden voyage August 17, 2016
- Manned: aloft for five days
- Unmanned: aloft for two weeks
- Four 325-hp (242-kW), turbocharged diesel engines
- Applications: Communication, Cargo transport, & Surveying

http://newatlas.com/airlander-10-first-flight/44956/

https://www.hybridairvehicles.com/aircraft/airlander-10

	Current GZ-20A Blimp	New Zeppelin NT
Length	192'	246.4'
Maximum Width	50'	64.79
Envelope Volume	202,700 cubic feet	297,527 cubic feet
Maximum Speed	50 miles per hour	73 miles per hour

http://www.airships.net/goodyear-blimp/

Lockheed Martin's

Hybrid Enterprises

Available in 2018

Capacity

- 10' x 10' x 60' cargo bay
- Flexible, customizable
- Roll-On Roll-Off, CAT D6, ATCO trailer
- Up to 44,000 lbs of payload
- Up to 19 passengers
- 5,000 gallon cargo fuel tanks built-in

http://hybridhe.com/hybrid-airship/hybrid-airship-advantages/built-cargo/

A Potential Application:
Humanitarian Assistance

http://hybridhe.com/hybrid-airship/hybrid-airship-advantages/humanitarian-assistance/

Ambri Liquid Metal Battery

Ambri System
500 kW / 1 MWh
5 Ambri Cores
Integrated with grid-tied power electronics

"Beta Core" Lab-based System

$11M from ARPA-E & Total (French oil co.)

20KWH

2MWH

2009 → 2011 → 2016 → 2018 → 2020?

$15M from Khosla Ventures

500KWH

Additional $25M from Bill Gates, KLP Enterprises, and Building Insurance Bern (GVB)

The 2MWH system Is intended for the Power Grid.

https://www.technologyreview.com/s/511081/ambris-better-grid-battery/

https://www.greentechmedia.com/articles/read/Ambri-Returns-to-The-Energy-Storage-Hunt-With-Liquid-Metal-Battery-Redesign

http://static1.1.sqspcdn.com/static/f/1497163/26853855/1455290007250/ambri_brochure_feb16.pdf?token=9Bw9RuK2Wpj1i5A9TeCJoNIZzGE%3D

Air Ship with Rectenna and Eight Mg-Sb Liquid Metal Batteries

Overall Dimensions:
- **Length**: 770 feet
- **Width**: 296 feet
- **Height**: 183 feet

aeros

ML 868

A Future Airship

Payload Deck Space:
- **Length**: 380 feet
- **Width**: 61 feet
- **Height**: 45 feet

Payload: 250 tons

https://en.wikipedia.org/wiki/Worldwide_Aeros_Corp

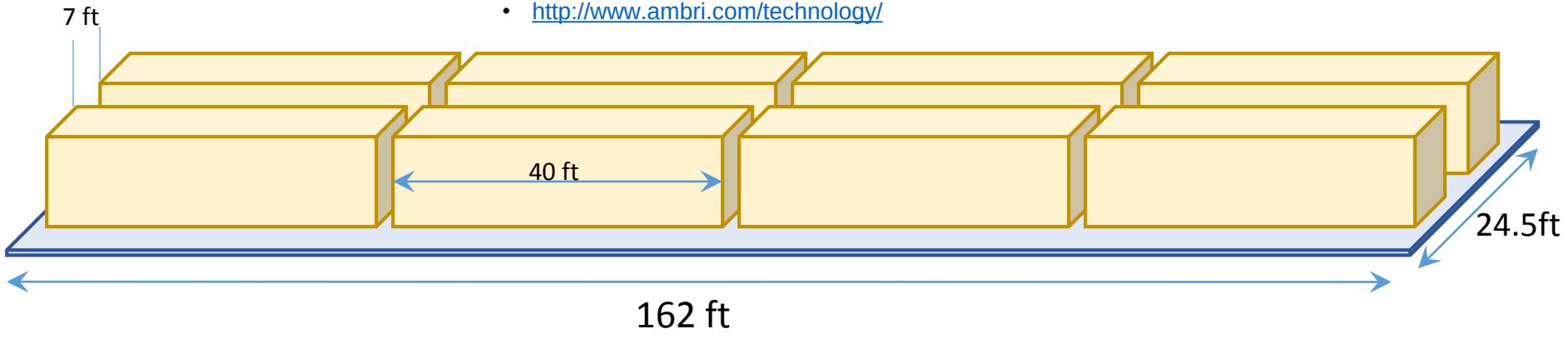
- Assume 210mx80m = 16,800 sq.meters Available for a rectenna.
- If only one third were usable at any point during the satellite passing overhead the usable area is 5,600 sq.meters
- With *one sun energy flux* of 1kW/m^2, the rectenna could receive 5.6 MW
- If the line-of-time of a MEO SSP satellite were one hour, 2.8 batteries could be charged and four orbits could charge eight batteries.

