Leverage Dual Space Access Architecture
Advanced Rockets and Space Elevators

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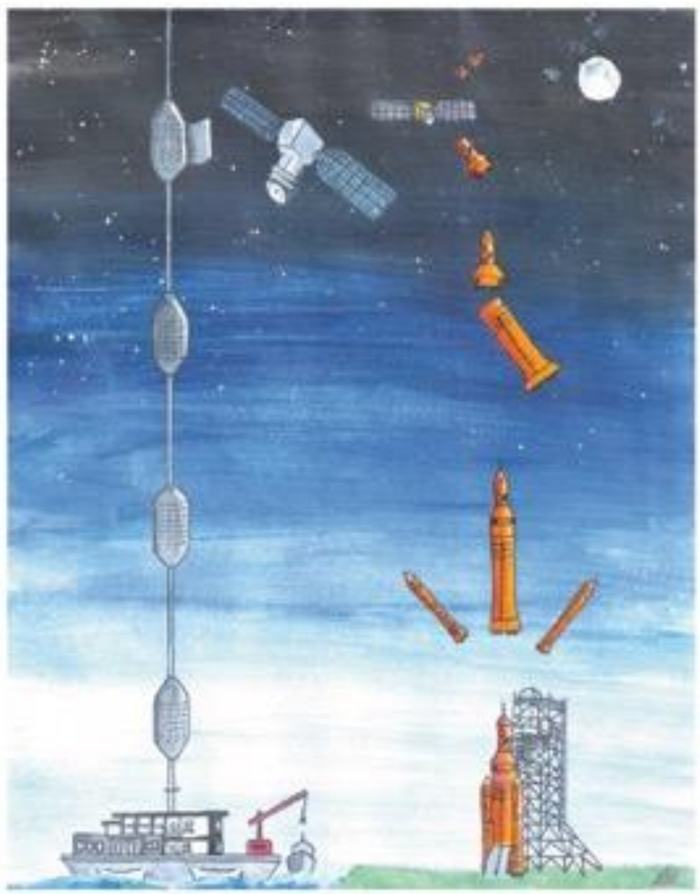

ISEC

A Primer for
Progress in
Space Elevator
Development

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Preface

This study assumes Space Elevators can and must be built. "Space Elevators: The Green Road to Space," completed in April 2021, emphasizes that Space Elevators will not replace rockets but would join them on parallel paths towards the stars. This Dual Space Access Strategy will carry out the missions that are now planned and ensure the future we dream of becomes a reality. Space Elevators are needed to do the "heavy lifting" for movement off planet. Their transformational characteristics will enable so many of humanity's dreams by moving huge mass to far away destinations.

> Space Elevator Vision: 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, efficiently, daily and they are environmentally neutral.

Space Elevators enable mass to be raised against gravity, without using rockets. This leads to Space Elevators defeating the Rocket Equation! Our future of moving off-planet includes Space Elevators as necessary, compatible, and complementary to rocket architectures. The future needs both communities to work together. It seems obvious that cargo should be moved by a permanent transportation space access infrastructure while humans rapidly transitioning through the radiation belts on advanced rockets.

Comparisons of rocket equation results show that delivery to LEO is roughly 4% of the mass on the pad (historically, 96% is burned up or thrown away) while delivery to GEO (or trans-lunar insertion) is about 2%. In comparison, delivery to GEO or Apex Anchor [AA] by Space Elevators is 100% of the payload at the Earth Port pad. The Earth's gravity numbers are draconian and have a considerable impact on efficiency at liftoff and flight for rockets. The resulting percentages are difficult numbers to overcome and then build our future around. However, if you raise 20 tonnes to GEO or the Apex Anchor with electricity, you have beaten gravity, added incredible potential energy, and tremendous velocity (7.76 km/sec at AA) for release towards mission destinations. Yes, Space Elevators defeat the Rocket Equation. As a result, when you look at the question, "Why Space Elevators?" the answer is – Space Elevators have:

- Unmatched efficiencies (70% of mass to GEO and beyond, with reusable climbers the other 30%)
- Unmatched velocities (7.76 km/sec at Apex Anchor - release to go beyond Mars, no fuel required)
- Unmatched movement of logistics mass (30,000 tonnes in their first year of operations — humanity has only put up 20,000 tonnes by rockets between 1957 and 2020)

Advanced Rockets to Open Up the Moon and Mars
Space Elevators will then supply and build-up settlements!

Acknowledgements

Having a vision for the future is the first step leading to programs that realize dreams. This process has been around forever; however, for the future of off planet movement, this dreaming has been accelerating over the last 200 years. The last 65 years have shown how hard it is to accomplish space-based visions. Dreams of establishing colonies on the Moon, Mars and L5 along with solving major Earth problems such as meeting future power needs, protecting Earth from outer space objects, global warming, and high-level nuclear waste disposal are the just a few of the new ideas. Can any of these become reality with rockets alone? This study considered how advanced rockets and space elevators need to work together to make these dreams come true. The International Space Elevator Consortium (ISEC) brought in a special team of experts to cover such diverse topics. The international team was very talented and accomplished much. We also give special thanks to the group of reviewers who finalized this document.

The Team:

Editor: Jerry K Eddy Ph.D: Secretary and member of the Board of Directors of ISEC and Retired Physics professor Indiana University of PA (IUP). Dr. Eddy was the director of the 2 MEV particle accelerator Laboratory at IUP and directed several NSF grants. Upon retiring from IUP he became The Science Chair at The Stony Brook School, Stony Brook NY

Primary Author: Peter A. Swan Ph.D.: President and member of BOD of ISEC. He retired from the Air Force early in his life and then retired from Motorola after the IRIDIUM launch. He then helped set up and operate Teaching Science and Technology, Inc. for many years. He's been researching space elevators since 1981.

Rocket Strengths and Shortfalls: Bassem Sabra PhD, Professor of Physics & Astronomy and Department Chairperson at Notre Dame University – Louaize (NDU), LEBANON. His field of research is observational astrophysics (supermassive black holes and active galactic nuclei: using multi-wavelength spectroscopy, modeling, and machine learning to study accretion physics, feedback, and the co-evolution with the host galaxy).

Space Solar Power: Shubham Gosavi is a strong advocate for Space Based Solar Power from India, actively promoting its technology within the country. He has collaborated with the Space System Engineering team at Entropy Research and Development Pvt. Ltd. in India, where they are currently developing the world's smallest Laser Based Space Solar Power Satellite. Dr. Aditya Baraskar is the Founder and Director of Entropy Research and Development Pvt. Ltd. in India. He also serves as Chief Scientist and Manager for the world's pioneering Laser-based Debris removal project at SKY Perfect JSAT Corporation in Japan.

Planetary Sunshades: Liz Scott is the Research Director of the Planetary Sunshade Foundation. She is a Ph.D. candidate in space resources at the Colorado School of Mines with a doctoral topic on planetary sunshade construction, and was formerly an aerospace engineer at United Launch Alliance. Ross Centers is CEO of Ethos Space, developing the logistical and manufacturing capability to build a planetary sunshade. He serves on the board of the Planetary Sunshade Foundation and holds a masters in Space Resources from the Colorado School of Mines.

***Planetary Defense*:** Paul W. Phister, Jr., Ph.D. is President of MANIAC Consulting and holds a professional engineering license in both software and electrical engineer from the State of Texas. He is currently an Adjunct Professor at the Mohawk Valley Community College (MVCC). Additionally, Dr. Phister spent 25 years in the military (Lt Col, retired) where he worked primarily in space systems development, acquisition, and operations.

Reviewers: David Raitt, Ph.D., is retired, as the former Senior Technology Transfer Officer, European Space Agency where he worked for 40 years. Albert (Bert) Molloy, M.Sc.(Nuclear Physics), is a retired High School Teacher of Physics and Computer Science who passionately supports the Space Elevator concept.

As in all projects, it takes a team. We wish to thank them for their contributions and their belief that Space Elevators will contribute significantly to each of their passions. This step is necessary to ensure the overall concept for Space Elevators is to join advanced rockets on the road to the future.

Indeed, Advanced Rockets and Space Elevators will ensure humanity has a brighter future including the remarkable expansion off planet.

Executive Summary

The International Space Elevator Consortium's (ISEC) research into future needs of customers, the strengths of advanced rockets, and the characteristics of Space Elevators have all culminated in this report. Along the research path, ISEC recognized three remarkable characteristics of Space Elevators that establish the need for its development in the near future: "Why Space Elevators?"

- Unmatched Efficiency of logistics to GEO and beyond – 70% of Climber mass is payload with no debris left in orbit and raised with electricity (a Green Road to Space) [Eddy, 2021].
- Unmatched Velocity upon release from an Apex Anchor going to the Moon and Mars. (7.76 km/sec from above the gravity well, some as fast as 61 days to Mars) [Swan, 2020a]
- Unmatched logistics movement of mass with 30,000 tonnes in the first year of Space Elevator operation and 170,000 tonnes per year to GEO and beyond once maturity is reached. [Swan, 2020a]

Another major concept solidified during this research. when looking at advanced rockets and the future of humanity's needs from/in orbit. There should be cooperation and coordination between advanced rocket projects and Space Elevators once they start operations (approximately 2037). This Dual Space Access strategy will leverage the best of future rockets and Space Elevators allowing humanity to reach farther and sooner for the implementation of remarkable dreams. This report looks at several of these major programs and recognizes that rockets alone will have tremendous challenges in moving mass against gravity and "playing nicely" with our atmosphere. As such, the ability of Space Elevators, as the Green Road to Space, will enable most missions to be achieved in much shorter timelines. One million tonnes to the surface of Mars will take decades to achieve with rockets while Space Elevators (once into mature operations) will be able to handle the delivery in less than a decade.

During this research, several missions were analyzed and presented in this report. Each one needs massive movement of logistics and requires satellites at GEO and beyond. Space Solar Power constellations can result in over 3,000,000 tonnes to GEO to impact the power needs and assist in reducing global warming. Solar Shades can reduce the temperature at the surface of the Earth but requires up to 20 million tonnes beyond GEO to the Sun-Earth L-1 location. In addition, examining Planetary Defense showed some promising solutions to intractable problems by using Apex Anchors as Planetary Defense nodes – garages for storage and assembly of large planetary defense mission vehicles as well as observation locations for additional views of the environment around Earth. Then there is the strength of Space Elevators of "assembly above the gravity well." By lifting satellite segments (at roughly 14 tonnes each) and assembling them above the gravity well, solar system science missions can become quite large and are then released with tremendous energy towards our outer planets – every day of the year launches. In addition, these factories or garages at 100,000 km above Earth will act as logistics centers for CisLunar activities or even astronaut rescue centers for storage of equipment, oxygen, water and food deliveries for emergencies. The 14 hour travel time with daily releases toward the Moon would enable "quick responses" to emergencies.

While the study team worked on this report, the consolidated effort also led to the recognition that: the modern-day Space Elevator will be transformational as a permanent space access infrastructure as they: are ready to enter engineering development, become a Green Road to Space, join the advanced rockets inside a Dual Space Access Architecture Strategy, and implement permanent transportation infrastructure characteristics leading to dominant support to customers. The image that has surfaced is: "Think of a bridge after centuries of using boats to cross a river."

This report has pulled together many concepts to help readers understand the revolution that is coming. In a previous ISEC study report, the following words were presented and still apply.

> *"Rockets to open up the Moon and Mars with Space Elevators to supply and grow the settlements. In addition, Space Elevators will enable Green Missions such as, Space Solar Power and L-1 Sun Shades. This approach is compatible and complementary with future rockets while leveraging the strengths of both inside a Dual Space Access Architecture."* [Eddy, 2021]

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Section A: Study Introduction

A.1.0 Introduction:

Space Elevators will open the heavens for humanity, because they can move massive logistics off our planet with unmatched efficiencies. The development of a permanent space transportation infrastructure is proposed with several significant transformational characteristics that must be visualized and then presented to the space community. The remarkable future of humanity living and working off planet will demand significant tonnage delivered off planet. Missions like Artemis, with SpaceX and Blue Origin delivering people and logistics to the surface of the Moon this decade, will have a constant and large demand for heavy lifting. In addition, there are remarkable concepts that will assist the population on Earth by cooling or providing power to distant locations around the globe. As explained in this study report, the Space Elevator has a revolutionary characteristic that will justify, "WHY Space Elevators." They will provide 70% of the lift off pad mass to GEO and beyond while current and advanced rockets can only deliver 2% of their liftoff mass to GEO and beyond. The report will show how this unmatched efficiency of delivery can help to fulfill the demands of these massive programs.

Figure A.1: Dual Space Access Architecture (Stanton image)

This study, conducted by the International Space Elevator Consortium, presents new perspectives on the Space Elevator, and compares it with advanced rockets to lead to a Dual Space Access Strategy for improving the human condition and for human movement off planet. This Dual Space Access Strategy is one that leverages the cooperation and coordination of Advanced Rocked and Space Elevators while satisfying the needs of these customers. Section A introduces the study with a general perspective of the Space Elevator. Chapter 1 describes the current (and planned for) Space Elevator with its unique characteristics and capabilities. Chapter 2 looks at the customer design for the Space Elevator of the near future. It will also recognize that there are tremendous visions out there that need to be fulfilled and can be enabled by massive movement of logistics support to GEO and beyond. The whole report will then compare advanced rocket capabilities with Space Elevator growth. Section B will compare the two methods to reach space: Advanced Rockets and Space Elevators. The next two chapters will illustrate the tremendous strengths of Space Elevators (chapter 3) and advanced rockets (chapter 4) Section C will focus on one of the major concerns of the 21st century, the Energy and Climate Crisis Remediation or how does the Space Elevator contribute to the health of the planet and its people. The following two chapters addresses major programs designed to improve humanity's future. Chapter 5 will discuss sunshades to cool the Earth while Chapter 6 will discuss power from space. Section D then looks at the remarkable missions that can be addressed when the Space Elevators have matured and have the capability to lift off every day, routinely, inexpensively, safely, efficiently with significant mass lift capability. Two additional missions are discussed that could have significant impact on humanity's future. Chapter 7 defines a new concept for planetary protection while Chapter 8 improves planetary science missions. Finally, section E will summarize and compare the discussions that preceded with conclusions and a recommendation.

Space Elevators will become the transportation and logistics system for GEO and beyond leading to new missions which have not been accomplished before or even thought of until the transportation and logistics system is a permanent space access infrastructure.

> "From a historical transportation perspective: canals, channels and deep-water ports are infrastructure - ships are vehicles. Likewise, the interstate highway, bridges, and trans-continental rail systems are infrastructures for ground transportation - the trucks and trains are the vehicles that use

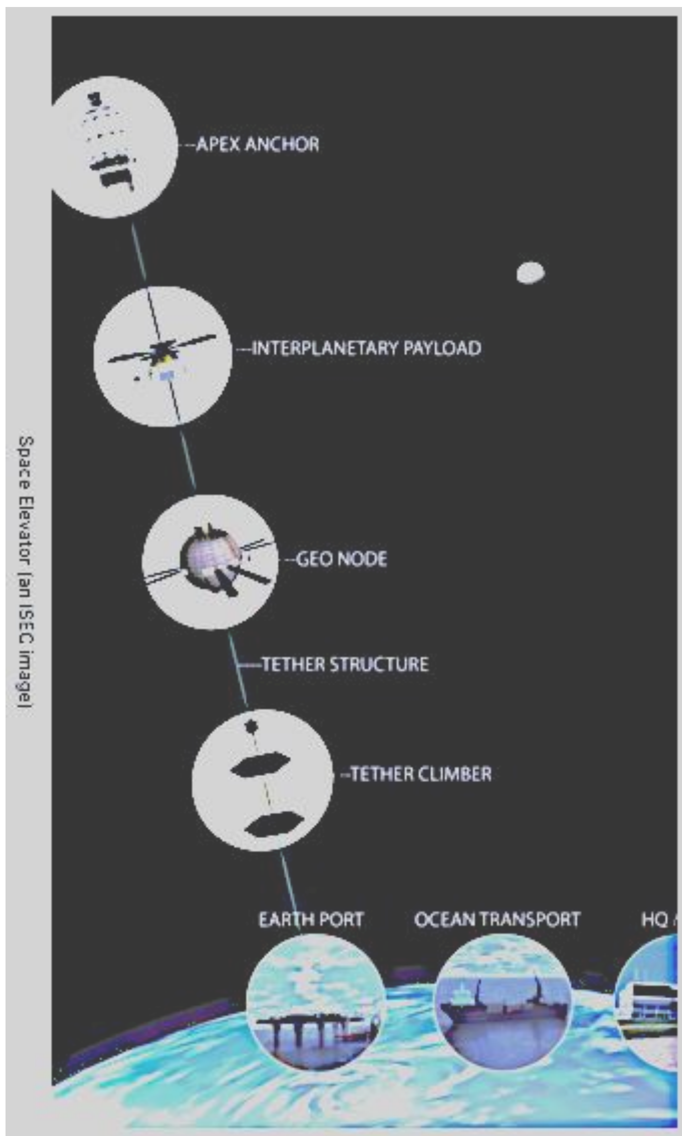


Figure A.2: Galactic Harbour

them. International airports and related facilities are the infrastructures for air travel and planes are the vehicles. From this perspective, rockets, no matter how large and reusable they may be in the future, will always be vehicles - not permanent space infrastructures."[Swan, 2020a]

In a Space Elevator system, climbers are the vehicles while the infrastructure consists of tethers, Earth Port with several termini and operational platforms, GEO construction facilities - repair garages/factories, and Apex Anchor. This transportation and logistics infrastructure defines the future space superhighway's main green road to space. From this perspective, rockets, no matter how large and reusable they may be in the future, will always be vehicles - not a permanent space infrastructure. Within the Space Elevator concept, climbers are the vehicles while tethers, Earth Ports with several termini and operational platforms, GEO construction - repair garages/stations, and Apex Anchor are the permanent, reliable space infrastructure. This permanent transportation infrastructure defines the future space superhighway's main green road to space with collaborating and complementary permanent infrastructures.

A.1.1 Eighth Architecture: Over the years, the Space Elevator Transportation System (SETS) has matured from a bright concept in 1895, through a NASA Innovation Study, with growth to an idea that is now able to be built. In addition, the concept has matured into one that leverages modern materials, space systems, communications strengths, and the concept of intermodal transportation transitioning from the suppliers manufacturing facilities through the terrestrial transportation infrastructure, to the Earth Port where it is initiated into the vertical movement and finally to the orbital release location supporting it primary mission. These refinements of the concept have resulted in an eighth complete architecture that is then joined with advanced rockets into a permanent transportation infrastructure raising massive cargo to geosynchronous orbit and beyond. This Dual Space Access Architecture (DSAA) is a transportation strategy where the strengths of both methods of transportation are leveraged in a cooperative and complementary approach.

The eighth SETS architecture, combined with advanced rockets, will enable the dreams of many and essentially fill the needs of humanity to move off planet and save the Earth at the same time. David Raitt, in his article "Space Elevator Architectures," [Raitt, 2021] lays out the growth of the concept and leads the reader to understand that the permanent transportation system has developed over many years with many improvements. This image of the Galactic Harbour displays the 8th architecture as one that leverages two Space Elevators inside a transportation infrastructure enabling massive movement of cargo in a routine, daily, safely and environmentally neutral operations. The ocean based initial segment is comprised of an Earth Port supporting two tether termini along with a floating operations platform. The two tethers stretch out beyond geosynchronous orbit towards the Apex Anchor (initial concept 100,000 km altitude) where cargos would be release at a rapid pace towards their mission destinations (7.76 km/sec for as little as 14 hours to the Lunar surface or 61 days to Mars). Tether climbers would carry cargo and release payloads at the GEO Node facilities and then go on to the Apex Anchor for additional mission support. In addition, the architecture includes the Headquarters and Operations Center to orchestrate the total operations for the Galactic Harbour. The concept shown in Figure A.3 is for three Galactic Harbours distributed around the equator as commercial competitive infrastructures.

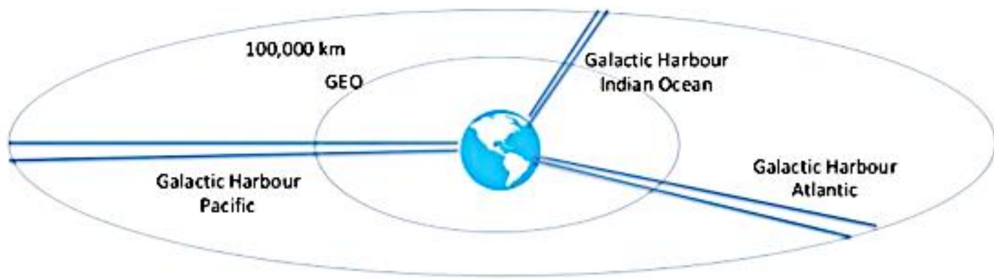


Figure A.3: Galactic Harbour Global Perspective

A.1.2 An awakening has occurred! How important is this new approach for a permanent transportation and logistics infrastructure to the commercial world as well as humanity? How will it affect the Earth's future progress? As an explanation of this remarkable transformation in thinking, the following statement was developed by Dr. Swan in the 2020 ISEC Study report, *The Space Elevator is the transportation story of the 21st Century*. [Swan, 2020a]

> "The Awakening: A NEW Space Transportation Paradigm has emerged. Ideas brought forward in a recent study report [Swan, 2020a], and this paper, are presented in clear and understandable ways, showing that a revolutionary concept is becoming realizable. The envisioned cooperative and collaborative operations between rockets and Space Elevators will benefit mankind into the next century. This architecture, with Space Elevators and rockets as a remarkable Earth to Space Transportation Infrastructure, provides logistics support to future missions throughout our solar system. This is a path to fully support interplanetary travel occurring by the second half of this century. This paper has highlighted the following realizations: a) Space Elevators can be accomplished because we now have a tether material, b) Space Elevators enable interplanetary, missions to Mars with releases every day ranging from 61 to over 400 days, c) Space Elevators are Environmentally Friendly – the Green Road to Space, and, d) Offer to all future scientists –experiments of any size – anywhere in solar system with releases every day."

> "How can this be possible? Simple - a working Space Elevator defeats gravity and the traditional rocket equation. Massive payloads to the Apex Anchor - raised by electricity - to be released at 7.76 km/sec towards destinations: daily, routinely, safely, and robustly all while being environmentally friendly. Combined with rocket architectures, future missions to GEO and beyond can be robustly supported." [Swan, 2020a]

This leads to the remarkable concept of teaming with advanced rockets in a Dual Space Access Strategy, ending with the recognition that:

Rockets will Open Up the Moon and Mars
Space Elevators will then supply and build up settlements.

A.2.0 Perspective of Space Elevators 2023: Modern day rockets (and new ones to come with reusability) are remarkable and will enhance the capability to get to orbit. However, the inclusion of a permanent space access infrastructure (such as a bridge to space) will transform our opportunities towards sooner and more massive movement off planet. The transformation of space access through Space Elevators will develop, based upon the following concepts and insights into the future.

A.2.1 View of Future Galactic Harbours: The future of Space Elevator Transportation Systems (SETS) will grow through a Galactic Harbour architecture approach. Galactic Harbours, with two Space Elevators each, will be the volume encompassing an Earth Port while stretching up in a cylindrical shape to include two Space Elevator tethers outwards beyond GEO to Apex Anchors. The estimate is for three Galactic Harbours to be deployed during the developmental phase between 2035 and 2043. Recently, ISEC completed an 18-month study [Eddy, 2021] that evaluated Space Elevator's environmental factors. This study started critical discussions by showing the additional benefits of Space Elevators being defined as "Massive Green Machines" as they do not burn rocket fuel in the atmosphere, do not leave debris in orbit, and enable environmentally enhancing missions that require massive movement to GEO and beyond. In fact, the operations of Space Elevators and Galactic Harbours will be carbon negative. Several of the concepts developed during this study establish the reality that Space Elevators can make the Earth Greener.

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, while being environmentally neutral.

A.2.2 Transformational Characteristics: The transformation of space access created by Space Elevator operations will be like moving from small boats crossing a large river to a permanent infrastructure such as a bridge moving traffic daily, routinely, safely, inexpensively, efficiently, and with little environmental impact. When one thinks logistics support, the logical outcome is a permanent infrastructure that allows these routine and on-time characteristics. The following short descriptions will set the stage for the rest of this study report, especially chapter 3 where the focus is Space Elevator transportation strengths. The permanent transportation infrastructures of Space Elevators will enable missions by leveraging these transportation characteristics as their main strengths:

- Daily, routine, safe, unmatched efficiency, and inexpensive permanent infrastructures: Routine operations are described as: the ability to schedule and depend upon "on time delivery" characteristics of permanent infrastructures which will change the way organizations plan on supporting mission to GEO and beyond.
- Unmatched massive movement of Logistics: This characteristic is the obvious strength that most users need. Massive delivery to the location of choice will enable dreamers such as SpaceX, Moon Village supporters, space solar power requirements, and routine historic missions to be enabled by this unique capability. A current estimate has been developed for Space Elevators which reflects growth from the Initial Operational Capability (30,000 tonnes per year) to the full operational capability (170,000 tonnes per year). High velocity release: The Apex Anchor is moving at high rotational velocity resulting in a linear velocity of 7.76 km/sec upon release of missions spacecraft. The release speed is sufficient to reach Mars in as little as 61 days, with a range of trip durations depending on the planetary orbits. [Swan, 2020a]

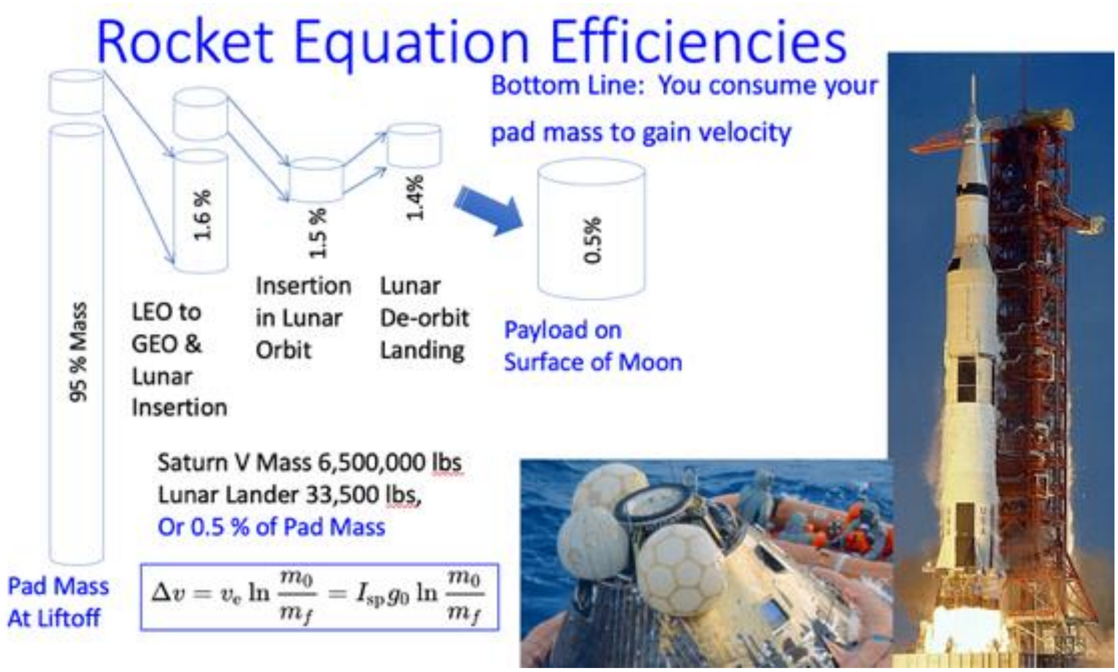


Figure A.4: Apollo Delivery Efficiency (0.5% of pad mass to lunar surface)

- Unmatched Efficiencies of logistics delivery: Comparison of Rocket and Space Elevator efficiencies shows the mass delivered to GEO & Beyond by rockets is minimal while the future of Space Elevators reaches towards 70% of the mass on the surface is delivered to GEO or the Apex Anchor. The capability of Space Elevators dwarfs advanced rockets rapidly because of its unmatched efficiency of delivery and environmentally friendly operations.
- Green Road to Space: Space Elevators ensure environmentally neutral operations: Solar energy to the tether climber motors ensures that there is no need for combustion within the atmosphere and no hardware left along the way in low Earth Orbit. As such, the operations are GREEN. [Eddy, 2021]
- Reduction of rocket fairing design limitations? The shake, rattle, and roll of rocket propulsion is very stressful to the designer of payloads. The extra volume from the Space Elevator Tether Climber and the soft ride enables far more design flexibility for customer payloads going to GEO and beyond.
- Assembly at the Top of the Gravity Well: The concept is simple – have a "train station" at the Apex Anchor, 100,000 km in altitude. Then assemble any desired space system from segments delivered by the climbers. The concept lends itself to phenomenal strengths that are NOT achievable by rockets because this is a location above the gravity well and as a result, can access anywhere in the solar system rapidly (release is at 7.76 km/sec).
- Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments: This economic strategy helps transition the thinking from the early century's discussions of rocket vs Space Elevator access to space towards what can be enabled by the development of permanent space infrastructures.

