IAC-21-D4.3.4

Space Elevators the Green Road to Space

Jerry K Eddy* Peter Swan**

***International Space Elevator Consortium (ISEC), Paradise Valley, Az, USA jkjpeddy@gmail.com,**
****International Space Elevator Consortium (ISEC), Paradise Valley, Az, USA dr-swan@cox.net**

Abstract

After an 18-month technical study, "Space Elevators are the Green Road to Space" is now available. This report considered the environmental impact of all aspects of Space Elevators: construction, operation and how it could improve the Earth's environment. In consideration of improving the Earth's environment, the following were considered: space solar power, permanent disposal of high-level nuclear waste, Sun Earth L-1 solar shade, setting up highly polluting necessary industries at GEO and the impact of dual space access architecture. We found how each of these impacts are feasible because of Space Elevators' ability to deliver large payloads to GEO and beyond on a regular schedule. The amount of material needed for each of these projects is considered and how operational Space Elevators can ensure their success. This study report highlighted the benefits of Space Elevators with respect to the Earth's environment and illustrated how future visions are dependent upon leveraging the strengths of both rockets and Space Elevators in a Dual Space Access Architecture.

Keywords: Space Solar Power, Space Elevator, Climate Change, High Level Nuclear Waste disposal

Acronyms/Abbreviations

FOC: full-operating-capacity
HNLW: high-level nuclear waste
IOC: initial-operating-capacity
ISEC: International Space Elevator Consortium
SE: Space Elevator
SPS: solar power satellite
SSP: space-based solar power

Introduction

Recently, the International Space Elevator Consortium (ISEC) completed an eighteen-month study "Space Elevators are the Green Road to Space."[1] Copies of the complete report are available on the ISEC.org website. One of the main topics, "Space Based Solar Power" is presented by Dr David Dotson in technical session C3.1, Solar Power Satellites.

The Green Road to Space is the first study done by the ISEC where it is assumed that a complete system of three Galactic Harbours exist in three different locations, each with two Space Elevators. (See figures 1 & 2) This space systems architecture has surfaced after 13 ISEC technical reports, two International Academy of Astronautics studies and one major corporation (Obayashi Corporation) design study. This maturation of a permanent space access infrastructure has focused upon the reality that there are huge missions being developed requiring the massive movement of cargo to geosynchronous orbit and beyond. As a result of these dreams, visions and plans, there is a need for a pollution free access to space with a capability to move large amounts of mass per year. Customer demands are there for this permanent space access infrastructure.

The main purpose of this study was to see if, and in what ways, the Space Elevator could be environmentally beneficial to the Earth. The results of the study will be presented along with additional ideas of what an existing Space Elevator system could enable.

Three major projects considered in the study were enhancements to ideas dreamed of in the early days of space. These are Space Solar Power, Nuclear Waste Disposal and Earth-Sun Shades at L1. In each of these, we contrasted the use of Space Elevators to that of using rockets to accomplish the same result. The study showed that advanced rockets were

[1] Eddy, J, Peter Swan, Cathy Swan, Paul Phister, David Dotson, Joshua Bernard-Cooper, Bert Molloy, "Space Elevators: The Green Road to Space," ISEC Study Report, lulu.com, 2021.

woefully short in delivery of mass to GEO and beyond.

The key points from this study leveraged the reality that Space Elevators are environmentally friendly by raising payloads with electricity and concluded:

- "We are building the Green Road to Space in response to so many customer needs. A key aspect is that the tether climber is propelled by electricity as it rises off the surface of the Earth, enabling zero-carbon footprint operations.
- "Our strategy is to propose a Dual Space Access Architecture: first, rockets will be better, less expensive, more robust and reusable in the near term; however, their payloads will still be restricted by the rocket equation. As such, the concept is to create a joint venture, rockets moving valuable assets to any orbit rapidly through radiation belts now and in the future; Space Elevators can transport huge cargoes to any desired destination. The second component of the Dual Architecture will be Space Elevators as permanent infrastructures.
- "The authors are ready to initiate a Space Elevator Developmental Program: The tether material (Single Crystal Graphene) is in the laboratory now and will be available in time for development."