Assume 8,000 kg available in each Liquid Metal Battery Container

Liquid Metal Battery Capacity of **one** container **2 MW*hrs** (Can serve 200 households)

8 Liquid Metal Battery Containers **16 MW*hrs**

- http://www.ted.com/talks/donald_sadoway_the_missing_link_to_renewable_energy?language=en
- http://www.ambri.com/technology/



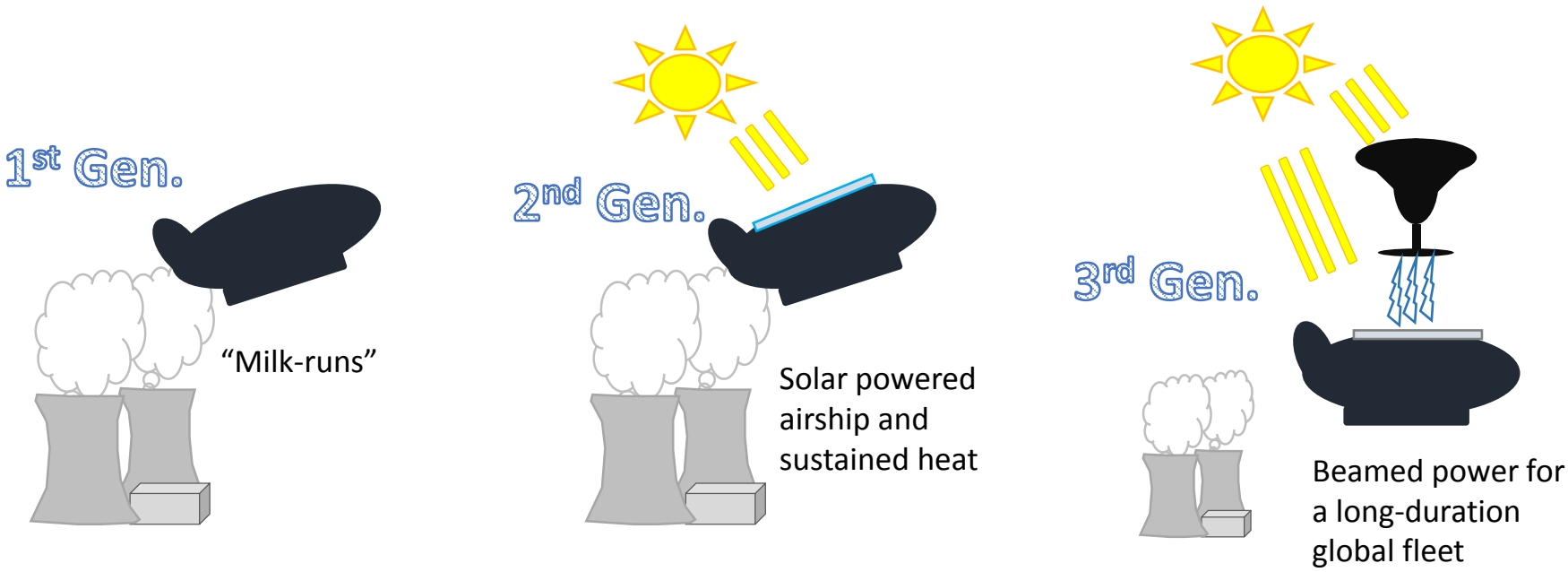
Three Generations of the Airship with Liquid Metal Batteries

Customers

- Disaster relief agencies
- Emerging nations
- Military logistics trains
- Explorers of oceans, deserts and jungles
- Outdoor venues for huge week-long events