A.3.0 Initial Findings: When one is wondering about Space Elevators, the question of "why" always surfaces – there are so many right answers. However, it can be summarized in two words and some simple explanation after that – Unmatched Efficiencies!

Space Elevator Insights:

Why Space Elevators? *Unmatched Efficiency*

Unmatched Efficiency is provided with a permanent space transportation infrastructure. Glaring examples: Space Elevators deliver 70% of the climber mass starting at the Earth Port to GEO while rockets only deliver 2% to GEO of their pad mass.

Chapter One: Introduction to Concepts

1.0 Galactic Harbours will Create Enterprises:

Galactic Harbours will be remarkable permanent space access transportation infrastructures which will enable so many future missions. From an engineering management perspective, the Galactic Harbour is the combination of the Space Elevator Transportation System and the Space Elevator Enterprise System (SETS). This leads to the remarkable volume encompassing the Earth Port while stretching up in a cylindrical shape to include two Space Elevator tethers outwards beyond the Apex Anchor. One of the key elements of this Space Elevator environment is that the customer product/payloads will enter the Earth Port and exit someplace up the tether. Inside the three regions (GEO, Apex Anchor and Earth Port), there will be enterprises to assemble spacecraft, refuel operational satellites, energy generation through solar power collection and, of course, businesses will emerge supporting flight operations, such as trips to interplanetary destinations. From an operational aspect, The transportation system is the "main channel" in the Galactic Harbour, moving cargo from the Earth Port to the destinations within the Harbour. In addition, the release of mission spacecraft along the total Space Elevators will enable innovative missions such as "on time delivery" of logistics to Mars settlements.

Figure 1.1: Galactic Harbour

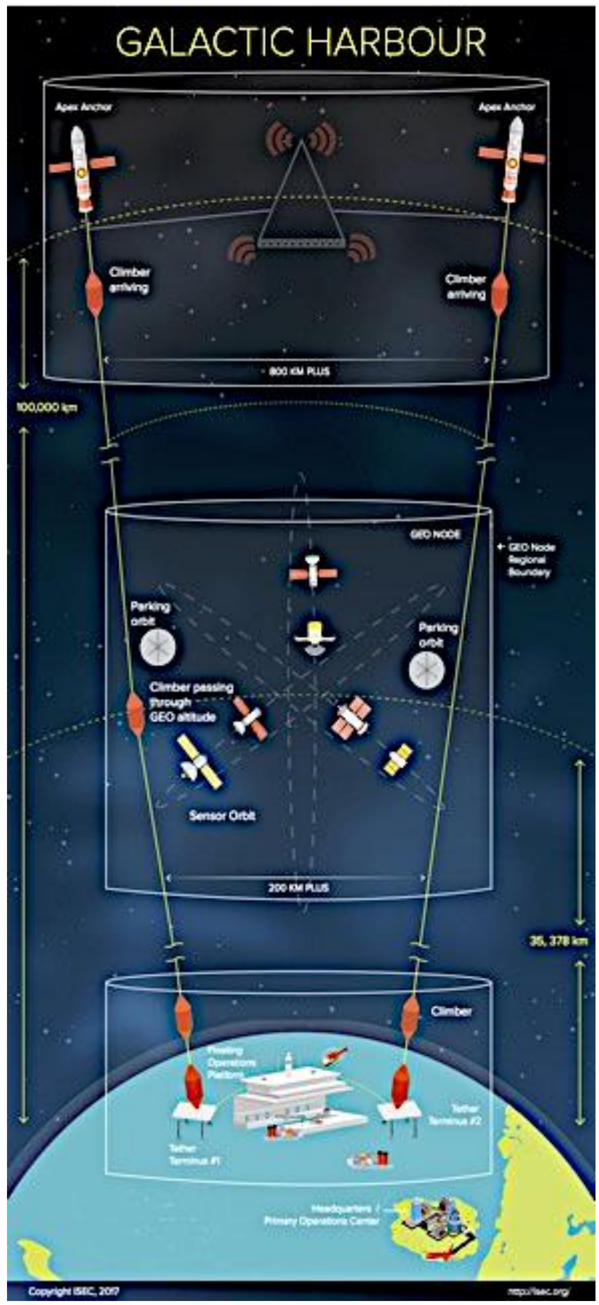


Figure 1.1: Galactic Harbour

The International Space Elevator Consortium (ISEC) and the Arizona State University (ASU) conducted several years of research on the release characteristics of Space Elevators, as a Permanent Space Infrastructure, with respect to interplanetary and CisLunar missions. [Swan, 2020a] The key discoveries from this research have been presented in many papers. Listed below are the four realizations that change the way researchers look at the strengths of Space Elevators. They change the paradigm of space travel to one of routine, daily, massive movement of cargo and environmentally friendly. Daily releases change the concept of going to Mars from once every 26 months to daily while enabling trips as fast as 61 days. When the students at ASU looked at the trip to the Moon from the top of the Space Elevator, the Apex Anchor, they discovered it took only 14 hours to reach the Lunar region; while requiring rocket motors to slow down as the space systems were moving rapidly at that point. Research into orbits and trajectories accomplished over the last five years has been focused upon Mars and Jupiter as well as several other planets. However, their research was applied to the segments Cislunar arena to help understand the meaning of their results. From this research, and other ISEC studies and activities, the realization surfaced that the Space Elevator will transform the concept of transportation for space access. These characteristics are explained in the next section, but the importance of these concepts must be pointed out to ensure appreciation of the changes: complex payloads (satellites with rocket motors) released from the Apex Anchor will travel faster, can be released daily, and can move more mass than possible by rockets, all while having ascended the tether as the Green Road to Space (no burning of rocket fuel in our atmosphere – all electric tether climbers).

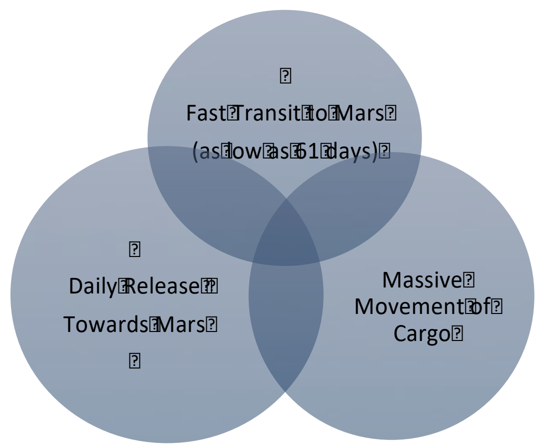


Figure 1.2: Unmatched Interplanetary Characteristics

- <u>Fast Transit to destination</u> (Mars as short as 61 days). Arizona State University (ASU) research into release from an Apex Anchor with the concept of a Lambert Problem solution shows remarkable transit times periodically during the 26 month repeating orbital relationship between Earth and Mars.
- <u>Unmatched liftoff capability</u> (14 metric tons payload per day, initial capability). Space Elevators start out with huge throughput capacity with daily liftoffs (5,110 tonnes per year- Initial Operations Capability 30,660 tonnes per year).

- Unmatched efficiencies Comparison of Rocket and Space Elevator efficiencies shows the mass delivered to GEO & Beyond by rockets is minimal while the future of Space Elevators reaches towards 70% of the mass on the ocean is delivered beyond GEO.
- Daily departures available (no waiting for 26 month Mars Launch Windows). The ability to launch each day towards Mars is a revolutionary concept vs. the traditional wait period of 26 months. Transit times for cargo can vary over the repeating planetary dance; but, they can be started towards Mars each day, simplifying the mission support concept.

1.1 Modern-day Space Elevator:

The term "Modern-day Space Elevator" has surfaced as the Space Elevator has matured through the eight Space Elevator architectures described by David Raitt in his Quest Magazine article [Raitt, 2021]. As the name implies, the Modern-day Space Elevator has evolved from a dream to a scientific reality so that we can move into the second phase of development (Engineering Development) [2020b] [Swan, 2014][Swan, 2019]. This change in maturity occurred as the limiting factor of the past (no material strong enough for the tether) has been identified. A current idea for the tether material focuses upon Single Crystal Graphene (SCG as a new material with 2D characteristics). This new material has been shown to be strong enough and can be manufactured long enough. SCG is currently being tested, as an initial phase of the tether development; and is proving to be very promising. Adrian Nixon (Nixon is on the ISEC Board of Directors and an expert on development of 2D materials) believes the material will be ready in time for Space Elevator development He recently stated: "The manufacture of tether-quality material for a space elevator still needs more development, but the trajectory to a high-quality industrial product is clear. It is not unreasonable to think that, as this graphene process continues apace, space elevator tether production could begin in five to 10 years using graphene as its material." [Nixon, 2023] Along with the thirteen ISEC Space Elevators research reports (and the two IAA reports and the Obayashi Corporation report), the baseline for the development of Space Elevators can be defined with processes outlined in how to proceed into this mega-project. The Space Elevator architecture baseline is developed and explained in "Today's Space Elevator," [Swan, 2020b] – the ninth ISEC 18-month study report. Currently, the six major thrusts for the development of the Modern-day Space Elevator focus on the following statements:

- Space Elevators are ready to enter Engineering Development
- Space Elevators are the Green Road to Space
- Space Elevators can join advanced rockets inside a Dual Space Access Architecture Strategy
- Space Elevator's major strength as a permanent transportation infrastructure is its ability to move massive cargo to GEO and beyond daily, safely, inexpensively and accomplish this environmentally neutral.

- Inherently have the economic strengths of strategic investment, ubiquitous access, and uninterrupted exchange of resources from the Earth's surface through the GEO region toward Cislunar and Mars.
- Space Elevators, as transportation core, attract and logistically enable future enterprises.

1.2 Space Elevator Developmental Status:

After the two International Academy of Astronautics study reports [Swan, 2014 & Swan, 2019], rapid improvement of the technologies needed for Space Elevator development has led to the "A Road to the Space Elevator Era."[Swan, 2019] These two studies included many engineering activities leading to multiple Preliminary Technological Assessments across the technological arena. This assessment surfaced after:

- ISEC produced ten year-long studies with resulting reports (Appendix D).
- The International Academy of Astronautics produced two study reports supporting the concept [Swan, 2019].
- The Obayashi Corporation conducted an independent study that focused upon humans on the Space Elevator and massive movement of space based solar power satellites to GEO. [Ishikawa, 2016]
- Internal ISEC assessments were provided by a series of ISEC Chief Architect's Notes. (See www.isec.org).
- The agendas of major international space agencies are aligning to target human presence and/or settlements on the Moon and Mars, thereby establishing demand pull.

This leads to a position by ISEC that the:

> Space Elevator development has gone beyond a preliminary technology readiness assessment and is ready to enter initial engineering validation testing -- leading to the establishment of needed capabilities. [Swan, 2020b]

1.3 Permanent Space Access Infrastructures: The building of the US transcontinental railroad was such a venture as the movement of commercial product from East to West and West to East was projected to be very valuable. These types of statements are commercially powerful when a projected technology is going to transform the "way of doing business." These transportation transformational leaps have enabled remarkable capabilities in communications, transportation, sports, business, and/or leisure. One ongoing transformation is electric cars with a significant lowering of environmental impacts from driving. Space Elevator electric tether climbers can be seen as one of these environmental game changers – no burning of rocket fuels inside our atmosphere or leaving of space debris in LEO. Indeed, a parallel between tether climbers and Tesla and Mercedes electric vehicles.

So, why will they come to support Space Elevators? The answers are straightforward – transportation stimulated profit! In addition: a) such commercial investments will lead to new industries, b) environment saving liftoffs, c) stopping or slowing down global warming, d) enabling massive power distribution across the globe, and e) enabling robust movement off planet inexpensively and with green operations. This commercially driven permanent transportation infrastructure will create a "bridge to space" – and who doesn't want a bridge after struggling to beat the gravity well for every launch over the last 60+ years.

Space Elevators' remarkable transformational capabilities as a permanent space access infrastructure dwarfs traditional space access. As a baseline, this transportation infrastructure provides to the user all the characteristics of a bridge --a permanent, daily, and routine approach for moving logistics – and on schedule"

The establishment of settlements off planet, the creation of a global power supply constellation, the blocking of the sun's rays, and other advanced concepts, will require massive movement of equipment, supplies, habitats, propulsion modules, energy sources, and people to the top of our gravity well and beyond. Humanity has beaten the gravity well at the basic level with chemical rockets; however, to supply massive infrastructure to GEO and beyond, a permanent transportation infrastructure must be built. If we are to satisfy our critical future needs of Space Solar Power and movement to Moon and Mars, a commercially successful transportation approach must be initiated along the way. As this is realized, the bridge builders will come with investors supporting the development of the transformational permanent space access transportation infrastructure.

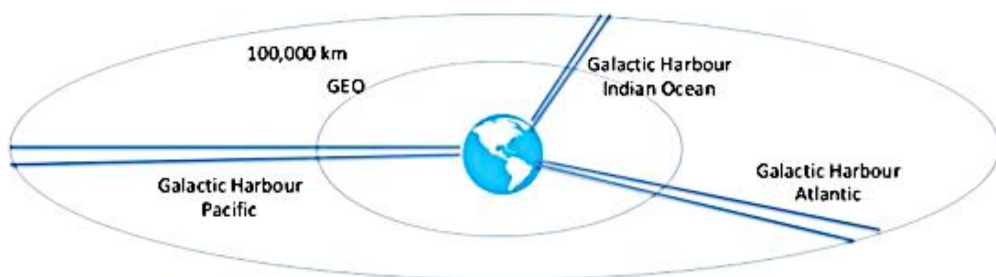


Figure 1.3: Initial Operational Capability

1.4 Advanced Rockets: Advanced rockets are being developed by several nations. The leadership of the American commercial industry is amazing and will result in at least the Starship (and Falcon Heavy) from SpaceX and the New Glenn from Blue Origin. In addition, there are new vehicles on the drawing boards in China, France, and other locations. The recent move to reusable, reliable, and cheaper rockets has disrupted the marketplace and ensured that humanity will have a better avenue off planet, safer and more user friendly. This will be discussed inside chapter 4 on advanced rockets, but a significant point is to ensure everyone recognizes the remarkable changes to the industry occurring as we progress forward. There are several significant questions on the table as we progress: who will be first with a small settlement on Mars or Moon? Who will develop space solar power and launch the components of a 2,000 tonne spacecraft to be assembled in GEO? All these dreams and programs require transportation characteristics as we move into a whole new era of spaceflight. It was stated, by Garretson and Havard, that "Starship, due to its reusability, size, and power, will dramatically improve access to low Earth orbit by yielding low-cost launches of payloads up to 100 metric tons. This will support the expansion of public- and private-sector activity in space, including space tourism, space-based solar power, and the installation and servicing of telecommunications and military satellites." [Garretson, 2023] A very good diagram (source BBC News) is shown here comparing the historic vehicles and the Starship. [Garretson, 2023]

1.5 Dual Space Access Architecture: When we look at the Moon and dream of spaceflight, we forget how extremely difficult it was to accomplish, both in energy and design complexity. Tsiolkovsky's remarkable rocket equation consumes so much mass to achieve orbit that, historically, we have been greatly restricted as to what can be delivered. Now that we have decided to return to the Moon and on to Mars in a combined international, government and commercial effort of great magnitude, we need to expand our vision of 'how to do it.' It would seem that the establishment of a more robust infrastructure with reusable rockets and permanent Space Elevators Is the answer. This ISEC Study will discuss the strengths and weaknesses of the components of this combined architecture with the purpose of placing mission equipment and people where they need to go and when they need to be there. The multiple destinations, complexity of orbits, magnitude of each transition to orbit, and infrequent launches currently means that the difficulty of fulfilling the dreams of the many is a monumental "reach." Expanding space access architectures to include Space Elevators will enable a robust movement off-planet.

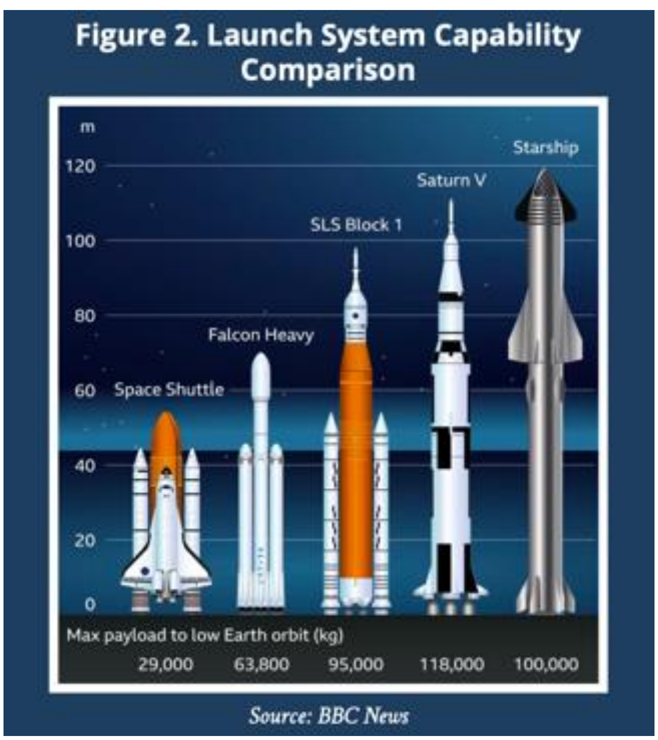


Figure 1.4: Rocket Comparisons

During the discussions for this study, we considered the strengths of rocket launches along with their difficulties. We recognize there are three principal strengths: 1) rockets are successful today and great strides are forecast for the future, 2) reaching any orbit can be achieved and, 3) rapid movement through radiation belts for people enables flights to the Moon and Mars. In addition, the strengths of the Space Elevator as a permanent infrastructure with daily, routine, environmentally friendly and inexpensive attributes is examined. The Space Elevator strengths will be compared to the difficulties of executing a Space Elevator developmental program. Space Elevators will not be ready for the initial human migration off-planet. However, once settlements are established on the Moon and Mars using rockets, Space Elevators will enable robust growth of them.

Figure 1.5, Dual Space Access
(Amelia Stanton Image)

The essence of this Dual Space Access Strategy is that the two methods of achieving spaceflight are complementary and compatible rather than competitive. Each has its own strengths and weaknesses. Future rockets are being designed now to deliver payloads to the Moon. Next comes their growth in launches, in both number and payloads, occurring in the second half of this decade with the 30's having mature rocket architectures. Development on the Moon, and initial bases on Mars, will be well along by the early 30's. By the end of that decade, Space Elevator infrastructures will be incrementally built with more and more capability leading to many complementary missions. Our vision towards the turn of that decade is that there will be six Space Elevators located around the equator helping with the delivery of massive amounts of payloads to GEO, Moon, and Mars. Our concept will have daily departures to each, rapid travel to each (as fast as 61 days to Mars and 14 hours to the Moon), and with massive amounts of payload to support people at both destinations. A good way to express the team arrangement could be:

Rockets to Open up the Moon and Mars with
Space Elevators to supply and grow the settlements.

The essential conclusion is that a combined architecture provides overlapping strengths and reduced shortfalls. The strengths of this Compatible Space Access Architecture will enable human migration off-planet robustly and safely. Space delivery can become as routine as Fed-Ex, Amazon, and DHL are today on Earth. One significant conclusion is that using the strengths of both parts of this architecture enables so much more than the individual parts.

During the research over the last few years, it has become clear that the access to space requires a strategy of Dual Space Access Architecture to ensure the strengths of both are leveraged for the phenomenal missions being planned. Rockets will be the principal mover of humans for the foreseeable future; while Space Elevators leverage their characteristics to move heavy cargo daily. Two things are important to keep in mind with this remarkable concept of Dual Space Access Architecture:

1. The Space Elevator community admires the remarkable progress being implemented within the rocket arena. Reusability, reliability, and redundancy with significant increase in launch pace are all remarkable. However, we must remember that the shortfalls of the basic concept associated with the rocket equation allows only 4% of pad mass to reach LEO, 2% to GEO or lunar insertion, with only 0.5% to any surface (Mars or Moon). The new strengths of rockets are remarkable; however, the rocket equation cannot be beaten.

2. The Space Elevator permanent space access infrastructure is called the Green Road to Space and has unmatched efficiencies in delivery statistics because it raises payloads with electricity and does not leave debris behind – 70% of the tether climber is payload while the other 30% is reusable.

With these two realizations, the combining of the capabilities to fulfill future missions such as support to the Lunar Village, delivery of 3,000,000 tonnes to GEO for space solar power missions, delivery of 1,000,000 tonnes to Mars to support human settlements, and all the historic missions that will be expanded as they have "easier" access to GEO. This Dual Space Access Strategy leverages the strengths of both capabilities to raise payloads to orbit and beyond – including the lunar surface. Indeed, Space Elevators, supporting the Moon Village, will be remarkable in that they will be:

- Transformational in how things get to space and support operations.
- Dual Space Access Architecture will leverage the strengths of rockets and Space Elevators
- Green: lifts payloads with electricity and enables Space Solar Power satellites to GEO with a timely schedule
- Ready for Development –Space Elevators have entered engineering testing.
- Create an economic boom as regions open up for commerce because of their routine, daily, and massive lift capabilities.
- They will allow assembly at the top of the gravity well will allow storage, repair, assembly, and timely release of large space systems for any mission, including Astronaut rescue.

1.6 Green Road to Space: Space Elevators will be permanent transportation infrastructures with a zero-carbon footprint. The beauty of a permanent space access infrastructure that is Earth friendly is that it can, in addition to lifting massive payloads without pollution, enable missions to help the environment, such as Space Solar Power. A recent ISEC study report, "Space Elevators are the Green Road to Space," [Eddy, 2021] shows how Space Elevators enable missions that cannot reasonably be accomplished with rockets; and thus, they can help improve the human condition on Earth. Space Elevators can move millions of tonnes of cargo with timely delivery to multiple destinations without contributing to global warming. Also covered are the "green missions" that are enabled by a Space Elevator architecture; space solar power, Sun-Moon L-1 solar shade and the permanent disposal of high-level nuclear waste. It assesses the environmental impact from development and operations of Space Elevators. The title of the report reflects the conclusions. This net assessment trade study conducted by ISEC showed that:

> "Space Elevators and Galactic Harbours are Big Green Machines designed to improve the Earth's environment through two significant contributions. The first is the remarkable "zero-emission" lift of cargo to space - reducing environmental impacts from rocket launches. The second is the ability to deploy massive systems to GEO and beyond that … minimize… rocket launches by becoming a partner in Dual Space Access Architecture." [Eddy, 2021]

1.7 Summary: As the Space Elevator is moving towards engineering test phase, it is recognized that development of multiple Space Elevators is not only beneficial, but essential for the future of humanity. The future can be astounding because they can deliver megatons of logistics support that can save the planet's atmosphere by enabling a space solar power constellation of 2,000+ tonne satellites and provide a robust, daily, green approach for humanity to move off planet. When one takes into account the rocket equation's restrictions on delivery statistics to both GEO (2% of launch pad mass) and beyond (<1% of launch pad mass) and the extraordinary mass being asked for at these locations, the implementation of a Dual Space Access Strategy seems essential. This combination of strengths of advanced rockets and Space Elevators for lifting massive loads within a collaborative and cooperative approach leads to a bright future enabling the dreams of many.

Space Elevator Insights:

The Modern Day Space Elevator will be transformational
as a permanent space access infrastructure:

- Space Elevators are ready to enter Engineering Development
- Space Elevators are the Green Road to Space
- Space Elevators should join advanced rockets inside a Dual Space Access Architecture Strategy
- Space Elevators, as transportation core, attract and logistically support massive future enterprises.

Chapter 2: Dreams of Many lead to Visions

2.0 Leadership Mission: One very active organization dealing with the space arena is the National Space Society (NSS) based at Kennedy Space Center. The NSS's mission is: "To promote social, economic, technological, and political change in order to expand civilization beyond Earth, to settle space and to use the resulting resources to build a hopeful and prosperous future for humanity." Within their membership are several of the major leaders looking beyond Low Earth Orbit and determining humanity's future at so many levels. This chapter will illuminate the remarkable dreams, visions and missions that should be driving the development of missions, systems, jobs, projects, and dreams. This chapter will try to put the current Race to Space within a perspective of advancing transportation systems that are on the drawing boards.

2.1 Projected Growth: Growth of space missions over time has been remarkable and will accelerate over the next few decades: customer needs for a Modern-Day Space Elevator have surfaced; however, in general the customers just do not recognize it yet. As such, big questions surface as mega projects are initiated: who are the customers and what will they demand? The first identification of potential customers for a Dual Space Access Architecture was detected in the International Academy of Astronautics' four-year study entitled: "Space Elevators: An Assessment of the Technological Feasibility and the Way Forward." [Swan, 2019] Table 3.1 shows the projected demand from a different perspective based upon past history and expansion into GEO leveraging a permanent space access infrastructure. This evaluation of future demands was accomplished across many countries and 47 IAA academicians leading to an intriguing set of missions for Space Elevators.

Table 2.1: Projected Demand (metric tonnes per year)

Demand in Metric Tons	2031	2035	2040	2045
Space Solar Power	40,000	70,000	100,000	130,000
Nuclear Materials Disposal	12,000	18,000	24,000	30,000
Asteroid Mining	1,000	2,000	3,000	5,000
Interplanetary Flights	100	200	300	350
Innovative Missions to GEO	347	365	389	400
Colonization of Solar System	50	200	1,000	5,000
Marketing & Advertising	15	30	50	100
Sun Shades at L-1	5,000	10,000	5,000	3,000
Current GEO satellites + LEOs	347	365	389	400
Total Metric Tons per Year	58,859	101,160	134,128	174,250

Some intriguing insights can be derived from this table of traditional and new missions. Many of these missions are not possible with rockets for any number of reasons, but the major impact is the delivery statistic of less than 2% to GEO and beyond. Massive movement of cargo can enable these innovative and challenging missions. Obviously, the community at that time did not foresee a major push by a commercial corporation to settle Mars or develop a Moon Village. Both would be much faster and significantly safer with Space Elevators. However, there will be a remarkable change in the last half of this decade with the execution of the Starship Program. With their projected carry capacity to LEO (somewhere between 100 and 150 tonnes), the dreams of many can be initiated. (it will take a second launch to support a single Starship to the Moon and a total of five launches to have a single mission starship to Mars.) The rocket equation is still valid. Reusability is a brilliant approach; however, the rocket equation still eats up resources.