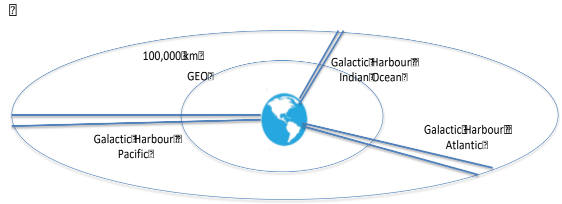

Figure 1: Galactic Harbour Distribution

The study report refined the arguments and showed the Space Elevator will be a Green Road to Space by raising payloads with electricity. In addition, the study showed how the missions enabled in the near future will ensure an Earth with a better environment and more effective support from its space assets. This paper will expand beyond the study and look at the three major topics discussed and then present future missions that requires Space Elevators to be successful.

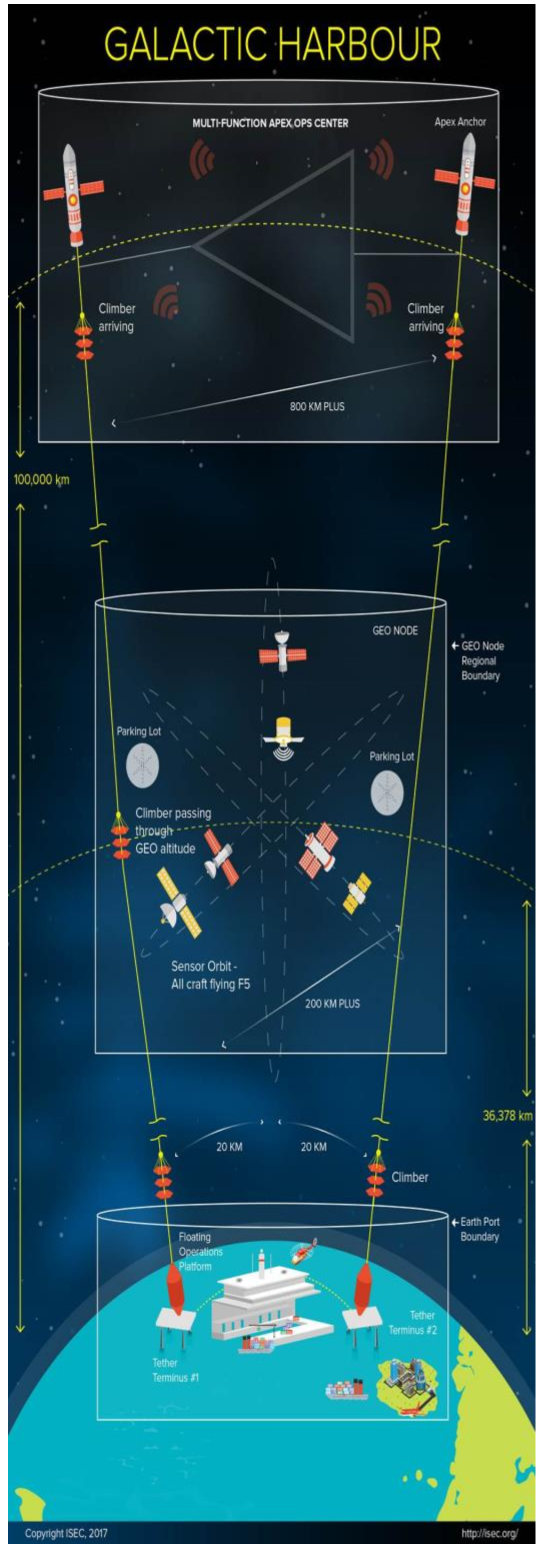

Figure 2: Single Galactic Harbour Layout

Quick Look at Three Missions enabled by Space Elevators:

Nuclear Waste Disposal: The idea of sending nuclear waste off into space is not new and was basically shelved because of the consequences of possible rocket failure with nuclear waste aboard. The Space Elevator eliminates that possibility as it is an elevator, not an explosive device.

Bert Molloy, the primary author of the chapter, researched all types of nuclear waste but focused on spent reactor fuel and nuclear weapons because of the extremely long half-lives involved. His research looked at all the various current ways that HLNW is contained and stored. The main result of this study found that “it is a monumental problem and has had minimal success for safe and long-term storage”. Table 1 shows a breakdown of what amounts are stored and a projection of how much it will be by 2050.The important thing to notice is that it may be as much as of 810,00 tons.