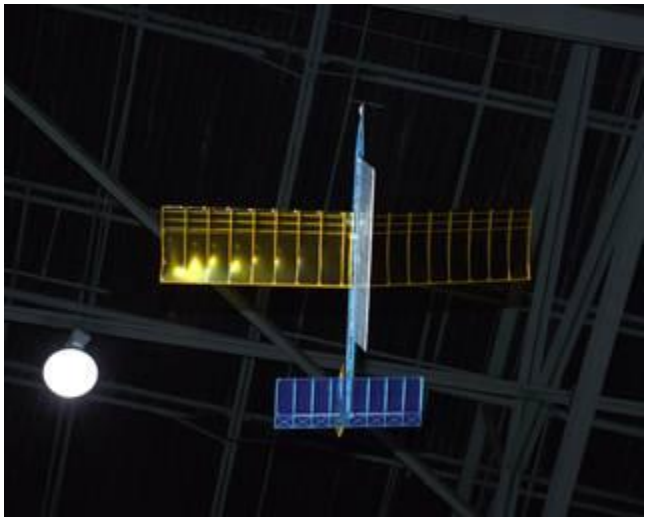
Conceptual Design Benefits

- A moving receiver enables a *lower orbit*
- A lower orbit *reduces* system & launch cost
- Molten metal, in batteries, need the heat
- Three generations provide early revenue
- Mobile infrastructure enables swift response to large power needs



Power Beaming to a Model Airplane

- In 2002 and 2003, a team Marshall Space Flight Center and Dryden Flight Research Center demonstrated power beaming to a radio controlled model aircraft
- The 2002 demo involved manually directed spotlight that illuminated a solar panel, which powered a six watt motor in a model airplane that flew inside of a building
- The 2003 demo involved a 1KW laser that transmitted power to a rotorcraft that operated along guide wires.
- Attempts to power model airplane at the Redstone Arsenal Laser range were unsuccessful due to gusty winds



