Dual Space Access: Minimizing the Rocket Equation Limitations for Space Solar Power

Peter A. Swan, Ph.D.,
International Space Elevator Consortium, dr-swan@cox.net

2.5 Space Based Solar Power, Powering Civilian Space Development – Day 3 – June 28th

X this paper was not published before

X I agree that Space Renaissance International will publish this paper on their websites and publications

ABSTRACT

As we look at the Moon and dream of spaceflight, again, we forget how extremely difficult it has been to accomplish. In the 70's, Peter Glaser saw the future with power projected to the surface of the planet ensuring a cleaner environment. As we turn into the third decade of this century, Dr. Mankins' SPS-ALPHA MK-lllA and Ian Cash's CASSIOPeiA Space Solar Power (SSP) systems are remarkable solutions for global warming. The major problem in execution of this impactful constellation of satellites at Geosynchronous orbit is that their mass to orbit is enormous. To supply the needed power to slow or stop global warming would require in excess of 3,000,000 tonnes to GEO. This paper will show a complementary approach combining advanced rockets and space elevators to enable Space Solar Power missions in the next three decades. Space Elevators – the green road to space – will relieve the initial rocket delivery systems once the program has been demonstrated by taking on the "heavy lifting" to GEO. The rocket equation is dominate; and, it must be avoided to accomplish these monumental missions to improve the human condition. This paper will discuss the strengths and weaknesses of the components of this combined architecture, including future reusable rockets and Space Elevators. Expanding space access architectures will enable a robust movement off-planet.

Dual Space Access: Minimizing the Rocket Equation Limitations for Space Solar Power

Peter A. Swan, Ph.D.,
International Space Elevator Consortium, dr-swan@cox.net

Abstract:

As we look at the Moon and dream of spaceflight, again, we forget how extremely difficult it has been to accomplish. In the 70's, Peter Glaser saw the future with power projected to the surface of the planet ensuring a cleaner environment. As we turn into the third decade of this century, Dr. Mankins' SPS-ALPHA MK-IIIA and Ian Cash's CASSIOPeiA Space Solar Power (SSP) systems are remarkable solutions for global warming. The major problem in execution of this impactful constellation of satellites at Geosynchronous orbit is that their mass to orbit is enormous. To supply the needed power to slow or stop global warming would require in excess of 3,000,000 tonnes to GEO. This paper will show a complementary approach combining advanced rockets and space elevators to enable Space Solar Power missions in the next three decades. Space Elevators – the green road to space – will relieve the initial rocket delivery systems once the program has been demonstrated by taking on the "heavy lifting" to GEO. The rocket equation is dominate; and, it must be avoided to accomplish these monumental missions to improve the human condition. This paper will discuss the strengths and weaknesses of the components of this combined architecture, including future reusable rockets and Space Elevators. Expanding space access architectures will enable a robust movement off-planet.

1 Introduction

This paper will assume that the Space Solar Power (SSP) Constellation of massive satellites is required to ensure that climate change issues are addressed aggressively with the potential to stop the increase in temperatures earlier than expected. Other papers at this conference will address these issues. This paper will speak to customer demand for mass to geosynchronous and how to achieve success by combining advanced rockets and Space Elevators.

1.1 The Vision of Peter Glaser

As we know, Peter Glaser conceptualized collecting solar energy at the Geosynchronous orbit and radiating it down to the surface for an environmentally friendly source of massive amounts of energy. "Even in the 1960's Mankins said, Glaser's vision of the future was one of both risk and opportunity – the risk that civilization might not act in time to develop the new energy sources that would be needed when fossil fuels eventually run out…"[1] This concept has been expanded upon over the last 45 years with a focus on "how to." The current focus is for massive satellites to collect solar energy at multiple locations around the GEO belt and radiate that energy to dispersed collection "rectennas." The major difficulty is raising their mass to that altitude.