The second description of future global needs occurred in a 2020 ISEC study entitled "Space Elevators are the Transportation Story of the 21st Century." [Swan, 2020a]

"We believe the future will enable massive movement of payloads while establishing Space Elevators as the Green standard. This will lead to remarkable missions in locations at GEO and beyond. Customers will ask for and receive massive delivery of payloads to unique locations. The mosaic of space will expand to fulfill the dreams of many because there will be a permanent infrastructure to space joining advanced rockets in a Dual Space Access Architecture. Mankind will no longer just be going to space, they will be conducting exploration, research, operations, trade and commercial enterprises robustly. This ability of the Space Elevator transportation infrastructure to become a logistics giant will ensure a new economic engine on (and off) Earth.

- "Traditional Geosynchronous Orbit Missions: Satellites such as weather, communications, and governmental missions will be enhanced and expanded as access becomes easier and cheaper. There are over 400 active GEO satellites as of October 2018 conducting these missions.[1] When the cost and simplicity of operations goes way down, this number will escalate with non-traditional missions.
- Revolutionary Geosynchronous Orbit Missions: New missions will be supported: refueling and repair of ailing satellites, construction of new systems larger than a single payload from tether climber or rocket fairings, and new enterprises not even thought of during the first three decades of this century. This will be a huge growth area when people realize the opportunities. One of these missions will be Space Solar Power transmitting electrical energy to the Earth's surface at remarkably low prices.
- Lunar and Interplanetary Missions: These include two reference missions (Moon Village and Mars Colony; see below for expansion); robotic missions to anywhere in our solar system; exploration missions to Moon and Mars and beyond; human

[1] Wikipedia, 23 March 2020. https://www.google.com/search?

missions to L-5 type colonies; and robotic missions beyond our solar system - on to the stars will be discussed." [Swan, 2020a]

When addressing the development of a major permanent infrastructure for space access, can we rely on remarkable advanced rockets (SLS, New Glenn, StarShip, Falcon Heavy and so many more)? We must remember the rocket equation is still dominant. The delivery statistic of about 2% of the launch pad mass reaches GEO and beyond (also remember less than 1% reaches lunar or planetary surfaces) restrict the movement of mass. Space Elevators avoid the rocket equation and delivers 70% of the pad mass to GEO and beyond with the other 30% being reused. This unmatched delivery statistic is a main thrust for Why Space Elevators.

With the realization that GREEN Delivery of massive cargo to GEO and beyond is achievable, the question becomes one of what missions requiring great mass could the Space Elevator enable? During the 2021 ISEC study report (Space Elevators are the Green Road to Space), four missions were identified and defined. This ISEC study will identify mass required in individual chapters, but this is a starting point for the whole discussion. Who needs massive payloads to GEO and beyond, inexpensively, safely, daily, robustly, routinely, efficiently – all while being environmentally neutral? This report brings six missions together as Reference Missions to include a Mars settlement, a Lunar village, Space Solar Power Constellation of satellites, planetary defense, solar system science missions, and Earth Sunshades. Table 1 shows this set of requirements.

Table 2.2: Reference Destinations - Mars, GEO & Moon [Swan, 2020a]

Reference Mission	Major Benefit from Space Elevators	Comment
Space Solar Power	5,000,000 tonnes to Destination	Power to 12% of Earth's population while being environmentally neutral.
Mars Settlement	1,000,000 tonnes to Destination	Supporting a settlement with logistics has been underappreciated in the movement off-planet
Moon Village	500,000 Estimated tonnes to Destination	Developing and supporting a settlement of residents will require massive movement from Earth
Earth Sun Shades	20,000,000 tonnes to L-1 between Sun and Earth	Reducing energy from the Sun that reaches the Earth's atmosphere, thus reducing global warming.
Planetary Defense	Assembly and storage above the gravity well	Building an observation tower and garage for storage and assembly of large space systems leading to remarkable velocities towards targets
Solar System Science	Assembly and storage above the gravity well	Building garage for storage and assembly of large space systems to be released at high velocity towards any planet in our solar system

A few other visions (from their websites) that can be enabled by massive movement of cargo to support customer needs would be:

- National Space Society Vision; "People living and working in thriving communities beyond the Earth, and the use of the vast resources of space for the dramatic betterment of humanity."
- Blue Origin's Visions: "Millions of people living and working in space" and "I am going to build the road to space." (Mr. Bezos)
- SpaceX's Vision: "Making Humanity Multi-planetary,"
- NASA has the Artemis Program for female boots on the Moon by 2024.
- "ESA Director General Jan Wörner and NASA Administrator Jim Bridenstine have signed a Memorandum of Understanding (MoU) to take Europe to the Moon." [Wörner, 2020].

2.2 Visions to Implement (example 1- Mars): What are these unique missions that are dreamed of and being planned? This process of moving from dreams to reality has been around forever. Future of movement off planet has been accelerating over the last 100 years. We first recognized how hard it is to accomplish grand space-based visions. In the last six months the Space Elevator has moved into engineering development. One dream illustrates the problem. One million tonnes of cargo delivered to Mars' surface. Our estimate is 100 tonnes for each mission Starship to Mars with four other launches into LEO to support it. This leads to 50 years at 1,000 launches per year to fulfill this dream when using Starships, or 50,000 launches. While a mature Space Elevator capability of 170,000 tonnes per year to GEO and beyond by a full operational capacity leads to only seven years to fulfill SpaceX's needs, while being "green."

Settlement on Mars can be established by Starships in the near term and movement of people by Starship spread over time. A key is that the massive logistics tonnage needed on the surface will be delivered by Space Elevators, after rockets initially establish the settlement in a strategy called Dual Space Access Architecture. The strategy combines Space Elevators with advanced rockets in a complementary manner to achieve the dreams of a Martian settlement.

2.3 Space Solar Power – a major example: To understand the significance of these numbers and the importance of the timing, an example of a potential demand pull from a customer is illustrated. Space Solar Power needs the massive movement of segments of their 2,000 tonne satellites (ranges to 8,000 tonnes each) to GEO. The program could leverage the Dual Space Access Strategy by using rockets for prototype placement in LEO and then GEO during the developmental years – and then leverage Space Elevators for the majority of the heavy lifting of operational satellite segments.

As it has been said, ‘good ideas are good ideas ONLY if you have a passionate advocate for that idea.’ In the space solar power arena - and there are many proponents around the world - most ensure their research and experimentation are supported by Dr. John Mankins. He has taken the concepts of Dr. Peter Glasser and has developed them into realizable engineering concepts that can achieve a monumental task. Dr. Mankins has stated that he believes a robust space solar power architecture would "Stop global warming, and even reverse it." [Mankins, 2013] However, to achieve his goal of replacing 12% of the global electrical power demand by 2060 with energy from Geosynchronous orbit, he needs five million tonnes [Mankins, 2019] of operating satellites (acres in size) delivered to a 36,000 km altitude. His objective is to eliminate 100's of fossil fuel burning plants. This is a remarkable mass number when you consider the rocket equation and realize that to accomplish this goal requires 250 million tonnes on the launch pad at liftoff (2% to GEO). If you take Mr. Musk's estimate of 21 tonnes to GEO (for his Starship booster), then that would be over 238,095 launches - even at 3 per day that is 217 years.

These two missions illustrate an example of what we call a demand pull for the Space Elevator. To reach Dr. Mankins' goal, Space Elevators should be a part of his implementation approach for his project….. are a mature infrastructure (six Space Elevators around the equator - three Galactic Harbours with a capacity of 79 tonnes per day per elevator - say 2045) we will be able to provide 173,010 tonnes to GEO per year. This leads to 29 years during his development time.

Demand pull is when a future customer needs something and asks the developer to supply it. A customer needs a capability by a certain time and will help to mature a technology and start a program with the offer to be an "anchor tenant." Two of Space Elevator demand pull customers could be: (a) SpaceX needs 1 million tonnes to Mars and (b) Dr. Mankins needs five million tonnes to Geosynchronous. It would seem they should now be demanding capability from Space Elevators.”

How many rocket launches are needed to support each of the below missions, spread out by year, and to where? How many Space Elevators climber loads would be needed for each mission, spread out by year to where? Two examples:

Table 2.3: Customer Dreams/Demands

	Customer Demand	Delivery Approach	# Launches Planned	Number of Launches Required
Mars Settlement	1,000,000 tonnes	Starship with 100 people and 100 Tonnes Cargo - five launches to support a Starship to Mars	over 1,000 per year (or about 3 per day)	1,000,000 / 100 = 10,000 x 5 > 50,000 launches and 50 years
Space Solar Power	5,000,000 tonnes	Starship with 21 Tonnes Cargo to GEO	over 1,000 per year (> 21,000 tonnes/yr)	5,000,000 / 21 = 238,000 launches

When listening to these dreams, a simple conclusion Becomes: Space Elevators will Enable Dreams of Others!

2.4 New Missions: In a recent paper by Fitzgerald (the Chief Architect for ISEC) he summarized four new missions for Space Elevators. [Fitzgerald, 2022]

> "Missions Enabled by an operating Space Elevator Transportation System: Several of the missions for the permanent space transportation infrastructure have been discussed such as Space Based Solar Power and the support to the movement off-planet. However, there are several that have not been discussed out in the space community. Several of these would fall into the following concepts.

1. "The Logistics Transshipment Mission: Simply stated, the Logistics Transshipment Mission manages the Galactic Harbour's cargo delivery service, the final delivery of the cargo to customers. It starts with identification and tracking from the initial loading at a customer's production facility, tracks it through its transportation history, stores the cargo until the enterprise customer requires the cargo, and then delivers as the customer requests at its destination.

2. "The Rescue Mission: Prepare for, store for immediate release (in the GEO Region and the Apex Anchor) and provide emergency response times appropriate for any crisis. This would include vehicles to replace damaged capsules, power source to replace failed sources, oxygen (and other supplies) for critical shortages, and medical assistance as needed.

3. "The (Extended) Situational Awareness Mission: This new and necessary mission envisions a Galactic Harbour operations center working closely with the Situational Awareness authorities regarding who/what is in each of the Regions (Earth Port, GEO and Apex Anchor), who/what is approaching the Regions, and keeping track of all those items - including debris and space detritus that might be wandering by and through the Regions. In addition, monitoring all of the objects inside the designated region of concern must be continuous with forecasting of motion to ensure no conjunctions, including the tether from Earth Port to Apex Anchor.

4. "The Explore the Solar System Mission: This mission leads to Transformational Release of Scientific Payloads from the Apex Anchor – Any Size, Every Day, Anywhere in the Solar System. Two main strengths enable these claims of revolutionary Scientific Payloads. The first is the ability to raise massive cargo against the Earth's gravity while being friendly to our environment. The beauty of Space Elevators is that they raise massive cargo with electricity [hence – "the Green Road to Space"]. The second operational capability is that it can release scientific spacecraft each day towards solar system bodies with great velocity (minimum 7.76 km/sec)."

2.5 Strategic Investment Perspective:

As a differentiation between rockets and Space Elevators, Eduardo Pineta and Kevin Barry explained a strategic investment perception: [Barry 2021]

> "This paper analyzes the economics of Space Elevators as infrastructure and a platform, utilizing relevant historical examples, such as the standardization of shipping containers, the transcontinental railroad, and the Panama Canal to explore its economic value and developmental impact. Infrastructure, at its core, provides value through the reduction of transaction costs. Therefore, trying to close a business case for infrastructure by charging high transaction costs is a doomed venture. However, expanding the picture to view the impact on the economy from increased access to value and more efficient markets through lower transaction costs and infrastructure becomes a very lucrative, stable, and reliable investment. Cost per kilogram is the language of rockets -- strategic investment, ubiquitous access, and uninterrupted exchange of resources are the staples of Space Elevators."

While understanding the economic "value proposition" approach towards development and operations, the logical recognition of tremendous empowering characteristics dominates the statement that we must build Space Elevators as soon as possible! The time is now for the Green Road to Space!

2.6 Conclusion:

From the Climate Crisis to the desire to move off planet, future demands will be extraordinary. To stop Global Warming and ensure humanity has sufficient energy for future generations, Space Solar Power must be immediately initiated – approximately five hundred 3,000 tonne satellites at Geosynchronous Orbit to supply 12% of the global baseline electrical need by 2050 (replacing most coal burning plants). In addition, communities off-planet will need greater than 1,000,000 tonnes beyond GEO. To reach these numbers using rockets (at less than 2% delivery statistics – and 20 to 50 tonnes capability to GEO) something like three launches a day is expected. This exorbitant demand for rockets – burning fuel in our atmosphere – would be hazardous to the environment. When putting this all together, Space Elevators' capabilities will be mandatory for the next significant step into the future. We must build upon the concept of dual space access strategy combining the strengths of both advanced rockets and Space Elevators.

A first step into our future must be to build Space Elevators. A leap into this bright future for humanity by using individual launches alone is counterproductive. There must be a permanent transportation infrastructure that can move massive logistics to GEO and beyond with environmentally friendly operations. This can be accomplished by starting with the Initial Operational Capability of Space Elevators at 30,000 tonnes per year to GEO and beyond (estimate 2037) growing to the Full Operational Capability of

170,000 tonnes per year (estimate 2047). Current and near-term rockets cannot grow to this capability without damaging our atmosphere.

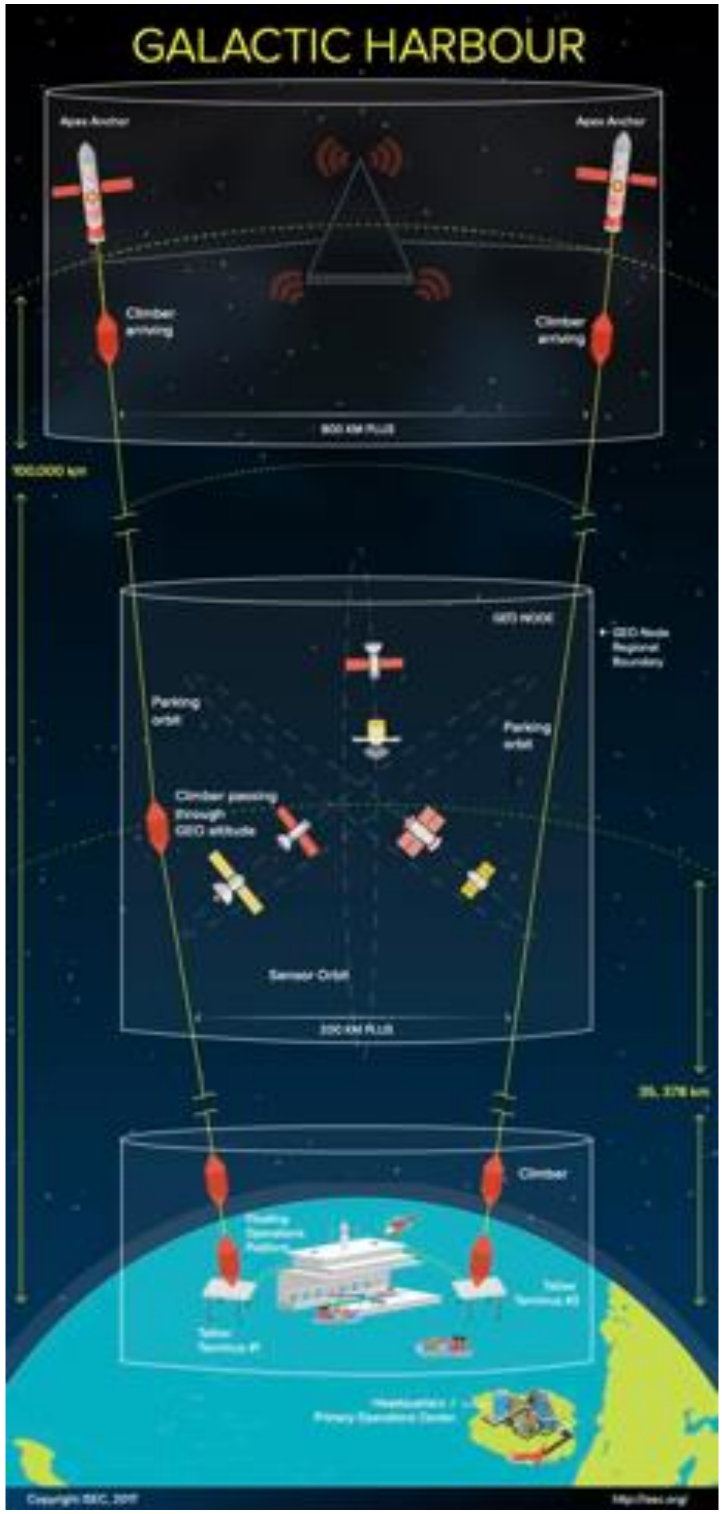


Figure 1.2: Unmatched Interplanetary Characteristics

Space Elevator Insights:

Space Elevators will open space for humanity
while saving the planet from global warming.

A first step into our future must be to build Space Elevators. A leap into this bright future for humanity by using individual launches alone is counterproductive. There must be a permanent transportation infrastructure that can move massive logistics to GEO and beyond with environmentally friendly operations.

Section B: "If we build it – They will Come!"

B.0 "If we build it – they will come!" This phrase has driven inventions and developments from the beginning of time. The Iridium program is still operating after 24 years. When starting, their driving motivation was "Cell phone service anywhere anytime." These types of statements are commercially powerful when a technology is going to transform the "way of doing business" and enable communications, transportation, sports, business, and/or leisure. The remarkable strengths of Space Elevators moving mass out of Earth's gravity well are their transformational properties for so many opportunities for the future. Just a few of them are:

- Massive daily liftoffs to GEO, Moon and Mars. - transportation
- Global inexpensive electric power to anyplace with environmentally friendly operations. Power infrastructure & Global climate improvement – Space Solar Power
- Lower the Earth's temperature by 1.5 degrees. Global Climate - Sunshades
- "Depart for anywhere, any day, with massive science payloads." Planetary Science
- Save the Planet; Planetary Defense with short warning times, immediate release, and rapid velocities for rapid intercept.
- Massive Science Satellites leaving the solar system at excessive speeds.

Clearly, the establishment of settlements off planet, the creation of a global power supply constellations, the partial blocking of the sun's rays, and other advanced concepts, will require massive movement of equipment, supplies, habitats, propulsion modules, energy sources, and people to the top of our gravity well and beyond. Humanity has beaten the gravity well at the basic level with chemical rockets; however, to supply massive support infrastructure, improved by two orders of magnitude, to GEO and beyond, a permanent transportation infrastructure must be built. This is not to be accomplished by exploration programs, although exciting, critical and impressive – one trip every one or two years is not supportive of the demands of commercial space and saving our planet. As this is a preliminary look at future rockets and future Space Elevators, there is much that is estimated. This report will be using projected mass movement for both Space Elevators and advanced rockets, as reference inside each chapter. The best estimates that are available today, with expanded estimates into the future, used for comparison purposes. These numbers are all projections of a future capability, built on creative engineering developments, funding, demands, hope, humanity's thrusts into "New Space" (represents commercial imperative pushing space projects) and movement off planet. This commercial imperative circles back to the initial words of this Section introduction: "If we build it – they will come!"

Looking at current projections of four extremely important missions for mankind, the magnitude of commercial support infrastructure required to enable the tremendous leap of humanity to GEO and beyond demands permanent infrastructure – Space Elevators.

1. The first is the phenomenal challenge we all have with respect to global warming and our climate crisis. It seems the necessary implementation of massive satellites at GEO to create clean energy at a huge scale must be undertaken by energy companies of the future. The current estimates show the "saving of the environment" with friendly external power sources could actually make a huge profit for these companies providing operational systems. The demand for future electricity is huge while environmentally sound approaches require massive investments early on. Power companies can make massive profits into the future with timely investments now – and perhaps early government stimulus in critical technologies.
2. It is obvious that SpaceX's approach to creating a settlement on Mars is structured around the travelers paying for the transit and initial settlement establishment. Their philosophy is that there is a recognized demand for a commercially supported off planet settlement. This insight will be necessary to fulfill those customer demands based upon a commercial imperative kicking in and ensuring plenty of investment in those trips to Mars. SpaceX is driving down the cost of lift while the desire to fly to Mars is developing as a true potential for thousands of travelers. Once again, if they build it – they will come.
3. A parallel commercial thrust is structured around the perceived need to create a multi-planetary species. Several global leaders have endorsed this concept, and many are investing in programs to lift people off planet (commercially) and initiate movement towards this objective. (New Glenn & SpaceX)
4. In addition to these commercially sponsored ventures, there is a whole movement of governments looking toward the Moon. They "are building it" so people will follow the visits of the Artemis program (23 countries as of 27 Dec 2022) and Chinese/Russian research base project to the South Pole of the Moon. There are many levels of motivation to accomplish a trip to the Moon from leisure (Dear Moon) to very serious endeavors such as mining Helium^3.

B.1 Mass to GEO & Beyond Comparisons: When comparing future Space Elevators and advanced rockets, customer demands and the future projected capabilities are the drivers. A conclusion at the end of the study report says: a dual space access strategy is a logical approach to expanding off planet and raising large quantities of mass to mission orbits of GEO and beyond. The chapter on Space Solar Power will discuss the need for power from geosynchronous while showing the required mass needed to support these programs. In addition, the discussions on space settlements will evaluate customer needs and the availability of rides to Mars for the estimated one million travelers creating a remarkable off world community.

The multiple charts and tables below will be used to compare and contrast Space Elevators and Advanced Rockets with the full understanding that the projections of mass movement to GEO and Beyond are: a) historic estimates for Space Elevators (from

2013 and beyond) (Sec B.2) and b) a futuristic projection of SpaceX's capability (Sec B.3), based upon SpaceX's estimate of 1,000 launches a year for support to Mars. The development of these numbers is explained in Appendix D. Throughput estimate of Galactic Harbours. Section B.4 shows the summary table and chart that will be used in each chapter of this study.

B.2 Introduction – Space Elevator Capacity per year: The initial global study report from the Academy of Astronautics [Swan, 2014] laid out a reasonable breakout for mass transportation into basically a two-step process: Initial Operation Capability (IOC) and Full Operational Capability (FOC) across the first few years of Space Elevators. The IOC loading is 14 tonnes of payload supported by 6 tonnes of tether climber. In the same year (2013), the Obayashi Corporation designed a system that would carry passengers to GEO and beyond with a system mass of 100 tonnes per trip. This resulted in a mix of 79 tonnes of payload and 21 tonnes of climber mass. Over several years of the International Space Elevator Consortium's annual conferences; an agreement evolved at a global level, that the Full Operational Capability of Space Elevators would include humans and be based upon the Obayashi Corporation estimates of mass to GEO. This resulted in a schedule of development and growth with mass delivery capability of approximately:

- Mass Movement Description Estimates
    - IOC payloads of 14 tonnes on each tether climber (6 tonnes) per day.
    - FOC payloads of 79 tonnes per tether climber (21 tonnes) per day.
- Operations Date (IOCs)
    - First IOC operational tether within first Galactic Harbour- 2037
    - Second tether within first Galactic Harbour - 2038
    - Second Galactic Harbour with two Space Elevators - 2040
    - Third Galactic Harbour with two Space Elevators - 2041
- Operations Dates (FOCs)
    - First Galactic Harbour with one FOC Space Elevator and one IOC SE - 2047
    - First Galactic Harbour with two FOC Space Elevators - 2048
    - Second Galactic Harbour with two FOC Space Elevators - 2050
    - Third Galactic Harbour with two FOC Space Elevators - 2051

The resulting spread of mass to orbit reflecting the growth of capability around the world is shown in the next chart:

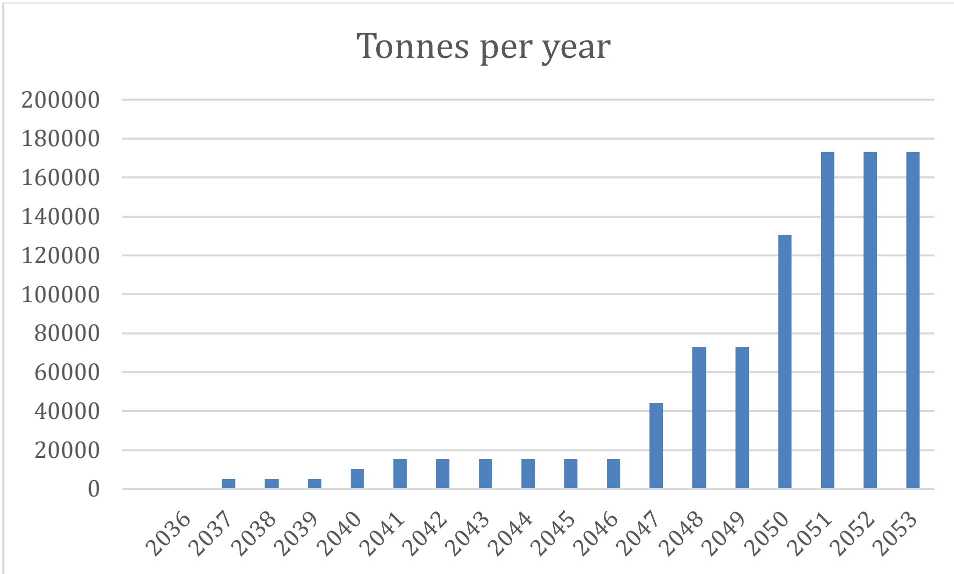


Figure B.1: Tonnes per Year to GEO & Beyond with Space Elevators

Table B.1: Space Elevator Capacity vs Year Summary [Swan, 2020a]

Year	# IOC SEs	# FOC SEs	# GHs	Tonnes per IOC	Tonnes per FOC	Total (T) per day	Total (T) per year
2036	0	0	0				
2037	1	0	1	14		14	5110
2038	2	0	1	14		28	10220
2039	2	0	1	14		28	10220
2040	4	0	2	14		56	20440
2041	6	0	3	14		84	30660
2042	6	0	3	14		84	30660
2043	6	0	3	14		84	30660
2044	6	0	3	14		84	30660
2045	6	0	3	14		84	30660
2046	6	0	3	14		84	30660
2047	5	1	3	14	79	149	54385
2048	4	2	3	14	79	214	78110
2049	4	2	3	14	79	214	78110
2050	2	4	3	14	79	344	125560
2051	0	6	3		79	474	173010
2052	0	6	3		79	474	173010
2053	0	6	3		79	474	173010

B.3 Introduction of Advanced Rocket Mass Movement to Mars: (estimate based upon SpaceX's Starship). The commercial imperative inside the advanced rocket development arena is initiating many ventures with massive movement to support commercial launches. SpaceX has leveraged many government contracts to establish the company and prove it's technologies with launches to LEO and GEO. Their capability and past experiences with government contracts has led to remarkable space launch systems that are reusable, reliable, inexpensive and a commercial stimulus to orbital missions only dreamt of before. As a result, the future of humanity's movement off planet waits for the refinement of SpaceX's launching system (growth from Falcon Heavy to Starship Heavy). During this transition, they are supporting a massive number of launches for governments and commercial customers, including themselves and their Starlight constellation. This study report will use the best guesses of what SpaceX will achieve based upon their statements and the performance of their rockets ongoing and in the near future. It is important to realize this is a description of one team's future projections. In parallel, there are aggressive programs inside Blue Origin to support an active habitat in LEO (Orbital Reef), New Glenn launch system, and a Blue Moon lander to support movement onto and off of the Moon. In parallel with these commercial programs are government efforts and other non-US commercial ventures advertising reusability, more frequent capability, and much lower costs. SpaceX is leading the way, but certainly not the only commercial player as a forcing function related to movement off planet. However, those several other "competitors" of SpaceX are not quite at their level of commitment at this point. As such, the numbers reflected in this document for launch to GEO and beyond are based upon SpaceX's desire to go to Mars. As things settle out, there will be several competing programs going to the Moon and Mars commercially. During the analysis of each mission in separate chapters, the numbers developed in this section will be based upon SpaceX's movement to Mars but utilized to layout a schedule of mass to GEO, the Moon, Mars and beyond. Essentially, lifting off to Mars is "close enough" to the required energy to join geosynchronous orbit, land on the Moon or land on Mars. Here are some of the statements that have been articulated as to SpaceX's Settlement of Mars.