http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-087-DFRC.html

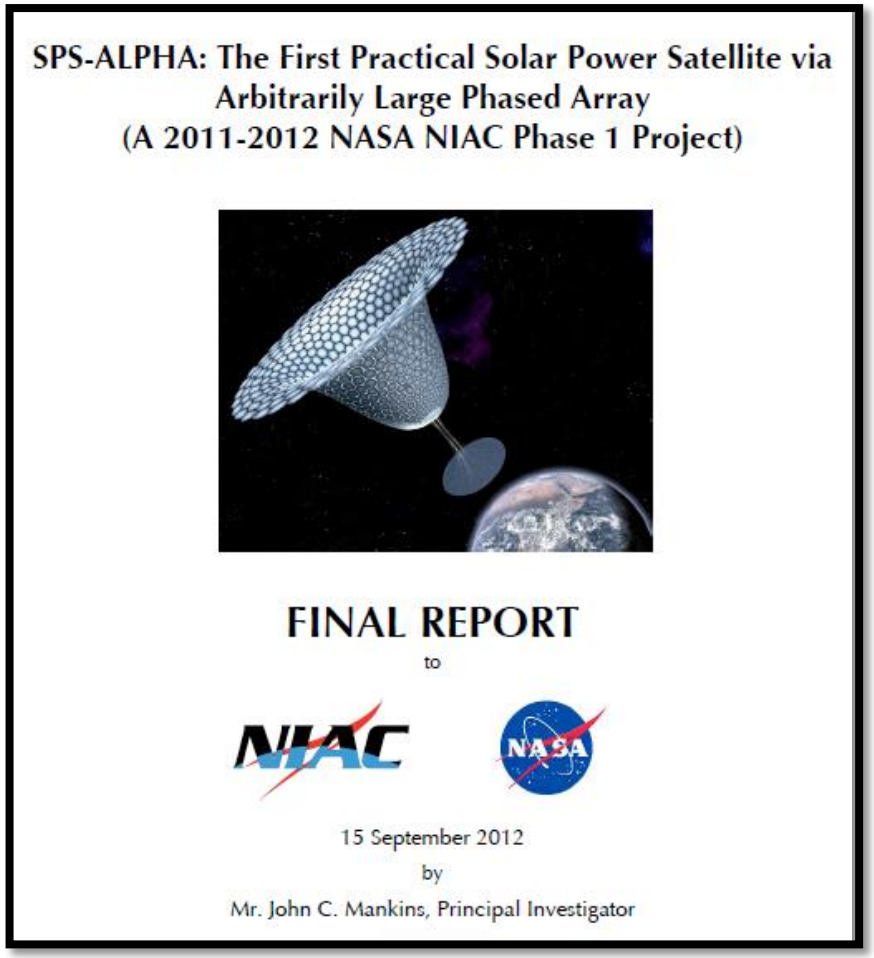
Power Beaming Demonstration

In 2008, John Mankins and Prof. Nobuyuki Kaya of Kobe University beamed 20 watts with an array of eight transmitters on top of the volcano Haleakala on Maui and received by signal detectors at Mauna Loa Observatory on Hawaii's Big Island, 92 miles (148km) away.

The Discovery Channel sponsored demonstration was produced in less than five months with less than a million dollars.

Sources: http://www.wired.com/2008/09/visionary-beams/
http://www.thespacereview.com/article/1210/1

Launch Costs for the SPS-Alpha


SPS-ALPHA: The First Practical Solar Power Satellite via Arbitrarily Large Phased Array
(A 2011-2012 NASA NIAC Phase 1 Project)

FINAL REPORT
to
NIAC
NASA
15 September 2012
by
Mr. John C. Mankins, Principal Investigator

A 500MW system in GEO mass = 34,813,882 kg @ $20,000/kg to orbit, the launch cost >**$696B**

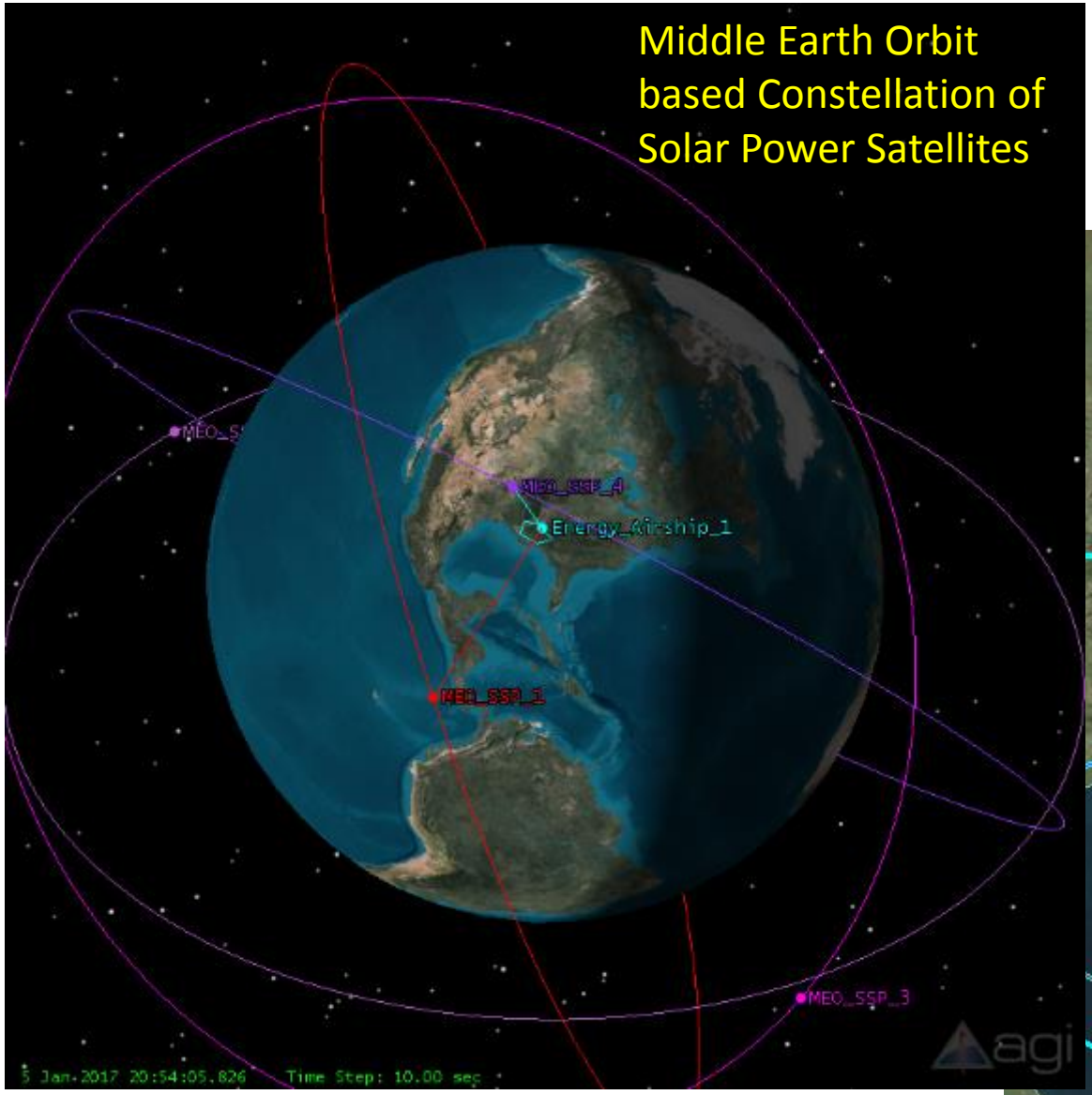
The mass of a 2MW system in Geosynchronous Earth Orbit (GEO) would be 232,610 kg @ $20,000/kg to orbit, the launch cost >**$4.6B**