1.2 The Current Vision For Space Solar Power

The beauty of the 21st century is that we have so many more technologies available to engineers for building complex – huge – infrastructures supporting mankind. There is a multi-national movement across the globe to understand, design, build and launch the magnificent designs that are SSP satellites. One current vision for this program was expressed by Dr. Mankins on 7 Sept. 2000. "Large-scale SSP is a very complex integrated system of systems that requires numerous significant advances in current technology and capabilities… A technology roadmap has been developed that lays out potential paths for achieving all needed advances – albeit over several decades…[2] The question has been, and still is:

> What if we could find a new source of power that would not only leave Earth's environment unscathed, but allow our planet's atmosphere to recover? One that was limitless, had zero carbon emissions, and was highly competitive with coal, natural gas, and nuclear power? One that will work in harmony with solar and wind power, free us from dependence on foreign oil and that can beam power directly to the most remote, impoverished regions on Earth?[3]

A dominate aspect of SSP is that it can help in our fight against Global Warming. Dr. John Mankins has stated that he believes a SSP constellation could significantly slow down global warming, perhaps even stop it.[4] A recent study looking at the potential benefits of space elevators concluded that they would enable: "Reducing the number of fossil fuel burning plants providing energy (100s of coal plants) by using the delivery of energy from orbit to anywhere all the time."[5] This would be achieved by raising over 3,000,000 tonnes of SSP satellites to GEO in a relatively short period of time.

1.3 The Quick Estimate of Energy Demands

China, Japan, Europe, India, Switzerland, Australia and the US are all evaluating opportunities to provide environmentally friendly power from space. Dr. Mankins has established some estimates to help identify the types of support needed to implement a Space Solar Power program. He sees this global effort fulfilling 12 % of the world's electrical needs by 2060. The next chart helps us to understand the magnitude of this need. If we were to extrapolate to 2060, the global demand for electricity would be larger than 5,000 GW, essentially twice today's global consumption. Space Solar Power satellites would then supply 600 GW of electrical energy.

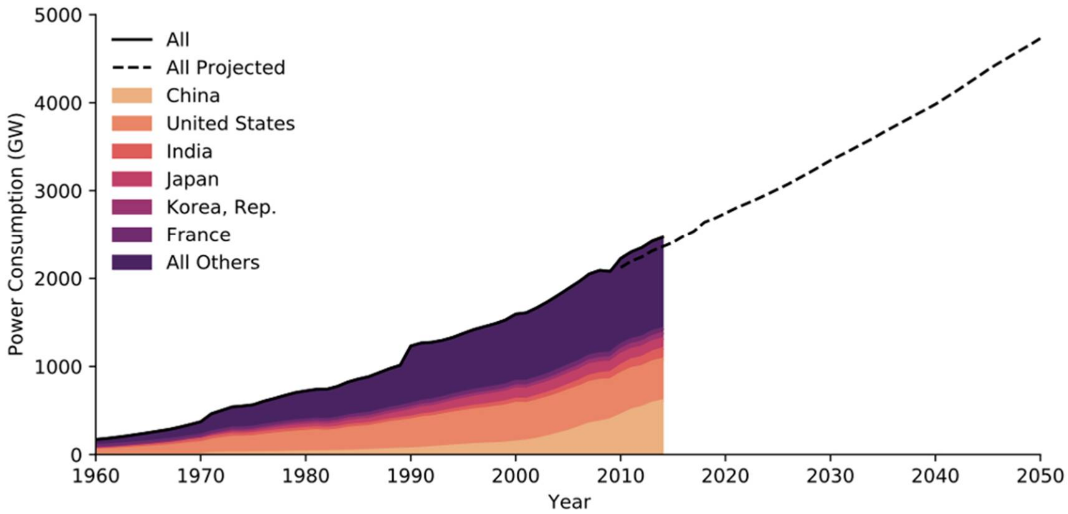


Figure 1, Global electrical power consumption measured in GW, time-averaged over usage within each year. The colors represent the 217 countries and territories included. The latest information, 2014, resulted in 2,467 GW being used. Data derived from World Bank Data Portal.[6]