The ideal disposal of the HNLW would be so that it no longer poses a threat to Earth and our way-of-life. Currently the consensus among 'Nuclear Nations' is for “Deep Geological Repositories,” DGRs. There are several interesting driving functions that are in play regarding this approach. Some of this waste must be stored for up to 500,000 years. Therefore 'disposal' implies it must be extraordinarily unlikely for humans to encounter it accidentally, or purposefully, and that no known natural or Geologic processes will make such exposure possible. The United States, to date, is the only nation to have done a significant amount of construction on such a site, Yucca Mountain in Nevada. However, the many delays since this project started have made the future of the Yucca Mountain facility extremely uncertain. Finland started planning for a similar project in 1983 and plans to apply for an operating license this year with hopes to begin actual disposal operations in 2025. Yes, started planning in 1983 and 42 years later actual usage may occur. This story is very similar to what other nations have experienced and thus a new method of storage or disposal is highly desirable.

With a mature set of three Galactic Harbours, the total amount of cargo that could be carried would be 84 metric tonnes per day and 30,660 metric tonnes per year by 2060. Thus the projected Nuclear waste could esily be handled. A mature Space Elevator infrastructure could carry 170,000 tonnes per year towards the Sun and permanent disposal.

The important thing to note here is that solving the HLNW problem would encourage a greater number of nations to use nuclear power to meet their future electrical needs and doing it in a non-polluting or green manner!

Table 1: Nuclear High Level Waste Amounts

Type of Highly Radioactive Material	Storage Method	'World' Total Amount, (Kt)	Planned 'Future' for the Material
Weapons	Dry	315	Permanent Disposal
'Vitrified'*	Dry	36.5	Permanent Disposal
'Repackaged'	Dry	145	Permanent Disposal
'Spent-Fuel'	'Wet'	190	Unknown
Future 2019 - 30		32.8	Permanent Disposal
Future 2031 - 50		90	Permanent Disposal
Total		810,000 tonnes	

Solar Sun Shades: The second benefit was proposed by Dr Roger Angel, a professor at Arizonia University, in 2006. He proposed the idea at a National Academy of Sciences conference in May and received a grant from NASA to pursue the idea that October. He proposed to put a sunsade in space at the L-1 point between the Earth and Sun. The plan was to make trillions of two foot in diamenter disks, ultra thin at about 1 gram each. The total mass needed is about 20 million tonnes. Again an enormous amout of rocket launches would be needed to handle it, as Dr Angel realized. With the Galatice

Harbors at full operational cpacity it could be done in a 11.5 years. The Space Elevator could do it in a crisis and much cheaper and greener than by any other means. See table 2

Reference Mission Sun Shade 20,000,000 tonnes	Saturn V Rocket	Galactic Harbor Initial Operational Capability (2039)	Galactic Harbor Full Operational Capability (2045)	Galactic harbor Robust Operational Capability (2052)
Throw Mass to L-1	45 tonnes	14 x 6 = 84 tonnes per day	79 x 6 = 474 tonnes per day	79 x 60 = 4740 tonnes per day
Launches Required	444,444	238,100	42,194	4,219
When Daily launches - How many years	1,218	652	115	11.5

Table 2: Sun Shade Rocket or Galactic Harbours

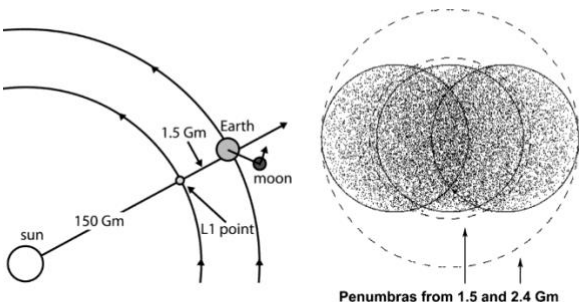

Figure 3: Sun Shade at L-1

Space Solar Power (SSP): David Dotson, Ph.D. researched this topic and showed that delivery of these massive satellites to geosynchronous can be accomplished within a reasonable time period by Space Elevators in partnership with advanced rockets. Rockets will initiate the program while Space Elevators will do the literal heavy lifting. The implementation of a SSP program will eliminate hundreds of environmentally hazardous coal buring plants while providing tremendous amounts of "green energy" to the growing population in the last half of this century. SSP could supply 12% of the population by 2060 with Green electricity without damaging the atmosphere or leaving debris in orbit around the Earth. Leveraging the strengths of Space Elevators (daily, routine, safe, environmentally friendly, and inexpensive) will enable the delivery of well over 3,000,000 tonnes of satellite segments to GEO supporting the time frame of Zero Carbon Target Programs. The implementation of SSP could be accomplished in a more timely and Earth friendly manner with Space Elevators after advanced rockets initiate the program by delivering prototypes and initial operations satellites to GEO.