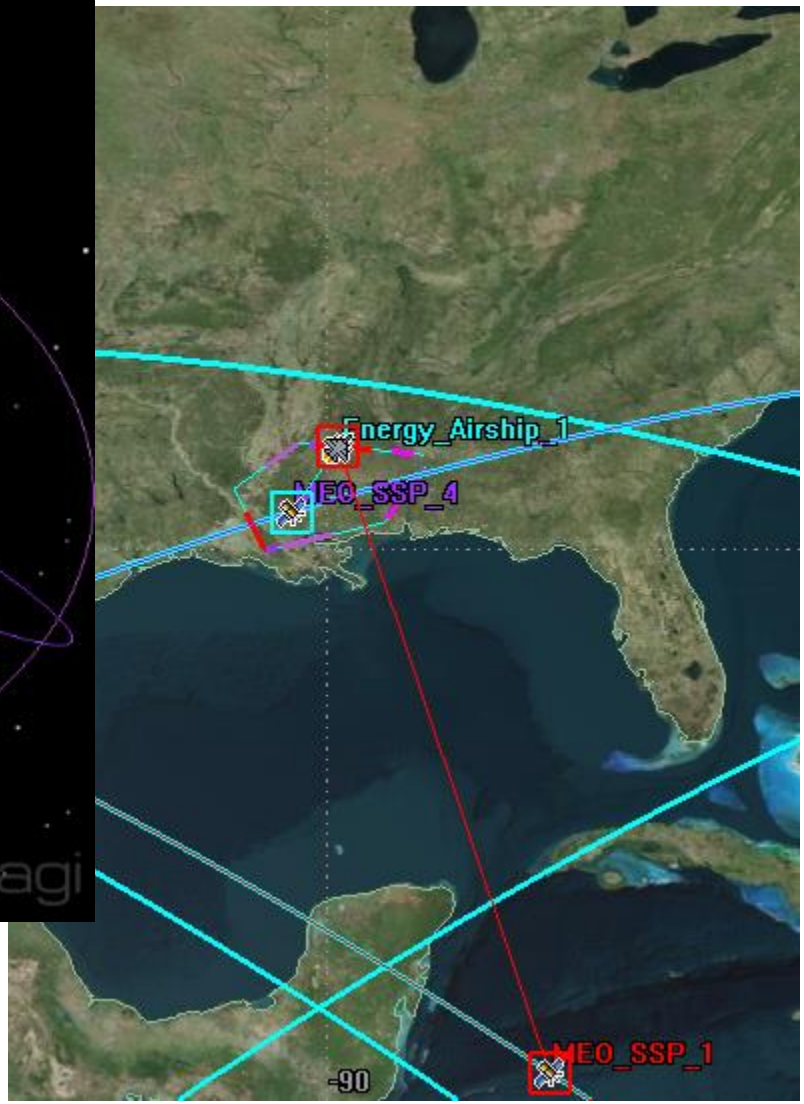
The transmitter on the GEO system has a mass of 106, 643. Moving the system to MEO could cut the mass of the transmitter by half and the launch cost to >**$3.58B**