1.4 The Quick Estimate of SPS Delivery Statistics (Mass to orbit)

In order to address the delivery dynamics of Space Solar Power satellites to geosynchronous orbit, a quick estimate is needed to set the stage. The normal "to GEO delivery statistic" is 20 metric tonnes per launch (more discussion under rocket delivery). When we take that number and use an estimate for the mass of Space Solar Power satellites, we end up with roughly 140 years to deliver the constellation of SSP satellites to GEO with 1,000 launches of the StarShip per year. This does not reflect the downside of launching 1,000 ships per year through the atmosphere or the consumption of resources to achieve this rate of launches. However, a permanent liftoff infrastructure could facilitate this challenge.

Simple Estimate of Number of Launches		
GW required in 2060	600	12% Global Electrical Need
GW per SPS Satellite	2	SPS Alpha IIA
# Satellites	300	
tonnes to GEO	2,760,000	at 9200 tonnes each
# Lunches	138000	20 Tonnes per Launch
# years at 1,000 per year	138 years	

Figure 2 – Simple Estimates: Note: This is my estimate using the numbers from the websites approximating many of the values – but they are so big, being off by even 50% will not make them any better.

2 Space Solar Power Programs – Customer Demands to GEO

2.1 John Mankins Approach

To supply 12% of global electrical needs by 2060 using a SSP constellation of satellites will require some massive parallel undertaking. Not only do they have to design and build major segments of each of the satellites to be assembled in orbit, but they have to have the ability to control close to 10,000 tonnes of a single satellite while pointing at a single location on the ground. The below map shows Dr. Mankins' approach with his mainline design concept (SPS Alpha IIA). He plans to provide 2 GW per satellite at a mass of 9,200 tonnes at locations in GEO.