These study results support the recent UK Space Energy Initiate that leads the global implementation of SSP programs. The future delivery of 1,000 tonne Cassiopeia satellites by Space Elevators will help the progam gain acceptance as an achievable mission.

Additional benefits of fully operatonal Space Elevator system:

It turns out that operational Space Elevators will provide capabilities not even considered today, because they are revolutionary. These capabilities will include green transfer of payloads to GEO and beyond because they raise everything with electricity and leave no debris in orbit during the process. In addition, the ability to gain tremendous energy from height and velocity at the Apex Anchor leads to daily releases from the Space Elevator at 7.76 km/sec enabling transit to Mars in as little as 61 days. These strengths of space elevators enable new missions that are radical in concept because they were impossible before using traditional (or even advanced) rockets. Can you envision building any size scientific payload at the Apex Anchor and combining it with any size rocket for release towards any place in our solar system any day of the year? Space Elevators can accomplish that feat by assembly at the Apex Anchor (or GEO and then raise it).

He-3 on Moon supplied to Earth

Fusion reactors are an additional way of meeting the world's future energy needs. Fusion reactor research initially considered a deuteron-tritium reaction; but, the high energy neutrons created in the reaction make it impossible to contain the reaction long term. The high energy neutrons produce in the D-T reaction would ultimately detroy the container. Research in using the He-3 +D reaction reduces the production of high energy neutron, has also been considered. The current research using the He-3 He-3 reaction is showing great promise. It is not as efficient, but avoids the production of high energy neutrons completely, which leaves residual waste.

He-3 is not abundant on the Earth due to the Earth's atmosphere and magnetic field deflecting the He-3 that comes from the Sun in solar winds. Small qunaties exist but only enough to do research, not enough for long term use in large scale fusion reactors. However, He-3 is abundant in the surface dust on the moon because solar winds are not deflected on the way to the Moon. A Lunar robot could collect moon dust, use a refining facility on the moon or have it shipped to a refining facility at GEO and then it could easily be shipped back to Earth using Galactic Harbours. It is said that the energy in He-3 on the Moon is ten times the amonut in all the fossil fuels on Earth. Twenty five tons of He-3 could power the US for a year, thus it has a value of over three billion dollars. One key is that the Space Elevator would be able to deliver the heavy mining and refining equipment to the surface of the Moon by raising it up the Space Elevator, adding a rocket motor to land it on the Moon. The refined He-3 could then be sent to the Apex Anchor (or GEO region) the to be stored for delivery to the Earth.

The Space Elevator system would enable large scale energy producion by fusion reactors leveraging He-3 fuel sourced from the Moon. The first fusion reactor is projected to be available by 2027 to 2040. This is one of the main reasons several nations have been planning missions to the moon and one of the major reason the US wants to place a Lunar colony at the Moon's poles since that is where major concentrations of He-3 is believed to be.[2]

Polluting Industries Moved to Geo

Refining of fossil fuels and metals is considered to be one of the major polluting industries on Earth. Alternative energy sources along with space solar power and fusion reactors should eventually severely reduce, if not nearly eliminate, the need for refining petroleum on Earth. The refining of metals, either from the Earth, Moon or other space sources will always be needed. Most of this refining could be done at several different locations other than the Earth. It could be done on the Moon or at various locations at GEO, near the Galactic Harbours. Either way the refineries could be set up, operated and supplied by the Galactic Harbours. All using non-polluting solar power. With the use of the Galactic Harbours' ability to move 170,00 tons per year, any major polluting industry should consider moving its operations to GEO.

Construction, Repair, Replacement at GEO

The construction or assembly of solar panels, living quarters, satellites, refineries, storage facilities will be needed everywhere in space. GEO being one of the major initial locations. The main requirement for all of these activities is lots of mass. Much of the assembly or construction can be done by robots, but even the robots have to be constructed. All major assemblies could be done in space.