- 1,000 launches for Mars missions each year (Essentially, 3 launches per day)
- Launch window to Mars from Earth every 26 months
- Five launches to "fill" each mission Starship going to Mars
- Combining the above, gives you 432 mission Starships each launch window with 100 people and 100 tonnes of payload [1,000 x 2.16 = 2160/5 = 432 mission Starships]
- The buildup to the full 1,000 launches per year will take time and is shown in the Table B.2.

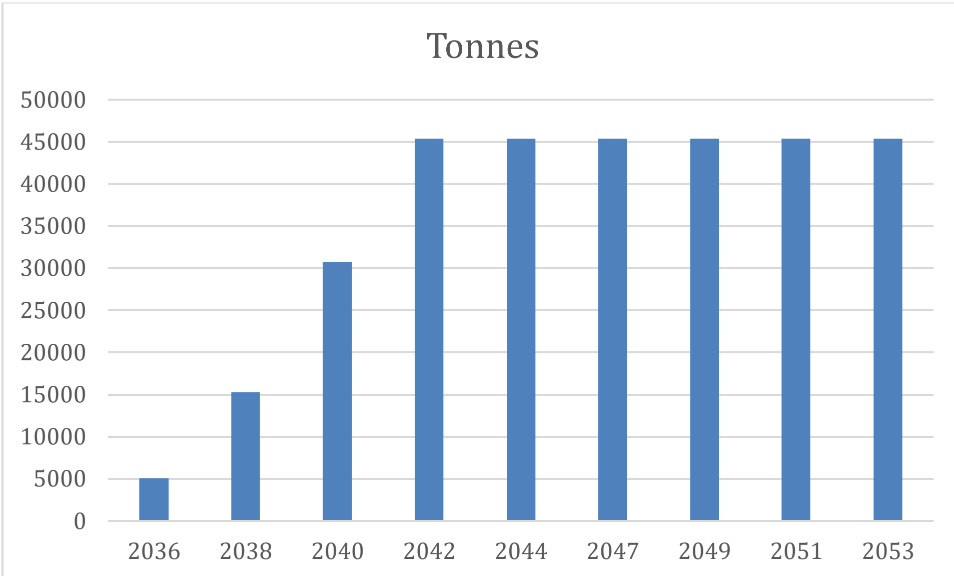


Figure B.2: SpaceX's statements lead to 1000 launches per year.

Table B.2: Spread of launches across 18 years

	Launch Windows (approx.)	Mission vehicles to Mars	# of passengers/vehicle	mass for passengers	Payload mass per vehicle	Total payload mass	# launches
2036	Jan	100	20	0.05	50	5100	500
2037				0			
2038	March	200	30	0.05	75	15300	1000
2039							
2040	May	300	50	0.05	100	30750	1500
2041						0	
2042	July	432	100	0.05	100	45360	2160
2043						0	
2044	Sept	432	100	0.05	100	45360	2160
2045						0	
2046						0	
2047	Jan	432	100	0.05	100	45360	2160
2048						0	
2049	March	432	100	0.05	100	45360	2160
2050						0	
2051	May	432	100	0.05	100	45360	2160
2052						0	
2053	July	432	100	0.05	100	45360	2160
	based upon 1,000 launches per year			total mass to Mars		323310	
	all mass numbers in metric tonnes			total number of launches			15960

B.4 Comparison:

This ISEC Study is comparing and contrasting the two advanced delivery approaches during the 2036 to 2053 time period. The concept is that if humanity leverages the strengths of both approaches to lifting off massive amounts of logistics from the Earth, humanity wins. The comparison of the mass to Mars numbers is definitely the basic question that must be addressed, with the methodology assessed. There are several factors that dominate the discussion. The first is: With a permanent transformational transportation infrastructure, what else do you achieve besides massive delivery of logistics? The answer has so many levels that it makes the Space Elevator an obvious choice to move logistics:

- Daily departures allows logisticians the opportunity to plan for "on time delivery" of products to various destinations on and around Mars.
- Rapid delivery (as short as 61 days) allows the delivery of important logistics when required.
- Environmentally friendly operations improves our world while delivering massive logistics to customers at GEO and beyond.

The chart and spread sheet below show the numbers to be used in each chapter to reflect movement of mass to GEO and beyond. Each chapter will assume that each method (Space Elevators and Advanced Rockets) is dedicated to their own mission. In reality, the movement of mass will be shared across a demanding customer base. The future is unknown, but a realization has surfaced that "IF we build it – they will come!"

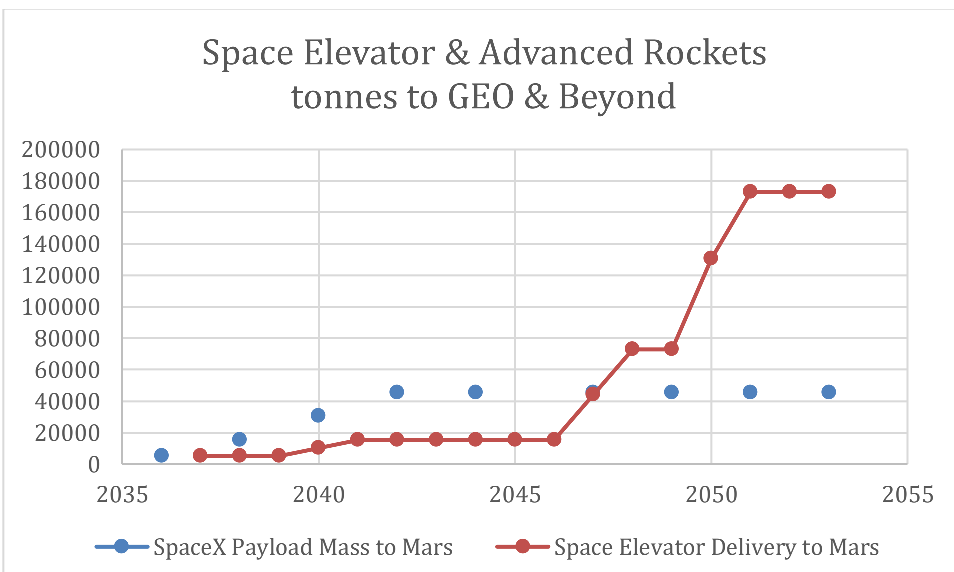


Figure B.2; Tonnes to GEO and Beyond Comparison

Mass in tonnes	SpaceX Payload Mass to Mars	Space Elevator Delivery to Mars
2036	5100	
2037		5110
2038	15300	5110
2039		5110
2040	30750	10220
2041		15330
2042	45360	15330
2043		15330
2044	45360	15330
2045		15330
2046		15330
2047	45360	44165
2048		73000
2049	45360	73000
2050		130670
2051	45360	173010
2052		173010
2053	45360	173010

The bottom line for the Dual Space Access Architecture will develop to become:

Advanced Rockets establish bases on the Moon and Mars while initiating huge programs such as Space Solar Power. Then the Space Elevator's characteristics as a permanent space transportation infrastructure dominant the future movement of logistics in a partnership approach.

Table B.2; Comparison of Mass to Mars (tonnes/yr)

B.5 Conclusions: Space Elevators have unmatched efficiencies for delivery of logistics to diverse location such as GEO and beyond. This characteristic is tied to the daily liftoffs and massive payload capabilities reminding people that permanent transportation infrastructures are constructed for a reason – they provide far better support to the customers at reasonable prices.

Space Elevator Insights:

What else do you achieve with a permanent transformational transportation infrastructure, besides massive delivery of logistics? The answer has so many levels leading to Space Elevators to move logistics:

- Daily departures allows logisticians the opportunity to plan for "on time delivery" of products to various destinations on and around Mars.
- Rapid delivery (as short as 61 days) allows the delivery of important logistics when required.
- Environmentally friendly operations improves our world while delivering massive logistics to customers at GEO and beyond.
- Unmatched delivery statistics – 70% to GEO and beyond

Chapter Three: Space Elevator Transformational Strengths as a Permanent Space Infrastructure

3.0 Introduction: From a historical transportation perspective, rockets have succeeded in placing small and medium size spacecraft into remarkable orbits/surfaces across our solar system. The basic strengths have enabled these successes on one hand, but held back our science and our quest to understand our solar system on the other hand. Afterall, we have only put into orbit 22,000 tonnes between 1957 and 2020 (estimate). The delivery statistics of rockets are dependent on Tsiolkovsky's rocket equation. The Saturn V rocket delivered only 0.5% of the pad liftoff mass to the surface of the moon. A spectacular historic event, but from a transportation point of view, it falls short of every other method of travel. Delivery to geosynchronous is somewhere around 2% of launch pad mass. The progress of rockets in the last ten years is remarkable with reusability, more reliability, less cost, and more launches. SpaceX launched six times during the month of April 2022. However, the delivery statistics of rockets are roughly 4% to LEO, 2% to GEO and translunar and less than 1% to the surface of the Moon or Mars. (note: when you incorporate reusable design into a rocket, the delivery statistic are reduced as each new rocket will be more robust) The basic rocket equation eats up the resources to escape from the Earth's gravity well. As such, Space Elevators need to be there to enable spectacular missions for all our dreamers. The transformation of space access will be similar to moving from small boats crossing a large river to a permanent infrastructure, called a bridge, moving traffic daily, routinely, safely, inexpensively, efficiently, and with little environmental impact. This chapter will delve into these strengths – first as a list and then further expanded explanations. Permanent transportation infrastructures called Space Elevators will enable missions by leveraging their strengths:

- Daily, routine, safe, and inexpensive permanent infrastructures:
- Unmatched Efficiencies of logistics delivery:
- Unmatched massive logistic movements:
- Unmatched Velocity at Apex Anchor release
- Green Road to Space
- Reduction of Rocket Fairing Design limitations
- Assembly at the Top of the Gravity Well:
- Transform economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments

3.1 Transformational Strengths: When Galactic Harbours are operational, the similarities to train operations will be remarkable. This set of six permanent transportation infrastructures (six Space Elevators in three Galactic Harbours – as shown in Figure 3.1) will have the ability to enable customers' missions while leveraging their inherent transformational strengths.

3.1.1 Strength One: Daily, routinely, safely, and inexpensively:
The preliminary design of Space Elevators has shown that there will be one climber initiating its departure from an Earth Port at sunrise each day with a 7 day travel time to the GEO region. This enables the logistician to send a 20 tonne climber up the Space Elevator daily, routinely, safely and inexpensively. This intermodal approach is to ensure that the vertical lift capability is transparent as payloads originate in a city far away and then travel to the Apex Anchor as one transportation infrastructure with the Earth Port transiting customers' packages from horizontal to vertical. In addition, with the extra velocity (identified in strength three) daily releases at an Apex Anchor can go to Mars any day of the year on different paths (some quick – 61 days - and some longer), thus eliminating the 26 month launch windows required by planetary alignments for advanced rockets. Routine operations are described as: the ability to schedule and depend upon "on time delivery" characteristics of permanent infrastructures which will change the way organizations plan on supporting missions to GEO and beyond. An example can be the trips to Mars when Space Elevators enable logisticians to send a 14 tonne payload daily. This daily release is revolutionary as release from an Apex Anchor can go to Mars any day of the year on different paths, eliminating the two + years long launch window restrictions for Mars and Earth alignments necessary for advanced rockets.

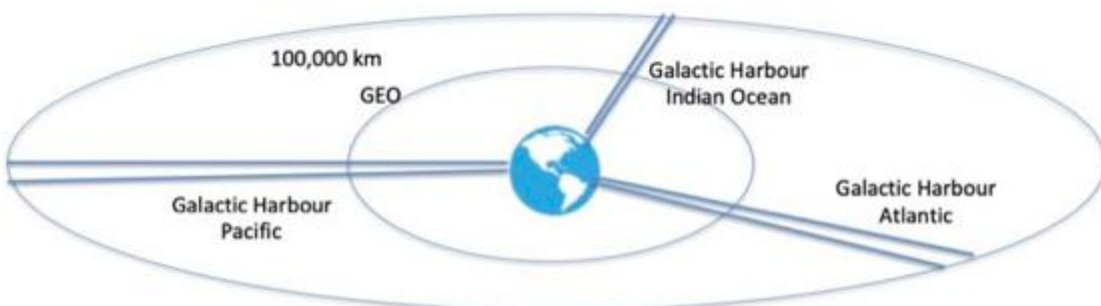


Figure 3.1, Three Galactic Harbours around the Equator

3.1.2 Strength Two: Unmatched Efficiencies of logistics delivery: Comparison of Rocket and Space Elevator efficiencies shows the mass delivered to GEO & Beyond by rockets is minimal while the future of Space Elevators reaches towards 70% of the mass on the ocean being delivered beyond GEO. The capability of Space Elevators dwarfs advanced rockets rapidly because of its unmatched efficiency of delivery and environmentally friendly operations. Indeed, 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 half percent of the launch pad mass to the surface of the Moon for Apollo 11. It is up to 2% for delivery to GEO and woefully small for delivery to Mars' orbit. The question is why would you employ a methodology for delivery that only delivers less than one percent to your desired location (let's say the future Gateway around the Moon). Space Elevators solve 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.

3.1.3 Strength Three: Unmatched Massive Logistics Movement: As noted earlier, the ability to move 30,000 tonnes during initial operations will be revolutionary when compared to our rocket history. [expanded upon in Appendix D] When one considers that Space Elevator complexes will grow to a capacity of 170,000 tonnes per year in the near term and 346,020 tonnes per year by 2062, the belief is born that any mission can be fulfilled. There will be no limitations on the needs of customers as Space Elevators can deliver every day of the year to any location at GEO and/or beyond. Currently, our dreams beyond low Earth orbit are glorious; however, no one ever askes the dreamers "how much does it weigh?" Rocket restrictions are catastrophic when the realization dawns on the dreamer – "That is all we can deliver to my location and so infrequently?"

This characteristic is the obvious strength that most users need. Massive delivery to the location of choice will enable dreamers such as SpaceX, Moon Village supporters, space solar power requirements, and routine historic missions enhanced by this unique capability. A current estimate has been developed for Space Elevator which reflects growth from the Initial Operational Capability (30,000 tonnes per year) to the Full Operational Capability (170,000 tonnes per year). The growth of mass delivered to GEO and beyond by Space Elevators has been studied for the last 20 years and the results have been consistent between the ISEC, the International Academy of Astronautics, and most researchers covering the topic. The capability starts with 14 tonnes of payload to GEO lifted off each day (with 7 day trips to GEO then 7 more to an Apex Anchor). This is multiplied by six as the competition develops for Space Elevators across three oceans. As these commercial ventures expand to meet customer demands, Space Elevators will grow to a more capable design with major redundancies for human travel. This capability would be 70 tonnes per Space Elevator each day times six Space Elevators times 365 days results in close to 170,000 tonnes per year. The growth of Space Elevators carrying capacity is explained as:

- Initial Operational Capability (IOC) growth: The first growth in the architecture will be the expansion 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 across three oceans. This results in the Modern-Day Space Elevator growth from IOC through FOC. The International Space Elevator Consortium (ISEC) projects starting development in 2022, IOC around 2037, and FOC around 2044. [Swan 2020b] The capacity throughput during early operations (IOC) starts with each Space Elevator Climber carrying 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.

- Full Operational Capability (FOC) growth: 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 total delivery statistics 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 missions requiring massive tonnage to GEO and beyond. (note: The development of these numbers was accomplished in multiple documents and summarized in chapter 5 of the ISEC Study report "Space Elevators: the Transportation Story of the 21st Century."[Swan, 2020b] That chapter is summarized in appendix D of this study.)

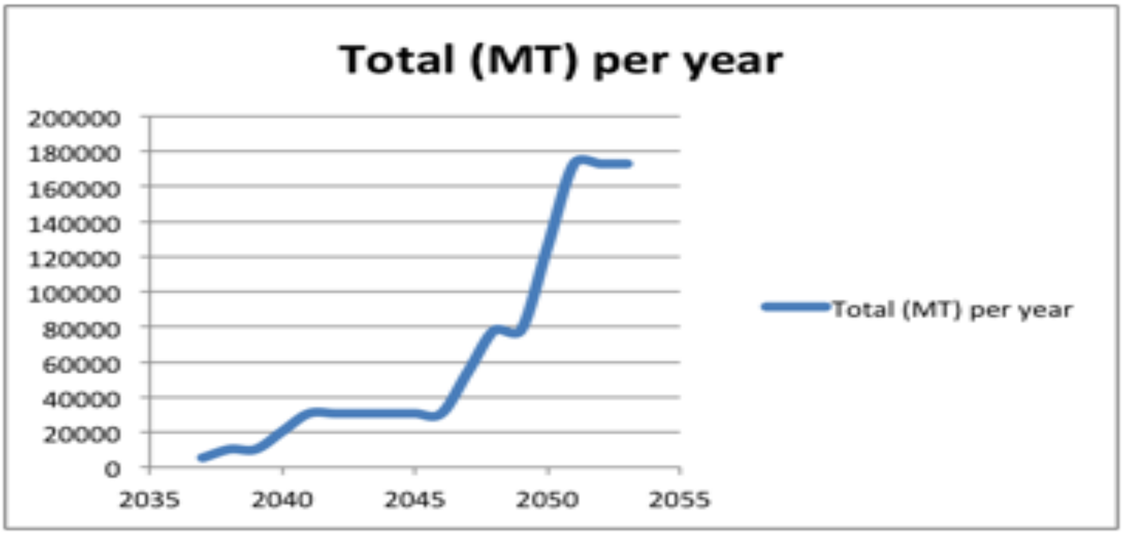


Figure 3.2: Capacity of Space Elevators per year to FOC [Swan, 2020]

- Outyear Growth: Continuing growth of the Space Elevator will occur as the benefits are tremendous for the commercial growth of space enterprises. This growth would look similar to the following chart:

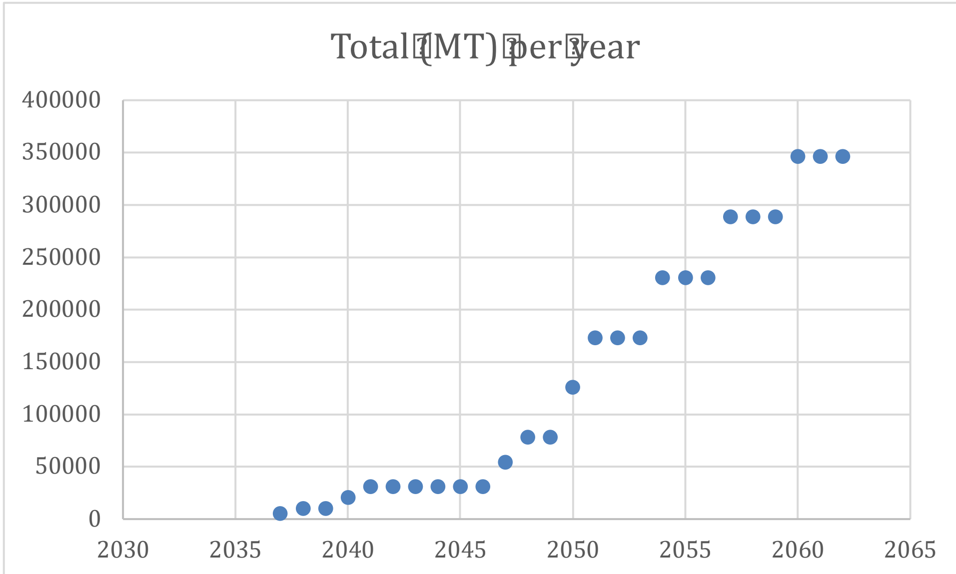


Figure 3.3: Capacity of Space Elevators per year for the Outyears

3.1.4 Strength Four: Unmatched velocity at release: This strength results from the increase in velocity at release as tether climbers raise their payloads. The rotation of the Earth with a long "arm" instills tremendous velocity as the altitude is gained. At GEO the velocity matches the Earth synchronous orbit. As the altitude is increased the payload release velocity increases rapidly. At the 100,000 km altitude of the Apex Anchor, the velocity is 7.76 km/sec, or enough to go beyond Mars with no extra propellent or reach Mars in as little as 61 days. If the height of the Apex Anchor is increased the velocities exceed the escape velocity of our solar system.

Surprising Interplanetary Strengths: [Swan, 2020a] [Torla, 2019] During a joint study between Arizona State University and the International Space Elevator Consortium, the researchers showed that the design of Space Elevators lends itself to interplanetary missions as it transfers tremendous amounts of energy at release from the Apex Anchor. This is reflected with approximately 7.76 km/sec towards mission destinations allowing:

- Fast transit to planets (Can you imagine, as fast as 61 days to Mars with average flight times in the 80 to 120 day region?).
- Daily releases of mission cargo towards Mars and other interplanetary locations. (Imagine no 26 month wait for a launch window?) In addition, the study showed that with longer tethers, the release velocity increases to enable Solar System escape. (See figure 3.4)

3.1.5 Strength Five: Green Road to Space:

Space Elevators are environmentally neutral as they raise tether climbers using solar power. This enables climbers to transfer through the atmosphere and not impact it with combustion by products. In addition, as the process is continuous with a single tether climber, there is no residual hardware left before its destination (space debris), especially in the Low Earth Orbit region. In addition to operating as a "green transportation infrastructure," it also is an enabler to many missions that can help stop global warming and climate change. These would be missions such as Space Solar Power (chapter 6) and Earth Sunshades(chapter 5), each of which can stall global warming. These missions are also discussed inside the 2021 ISEC 18-month study entitled: Space Elevators: The Green Road to Space. [Eddy, 2021]

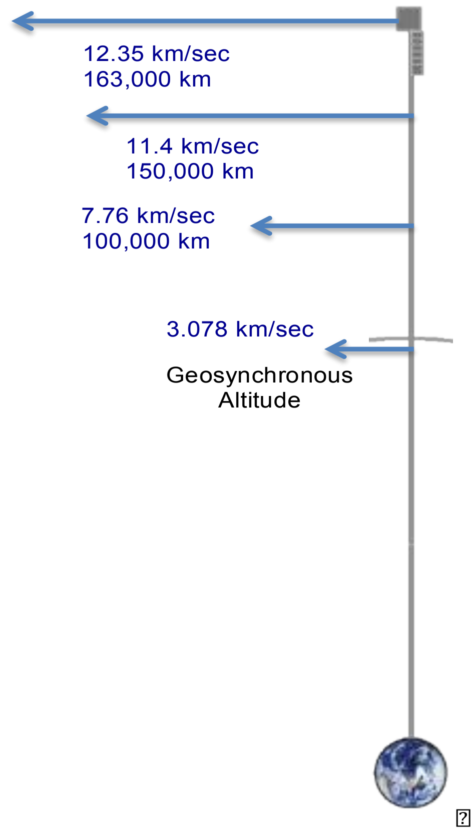


Figure 3.4: Release Geometries

3.1.6 Strength Six: Reduction of Rocket Fairing Design limitations:

The beauty of a permanent transportation infrastructure, such as Space Elevators, is that cargo can move across distances efficiently, effectively, and with little effect on the cargo. This intermodal transportation technique is called containerizing. This concept is exceptional and is used for movement of supplies across the globe. There are roughly 45 million containers moving across the oceans, land, and air. With the Space Elevator Transportation System, this concept transforms to vertical - containerized supplies on tether climbers. As such, the customer may load the container with any shape and any size satellite inside the standard TEU (twenty-foot equivalent unit) container. In addition, the gentle acceleration of electric climber motors on a tether will not disturb the product being moved. The lack of rockets' "shake, rattle, and roll" will simplify the design of satellites as well as storage and transportation requirements for transit to GEO and beyond. In comparison, loading the James Webb Telescope into its rocket faring, and then releasing into space, had 344 single point failure milestones to achieve deployment of the complex telescope and supporting infrastructure. This was after shaking it with tremendous vibrations and forces during both launch and release. The rocket community set of requirements for launch vehicle compatibility is extraordinary. In addition, the restrictive faring enclosing the payloads for launch has design implications. The extra volume from the Space Elevator Tether Climber and the soft ride enables far more design flexibility for customer payloads going to GEO and beyond.

3.1.7 Strength Seven: Assembly at the Top of the Gravity Well: This characteristic is a surprising one that has only recently been understood and explained. The concept is simple – have a "train station" at the Apex Anchor, 100,000 km in altitude. The concept lends itself to phenomenal strengths that are NOT achievable by rockets because this is a location which is above the gravity well and allows access to anywhere in the solar system rapidly (release is at 7.76 km/sec). The concept includes the ability to raise any amount of mass (14 tonnes per climber – later 70 tonnes containers) to this train station and assemble any size space system. In other words, planetary scientists will not be restricted by mass for their future missions; plus, the cost is miniscule compared to today's mission costs. They can have multiple payloads teamed with multiple rockets to go anywhere. When thinking about CisLunar support, the secret is that replacement parts, safety components, lifesaving facilities can all be only 14 hours away. In addition, having these Apex Anchors in sight of the lunar region allows them to conduct situational awareness continuously.

Impact upon Solar System missions: The ability to have flexible design criteria for space systems leaving the Apex Anchor is one of its strengths. Once the major segments of a large planetary science space system arrive at the Apex Anchor, they can be joined to large rocket motors and great scientific payloads so that it has tremendous reach across several scientific disciplines. With large batteries and robust spacecraft, scientific payloads can be designed toward any mission requirements. The raising of the segments of planetary mission satellites can take advantage of no "shake, rattle, and roll" and suffer significantly fewer restrictions from rocket fairing size and shape. (see chapter 8)

3.1.8 Strength Eight: Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments: [Barry, 2021] This strength is probably less subtle, but more important. The transformation results from the economic impacts of permanent space access infrastructures. This discussion is paraphrasing an article by two Space Elevator enthusiasts Kevin Barry and Eduardo Alfaro. [Barry, 2021] From the beginning of this century, the Space Elevator community has played the rocket game – trying to show that it will be an inexpensive transportation infrastructure. We can show this low cost at so many levels; but, the discussion needs to be raised to another level by actually explaining that Space Elevators reach across economic growth arenas of enterprises across the solar system. The paper by Barry and Alfaro says, "With the current global trends favoring a burgeoning space economy, it is even more crucial than ever to develop a long-term sustainable economic overview for Space Elevators to accelerate the development of this megaproject." [Barry, 2021] In addition, they move the discussion from $/kg (which they call the language of rockets) to future key elements of economics and exchange of resources. Their argument is essential to the understanding of this transformational issue. The whole paper is worth reading to transition from the early century's discussions toward what can enable development of Space Elevators.

"The economic paradigm of building Space Elevators needs to shift from a focus on cost to the consumer to focusing on its value to the investor. In infrastructure, this paradigm shift is especially important because the value of infrastructure comes from a reduction in transaction costs to increase the rate of utilization and thereby enhance economic productivity. To an investor, a Space Elevator is far more valuable as a departure point to the solar system and harbor for interplanetary trade than a business fighting to generate profit from selling ever-cheaper tickets to space. The true value of space is not based on merely reaching space, it is in what can be done once there. Space Elevators successfully address six of the seven major value streams for space development and creates a launching platform for extraction efforts (the final value stream) anywhere in the solar system." [Barry, 2021]

3.2 Space Elevator Shortfalls: Space Elevators will be transformational in so many ways, but there are a few shortfalls that must be recognized.