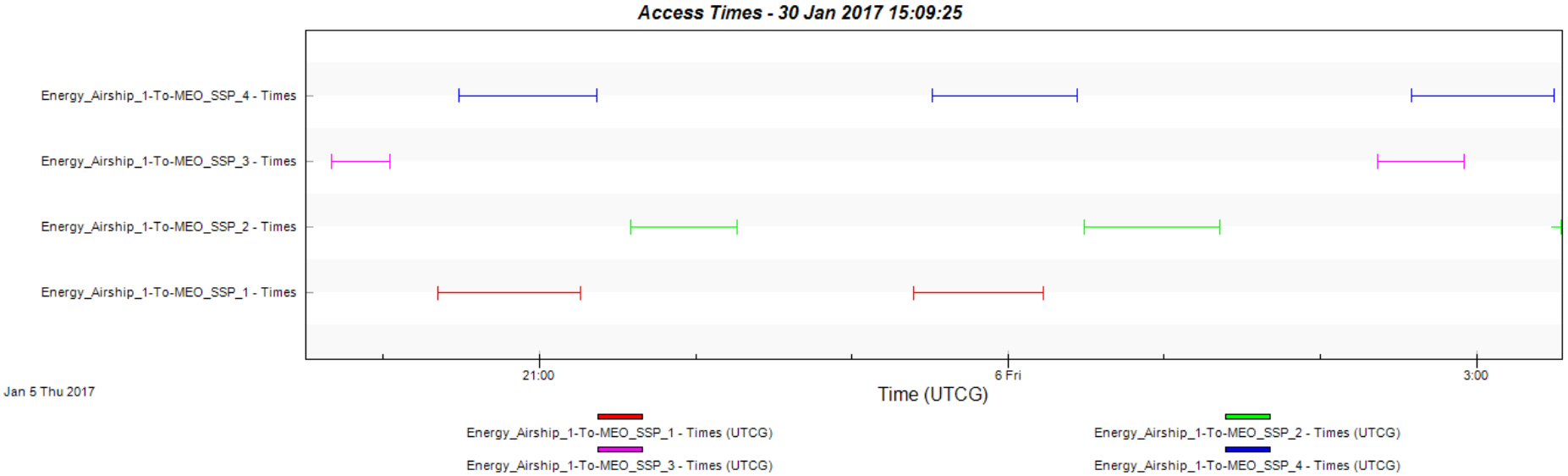
A 2MW system in Middle Earth Orbit (MEO) could be sufficient to supply airships with Liquid Metal Batteries (LMB).

http://www.nasa.gov/pdf/716070main_Mankins_2011_PhI_SPS_Alpha.pdf

Middle Earth Orbit based Constellation of Solar Power Satellites







Each Day

	Mean Duration (seconds)
Energy_Airship_1-To-MEO_SSP_1	**3138**
Energy_Airship_1-To-MEO_SSP_2	**1865**
Energy_Airship_1-To-MEO_SSP_3	**1671**
Energy_Airship_1-To-MEO_SSP_4	**3274**
Total	**9,948 seconds**
	2.76 hours

Assume 50% loss due to angles and atmosphere

1 MW * 2.76 hours = 2.76 MW-hours

= 17% of the 16MW-hr storage capacity

Conclusions

- First generation of energy air ships provide revenue
  - Enables development of solar-powered 2nd generation
  - Eliminates issue of revenue delay to “first light”
  - Provides franchise opportunities for power plants
- Flight plans for air ship fleets can be flexible
  - Flights can be timed for coverage by a small constellation
  - Larger constellations provide greater planning flexibility
  - A constellation of four satellites can “top-off-tanks” by 17% per day
- Customers in *space*: a new generation of LEO satellites with rectennas
  - When the Middle Earth Orbit (MEO) satellites are not beaming power to the air ships
  - Future satellites could replace bulky self-shadowing solar arrays with rectennas
  - Satellites would receive energy each time they pass under a MEO solar power satellite
- Customers in the *air*: cargo delivery electric airships
  - Solar arrays and rectennas would receive power for the electric propulsion
  - Electric airships would provide an alternative to trains and ships
- Customers on the *ground*: Fleets of energy storage airships could support
  - Disaster relief efforts
  - Temporary remote projects, such as expeditions
  - Military logistics
  - Remote villages