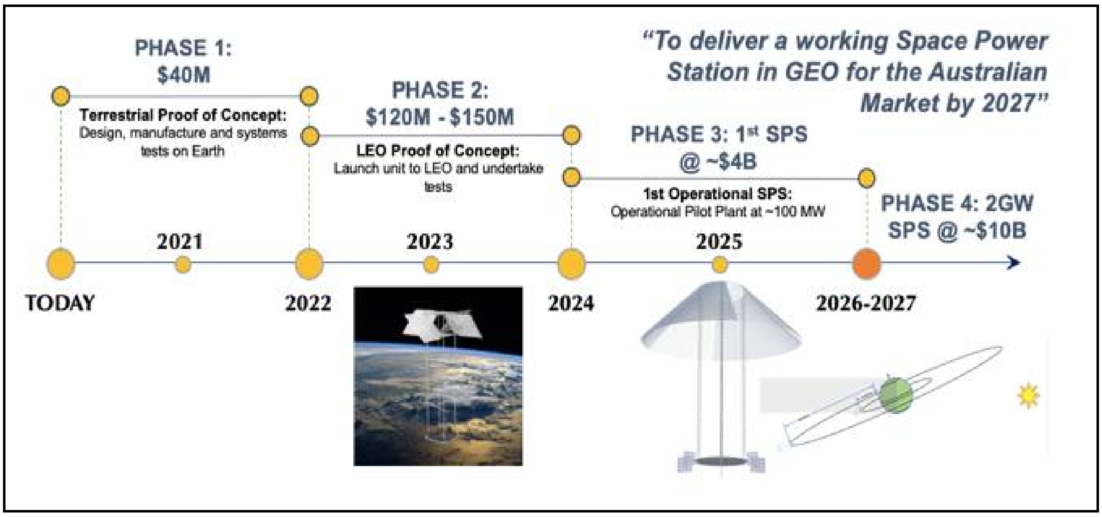


Figure 3: Roadmap for SPS-Alpha

2.2 Multiple Programs

Developmental programs are always in flux and the best estimates are the numbers you must leverage to look into the future. As the Alpha IIA system is to weigh 9,200 tonnes each and as such requires 300 of these satellites to fulfill his customer demand of 600 GW around the globe. The estimated total mass was 2,760,000 tonnes lifted to Geosynchronous. We also know there are multiple approaches to the design of satellites to achieve the 600 GW. The Alpha IIIA is slightly less massive while the Cassiopia, with less output of power, is lighter for delivery to GEO. In addition, there are many concepts for building much of the hardware on the Moon and shipping it down to GEO. Each of these concepts have tremendous arguments supporting them; however, the best option would be to manufacture the sophisticated design components and massive structures where humans have their factories and design tools. Doing these massive projects on the Moon will be possible in the future, but would delay delivery to GEO by a decade or more. The mass needed at GEO (customer pull) to supply 600 GW to humans around the globe is shown to be 2,760,000 tonnes. Other alternatives can be evaluated later in further discussions.

3 Satisfying with Rockets

As we know, rockets are very good at delivering payload to specific locations, especially LEO and GEO. The first look at delivery of SPS Alpha Mark IIA is by rockets to GEO in the traditional way, but with advanced ones that are reusable and less expensive. One essential note is that reusability and cost factors are NOT included in the famous Rocket Equation and are therefore not discussed in this paper. Yes, we concede that launches to GEO will be significantly less expensive than historic ones, but also a consumer of Earth resources and a polluting source in the atmosphere (going to 1,000 launches a year has not been assessed for their global environmental impacts).

3.1 Capability to GEO

Problem: Gravity is a one over radius squared factor and from the perspective of a big planet it is a difficult problem that needs to be defeated or avoided. To escape is the first step of moving off planet. All space efforts in the past have required huge masses of fuel and structure to leave the planet and gain orbital positions. This is usually explained in the terminology of gaining enough velocity to stay in orbit. To reach LEO, the accepted value is 9.3 km/sec velocity gained by burning fuel. Herein lies the problem: We must burn fuel and send it out as exhaust to move the mass of the vehicle forward. Over the years, the consumption of 96% of the mass that starts on a launch pad is thrown away as the "cost of doing it this way." This included all the fuel needed to burn and push the rocket, the structures to hold the fuel, the rocket nozzles, and all the other structure needed to hold the payload safely in its grasp. We can all discuss the numbers, but a reasonable assumption is 4% of the mass on the pad gets to Low Earth Orbit. Another baseline assumption is that of the 4% that made it to LEO only half of that will get to GEO, resulting in 2% available at 36,000 km altitude. This standard 2% to GEO could be 3% if using high energy electric or nuclear thermal or it could also be 1% if all parts of the rocket are reusable for return. Another tough example was delivery of the Apollo lunar lander to the surface of the Moon -- estimated showed one-half of one percent of the launch mass (0.5%) reached the lunar surface. The words of consequence are: "a device that can apply acceleration to itself using thrust by expelling part of its mass with high velocity can thereby move due to the conservation of momentum."[7] This Tsiolkovsky rocket equation still responds to that critical factor called gravity. The Earth's gravity numbers have a consistent impact on effectiveness at liftoff and flight – It is DRACONIAN! As such, this paper assumes that rockets lifting off from the surface of the Earth delivers about 2% to GEO of launch pad mass. Which then leads to the number of 20 tonnes to GEO by many launchers (some less, SLS more).

3.2 The Current Delivery Statistics of Rockets For Space Solar Power

With the information available today (past performance of rockets and estimates of advanced rockets) the numbers are simple: 20 tonnes delivered to GEO for each launch. This result leads to approximately 138,000 launches to reach 600 GW of electrical power in GEO (shown in Figure 2 previously). The question explained in the Conundrum of Rockets is: Can we believe we can implement future dreams and visions, each with massive cargo demands to GEO and beyond, when the delivery statistics is only 2% of our starting mass?