3.2.1 Operational by 2037: This estimate of first operations is based upon several studies and projected development schedules. [Swan, 2014] [Swan, 2019] [Fitzgerald, 2017] The massive study by the International Academy of Astronautics entitled Space Elevators: An Assessment of the Technological Feasibility and the Way Forward" [Swan 2014] established a baseline architecture, addressed the technological readiness, and estimated a developmental schedule. The first operational date was estimated at 2037. As such, the movement of massive cargo to support the projects of the future will not be initiated until that date. However, the concept of the Dual Space Access Strategy discussed the beauty of having advanced rockets start aggressive dreams such as Space Solar Power constellation or a settlement on Mars with prototypes being delivered. Then, when these aggressive programs need large, massive cargo moved, the Space Elevator will be initiating operations.

3.2.2 Optimized for GEO and beyond: Space Elevators are optimized for delivery to Geosynchronous orbit and beyond as their speeds of the tether climbers do not match orbital speeds at altitudes almost to geosynchronous. This means that the payload cannot enter orbit until it reaches that altitude with enough velocity to gain an orbit. In addition, the equatorial plane is where the Space Elevator excels. It releases its payloads in this plane with quite a lot of energy as it gets to GEO and beyond enabling support to all manner of missions. However, low Earth orbit missions and high inclination missions require significant velocity from rockets

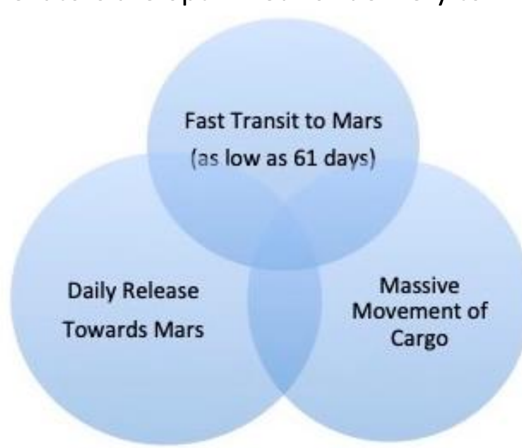


Figure 3.5, Apex Anchor Release Strengths

instead of simply releasing from the Space Elevator at a designated altitude.

3.3 Avoiding the Rocket Equation: One of the elemental ideas related to Space Elevators is that "we can beat the rocket equation!" Gravity on Earth has been a huge benefit for development of life, just the right amount of gravity to hold us on, but not so much we could not grow. However, for space missions, overcoming gravity is a real difficult task. We partially overcame it by going to the Moon with Apollo and we have sent Voyagers beyond the Sun, but at what cost? Those were marvelous engineering feats of wonder, but now we need to do it routinely to support massive movement off planet. The principal problem is that it takes 98% of the mass to gain geosynchronous orbit and 99.5 % of the pad mass to reach the surface of the moon. Oops! A key distinction is that the reusability of stages and resulting cost effective approaches to reach orbit will not be more efficient in the delivery of mass to their destinations. The rocket equation dominates! This is explained well in what is called the "Conundrum of Rockets." This has been explained often, but was recently illustrated in Linked In by one of the authors [Swan 2022b].

Solving 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 Martian 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."

3.4 Summary: The obvious emphasis from the above discussion is that the descriptive word is transformational. The implementation of Space Elevators around the world will enable remarkable capabilities to move cargo massively and routinely. This will transform the future of space activities. Space Elevator leadership must point out and emphasize to both the general public and project managers of visionary space activities that the modern-day Space Elevator will be:

- Transformational,
- Partnering with rockets in a Dual Space Access Architecture, and
- Greening is lifting payloads with electricity and enables Space Solar Power satellites to GEO with a timely schedule

All this is closer than they think as we have entered engineering development. In addition, the mature Space Elevator program promises timely delivery of massive loads for future missions while stimulating an economic boom as regions open up for commerce because of routine, daily, massive capabilities.

When placing economic "value proposition" approaches towards development and operations, the logical recognition of tremendous empowering characteristics dominates the statement: We must build Space Elevators as soon as possible. Now that the tether material will soon be available, the time is NOW. The Green Road to Space must be initiated as soon as possible. Space Elevators, and Galactic Harbour architectures, are no longer simple strings to space. They have become a transformational element in the movement off planet and thrust to control climate change. The development team has huge responsibilities to contribute significantly towards the health of the Earth and humanity's critical movement off planet. This new capability will be revolutionary in approach but evolutionary in scope.

Space Elevators have many strengths; the most remarkable ones relate to their being permanent space transportation infrastructures. They will move massive cargo daily, routinely, efficiently, and safely with environmentally friendly operations. The level of impact on our future movement beyond LEO is obviously transformational. This new capability will be revolutionary in approach but evolutionary in scope.

3.5 Conclusions: The ISEC has shown that there must be major changes in the approach for humanity's migration off-planet. Some of these changes include:

- Change of vision for interplanetary movement when delivery of mass is inexpensive, timely, environmentally friendly, daily, and supportive. It turns out the revelations in transportation capabilities of Space Elevators open up immense possibilities and ensure that humanity can "bring with them" the essential elements for survival and aggressive growth. This new vision of Space Elevator architectures will change the thinking for off-planet migration - We CAN bring it with us!
- Movement off-planet will require complementary capabilities -both rocket portals and Space Elevator infrastructures - each with their own strengths and short-falls. Inserting payloads into Low Earth Orbits and moving people through the radiation belts rapidly are strengths of rockets while massive movement in a timely, routine, inexpensive and Earth friendly manner are the strengths of Space Elevators.
- A discussion of various destination mission needs, when analyzing mass to location, will start the analysis of "how much carrying capability" is required by each supportive infrastructure: when, to where, and their priorities. In the past, the rocket approach valued lightweight and compact designs of support equipment while the Space Elevator permanent infrastructure will enable mass to be moved to desired destinations easily. The driving function for

infrastructure design becomes a description of the customers' needs, not light weight designs.

- An interesting insight in parallel with this analysis says that planetary scientists can be offered as much mass as they require for any of their missions. There will be zero restrictions for scientific instruments going to any place in the solar system - including the survival from the shake, rattle, and roll of rocket launches. If you cannot include it in one 14 metric ton payload capable tether climber, you can assemble parts at the Apex Anchor and release them once a day towards any destination.

Space Elevator Insights:

Space Elevators have many strengths; but, the most remarkable ones relate to their being permanent space transportation infrastructures.

Move massive cargo
Daily – On Schedule
Routinely – "just in time"
Efficiently – 70% delivery statistic
Environmentally friendly operations
Safely – think trains

Chapter 4: Rocket Strengths and Shortfalls

4.0 Introduction:

This chapter discusses the use of rockets in advancing the projects that could be done with and without Space Elevators. The main thrust of the chapter will look at operational rockets and at the ones under development that will be operational in the foreseeable future. The focus will be upon the chemical rockets that have the lift-off capability from the surface of the Earth. One continuing interest will be to understand delivery statistics: historic totals, how much per launch, how often, destination percentage of launch pad mass, and to where. The current workhorse of delivering high mass payload to orbit and beyond is chemical propulsion. Ion propulsion is in a few deep space exploration missions with low payload masses or used for small movements in orbital location maintenance. Chemical propulsion provides the most thrust but has a small specific impulse efficiency. Presently, it is the only approach to put hardware in Earth orbit (LEO, MEO, GEO, or beyond). Two new large commercial launch systems are under development, and both include reusability and payload capabilities of less than 50 metric tons to GEO. A hybrid propulsion approach is probably best suited for long-haul, heavy payload missions: very high thrust of chemical engines (Saturn V – like rockets, such as SpaceX's Starship, NASA Space Launch System (SLS), Blue Origin's New Glenn) to put spacecraft components in Earth orbit. These will be followed by large (not operational today) ion engine thrusters for efficient movement beyond Earth's orbit.

Rocket motion, for over 120 years, has been described and limited by the Tsiolkovsky equation shown below. [Rk Equation, 2023] A measure of a rocket's efficiency is the specific impulse, ISP, which is equal to the exhaust velocity divided by Earth's gravitational acceleration. A rocket's thrust, the forward force it exerts on its payload, is the mass ejection rate multiplied by the exhaust velocity.

The maximum change of velocity of the vehicle, Δv (with no external forces acting) is:

$$\Delta v = v_e \ln \frac{m_0}{m_f} = I_{sp} g_0 \ln \frac{m_0}{m_f},$$

where:

- $v_e = I_{sp} g_0$ is the effective exhaust velocity;
  - I_{sp} is the specific impulse in dimension of time;
  - g_0 is standard gravity;
- $\ln$ is the natural logarithm function;
- m_0 is the initial total mass, including propellant, a.k.a. wet mass;
- m_f is the final total mass without propellant, a.k.a. dry mass.

The words of consequence within the rocket equation 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." [Rk Equation, 2023] The 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 - DRACONIAN! ?

Table 4.1: Specifications current state-of-the-art rockets (both chemical and ion)

	Specific Impulse (sec)	Thrust (Newtons)	Mass of Launch Vehicle at Pad (Tonnes)	Delivery to Trans-Lunar (tonnes - %)
Space X's Starship Heavy (chemical)	350	78 million	5,000	100 (0.02%)
NASA's SLS (chemical)	400	40 million	2610	85 (0.03%)
Blue Origin's New Glen (chemical)	Not available	1.4 million	Not available	Not available
NASA's NEXT (ion, DART mission)	4170	237 milli	N/A	N/A
ESA's BepiColombo	4300	145 milli	N/A	N/A

Chemical rockets have low specific impulse. They have very low efficiency but are useful due to their very high thrust – on for several minutes only. Ion engines, on the other hand, have very high efficiency but very low thrust. The earlier ISEC Study,
The Green Road to Space report [Eddy, 2021], contains mass estimates for several of the projects that could be tackled by Space Elevators in the future. The required masses at destination are in the range of a half to several million metric tons to GEO and beyond. For example, Lunar Village requires a mass of 500,000 metric tons, whereas L-5 colony's mass is 11,000,000 metric tons. Keeping in mind that the delivery mass from Earth's surface to such destinations is a fraction of one percent and decreases with increasing destination distance. It becomes very clear early on that current rocket propulsion concepts will take decades to centuries to deliver the required masses to their destinations. In the next section, we present delivery statistics of the current and most promising launch systems that rely on chemical propulsion. We also briefly discuss ion propulsion and nuclear propulsion.

4.1 Chemical Propulsion

Rocket engines with chemical propulsion are currently the workhorse for putting any payload in Earth orbit and beyond. Chemical propulsion provides a large amount of thrust, meaning that it can be used to lift off huge payloads. However, this high thrust comes with several downsides.

(1) The specific impulse of chemical propulsion is a few hundred seconds. In other words, chemical rockets can stay on for a maximum of only several minutes to lift off the mass that needs to be lifted. Strapping on more fuel will make the rocket even heavier. The needed thrust must be more than the mass on the pad or it will not be able to lift itself off the ground. Technically speaking, chemical rockets are energy-limited because the propellants have a fixed amount of energy per mass, which comes from the specific impulse of each fuel.
(2) Currently, there are several research studies looking into the dangers of burning rocket fuel in the upper atmosphere. The only choice in the past has been to use chemical rockets to achieve orbit. As such, the need has overpowered the concern for our atmosphere. There are multiple studies looking at the significant effects of increasing the launch rate to thousands of launches each year instead of about one hundred. This increase of over 10 fold could cause a dramatic increase in the effects on Earth's atmosphere, including black carbon devastating the (currently healing, but troublesome), Ozone hole.

4.1.1 Strengths of Chemical Rockets

Chemical rockets are currently the only means to put any payload in Earth's orbit and beyond. Every single kilogram that has been placed in orbit or beyond since the dawn of the space age has been put there using chemical rockets. The attraction of chemical rockets is that they can be launched from almost anywhere to anywhere. They can be scaled up or down depending on payload mass and destination. They move fast through Earth's radiation belts thus minimizing health hazards to astronauts. Moreover, chemical rockets have a long and proven heritage in space missions, together with the pre-requisite human expertise in all issues related to chemical rockets. For all these reasons, chemical rockets are the first, and so far, only option in launching space missions. Chemical rockets are the solid foundation on which space missions have been built. In recent years, the commercial sector has made great strides in advancing chemical rockets to put heavier payloads in space for less money and on more rapid schedules, thanks to the competitive imperative that drives relatively new companies such as Space X. Space X has been a game changer in increasing the payload mass, decreasing the cost of launch per kilogram, and increasing launch cadence. This three-pronged advancement has been based on mastering new design and construction techniques of chemical rockets. In addition, the commercial imperative of the new companies, such as SpaceX and Blue Origin, are pushing for reusability, cost effectiveness, more frequent, and of course less expensive.

Escaping Earth's surface is the first step in moving off planet (Low Earth orbit – first achieved in 1957). It required the best of engineering feats by the Soviet Union. All space efforts since then 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 gain LEO, the accepted value is 9.3 km/sec velocity. Here 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 example: Delivery of the Apollo lunar lander to the surface of the Moon. It was estimated that one-half of one percent of the launch mass (0.5%) reached the lunar surface. In addition, the roughly 80% of the mass that is fuel is consumed, mostly, within the atmosphere – thus endangering it.

4.1.2 Chemical Rocket statistics

As mentioned above, chemical rockets have so far been the only means of lifting mass from Earth's gravitational well. The table below gives some statistics on the amount of mass delivered by chemical rockets. The total mass launched to space between 1957 and 2020 is about 22,216 tons. [Note: A recent article estimated 18,000 tonnes as delivered in 65 years. [Stack, 2023]] The corresponding launchpad mass is 568,650 tonnes. This shows that on average roughly 4% of the launchpad mass eventually makes it to space. Kindly note the 4% is dominated by space stations and shuttle deliveries to LEO. Of course, the percentage varies depending on the destination. For example, 2% of the launchpad mass goes to GEO or interplanetary space. The percentage is lower - less than one percent of launchpad mass – for deep space destinations.

Table 4.2: Tonnes to orbit

Type of Systems	***Orbit***	***Mass***	***Mass on pad***
		Tonnes	tonnes
Space Stations	LEO	431	10775
Earth Orbiting Sat's 2020	LEO, MEO, GEO	3220	80500
past satellites deorbited	LEO, MEO, GEO	1000	25000
Interplanetary	Solar System	100	5000
Lunar spacecraft	to the Moon	94	4700
Human to LEO	LEO	535	13375
Apollo Capsule to Moon	Lunar	336	16800
Space Shuttle*	LEO	16500	412500
Totals		22,216	568,650

Note: Leo is 4% of launch pad mass
GEO, Interplanetary, Lunar 2% of pad
*Shuttle launch vehicle reached orbit as an operational satellite

Taking a closer look at the masses, one can see that the heaviest launchpad mass system, Space X's Starship, delivers 21,000 tons to GEO. Its launchpad mass is 4,000,000 tons, making the percentage of mass delivered 0.5% to GEO (see table below). The extra design criteria (reusable first and second stages – including heat shielding for reentry of the Starship) adds mass which lowers the delivery statistic but decreases cost through reusability – a trade off that SpaceX chose.

Table 4.3: Launch examples [Eddy, 2021]

Launch Vehicle	***Mass on Pad (kg)***	***Mass Delivery***	***%***
Apollo Saturn V	3,233,256	Lunar lander = 15,103	0.5
		ocean landing = 5,557	0.17
Atlas V	590,000	to GEO = 8,700	1.5
Falcon Heavy	1,420,788	to GEO = 26,700	1.9
Starship	4,000,000	to GEO = 21000	0.5
New Glenn	1,323,529	to GEO = 13,000	1

After all the calculations and insight into the physics of lifting mass from the surface of the Earth, we are left with the conundrum of rockets. It is important to keep in mind that humanity has sent 20,000 tons to space between the beginning of the space age in 1957 and 2020. The bulk of this mass was delivered to LEO by the space shuttle. Can we continue to depend on a delivery system that only delivers a small percentage of mass to orbit if humanity continues to undertake more ambitious space missions? The percentage of launchpad mass delivered to GEO becomes 2%, and 0.5% of the launchpad mass when delivered to deep space. Obviously, another way to deliver huge amounts of mass must be found. Moreover, increasing the rate of rocket launches to deliver payloads to space will have adverse effects on the environment.

4.1.3 Environmental Impact of Chemical Rockets:

Recent studies have explored the impact of chemical rocket launches on the Earth's atmosphere and the consequential effects on the environment. [Maloney, 2022] [Ryan, 2022] Current chemical rockets emit pollutants directly into the stratosphere. These pollutants include black carbon (BC), commonly known as soot and chlorine from solid rocket boosters. In addition, the re-entry of space debris from rocket launches and re-entry capsules lead to heating that produces nitrogen oxides and alumina. All these pollutants are bound to affect the ozone layer, upset the energy balance in the atmosphere, and adversely affect stratospheric chemistry.

Soot injection into the stratosphere leads to the increase of stratospheric temperature. which changes global circulation and leads to the depletion of ozone. [Maloney, 2022] The author assumed a soot injection rate an order of magnitude larger than the current soot injection rate due the annual rocket launch, estimated at about a hundred launches per year. Maloney's projections simulated the effects of the anticipated increase of rocket launches to about 1000 launches per year within the coming years. They found that the soot emission from a thousand launches per year will increase stratospheric temperatures by 1.5 K, enough to affect global circulation. The subtropical jet wind speeds decrease by up to 5 m/s. Higher stratospheric temperature increases ozone depletion that might become most pronounced during northern springs. The effect of stratospheric soot on global warming is two orders of magnitude more powerful than the effect of all the other sources of soot combined. Figure 4.1 illustrates this.

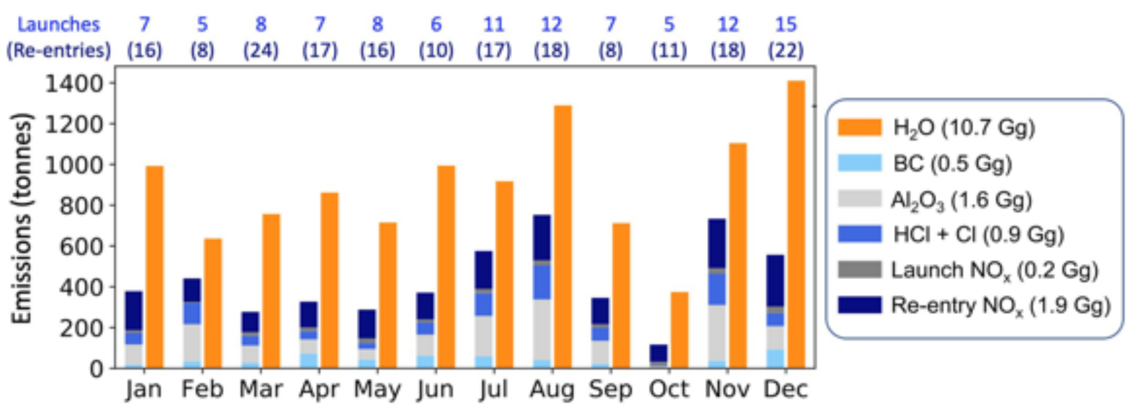


Figure 4.1: Monthly space sector emissions in 2019 from boosters, first stages and reentry burns. [Ryan, 2022]

Rocket launches also release copious amounts of water vapor, nitrogen oxides, chlorine, and alumina. These pollutants directly attack ozone via several chemical pathways. Figure 4.1 gives annual emissions of pollutants based on 2019 launches. These numbers must be multiplied by ten when the number of rocket launches approaches one thousand, as is anticipated for the near future. The effect on the environment will be huge. Rockets are long-range polluters. Rockets inject pollutants to all layers of the atmosphere, so their effect is pervasive and more powerful than other pollutants that are injected from ground level. Pollutants injected at ground level take years to reach the stratosphere, while rockets inject their most harmful pollutants directly into the upper atmosphere making their impact almost immediate. Executing the ambitious space missions currently being planned will require thousands of launches per year. This will have an almost instantaneously impact on the environment.

4.2 Advanced Rockets:

The next three rockets are now on schedule to be the principal movement of mass to the Moon and Geosynchronous orbit. They have many similarities to historic vehicles, but have also advanced in many areas.

4.2.1 Space Launch System

The Space Launch System (SLS), developed by NASA, is the highest payload capacity operational launch system, as of November 16, 2022, the date Artemis I was launched into a translunar-injection (TLI) orbit. Payload delivery to TLI is 46 tons. The launchpad mass of SLS is 2610 tons, leading to 1.7% of launchpad mass delivered to TLI. To give an operational example, approximately one-quarter of a million SLS launches would be required for the L-5 colony (a more complete discussion of this and other delivery statistics are in the Green Road to Space report (ref. Ch. 7). Assuming ten SLS launches per day, a very unrealistic schedule given that the launch price is currently 4 billion USD, means that it will take 67 years to assemble L-5 colony to the tune of a thousand trillion USD! The cost is prohibitively large. The very launch cost of this settlement project makes it unfeasible from the start, regardless of possible returns. On the other hand, a crewed mission to Mars will require a payload of 100 tons (food, water, oxygen, habitat, and life-support systems). This mission duration will be 3 years including one-year round-trip transit and one year of surface activities, leaving an additional year worth of supplies in case of emergencies. The overall cost of using SLS as the transportation infrastructure for a government mission (and especially a commercial mission) would be overwhelming. The numbers above show that more than 3500 SLS launches per year would be needed for Mars support missions. The effect on the environment of the large number of launches to deliver the L-5 colony, or the settlement on Mars, would be disastrous (see section 4.1.3 above). The current SLS mission is to conduct exploration with limited crews and limited destinations, and as such, NASA will proceed on these missions.

Table 4.4; SpaceX numbers

SpaceX's Rocket Numbers - Delivery Statistics - % of pad mass reaching Destinations				
Rocket	Payload Mass (Kg)	Destination	Pad Mass (Kg)	Delivery Efficiency % of Pad Mass to destination
Falcon 1	180	LEO	28,000	0.006
Falcon 9	10450	LEO	333,400	0.031
Falcon 9-1	13200	LEO	505,846	0.026
Falcon 9 Block 5 Reusable	22800	LEO	549,000	0.042
Falcon Heavy to LEO	63800	LEO	1,420,000	0.045
Falcon Heavy to Moon	16500	Moon	1,420,000	0.012
Falcon Heavy to Mars	3500	Mars	1,420,000	0.002
Starship Estimates	100,000	LEO	5,000,000	0.020

source: Flatlife "Evolution of SpaceX Rockets [2002-2023]"

4.2.2 Starship:

Space X's Starship is currently in development, while being the most advanced launch vehicle/spacecraft concept to date. It's launchpad mass is 5,000 tonnes. Its fuel capability is 4600 tonnes divided between the 1st stage Superheavy (3400 tonnes) and the Starship 2nd stage and spacecraft (1200 tons). It can deliver 100 tons to LEO and 21 tons to geo-transfer orbits (GTO). It requires refueling to deliver payloads to deep space destinations. The 1st stage lands for re-use later. Exact details about on-orbit refueling are not available. However, we can estimate the number of launches needed to send a Starship (2nd stage + spacecraft) to Mars as shown in the image below (5 total launches for one Starship mission vehicle to Mars). If we want to send 100 tons to Mars, the second stage needs to be refueled. Its fuel capacity is 1200 tons (or 300 tonnes x 4). Therefore, for every 100 tons to Mars, four refueling missions to LEO are needed (SpaceX numbers are close to this estimate). In addition, SpaceX plans on a fifth launch to place people and supplies inside the mission vehicle. The four refueling/resupply missions is 25,000 tons of total launch mass. If we add to this 5000 tons of the spacecraft mission then we get a total of 30,000 tons, resulting in effectively only 0.33% of the total launch mass reaching Mars. The one mission spacecraft results from five refueling, resupply, human launches which could be lifted off in the space of two days, assuming a cadence of 3 launches per day (or the estimated 1,000 launches per year. The History of SpaceX is remarkable, and it has a tremendous track record of developing revolutionary capability. Table 4.4 has the layout of tonnes to orbit of SpaceX vehicles and shows the progress over the last two decades.

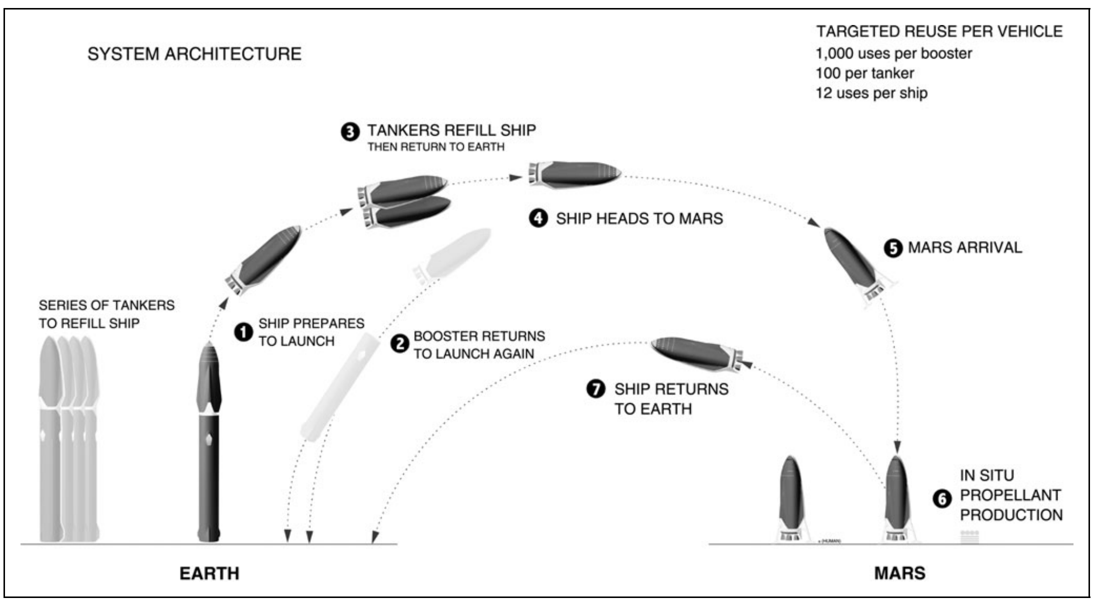


Figure 4.1 SpaceX Mars Strategy [Musk, 2017]
Note: 5 launches for one mission Starship to Mars

4.2.3 New Glenn

Blue Origin's New Glenn is still lagging in development compared to SLS and Starship. Its payload delivery to LEO is 45 tons, and 13.6 tons to GTO. Its launchpad mass is 1,323 tons. It can deliver 1% of its launchpad mass to GTO as payload. It is mostly developed to cater to the communication satellites market and LEO habitat (Orbital Reef development and maintenance) with a commitment up to eight launches per year.

It has a small payload delivery capability that doesn't make it well suited for missions that require hauling huge payloads, on the order of several thousand tons. It is also not designed for deep space missions. However, much is unknown about New Glenn and it could be upgraded or improved along its commercial developmental path. In addition, the current environmental studies are pointing out that the New Glenn has a few significant issues with the atmosphere it must go through to reach space??

4.3 Other Propulsion Types

4.3.1 Ion Propulsion

Ion propulsion, regardless of its variation, is NOT capable of lifting anything off Earth's surface because of its low thrust to weight ratio. It provides very little thrust compared to chemical propulsion, but its high specific impulse makes it ideal for long-haul missions in deep space. Ion propulsion could save 100 days to Mars because of its continuous thrust (always on with small thrust) nature. The idea is to put a spacecraft in LEO using chemical propulsion and then send it on to deep space with ion propulsion. The thrust of the strongest ion engines is less than 1 Newton and its specific impulse is about 1000 seconds (compare this to chemical propulsion with thrust of millions of Newtons and specific impulse of a few hundred seconds). Ion engines are ideally suited for deep space missions where large distances are involved; it takes a lot of time for the spacecraft to pick up speed, but it can achieve this with very little fuel, compared to chemical propulsion.