A major activity at GEO could be the placement of new satellites and the repair or decommissioning of old satellites. A decommissioned satellite could be stripped of its valuable parts and the waste, if any, could be placed in disposal orbits, or into the Sun. Other space junk could be collected and disposed of in a similar manner.

Planetary Defense - Apex Anchor Ready Room

The importance of defending the Earth against asteroids and comets has been raised as we have more knowledge and more capability. The idea of

[2] See https://www.youtube.com/watch?v=94rEqHP9dOQ

having rockets ready to send deflecting technologies on an intercepting trajectory currently leads to images of long waits for capable rockets with the chance of catestropic failure before they reach orbit with slow transit speeds towards the target. The strength of a Space Elevator, with its Apex Anchor positioned 100,000 km above the surface of the ocean going at a speed of 7.76 km/sec, would enable an immediate response to a discovered threat every day of the year. Both high-speed trajectories and any size and mass of interceptor systems are enabled by Space Elevators. The Apex Anchor Ready Room could then have, in permanent readiness, a set of deflection tools appropriate for a wide range of threats. Defender satellites would have a range of capabilities to include rendezvous, assessment of threat, attachment to threat object, and actions including propulsive movement or other types of deflection technologies. The storage at the Apex Anchor would eliminate the time consuming process of setting up a rocket launch, loading the payload, going through many stages of propulsion and the long coast to the potential threat as slower speeds. By stationing defender satellites at the Apex Anchor, the inherent velocity of the Earth's rotation will enable daily releases in all directions with very high speeds. In addition, by having a holding bay for planetary defending satellites, a variety of options could be readied for immediate release to include attachment to target and the use of propulsion to deflect, gravity perturbations of flightpath, kinetic impacts, laser ablations, etc. Accepting a mission on the Space Elevator for planetary defense becomes highly desireable, as soon as Space Elevators are established.

Galactic Harbours are Green!

In considering this statement, we examined what an Environmental Impact Study requires. There are twelve items that need to be addressed in such a study.

1. Ecological Resources
2. Cultural/Native American Resources
3. Hazardous Materials/Waste Management
4. Land Use
5. Visual Resources
6. Noise
7. Geology and Soils
8. Natural Resources and Energy Supply
9. Traffic and Transportation
10. Water Resources (including Wetlands and Wild and Scenic Rivers)
11. Airspace
12. Environmental Justice

As Earth Ports are on oceans far from land, only numbers 3,8,9,10 and 11 need to be considered. Most of these items are commonly addressed on ocean oil platforms and would be handled similarly on the Galactic Harbours Earth Ports. All traffic would be by ships and planes. Facilities would be established for container ships to off load; and, adequate space would be provided for material storage waiting for loading onto climbers. Any air pollution would not be any more then at a small seaport or airport. Airspace would have to be carefully controlled to avoid the tethers and regulate landings and takeoffs, mainly by helicopters. Seaplane facilities may also be included. Refueling facilities for all craft both sea and air would be handled using standard procedures.

With the platform and tether climbers powered by solar arrays the Galactic harbor would be totally green.

Conclusions

Many of Earth's dreams for the future are enabled by Space Elevators. Future energy needs can be met by several different means: increased use of nuclear power with the solution of high level nuclear waste disposal, use of Space Based Solar Power and fuel for He-3 fusion reactors.

The large amount of material required by space colonies can be supplied easily with transit times from GEO to the colonies greatly reduced with daily releases.

Thus, we (ISEC) claim the Space Elevator and Galactic Harbours are "The Green Road to Space."

References

Eddy, J, Peter Swan, Cathy Swan, Paul Phister, David Dotson, Joshua Bernard-Cooper, Bert Molloy, "Space Elevators: The Green Road to Space," ISEC Study Report, lulu.com, 2021.

Mankins, John, The Case for Space Solar Power, Virginia Edition Publishing Co. Dec 2013.

Raitt, David, Space Elevators: A History, ISEC Report 2017.

Swan, P., 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

Swan, P., Raitt, Swan, Penny, Knapman. International Academy of Astronautics Study Report, Space Elevators: An Assessment of the Technological Feasibility and the Way Forward, Virginia Edition Publishing Company, Science Deck (2013) ISBN-13: 978-2917761311

2017 https://www.earth.com/news/commercial-fusion-reactor-2027

2020 https://www.powermag.com/fusion-energy-is-coming-and-maybe-sooner-than-you-think/