> ***Space Elevators answer the Conundrum of Rockets***
>
> The conundrum of rockets is the simple realization that the delivery of mass to its destination is an insignificant percentage of the mass on the launch pad. The glaring example is the delivery of a half percent of the launch pad mass to the surface of the moon for Apollo 11. It is up to 2% for delivery to Geosynchronous Orbit and woefully small for delivery to Mars' orbit, much less Mars' surface. The question is why would you employ a methodology for delivery that only delivers less than one percent to your desired location (lets say the future Gateway around the Moon). The Space Elevator solves that conundrum by delivering 70% of the mass at liftoff (the other 30% is the tether climber and will be reused repeatedly) to GEO and beyond by leveraging electricity.

4 Avoiding the Rocket Equation with Space Elevators

The optimum delivery of cargo by space elevators is associated with large masses to GEO and beyond. One such location matches the historic geosynchronous altitude where the SSP satellites will be located. Missions such as spacecraft repair and/or refueling and assembly of larger spacecraft will expand rapidly once this low cost of delivery is developed. Because of their characteristics, Space Elevators deliver payloads to their intended destination without consumption of mass. Essentially, at the Earth Port, the payload is about 70% of the mass and will be raised to its release destination without losing anything. The tether climber remains intact as it is energized from an external source (the Sun) and is then reused once it completes its mission(s). In addition, the use of Space Elevators ensures that space missions can be initiated without endangering the Earth or its environment. There will be no rocket exhaust reacting inside the atmosphere nor rocket bodies cluttering up low Earth orbits. A permanent infrastructure which raises tether climbers using electricity is inherently Earth friendly. The massive payloads inside tether climbers will gain energy as they rise up on the space elevator resulting is very rapid velocities – matching at GEO and increasing in velocity and altitude leading to the ability to escape the solar system. This increase in energy allows the cargo to rapidly transit to mission destinations without rocket fuel.

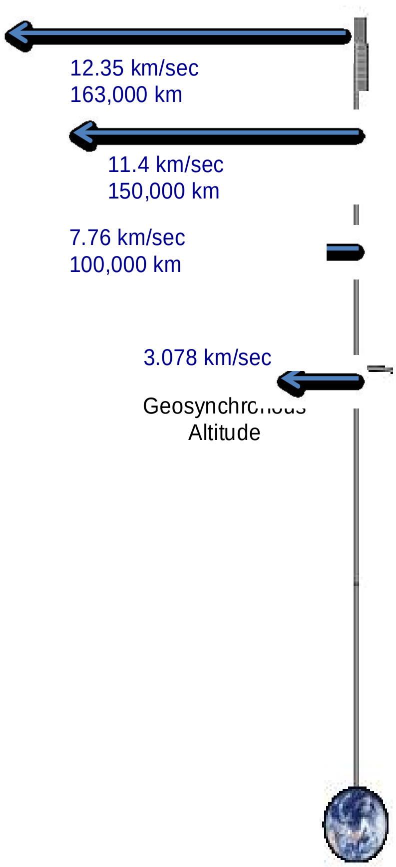


Figure 4, Velocity gains by Raising with Electricity on Space Elevator

The vision of space elevators is to ensure that there is a Dual Space Access Architecture, where future rockets and Space Elevators are compatible and complementary. Rockets do what they do best and Space Elevators avoid the rocket equation and move massive cargo on a daily, inexpensively, routinely and safely – all while being environmentally friendly. The vision is:

> Space Elevators are the Green Road to Space while they enable humanity's most important missions by moving massive tonnage to GEO and beyond. They accomplish this safely, routinely, inexpensively, and daily; they are environmentally neutral.