The current most powerful ion thruster is the X-3. It has achieved 5.4 Newtons. The engine itself is 230 kg and uses 200 kW of power. It has a maximum specific impulse of 2640 seconds. Tests in 2018-2019 ran for 100-hours, an un-heard of feat in rocketry. The fuel consumption rate of the X-3 is 0.0002 kg/s. Such an engine, if run for 1 year, will consume only 6.3 tons of fuel and accelerate a 100-ton spaceship to at least 5.4 km/s, if starting from rest. One can imagine having several engines used together to achieve higher acceleration and/or moving heavier payloads or large distances into deep space. In addition, they are quite useful in GEO to maintain an orbital position and make up for "orbital drift." As they are only operational in vacuum, they do not affect the Earth's atmosphere significantly. However, if ion engines are taken to the Apex Anchor of Space Elevators and then attached to preassembled spacecraft above the gravity well, the road to our solar system becomes phenomenal. They start at 7.76 km/sec with essentially no drag from the Earth's gravity ($1/r^2$), and then accelerate continuously toward their destinations. Of course, the ion engines then must slow the spacecraft down for rendezvous or landing at the destination.

4.3.2 Nuclear Propulsion

There are a few nuclear propulsion technologies currently under research and development. The first is Magnetized Target Fusion (MTF), the second is Bimodal Nuclear Thermal Rockets (BNTR), the third is the Variable Specific Impulse Magneto plasma Rocket (VASIMR), and the fourth is advanced Nuclear Electric Propulsion (NEP) with magneto plasma dynamic (MPD) thrusters. It is worth keeping in mind that all nuclear rocket concepts are for use in space and not for liftoff from Earth's surface. While NTR is, in principle, capable of lifting huge payloads thanks to its very high thrust, yet safety consideration, and many international treaties prohibit the use of nuclear rockets on Earth. The specific impulse of NTP is twice that of the best chemical rockets, while its thrust is 222,000 newtons. NTP engines are more energy dense than chemical rockets. We give a very brief description of each of the advanced propulsion systems mentioned in the previous paragraph.

- MTF uses deuterium fusion to generate heat. This heat is used to heat up hydrogen propellant and drives a power cycle for the electricity.
- BNTR uses a nuclear fission reactor, like the ones found in submarines, to generate heat that heats up hydrogen propellant and drive a power cycle for electricity and to provide thrust as in chemical rockets.
- NEP with MPD uses nuclear fission to generate heat to produce electricity. This electricity is used to power a magneto plasma dynamic thruster, a type of ion engine.
- VASIMR uses nuclear fission to power a thermodynamic cycle that produces electricity to power a plasma rocket in which ions are heated by radio waves and magnetic fields holding them in place and accelerate the ions to produce thrust.

The requirement from any propulsion system is that it must have a specific mass of few kg per kW and a specific impulse on the order of several thousand seconds. Depending on which propulsion system is employed, and the planned trajectory, the rockets will have to provide thrust for part of the trip then shut off for the cruising phase, and then provide reverse thrust to slow down when the destination is reached.

These advanced propulsion concepts have not yet been used in any actual space mission. However, it is anticipated that the concepts will mature to an actual operational level (technology readiness level, TRL 9) within two decades. The common technical points among the concepts discussed, is that the nuclear rockets provide both high specific impulse and modest thrust. The fact the thrust can continue for an extended period of time, compared to conventional chemical rockets, allows the movement of large payloads over large distances. Another way to look at it is that nuclear rockets combine the higher specific impulse of ion propulsion and the higher thrust of chemical propulsion. Nuclear propulsion offers four orders of magnitude higher thrust-to-weight ratio than ion propulsion and almost five times the specific impulse of chemical propulsion. Research and development is currently underway with DARPA seeking a demonstration of NTP propulsion in cis-lunar orbit by 2026 through its Demonstration Rocket for Agile Cis-lunar Operations (DRACO) program.

4.4 Dual Space Access Architecture

The bottleneck in space access is putting hardware in Earth orbit because of the tremendous gravitation force it must overcome and the atmospheric draft it must "punch through." As shown Table 2.3 in Green Road to Space, Starship promises to put 2% of the launchpad mass in LEO. Calculations above show that Starship delivers 0.33% of the total launchpad mass to both Moon and Mars orbits, proving that once the starship makes it out of Earth's gravitational potential well, it becomes relatively inexpensive, fuel-wise, to go anywhere in the solar system. We stress and reiterate here the main component of our argument: we need to break free from Earth's gravity without using the rocket equation. The best applications of the rocket equation, the Starships, SLS's, etc., still fall short of delivering meaningful payload amounts of hardware to orbit. A case in point is the ISS. It is less than 500 tonnes , however, it took two decades and more than thirty missions to build in LEO. If Starships were used to build the ISS, it would have taken only five Starship launches, $50 million in launch costs, and less than a week to deliver the various pieces to orbit. More ambitious space projects such as Space Solar Power Systems, Lunar Village, Mars Colony, etc. are three orders of magnitude more massive than the ISS and, as calculations above have shown, will take several decades to achieve using Starship. The current situation is like that of assembling the ISS three decades ago: we painstakingly used rockets to build a structure in near space and took a few decades to do that. There was, and is now, no infrastructure. Relying on rockets to deliver cargo to orbit or beyond is basically like delivering cargo from one city to another and having to excavate and pave the road for every trip! Imagine FedEx trucks bulldozing their roads for every package they want to deliver.

This need not be the case. We need not succumb to the status quo. Space Elevators are the highways on which trucks can transport their packages to distribution centers. Space Elevators will be the permanent transportation infrastructure. Once a spacecraft is delivered to orbit by a Space Elevator, its rockets can send it to anywhere in the solar system. Being able to release spacecraft at a minimum of 7.76 km/s to anywhere in the solar system, Space Elevators give a great kickstart to spacecraft for their missions. Consequently, the fuel carried by our interplanetary spacecraft will be less than that in spacecraft launched by rockets. The lower the fuel requirement the greater the payload mass.

4.5 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. Figure 4.2 illustrates the glaring example is the delivery of a half percent of the launch pad mass to the surface of the moon for Apollo 11. The question is why employ a methodology for delivery that only delivers less than one percent to your desired location. The Space Elevator solves that conundrum by delivering 70% of the mass at liftoff to GEO and beyond by leveraging electricity.

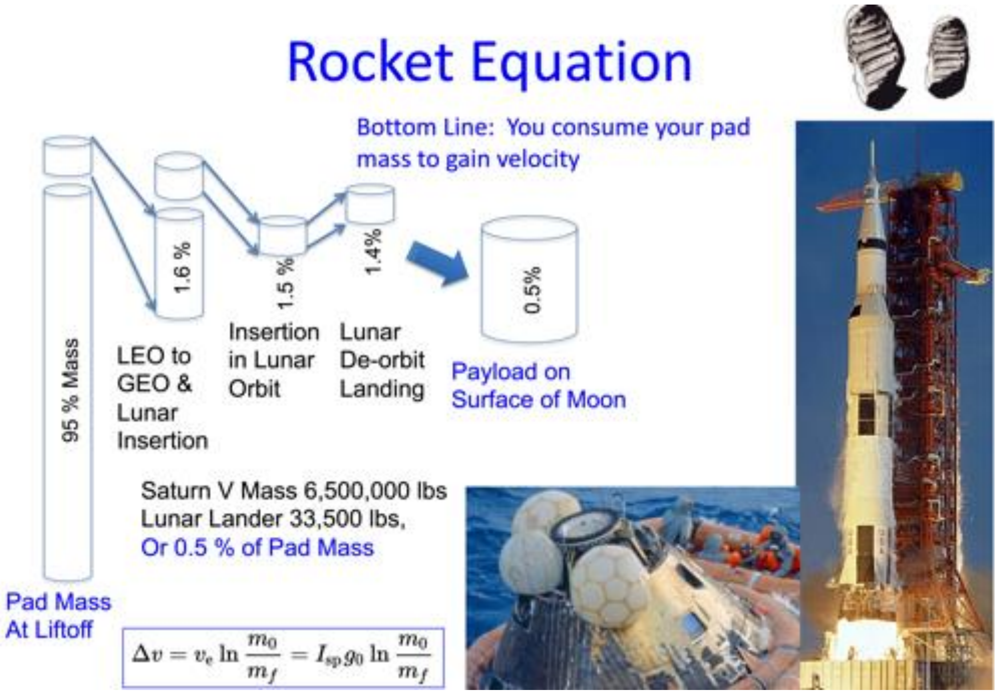
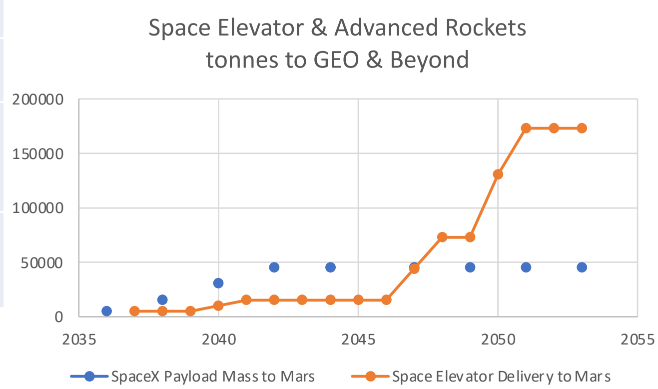


Figure 4.2, Apollo Delivery Efficiency – 0.5% of pad mass to Lunar Surface

Space Elevator Insights:

	Starships	Space Elevators
Daily Departures	3	6
Rapid Delivery	8 months to Mars – 26 month wait	range 61 to 400 – every day
GEO Delivery statists	21 tonnes at 0.5 % pad mass	14 tonnes at 70% of pad mass



Section C: Energy and Climate Crisis Remediations

C.1 Significant Demands for Space Elevators: The future is always a puzzle with the fate of humanity hanging in the balance. At this juncture there are two overriding crisis that will be addressed within Section C, and Chapters 5 and 6. These overriding problems gaining momentum are future global power demands and global warming or the Climate Crisis.

C.1.1 Future Power Needs: The first problem is the rapid growth of the human race inside the developing nations. This increase in population leads to demands for sustainability, especially an increasing expectation level for energy to their home environments. One approach to understanding the future challenges is to describe the power required to satisfy the various populations around the world. The next chart shows the expected demand for electricity over the next 80 years. [Dotson, 2022] The world population is projected to reach 8.5 billion in 2030, and to increase further to 9.7 billion in 2050 and 10.4 billion by 2100. More than half of global population growth between now and 2050 is expected to occur in Africa. In sharp contrast, the populations of 61 countries or areas in the world are expected to decrease by 2050. [Dotson, 2022] The remarkable projection is that the growth of humanity will be outside of the industrial countries with an associated need for basic electrical power needs inside developing countries.

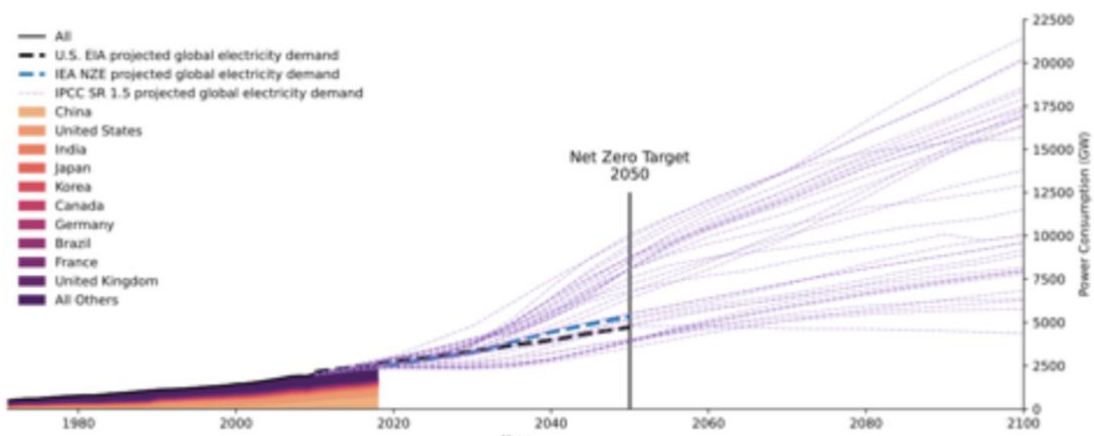


Figure C.1: Global Power Demands [Dotson, 2022]

As the chart shows, the need for roughly 5,000 GigaWatts by 2050 of base power will be spread globally with the potential increases from there wildly speculative. However, the one item that seems true is humans demand access to energy if at all possible and this will accelerate over the next 30 years and then grow rapidly from there. These multiple questions ensure complex answers. Can humanity provide itself these growing demands for power? Can they accomplish this in a manner that is Earth friendly? One current concept is that the fulfillment of needs for energy by the growing population could be met with the space program called Space Solar Power. Dr. John Mankins, a visionary and leader in the industry, has established a goal of power from space equaling 12% of the global supply. The rationale is that this objective can fulfill the new needs over the future decades and replace environmentally unfriendly sources of power such as burning fossil fuels. The substitution of power source from space and elimination of environmentally harsh sources would greatly improve the situation in the future. Chapter 6 explains how this can be achieved.

C.1.2 Global Warming, a Larger Problem: This parallel crisis recognizes that the Earth is experiencing a growth in temperature that could lead to catastrophe through so many environmental changes. Over the last few years, the results of global warming reflect an average temperature of 1.09°C over pre-industrial temperatures. [IPCC, 2021] Two quick questions are can humanity change or slow this trend and can space programs contribute to solutions? Chapter 5 focuses upon an approach to use space systems to decrease the temperature of the Earth's environment by shading it. Chapter six approaches the dual problem by providing environmentally friendly power to replace carbon burning sources.

C.2 Introduction to the problem This section will deal with the potential of stopping or slowing down significantly the warming of our atmosphere using space programs approaching this global problem. The authors believe that both of these proposals can be achieved with today's (and near future) space systems; however, the scale is defined as mega-projects; complex, difficult, taking at least a decade, and costly. One recent report [Greenhous Gas, 2022] explains the problem:

> "The science is clear—climate change is one of the greatest threats facing humanity. Almost every day the news reports on one or more new extreme weather-related events having serious impacts on some part of the world. Many thousands of observational-based studies have documented the increasing surface, atmospheric, and oceanic temperatures on climate time scales. These observations also show many other aspects of a changing climate—for example, the vast majority of glaciers, including major parts of Greenland and Antarctica, are melting, snow cover is diminishing, sea ice is shrinking, sea levels are rising, oceans are acidifying—and many of these extreme weather events are becoming more intense than they were in the past. It is also certain now more than ever, based on many lines of evidence, that human activities are largely responsible for these changes in the Earth's climate."

Climate change is the defining challenge of our time. Global warming has already increased average temperatures by 1.09°C over pre-Industrial temperatures [IPCC, 2021] . To limit global warming to 1.5°C, the IPCC estimates that the remaining carbon emissions budget is around 500 million tons of carbon dioxide. The cumulative net CO2 emissions between 2010 and 2019 was 410 million tons which means, on the current emissions trajectory, we will exceed the threshold for 1.5°C of warming sometime in the early 2030s. Temperatures this warm on Earth have not been seen for around two million years, and some plausible global warming trajectories could increase temperatures to levels not seen since the Eocene, over 50 million years ago.

While the Earth has seen such high temperatures in its history, humans and modern ecosystems have not. The effects of climate change are already detectable: temperature differences of up to 5°C above 1981-2010 averages have been detected in Arctic and Antarctic regions (see Figure C-2); ecosystems are undergoing unprecedented degradation and loss of biodiversity; floods and droughts have caused food insecurity and displacement for tens of millions of people [WMO, 2022].

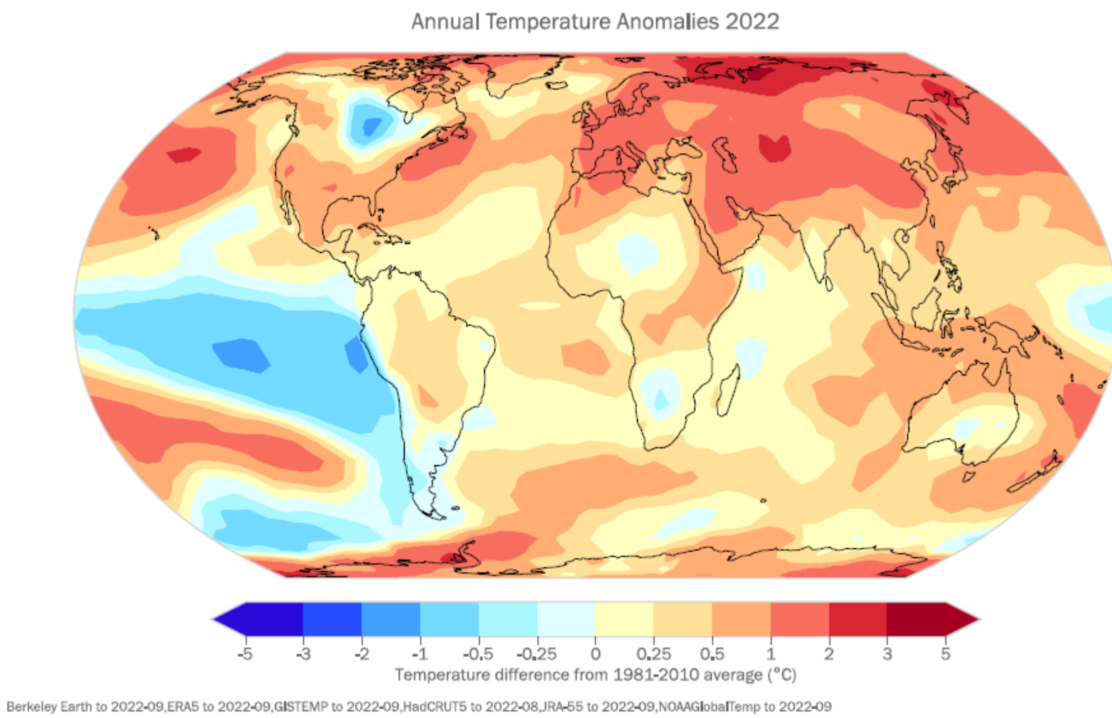


Figure C-2: Near-surface temperature differences relative to the 1981-2010 average for 2022 to September [WMO, 2022]

The energy budget of Earth is the difference between energy entering and energy leaving the Earth system. Energy enters the system through solar radiation from the Sun, expressed as the rate of energy transfer (watts) per area (square meters). At Earth's distance from the Sun, the average solar energy impacting any given point on Earth is about 340 W/m^2. When the energy budget is in equilibrium, global temperatures are relatively stable. However, carbon dioxide and other greenhouse gases (GHG) have accumulated in the atmosphere, causing it to absorb thermal energy that would have otherwise radiated back out to space; as a result, the Earth no longer radiates as much energy as it absorbs. This additional absorbed energy, about 0.7 W/m^2, is the cause of climate change (see Figure C-3).

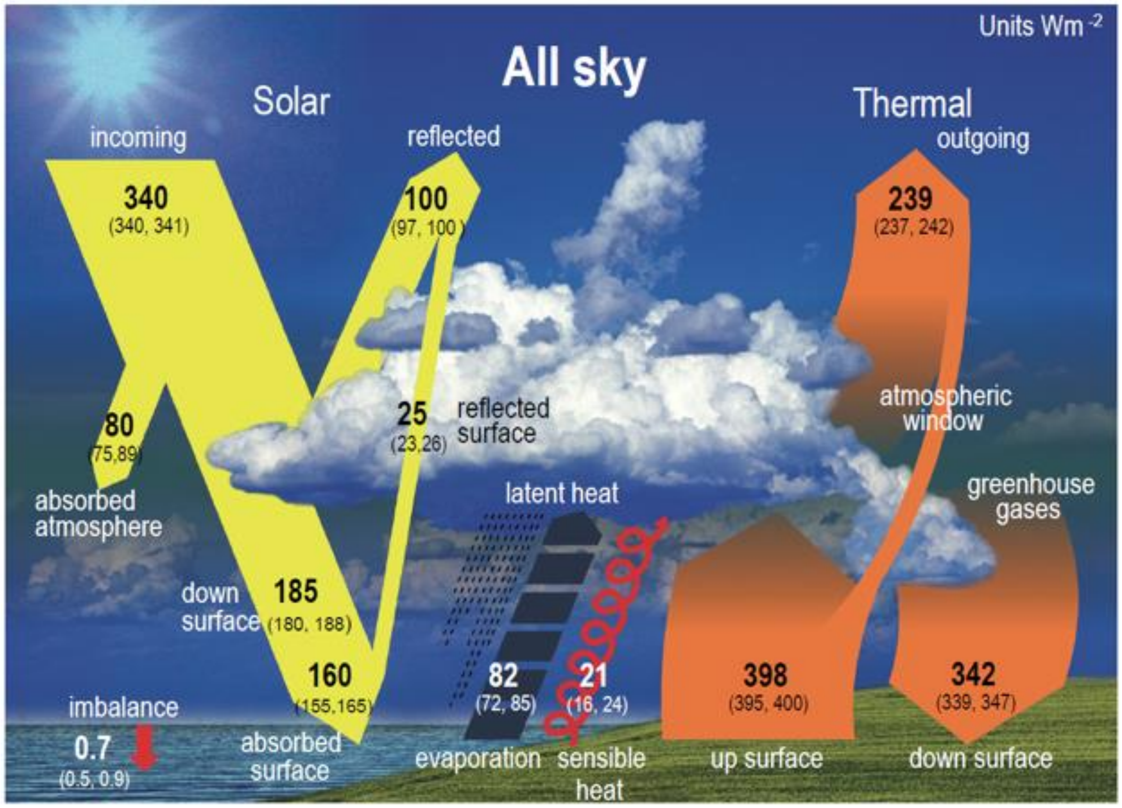


Figure C-3: Global mean energy budget of the Earth (values expressed in W/m^2, uncertainty ranges shown in parentheses) [IPCC, 2021]

The energy imbalance can be addressed in two ways. The first is to restore Earth's atmosphere to pre-Industrial conditions. This first step requires ceasing fossil fuel use as quickly as possible. This step is essential to address the full effects of climate change and the energy transition away from fossil fuels and toward renewable energy must occur as quickly as possible. However, to limit global warming to 1.5°C, the IPCC estimates that the remaining carbon emissions budget is around 500 million tons of carbon dioxide (IPCC, 2022). The cumulative net CO_2 emissions between 2010 and 2019 was 410 million tons of carbon which means, on the current emissions trajectory, we will exceed the threshold for 1.5°C warming sometime in the early 2030s. Even if emissions were to cease today, the carbon already present in the atmosphere has committed Earth to about 1.5°C of global warming (IPCC, 2021). Although progress has been made on international commitments to reduce GHG emissions, proposed cuts are insufficient to reach the goal of limiting global warming to 1.5°C (see Figure C-4).

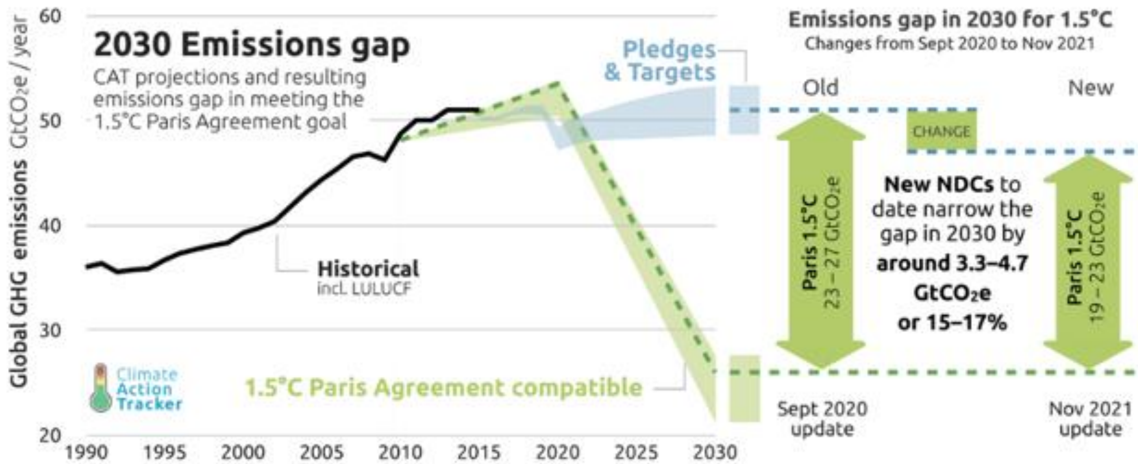


Figure C-4: 2030 emissions gap, showing the difference between international emissions reduction pledges and targets and the emissions trajectory required to limit global warming to 1.5°C (LULUCF: land use, land use change, and forestry; NDC: nationally determined contribution.) [Climate Tracker, 2020]

The second step to restoring Earth's atmosphere is to remove the excess carbon from the environment through carbon dioxide removal (CDR). As with ceasing carbon emissions, carbon removal is necessary to undo the effects of climate change. It is the only solution that will address global warming as well as other side effects of climate change, such as ocean acidification and altered weather patterns. There are many forms of CDR, but they all share a goal of removing and sequestering carbon that would otherwise go into the atmosphere. Some methods, such as reforestation, propose land use changes that would sequester carbon in trees or soil. Others, such as direct air capture, scrub carbon directly from the atmosphere and sequester it in underground rocks. Removing carbon from the atmosphere is likely to be a very slow process; although progress is being made on the technology, it has not been scaled up to address current GHG emissions, much less address the carbon already in the atmosphere. CDR can only occur at scale once the transition to renewable energy is complete and there is sufficient excess energy to support the enormous energy requirements of CDR. As such, it could take a century or more to restore pre-Industrial carbon levels. Meanwhile, catastrophic effects of global warming are already being felt around the world and conditions will only worsen as emissions, and temperatures, continue to rise.

C.2.1 Multiple programs: Many programs have been proposed to help stop global warming. Several are based in space and could have significant positive impacts on our atmosphere. An intriguing approach could be to cool the Earth by lowering the incoming energy from the sun, thus directly effecting the temperature of the atmosphere. This is called Sunshades which actually blocks sunlight at the Earth-Sun L-1 location (Chapter 5). Another large effect could come from Space Solar Power which comprises a constellation of very large satellites in a high Earth orbit, where the sun is visible almost 100% of the time, collecting solar power and beaming it securely to fixed points on the

Earth (Chapter 6). Its main attribute is the ability to deliver clean, baseload energy, day and night throughout the year and in all weather. This responds to the projected global needs of doubling (by 2050) the base power needs, while saving the environment by eliminating the need for fossil fuel power plants . Recent technology and conceptual advances have made these two concepts both viable and economically competitive. This separation of the Climate Crisis problem into meeting future power demands and cooling of the Earth is an approach to show that there are proposals that are real and could significantly impact our future.