4.1 Capability per IOC/FOC

The growth of the daily liftoff from Space Elevators will mature with time in two dimensions: The first is the architecture will grow from one Space Elevator to two inside a Galactic Harbour (one up/one down or one principle and one backup). Then competition will increase such that there will be three Galactic Harbours established within the first ten years. This results in the Modern Day Space Elevator IOC as shown in Figure 5. The International Space Elevator Consortium projects starting development in 2021, IOC around 2036, and FOC around 2044. (see engineering support documents at www.isec.org)

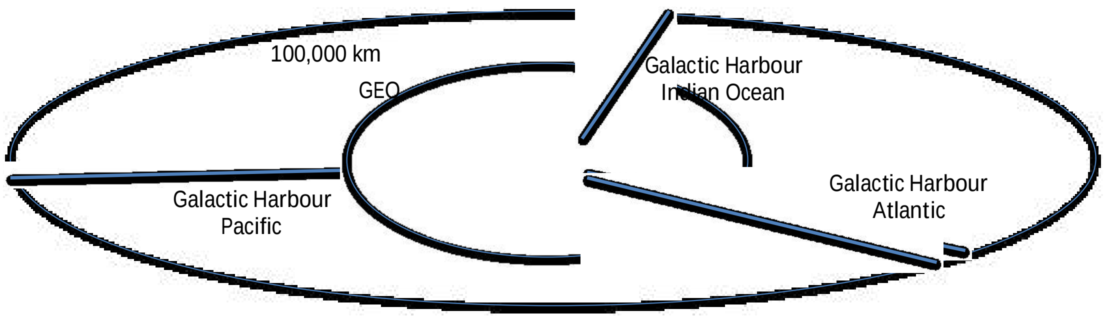
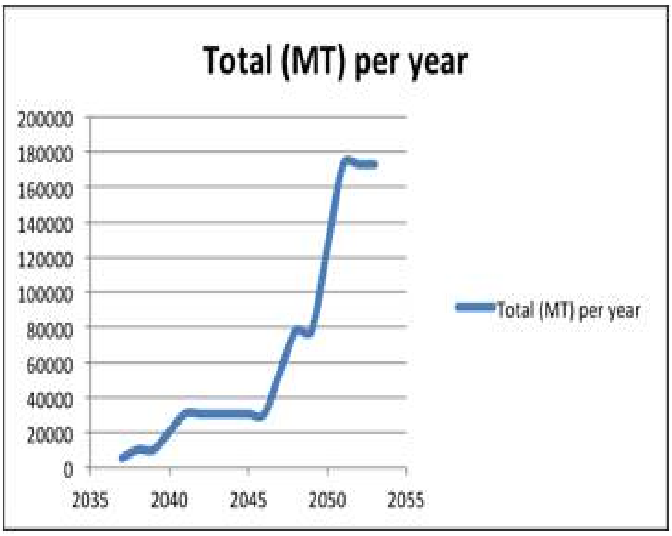


Figure 5: Architecture of three Galactic Harbours

Figure 6: Massive Cargo Movement by Space Elevators



During early operations (IOC), each Space Elevator Climber will carry 14 metric tonnes of payload to GEO and beyond with departures every day, or 84 metric tonnes per day (14 x 2 SE x 3 GH) around the globe. This will happen 365 days a year, or 30,660 metric tonnes per year to GEO and beyond. Next, each Initial Operations Capability Space Elevator will grow into the Full Operations Capable Space Elevator. As maturity is reached in massive liftoff Space Elevators, the number moves up to a little less than 200,000 metric tonnes per year to GEO and beyond – 79 tonnes x 2 x 3 or 173,010 tonnes per year at FOC. The resulting layout of tonnes to GEO and beyond is shown in the next chart. This amazing throughput is one of the principal strengths that will enable the concept of Space Solar Power to become a productive program supporting the necessary mission of helping to stop Climate Change.