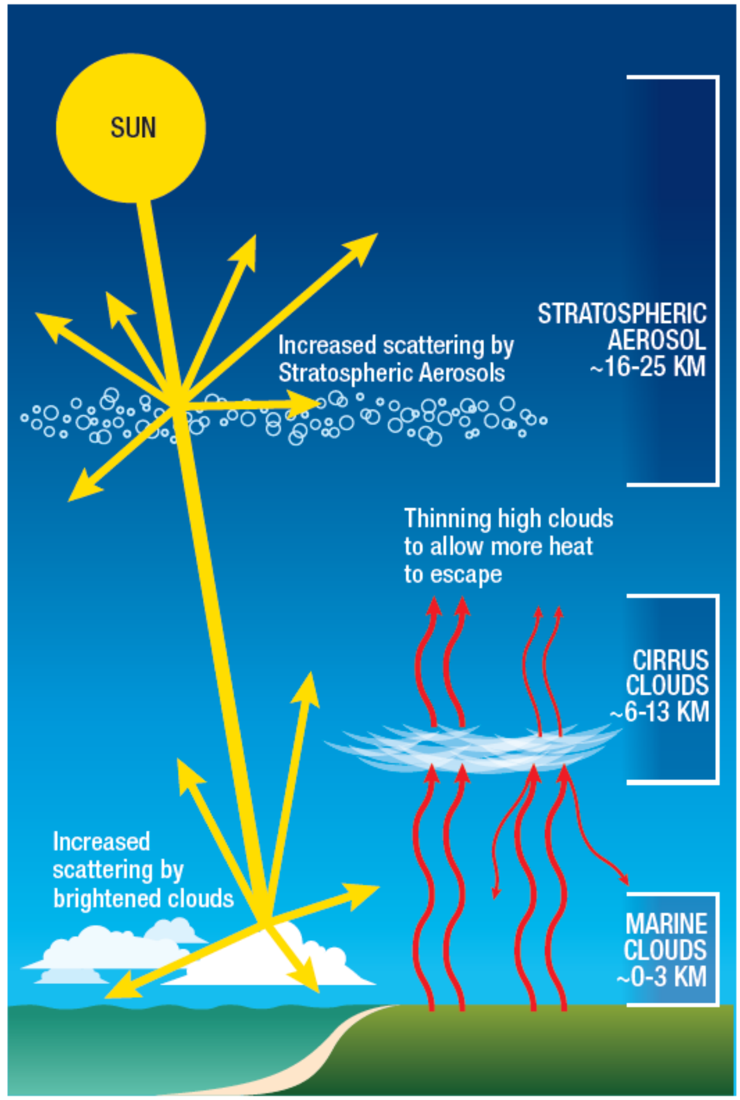


Figure C-5: Terrestrial solar radiation management techniques

C2.2 Solar Radiation Management: The second way to restore the balance between energy entering and energy leaving the Earth system is to reduce incoming solar energy. This solution is referred to as solar radiation management (SRM). Unlike CDR, SRM it does not solve the underlying imbalance of the atmosphere's chemistry (too much carbon in the atmosphere). Instead, SRM addresses one of climate change's most severe consequences - global warming - to buy time for carbon removal while minimizing the ecological, economic, and human impacts of climate change.

Many regional forms of SRM have been proposed and studied in models, including modifying land to increase its reflectivity, preserving highly reflective ice sheets, brightening marine clouds by seeding them with saltwater, and thinning cirrus clouds, which trap heat in the atmosphere. While these concepts are worthy of additional study, the effects of these solutions appear to be regional. Since climate change is a global problem, addressing it will require a global solution. The most viable SRM method, and the one that has generated the most attention and study, is stratospheric aerosol injection (SAI) (see Figure C-5).

In stratospheric aerosol injection (SAI), tiny particles, called aerosols, are injected into the stratosphere to reflect a small percentage of incoming solar energy. The stratosphere is high in the atmosphere, where the air is thin and relatively stable; aerosols injected at this altitude can last for around two years before migrating to the poles and falling back to the surface. The motion of currents in the stratosphere is primarily horizontal, so injections made at one longitude will distribute relatively evenly around the globe at that latitude. To cool the Earth enough to offset 0.5-1.0°C of global warming, several million metric tons of aerosols must be injected into the atmosphere each year. Although significant additional study is required to fully characterize the effects of SAI, we know that the concept works because of a natural, destructive 'field test' of the concept: massive volcanic eruptions. Volcanic eruptions, such as Krakatoa in 1883 and Mount Pinatubo in 1991, sent millions of tons of sulfur dioxide, the aerosol most commonly proposed for SAI, into the stratosphere and had measurable impacts on Earth's temperature. The Krakatoa eruption reduced global temperatures by up to 1.2°C and Mount Pinatubo's eruption reduced temperatures by 0.5°C, with effects lasting one to two years.

There are several crucial benefits to SAI. First, it is effective very rapidly. As demonstrated by volcanoes, injecting aerosols into the stratosphere can result in dramatic temperature reductions within a year or two. SAI also provides flexibility in desired temperature. More aerosol injection could fully return Earth to pre-Industrial temperatures; less SAI could shave a few tenths of a degree off global temperatures to avoid the worst temperature-related outcomes of climate change. The third benefit of SAI is that the cost is relatively low. A fleet of one hundred purpose-built high-altitude aircraft, plus the infrastructure to support deployment, could cost several tens of billions of dollars: vastly less than the trillions of dollars needed for CDR or to adapt to unmitigated climate change. The technical capabilities to deploy SAI at scale are not available today but could be developed with existing technology if a decision was made to pursue SAI.

Despite its benefits, SAI is not a perfect solution. Sulfur dioxide is a precursor to sulfuric acid, which causes acid rain. While the amount of SO_2 needed to counteract anthropogenic warming is an order of magnitude less than the SO_2 currently emitted by the world's industry, it would still have a measurable impact. Deployment at the level needed to significantly mitigate global warming will also result in a cloudy or milky appearance to the sky. SAI may have undesirable impacts on the hydrological cycle, and more modeling is needed. Injecting sulfur into the atmosphere will also cause damage to Earth's ozone layer, as sulfur reacts with ozone to become sulfuric acid, although ozone damage is also an order of magnitude less than that caused by current pollution.

Decision makers will need to weigh these factors against climate change impacts when making a decision to implement this technology.

Like all SRM, SAI sets up the conditions for termination shock. If an intervention is implemented and is successful in reducing temperatures, and is then rapidly halted, the climate would suffer a temperature snap-back, where the full effects of global warming would return over the course of 1-2 years. The speed of this rapid snap-back could be more damaging than gradual global warming. Once SAI begins, it must be maintained until carbon is removed from the atmosphere: since CDR is expected to take generations, SAI must be maintained at some level until that task is completed.

Now that limiting Earth to a 1.5°C temperature rise is no longer achievable, and there are credible scenarios for 3.5°C to 4.5°C of warming, the eventual deployment of SAI is becoming increasingly likely. No other technology currently under consideration can reverse global warming as quickly or as cheaply as SAI. However, the side effects of SAI may be severe and may worsen the longer SAI is deployed. Now is the time to consider wind-down strategies in the event SAI is deployed. Fortunately, there is another global SRM solution that complements SAI: a planetary sunshade.

C.3 Separation of each approach: These massive global efforts approach the problem of climate change from two directions. The future demand for power will drive the climate temperature if it is not fulfilled with ecological friendly approaches. The Space Solar Power approach is grand enough to achieve its objective as it leapfrogs over the terrestrial solutions and goes to a global solution for a global issue. (see chapter 6) The second suggestion is for a lowering of the amount of energy that is impacting the Earth's upper atmosphere, thus allowing the temperature of the Earth to regain the lower boundaries it had prior to this century (see chapter 5). Each of these concepts have tremendous potential to stop/slow global warming, along with tremendously large projects never attempted in space before. However, humanity has come a long way and when it recognizes the seriousness of this Climate Crisis, it must move out to at least assess these two global solutions to the global problem. The following two chapters jump into the proposed engineering concepts for helping to lower the temperature of the global atmosphere and still enable humanity to have the base power loads that it needs to maintain the expected lifestyle of our future.

Space Elevator Insights:

The problems of Humanity's future power requirements, the cooling of the Earth, and Global Climate Change have all focused a need for satellite based solutions.:

- The power needs will double within the next 25 years, the ramping up of the global temperature is frightening, and major disturbances in weather are showing up in surprising locations.
- It seems that long term answers to these dangers require massive satellite projects initiated in the near future.

Chapter 5: Sunshades to Cool the Earth

5.1 Planetary Sunshades

The concept of a planetary sunshade is relatively simple. Like an umbrella on a hot day, an object placed between the Sun and the Earth will reduce the amount of incoming solar energy and, therefore, the temperature of the Earth. Figure 5.1 shows an artist's concept of what a planetary sunshade element could look like.

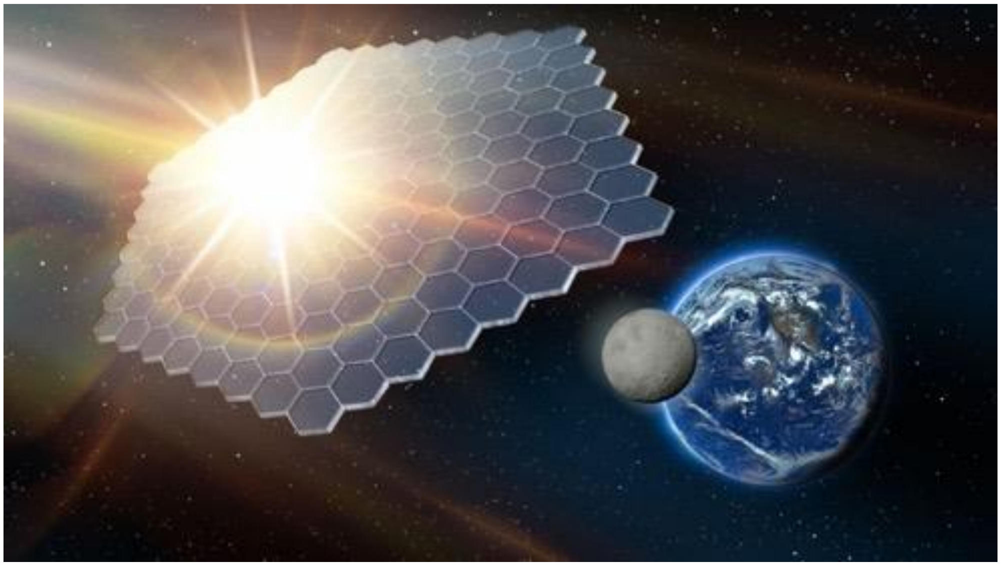


Figure 5.1: Planetary sunshade element

A natural demonstration of this concept was the transit of Venus between the Sun and the Earth in June of 2012. Although the transit time was much too short to have a measurable effect on Earth's temperature, the SORCE spacecraft measured that, at the center of the transit, incoming solar radiation was reduced by 1.4 W/m^2 (0.35 W/m^2 averaged over the Earth), or about 0.1%. Figure 5.2 shows how the transit of Venus appeared from Earth.

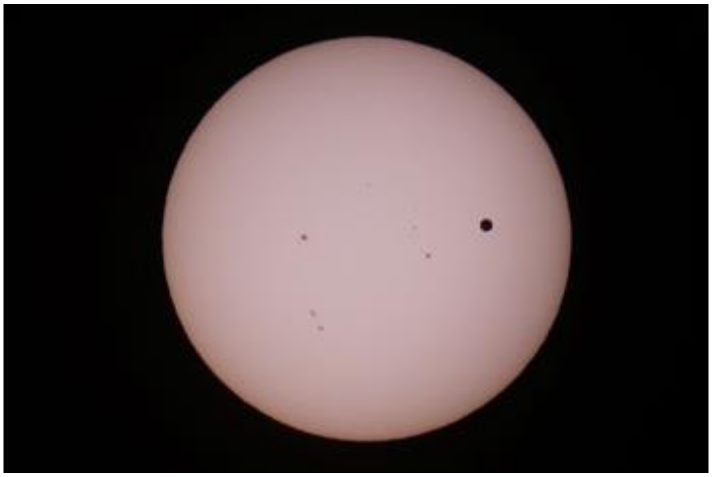


Figure 5.2: 2012 transit of Venus (large spot), (smaller dots are sunspots) [Rector, 2012]

Like stratospheric aerosol injection(SAI), planetary sunshades have the benefit of being adaptable for different levels of planetary cooling. Blocking more solar energy (with a larger-area sunshade) results in cooler global average temperatures and blocking less solar energy (with a smaller-area sunshade) results in less cooling. The desired level of cooling will depend on how much warming will be offset by the sunshade; different sunshade sizes could be used to restore pre-Industrial temperatures, reduce temperatures by only a few tenths of a degree to circumvent certain climate tipping points, or used in conjunction with SAI.

Due to the realities of gravitational physics, the only feasible location for a planetary sunshade is near the Sun-Earth Lagrange point 1 (SEL-1) (see 5.3). Lagrange points are equilibrium points where the gravity of two large bodies (in this case, the Sun and the Earth) and the centrifugal orbital forces balance. Objects located at SEL-1 remain on the line between the Earth and the Sun and require relatively minor station keeping to maintain their orbital location. Solar radiation pressure also acts on relatively light objects with large surface area, such as the planetary sunshade; this force acts outward from the Sun, thus bringing the equilibrium point Sunward. Although the exact location of the equilibrium point depends on the mass and optical parameters of the sunshade, the sunshade's minimum mass location is about 2.4 million km from Earth, or about 5 times further away from Earth than the Moon.

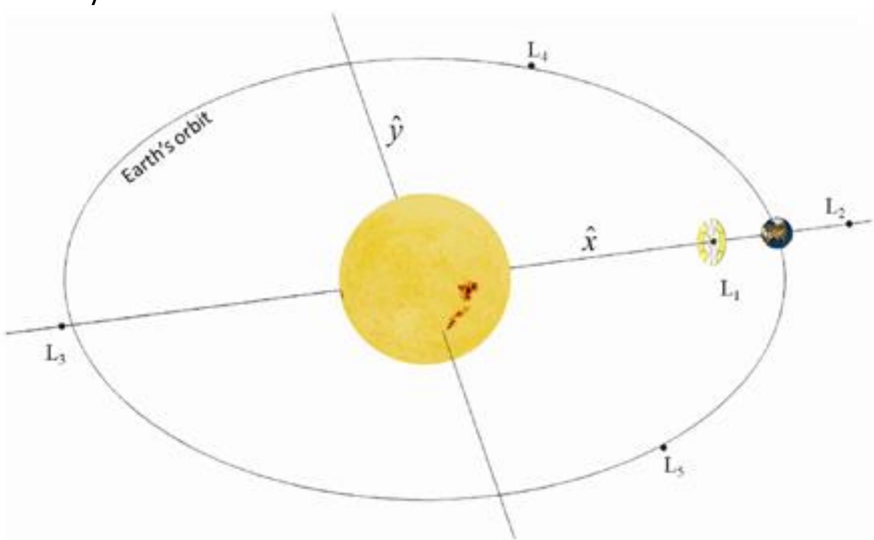


Figure 5.3: Planetary sunshade location at SEL-1 [Sanchez, 2015]

Although the total area of the planetary sunshade would be enormous – several hundred thousand to several million square kilometers – SEL-1 is far enough away from Earth that the sunshade would cast a diffuse shadow on the Earth, rather than a dark, acute shadow. The fully shaded region (umbra) of the sunshade would not reach Earth, so no point on Earth would see a dark shadow. Instead, the sunshade's penumbra, or diffuse shadow, would cover the Earth (see 5.4).

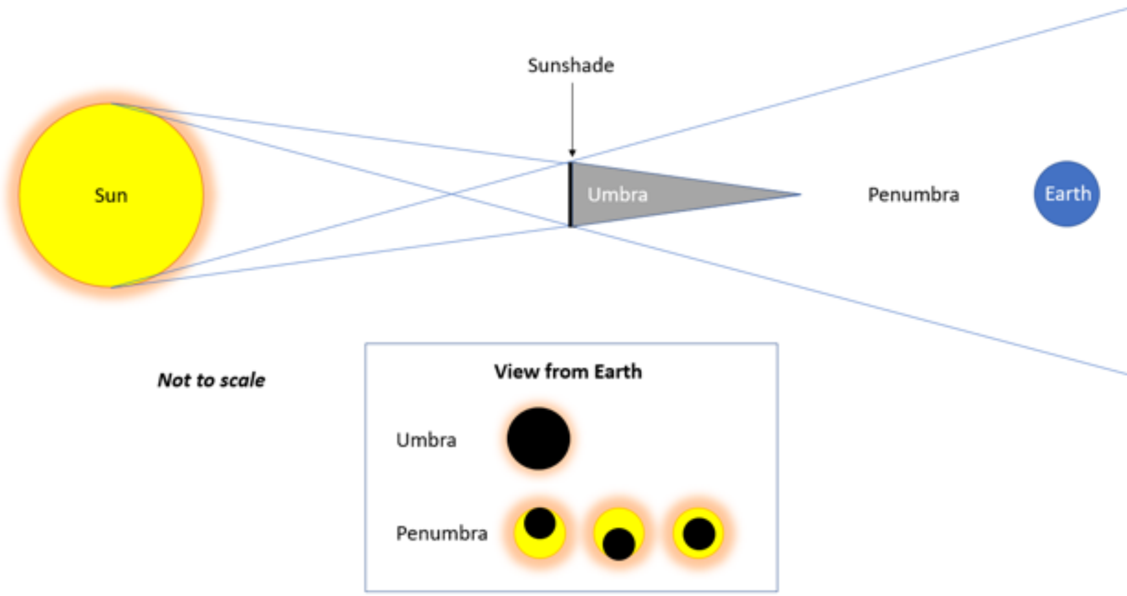


Figure 5.4: Location of the Earth within the sunshade's penumbra (not to scale)

Minimizing the mass of the system depends on several factors. The first is the sunshade's position between the Earth and the Sun. Geometrically, the closer a sunshade is to the Sun, the larger its area must be to block the same amount of solar energy. The second factor is the optical properties of the sunshade material. Shinier materials are more susceptible to solar radiation pressure; they must therefore orbit closer to the Sun to offset the additional outward force. Conversely, darker materials are less susceptible to solar radiation pressure and can be located closer to Earth, thus lowering the required area and mass. The third factor is the areal density (mass per area) of the sunshade material. The more massive the sunshade is, the less susceptible it is to solar radiation pressure and the closer to Earth it can orbit and the smaller the area can be. Lighter sunshades, like shinier sunshades, must orbit closer to the Sun and must have increased area. Figure 5.5 shows the location of minimum mass for a sunshade to block 0.52% of solar radiation.

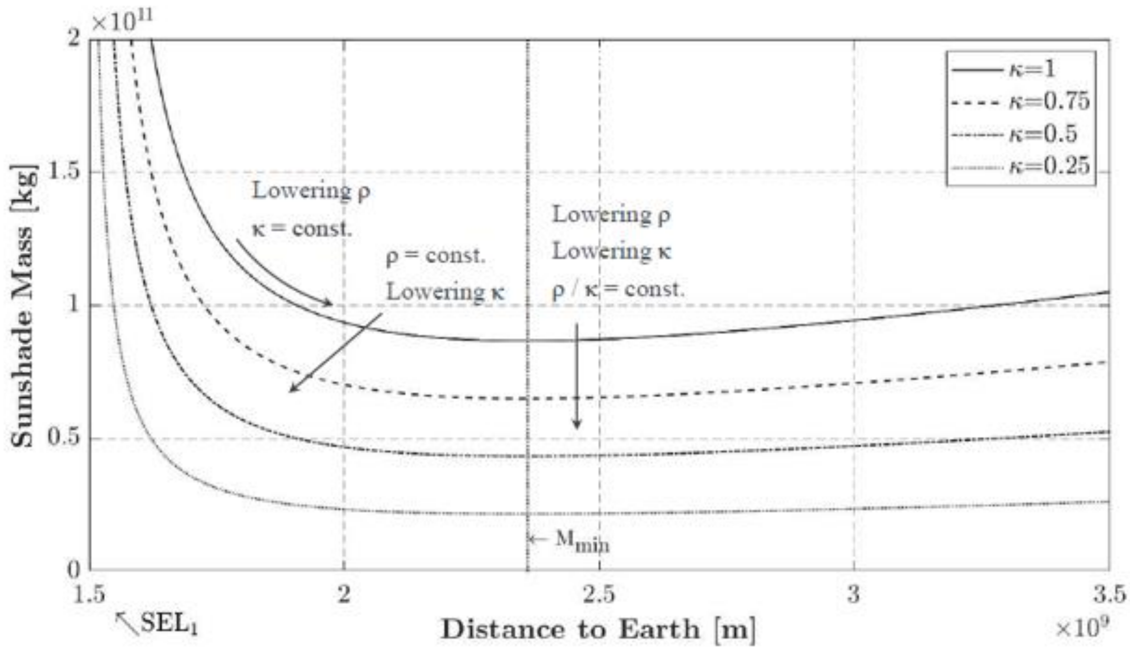


Figure 5.5: Sunshade mass to block 0.52% of incoming solar energy
(k = optical parameter, ρ = areal density) [Fix, 2021]

One exciting proposition is to use the sunshade for power generation. The sunshade is a very large object that constantly faces the Sun; if the sunshade were produced from photovoltaics, it could generate terawatts of energy that could be beamed to Earth or used in space. Even the thinnest photovoltaic materials, however, are substantially heavier than thin film.

Several sunshade architectures have been proposed in the literature (see Table 1). The various architectures assume different levels of insolation reduction and different construction methods, so the overall size of the sunshades is different. However, all proposed sunshade architectures have a total mass of millions of tons.

Table 5.1: Selection of Proposed Planetary Sunshade Architectures

Proposed Architecture	Total Mass (millions of tons)	Total Area (millions of km^2)	% Insolation Reduction
Minimum Mass [Angel, 2006]	20	4.7	1.8%
Photovoltaic [Kennedy, 2013]	72	0.55-1.1	0.25%
Space Resources [Fix, 2021]	74	1.7	0.52%

5.2 How to Build a Planetary Sunshade

There are two ways to construct a megaproject such as the sunshade in space: build it on and loft it from Earth or use space resources to build it outside of Earth's gravity well. Both approaches have benefits and drawbacks. To date, the aerospace industry has solely comprised hardware built on and launched from Earth using chemical propulsion. The spacecraft launched from Earth are exquisitely designed machines, built using the most advanced methods available to humanity. Terrestrial construction allows for the use of Earth's full resource processing, manufacturing, assembly, and supply chains, with human oversight at every step. The technology to build sunshade elements on Earth already exists, allowing for construction of a sunshade to begin quickly. The drawback of terrestrial construction is the location at the bottom of Earth's gravity well. Launching tens of millions of tons of material to SEL-1 is both cost- and time-prohibitive. Of course, Space Elevators radically change that value proposition (see next section).

The proposed architectures for sunshade elements built on Earth have mostly centered on using trillions of small (one or two meters in diameter) screens that may have mass as little as several grams each. These screens would be stacked by the thousands into launch vehicles for deployment in space.

The use of space resources for in-space construction brings many benefits. Materials harvested from the Moon or asteroids are not bound by Earth's gravity. Sunshade elements built in space would not be required to withstand the forces of launch or fold to fit into a launch vehicle. Using space resources does not obviate the need for terrestrial launch; the equipment needed to extract resources and manufacture parts must still, at least initially, come from Earth. However, by some estimates, use of space resources could provide a mass fraction of one hundred tons of finished products for every ton of equipment launched from Earth. Even at this optimistic mass fraction, 740,000 tons of material must still be lifted from Earth to complete a space resources sunshade.

The proposed architectures for sunshades built from space resources focus on construction that uses the simplest techniques possible. This could be cold-rolled aluminum foil stretched onto an aluminum frame. Since these sunshade elements would not be bound by the constraints of launch or lift from Earth, they can be substantially larger than those built on Earth (several kilometers in diameter).

5.3 Space Elevator Orbital Insertion Approach [Eddy 2021]:

Space Elevators allow one to launch large mass rapidly, daily and efficiently. As such moving the tremendous amount of equipment to the Earth-Sun L-1 location seems like a logical job for Space Elevators. the key element to this proposed idea is that it can initial a stream of sunshades towards their destination by releasing from the Apex Anchor at the proper time of day with small engines attached to correct for inclinations and the final placement in the appropriate L-1 location. This concept would "enable trillions of two-foot diameter flyers to be available when the Space Elevator reaches its full operating capacity leading to 170,000 tonnes being placed at L-1. This approach could "enable this environmentally significant mission." The following steps would place the trillions of flyers in the L-1 location. [Eddy, 2021]

Starting Point, Earth's Orbit (149 million km approx. circular)

Destination Point, L-1 Orbit (1.5 million Km from Earth - orbital period matches Earth's)
Approach:
Step One: climb space elevator tether to 100,000 km altitude
Step two: Release in negative direction resulting in 21.94 km/sec velocity
Step three: at perihelion thrust to reduce orbital energy
Step four: at aphelion thrust to circularize orbit
Step five: refine orbital characteristics and maintain orbit
Step six: release the flyers

5.4 Space Elevators vs Rockets for the Planetary Sunshade

When comparing advanced rockets to Space Elevators in the outyears, the comparison is remarkable. With SpaceX's Starship delivering 100 tonnes to LEO and 50 tonnes to GEO and beyond with three rockets per day, the time to lift 20 million tonnes would be 365 years. [50 x 3 lifts/day x 365 tonnes per year = 365 year] Delivery to Sun-Earth L-1 by Space Elevators would be roughly 57 years in an environmentally friendly transportation infrastructure. [20 million divided by 346,020 tonnes (outyear capability) = 57] If this is the chosen approach to cool the Earth, many Space Elevators can become operational rapidly for parallel development turning 57 years into maybe 5.

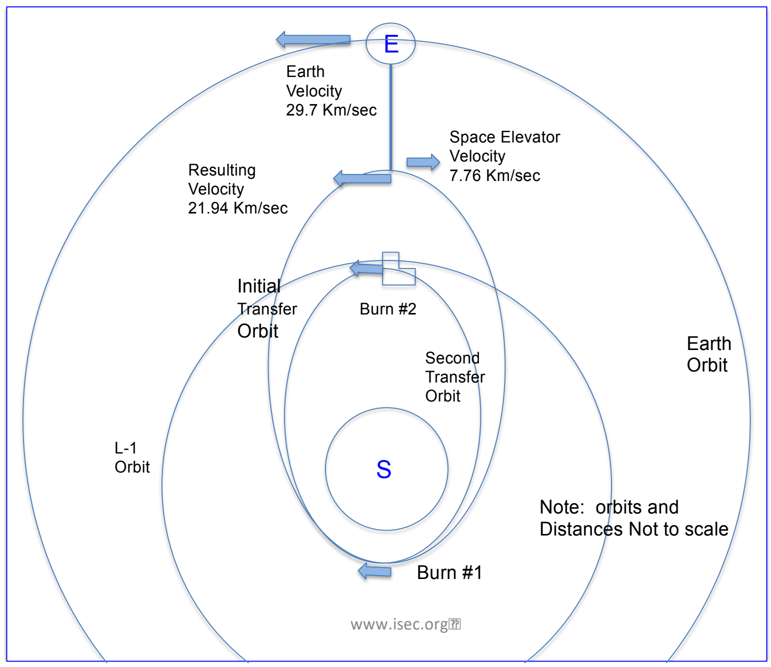


Figure 5.2, Orbital Approach for L-1 Solar Shield

Space Elevator Insights:

The rising temperature around the globe has increased the awareness of the need to evaluate satellite solutions. The idea of a SunShade has tremendous validity in that there is a direct relationship between blocked sun and temperature lowering on the receiving planet.