5 Conclusions and Recommendation

5.1 Space Elevator's can deliver heavy cargo while Rockets initiate Space Solar Power program

The simple conclusion is to "Initiate a Space Elevator Program in the context of Dual Space Architecture development." This comes from the conclusion that the Space Elevator is essential to stopping (or slowing down significantly) global warming. The Dual Space Access Architecture must be executed with rockets initiating the constellation of SSP satellites by placing prototype SSP satellites into LEO and then GEO locations and then placing the initial operational satellites into GEO. At this time, the Space Elevator will initiate the heavy lifting and finish the task of depositing SSP satellite segments into their orbital locations. This SSP satellite deployment would ramp up to 170,000 tonnes per year resulting in the establishment of the global system within 16 years – MISSION COMPLETED.

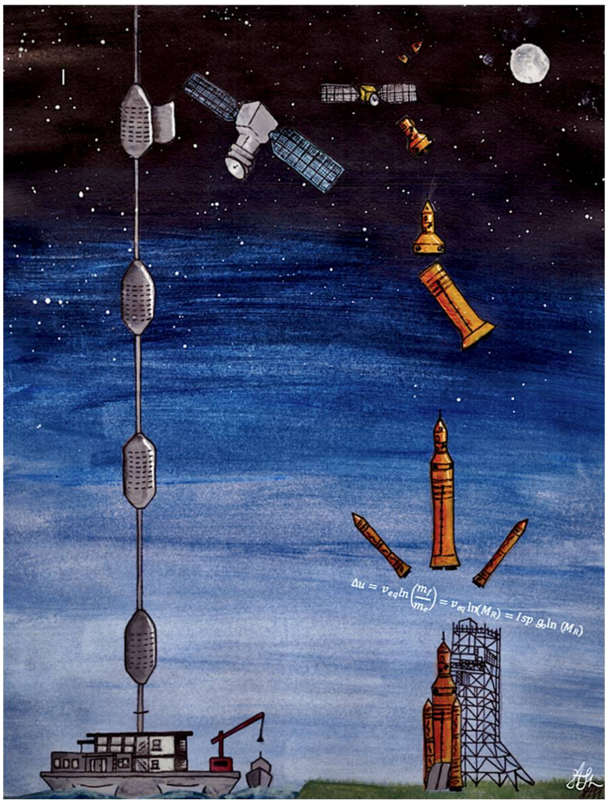


Figure 7, Dual Space Access Architecture (an Amelia Stanton Image)

This concept will result in a program such as:

Rockets to initiate the Space Solar Power program with Space Elevators to supply and grow the architecture with massive cargo movement.

5.2 The Current Vision For Space Solar Power can be achieved

The delivery of approximately 3,000,000 tonnes to GEO can be achieved by the implementation of a robust Space Elevator architecture. Space Elevators could deliver the needed mass to GEO within approximately 16 years. The deployment strategy is shown in the next chart with the conclusions as follows:

- Humanity needs 12 % of electrical demand delivered from space (orange dashed line)
- Also shown are 1/4th (green dashed) and 1/16th (blue)
- The red line is movement by rockets (1000 Starships/year) which falls way short of the need for global electricity
- Mission success with Dual Space Access Architecture and Space Elevators is shown in the purple line that grows from IOC to FOC capability and then satisfies global needs.

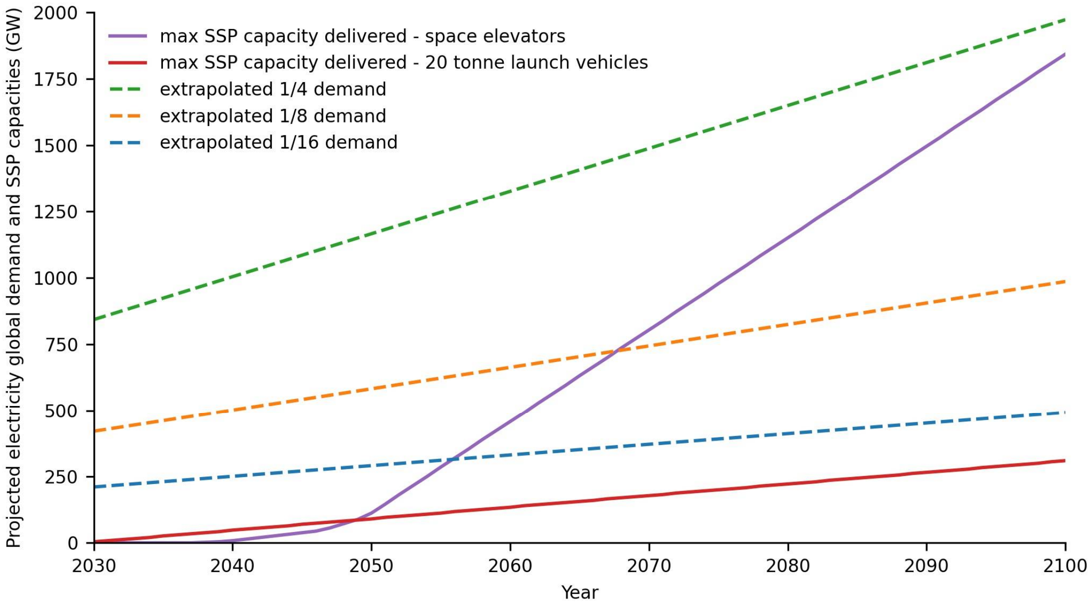


Figure 8: As we show in this chart, one thousand launches of rockets (red line) does not reach the needs of Space Solar Power (dashed lines for different levels of fulfillment). The purple line is the rapid movement of massive cargo to GEO by Space Elevators and fulfills each of the desired levels in time.

6.0 Recommendation:

Initiate a Space Elevator Development Program – NOW
- to fulfill the Current Vision For Space Solar Power

REFERENCES

Jerry Eddy, P. Swan, C. Swan, P. Phister, D. Dotson, J. Bernard-Cooper, B. Molloy, Space Elevators: The Green Road to Space," Apr 2021, ISEC Study Report, www.isec.org.

John C Mankins. A TECHNICAL OVERVIEW OF THE "SUNTOWER" SOLAR POWER SATELLITE CONCEPT. March 2002, Acta Astronautica, 50(6):369–377,.

John Mankins,, N. Kaya, and M. Vasile, "SPS-ALPHA: The First Practical Solar Power Satellite via Arbitrarily Large Phased Array (A 2011-2012 NIAC Project)," July 2012, in 10th International Energy Conversion Engineering Conference, (Atlanta, Georgia), American Institute of Aeronautics and Astronautics.

John C Mankins. The Case for Space Solar Power. Virginia Edition Publishing, LLC, 2013.

John, Mankins, Webinar entitled "NSS Space Forum - A Case for Space- Based Solar Power," 20 August 2020.

Peter Swan, David Raitt, John Knapman, Akira Tsuchida, Michael Fitzgerald, Yoji Ishikawa, Road to the Space Elevator Era, Virginia Edition Publishing Company, Science Deck (2019) ISBN-19: 978-0-9913370-3-3

Peter Swan, "Space Elevators are the Transportation Story of the 21st Century," Mar20 , ISEC Study Report, www.isec.org

End Notes:

[1] David, Leonard, "Peter Glaser, Father of Solar-Power Satellite Idea, Dies at 90," Space Insider, Space.com, no date given.
[2] Mankins, John, and Joe T. Howell, "Space Solar Power Exploratory Research and Technology Program," 51st International Astronautics Congress, January 1, 2000.
[3] NSS Paper, "Space Solar Power, the Way Forward for Clean, Limitless Energy," National Space Society Position, website 1 June 2021.
[4] Mankins, John, "NSS Space Forum – A Case for Space-Based Solar Power," NSS webinar, 20 Aug 2020
[5] Eddy, J et.al, "Space Elevators: The Green Road to Space," International Space Elevator Study Report, April 2021.
[6] "Population Total, World Bank Data Portal," 2014.
[7] Tsiolkovsky's words reported in Wikipedia 22 June 2020