- The concept of a planetary sunshade is relatively simple. Like an umbrella on a hot day, an object placed between the Sun and the Earth will reduce the amount of incoming solar energy and, therefore, the temperature of the Earth
- There are two ways to construct a megaproject such as the sunshade in space: build it on and loft it from Earth or use space resources to build it outside of Earth's gravity well. Both approaches have benefits and drawbacks

6. Space Solar Power Satellite

6.1 Overview:

The Renewable Energy sector is undergoing rapid transformation, with emerging technologies such as Space-Based Solar Power (SBSP) gaining increasing popularity. SBSP technology harnesses solar energy from our sun using large satellites, promising a sustainable solution to the world's energy demands. One of the significant advantages of SBSP technology is its ability to offer a constant energy supply that is independent of weather patterns, geopolitical events, and time of day and night. This feature distinguishes it from conventional fossil fuels, which are often subject to supply disruptions and is a major cause of global warming. An additional strength of this approach is that the concept supports commercial development leading to continuous profits with low rates to the users and at the national level. This leads to Energy Independence. To launch large-sized SBSP satellites and meet the world's energy needs, some SBSP organizations are evaluating the Space Elevator as a more efficient and effective alternative to rockets. The Space Elevator, a proposed transportation system that would use a tether, with climbers, is optimized to transport materials and equipment from Earth to geosynchronous orbit (GEO). This would substantially reduce the number of rockets and cost of placing SBSP satellites at GEO, making the technology more accessible to people worldwide. In addition, the ability to move massive logistics support (upwards of 170,000 tonnes to GEO per year) will enable delivery of SBSP satellites inside a daily, routine, safe and environmentally friendly permanent infrastructure. The Space Elevator has the potential to make SBSP technology the answer for energy sustainability and reaching worldwide Net Zero Carbon goals.

6.2 Introduction of Space Solar Power:

Many countries have established ambitions of attaining carbon neutrality, Net-Zero and limiting the rise in global temperatures below 1.5℃ by 2100, necessitating innovative energy generation approaches. One promising avenue toward these targets is the utilization of SBSP technology, in which space technology plays a vital role.

6.2.1 SBSP Characteristics:

SBSP Satellites represent a concept wherein the sun's energy is harnessed in space and relayed to Earth via microwaves, millimeter waves, or lasers. The envisaged objective is to construct solar power satellites capable of continuously capturing solar energy, immune to interruptions caused by weather fluctuations or the day-night cycle.
SBSP holds immense potential for the future as it has the capacity to supplant existing energy generation modalities. Its viability in the future is bolstered by continuing technological advancements and escalated investment in research and development. Presently, several energy generation sources, namely fossil fuels, hydroelectric power, nuclear power, and wind power cater to global energy requirements. Coal-based power plants generate significant carbon emissions, posing a substantial threat to the planet's climate. Replacing such plants with renewable energy sources, including SBSP technology, is crucial in mitigating the consequences of climate change. As the world

population expands, electricity demand is also rising correspondingly. To meet this demand sustainability is imperative to transition to renewable energy sources that generate clean energy without causing environmental damage.

The distinguishing features that make SBSP a unique and clean energy source include its continuous availability, high efficiency, scalability, minimal energy storage issues, and absence of harmful emissions. Space-based solar panels can receive solar energy around the clock without interruptions, resulting in a dependable source of energy. Furthermore, the absence of atmospheric interference makes space-based solar panels more efficient, allowing them to capture more energy from the sun and convert it into electricity. SBSP has the potential for scalability as additional solar panels can be placed into space as required to cater to increasing energy demands. The wireless transmission of electricity from space-based solar panels using the microwave, millimeter, or laser technology reduces energy storage issues. Furthermore, SBSP produces no harmful emissions, making it a cleaner and more sustainable energy source than traditional fossil fuels. [Frazer-Nash, 2021] Overall, the SBSP technology represents a potential game-changer in the energy generation domain. There are several planned SBSP missions in the upcoming decades that will launch the most massive satellites to be assembled in space, ranging from 250 Kg to 10,000 tonnes per satellite (maybe even 26,000 tonnes per satellite – Japanese early design). These satellites will mainly consist of photovoltaics (possibly joined with reflectors/concentrators) in orbit to collect solar radiation and a microwave or laser transmitter module that converts the accumulated energy into a beam directed towards Earth's surface. The heavy mass of these satellites will divide into mechanisms, subparts, and folded panels. which will need to be assembled remotely.
Due to its advantages, the preferred location for most SBSP satellites is in geosynchronous orbit (GEO) 35,780 km above the Earth's surface. One advantage is the constant antenna geometry that simplifies the alignment of the antennas. Furthermore, a space power station in geostationary orbit provides nearly continuous power transmission, unlike other space-based power stations that require extended start-up times. The Solar Power Satellite system requires the placement of giant satellites, with wide arrays of solar cells, at GEO. With Space Solar Power technology, countries can access 24/7 energy from space. [Baraskar, 2021]

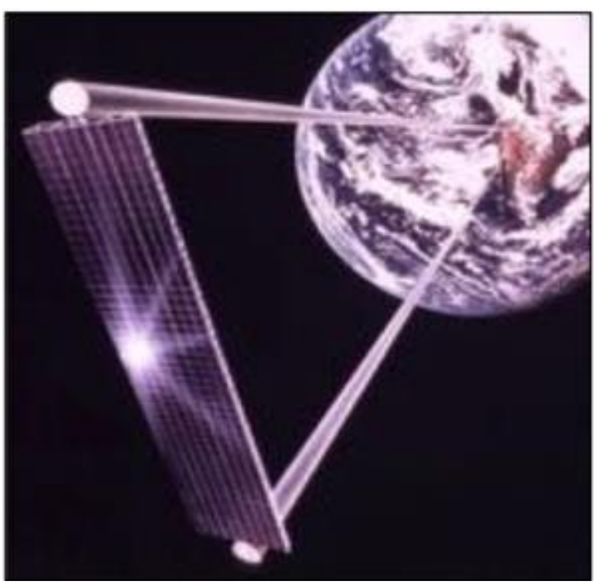


Figure 6.1: 1979 Reference System design [Mankins, 2021]

6.3 SBSP Fills a Future Need: Increased demands for electrification around the globe is predicted to be tremendous, with it growing rapidly to 2050 and beyond. This is being driven by two forces, massive population increases in developing countries and desires/needs to have better support to include heat, cooking, comfort and manufacturing where very little exists today. The drive to replace coal plants to help save the environment is driving power development towards wind, hydro, geothermal, and solar; however, this is complicated by long distance transmission and distribution of the energy produced. When looking at the predictions of electrical needs by the year 2050 and beyond, one realizes that the demand will double while trying to reduce the coal fired furnaces which are driving global climate change. The next chart shows an estimate [World Energy, 2021] of the needs for global electrification over time. [Dotson, 2022] Essentially, the numbers grow from 2,500 GW of base power consumed around the globe in 2018 to double that to 5,000 GW needed in 2050. For the purpose of this report, the team has estimated that a sizable amount of energy needs to come from space to satisfy the global electrification needs. The simplicity of supplying that energy from space directly to the customer enhances the argument that there is a potential significant alternative to terrestrial power enhancement alone.

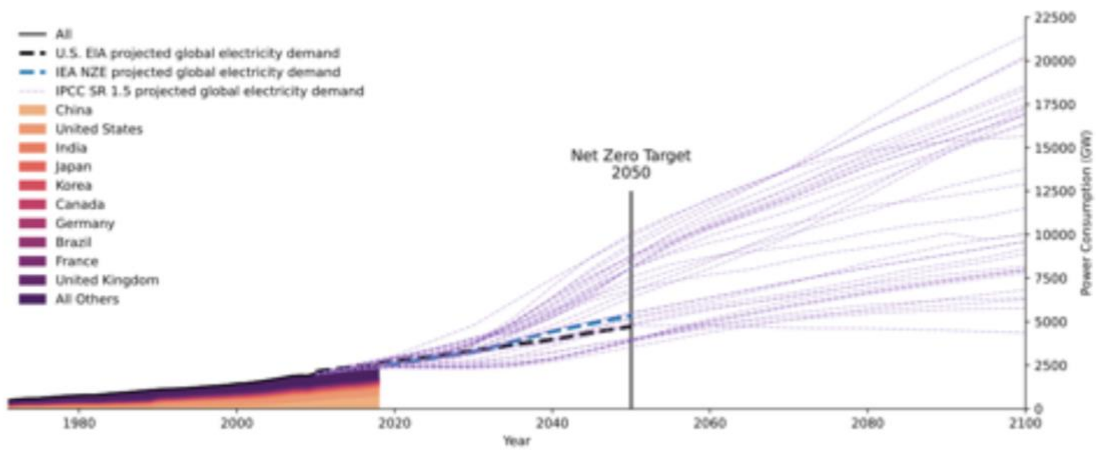


Figure 6.2: Projection of Baseload Electrical Power, Globally [World Energy, 2021]

Dr. John Mankins has made the calculation and states that if the SBSP component of the global need for power in the developing countries could provide 1/8th of the global need, the situation in the future would be benefited greatly. As shown in the next few sections of this chapter, the baseline for output from an SBSP satellite will be about 2 GW of continuous power, delivered anywhere on the planet. The two latest modern day SBSP satellite designs are the Cassiopeia at 2,000 tonnes delivered to GEO and the Mark IIIA system at 7,500 tonnes delivered to GEO. If one were to have a goal of 1/8th of 5,000 GW (625 GW) demand for base power by 2050, that would mean 313 Cassiopeia satellites at 2,000 tonnes or 626,000 tonnes lifted to GEO. In the case of the Mark IIIA satellites at 7,500 tonnes; the numbers become 2,347,500 tonnes to GE0 for those 313 satellites. The future answer is somewhere between those two numbers. As scientists and engineers, we will estimate a baseline architecture between those numbers as our guideline for analysis – or 1,095,500 tonnes lifted to GEO, as the global need of SBSP mass, or 313 satellites at 2 GW and 3,500 tonnes each. As an estimate (using the baseline) to fulfill the requirement to meet society's demands for future electrification, the space launch community needs to launch enough satellites to fulfill 625 GW of power, leading to a generic estimate of a SPS satellite of 2 GW power output weighing at 3,500 tonnes, resulting in:

> Baseline Global NEED for Base Power by 2050 to be supplied for SBSP:
> 1,095,500 tonnes to GEO, or 313 satellites, each with 2 GW continuous output.

Various countries such as the UK, US, China, Japan, and India are developing SBSP satellites for placement in the geostationary orbits. However, launching such massive satellites or their components will be challenging and would require thousands of launches of reusable and high-payload capacity rockets. The problem is that the large numbers of rocket launches needed causes environmental concerns, launch site competition, and other challenges. To ensure consistency in satellite placements, the permanent space infrastructure of the Space Elevator can integrate with rockets to overcome the limitations of launching SBSP satellites. [Dotson, 2021] With the feasible support of the Space Elevator, SBSP could be done on a large scale contributing to the achievement of net-zero goals on Earth before it is presently anticipated.

In the future, SBSP satellites can also be placed at the L1 and L2 points for deep space missions and solar observation missions. [Gosavi, 2021] SBSP technology is not limited to GEO, as it could also be placed into lunar and Mars orbits in the coming years to support habitats, rovers, orbiters, and UAVs. The Space Elevator will assist such missions in the future by injecting payloads at a high orbital velocity of 7.76 km/sec from well above the gravity well [Apex Anchor, 100,000 km altitude]. This means that large fuel tanks for orbital maneuvers will not be required to be raised against gravity necessary for interplanetary SBSP spacecraft. [Eddy, 2021] Table 6.1 shows the Historic missions by dimension or mass.

Table 6-1: Table of Historic SBSP Proposed missions with dimension and mass.

SSPS	Shape	Orbit	Dimension/ Mass	WPT (MW)	Country
Peter Glaser, 1973	Disk Type	GEO	64.749 km^2	10,000	USA
DoE/ NASA, 1979	Rectangular	LEO/ GEO	10 × 5 × 0.5 km	5,000	U.S.A
JAXA SSP2000, 1993	Prism	LEO	336 × 336 × 303 m	9.8	Japan
NEDO Sunshine Project	rectangular	GEO	3.2 × 2 km	1,000	Japan
Sun Tower 1997-1999	Multiple Disk	GEO	200 × 300 m	1,200	U.S.A
SERT, NASA 1999-2000	Multiple reflectors	GEO	4 × 7.2 km	0.1 ~ 10,000	U.S.A
Sail Tower SPS 2001	Multiple Square	GEO	60 pair × 150 m	450	Europe
SSPS JAXA Model 2004	Pair reflector	GEO	2.5 × 3.5 × 2 km	1,000	Japan
Solarbird SPS Mitsubishi Electric 2004	Pair Reflector	LEO	1000 kg	1,000	Japan
SSPS USEF model 2006	Square	GEO	2.6 × 2.4 km	1,000	Japan
JAXA L-SSPS 2006	Reflector	GEO	0.4 × 0.2 × 12 km	1,000	Japan
Solar Power Beaming, LLNL 2009	Concentrator and Reflector	LEO	9125 kg	1	U.S.A
Aerospace Corp Laser Concept 2009	Multiple PV array	GEO	29.7 tons	1200	U.S.A
Solaren SSP 2011	Reflector	GEO		250-2,250	U.S.A
SSPS ALPHA, 2011	Multiple reflectors	GEO	25,260 metric tons	2,000	U.S.A
Multi-Rotary Joints SSP 2015	Multiple PV	GEO	10,000 tons	1300	China
Sunflower Thermal Power Satellite 2015	Concentrator and heat engine	GEO	29,500 tons	5,000	U.S.A.
SSPS OMEGA 2015	Multiple reflectors	GEO	3.4 - 4.5 km	2,000	China
Cassiopeia 2017	Rotating Multiple reflectors	GEO	866 tons	688	U.K.
Energy Satellite 2019	Bifacial PV and Reflectors	SSO	250 kg	0.01	India
Korean SSPS 2019[7]	Large Rectangular with Thin Film Roll-Out solar array	GEO	10000 Tons	2000	Korea
MMR-SPS, CAST, 2021	Multiple reflectors	GEO	~ 100 tons	2,000	China
Energy Orbit 2021	Constellation of Energy Satellite	LEO, LLO, LMO	240 metric tons	16	India
UK Space Energy Initiative 2022	Multiple reflector	GEO	few km	2,000	U. K.

Figure 6.3: Mark III 2 GW 7,500 tonnes [Mankins, 2022]

6.4 Space Elevator: The best option for launching Space Based Solar Power is the Space Elevator. The use of microwave based SBSP technology necessitates the creation of solar panels with areas of several square kilometers in size to produce gigawatts of power. Supporting such large solar arrays will require lightweight structures as well as electrical and mechanical connections. Distributed beam pointing and solid-state devices for phased array has advanced and are capable of pointing where beams can be directed toward ground-based receivers or rectennas [5]. However, due to the approximately 36,000 km distance between the Earth and GEO, satellites the size of the antennas and rectennas must be substantial, and solar panels must be packed or folded into a compact shape and launched to GEO in multiple launches. The Space Elevator will be capable of lifting 474 tonnes into GEO per day [Eddy, 2021] once it has reached Full Operational Capability.

There are two designs for GEO operational SBSP satellites that currently lead the community in accomplished designs. These are: John Manikin's Alpha III at 7,500 tonnes to GEO for 2 GW [Figure 6.3] and Ian Cash's Cassiopeia at 2,000 tonnes for 2 GW of continuous power [Figure 6.4]. Each of these are shown below to illustrate those designs.

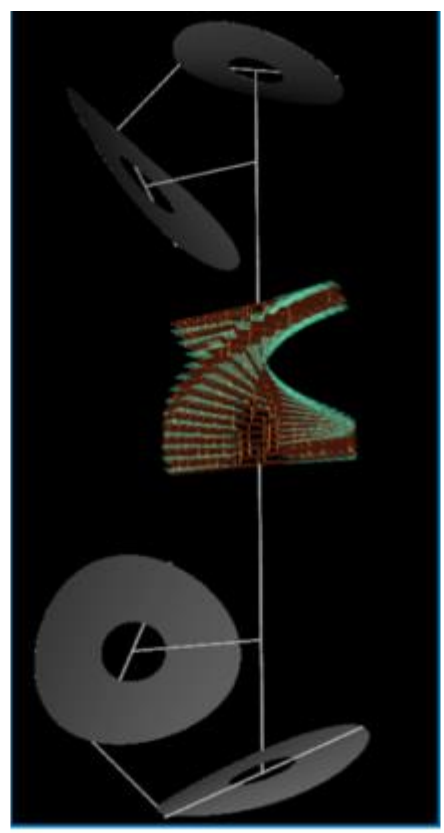


Figure 6.4: Cassiopeia System, two GW 2,000 tonnes [Cash, 2022]

It is crucial to highlight that the data presented in this study pertains exclusively to fully operational missions that will be placed into GEO orbits, excluding demonstrations or missions in Sun Synchronous Orbit (SSO), High Earth Orbit (HEO), and Medium Earth Orbit (MEO). It should also be noted that tens of advanced rocket launches will be necessary to achieve the total mass required for GEO SBSP missions. [on the order of 40 tonnes per launch divided into 2000 tonnes each, or 50 launches with assembly required at GEO] However, a permanent infrastructure with higher and consistent load-carrying capacity would make SBSP goals more quickly obtainable. The basic characteristics of this permanent transportation infrastructure would be daily, routine, safe, inexpensive, environmentally friendly with a remarkable delivery of mass to GEO per year (170,000 tonnes to GEO per year when fully operations).

The following table demonstrates how the permanent infrastructure of the Space Elevator will offer an efficient option for placing such large satellites, thus advancing space logistics. By leveraging the potential of the Space Elevator, it will be possible to significantly reduce the cost and time required for placing SBSP satellites in space, thus making this technology more accessible and feasible for commercial and research purposes. The Space Elevator's basic characteristic is that it moves tremendous cargo loads daily, safely, routinely and with environmentally friendly operations.

Table 6.2: Permanent Space Elevator infrastructure
vs. the current launch vehicles [mass to GEO & beyond]

Comparison to GEO	Between	Rockets	Space Elevators
Space Elevator Full Operational Capacity - tonnes per year			173,010 tonnes (6 SE x 79 x 365) per year
Launch vehicle	Approximate Payload Capability for GTO (tonnes) per launch	Number of rockets to launch per year for sending 173,010 tonnes into space	Number of launches required per day
Starship	40	4325	12
Falcon Heavy	26.7	6480	18
Long March 5	14	12358	34
Delta IV	13.1	13207	36
New Glenn	13	13308	36
Vulcan	16.3	10614	29
Ariene 6	11.5	15044	41
Ariene 5	10.7	16169	44

The current launch system based on rockets, as given in the table, can only transport a small fraction, 2%, of the launch pad mass to GEO. This poses a challenge for delivering various types of cargo required for SBSP satellite assembly within the allotted time while fulfilling the energy needs of robotic assembly machines located at GEO. In contrast, the Galactic Harbour provides a 70% lift-off cargo capacity for delivering cargo to the desired destination. Given the placement options, the Space Elevator will be suitable for routine use during SBSP satellite assembly. [Eddy, 2021] Launching rockets multiple times with robots or orbital transfer vehicles with repair and assembly tools will take much time and significantly increased cost. These large solar panels will require a permanent space-based infrastructure (Space Elevators) to get quick repair services.

Space based assembly will also be needed for each square-kilometer-sized Space Solar Power satellite – again a permanent infrastructure is needed. Free-flying robots and assembly robots should be kept at GEO for SBSP satellite assembly and repair. [Baraskar, 2021] A total of six Space Elevators with pairs located in the Pacific, Atlantic and Indian Oceans will provide quick delivery of the mass needed for assembly of the satellites. Again, all these multiple lifts for each SBSP satellite can be accomplished daily, routinely, safely, inexpensively, and environmentally friendly with the capacity of massive logistics support.

6.4.1 Clean Energy from Space: Has Space Solar Power's Time Come? [NSS, 2022]

A National Space Society Position Paper has summarized the "state of Space Solar Power as of January 2022." Here are a few of the conclusions that are related to the progress of this huge endeavor:

Introduction: Specifically, Space Solar Power (SSP) is coming. SSP has been studied for decades and found to be technologically feasible but thus far not competitive financially. In the past, projected costs, particularly launch and manufacture, were too high to be commercially viable. However, that situation is changing.

Recent Achievements:

- UK Department for Business, Energy and Industrial Strategy reviewed positively a report from Frazer-Nash Consultancy stating; SSP is feasible, SSP is environmentally sound and supports Net Zero pathways., SSP is affordable with competitive cost of electricity, SSP can supply baseload power, 24x7, SSP can provide 15% of UK electricity demand by 2042., and Development of SSP would bring substantial economic benefits to UK.
- UK established a Space Energy Initiate to develop SSP.
- CalTech received $100 million to develop technologies. (recent testing showed transmission from space to receiver at CalTech – 2023)
- ESA is pursuing the developmental concept actively.
- Cost of launch is coming down rapidly and this encourages the projects as they need to lift upwards of 3,000,000 tonnes to GEO with assembly of massive satellites in orbit.

Baseload Power Discussions: "New green energy is needed to eliminate global warming without a massive reduction in lifestyle for the fortunate or forcing the poor to stay that way. Wind and ground solar can provide a significant portion of that energy. However, since wind and ground solar are intermittent they must be combined with baseload power or large amounts of energy storage. This is necessary for intermittent renewables to be part of a reliable power system." [NSS, 2022]

NSS Conclusion: Mass production of SSP modules combined with fully reusable, very large launchers in flight test today are changing the playing field. The potential of a two orders of magnitude cost reduction in the most expensive parts of a spacecraft, launch and manufacture, means the business case for SSP may at long last be closing. Of critical importance is that SSP can provide vast quantities of clean power to help decarbonize civilization. An important detail is that SSP may provide baseload energy to terrestrial grids at an affordable price, making achievement of Net Zero much easier. At its core, this is why there is so much current interest.

6.4.2 The SBSP United Kingdom program – status as of early 2023

The following comments are related to the current (as of 1 June 2023) perception of where the Space Solar Power program is in the UK. The comments reflect well on the status of the program. Mr. Paul Marks made the following remarks in the Aerospace America [Marks, 2023].

"Space Solar, a company set up by U.K. government space startup incubator to develop and eventually, launch a 25 satellite, 50 Gigawatt British space-based solar power constellation."

"The rival space solar power concepts diverge greatly. But they share two critical, interrelated needs: the ability to manufacture components in vast numbers on Earth and assemble them in space, and an enormous payload uplift capacity to deliver the required supplies and components to the high orbits where they will suck up sunshine." [Talking about John Mankins' Alpha Mark III (7,500 tonnes each) and Ian Cash's Cassiopeia (2,000 tonnes each)].

"So, plans call for Space Solar Limited by 2030 to launch a 6-megawatt demonstrator satellite capable of beaming power to a ground station, followed by the launch and commissioning of the first 2-gigawatt solar power satellite by 2035."

Time, as they say, will tell. One independent observer hoping for the success of the space solar power arena is Peter Swan, president of the California-based International Space Elevator Consortium. He also hopes, one day, to supply super heavy lift for the satellite builders, but without Starship's emissions. Of course, this depends on a viable elevator tether technology emerging – graphene super laminate being the latest wunderkind material (after carbon nanotubes failed to live up to their promise). Swan likes that the U.K. sees space solar power as a great way to generate high-tech jobs, and that the EU, in the wake of Russia's invasion of Ukraine, seems to recognize that it must ultimately develop sources of energy that it controls.

"You know," says Swan, the U.K., ESA and the EU "have gotten to the point where they're asking the question, "How do we do it?" and "should we do it?" and the answer, of course is going to come back: "Hell yes, we've got to do it."

After reading these comments, the following concepts emerge: Did they discuss the question? How much does it weigh? Just two multiplications lead to huge numbers of mass to be delivered to GEO – 2,000 tonnes x 25 (50GW/2 GW/sat) = 50,000 tonnes, and 7,500x 25 = 187,000 tonnes to GEO. As we know the delivery of mass to GEO is roughly 2% of the launch pad mass, that means Cassiopeia would need 2,500,000 tonnes at the launch pad while Mark III would need 9,375,000 tonnes at the pad. Space Elevator permanent space transportation infrastructure seems like a timely helper in delivering huge amounts of logistics support to build Space Solar Power constellations designed to help reach goals inside Net Zero. They would do it with a 70% delivery statistic, with the other 30% reusable.

6.5 Matching timelines of Space Elevator and SBSP missions

The following operations timeline for Space Elevators is compared to the timeline for SBSP. The intensity of SBSP satellite parts manufacturing and placements will increase with respect to time as SE's service progresses.

Dates of Initial Operational Capacity (IOCs) of Space Elevators

2037 - First IOC operational Elevator tether
2038 - The second tether becomes the first Galactic Harbour
2040 - Second Galactic Harbour
2041 - Third Galactic Harbour

Dates of Final Operational Capacity (FOCs) of Space Elevators

2047 - First Galactic Harbour one FOC Space Elevator and one IOC Space Elevator
2048 - First Galactic Harbour with two FOC Space Elevators
2050 - Second Galactic Harbour with two FOC Space Elevators
2051 - Third Galactic Harbour with two FOC Space Elevators

The development and deployment of Space Elevators can have significant implications for the future of space exploration and energy generation. The capacity of Space Elevators to transport large payloads to space with significantly reduced costs and increased efficiency can revolutionize the way we approach space travel and energy generation. Because of the tremendous improvement between the IOC delivery [baselined at 14 tonnes per day to GEO and beyond] and the FOC [baselined at 79 tonnes per day to GEO and beyond] the capacity of Space Elevators will improve to support the needs, especially the SBSP requirements. The potential for Space Elevators to enable the widespread deployment of SBSP satellites, as well as support the establishment of permanent habitats on the Moon and Mars, makes them a critical technology for the future of space exploration and sustainability. The next chart shows the growth of the Space Elevator capacity compared to the advanced rocket delivery capacity. In this case, the expansion of rocket launches goes up to 300 per year dedicated to SBSP [with a payload of 40 tonnes to GEO, Starship like] while the advancement of Space Elevators follows the growth from IOC to FOC of the six Space Elevators.

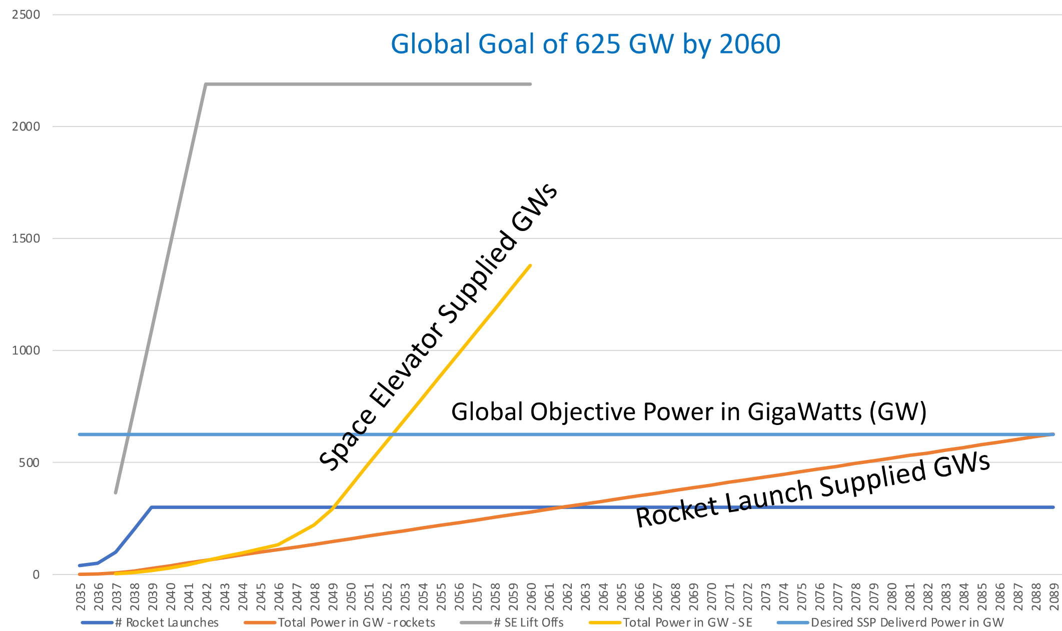


Figure 6.5: Meeting the Goal of 625 GW by 2052

Unlike rocket launches, Space Elevators are permanent infrastructure. With a possible future scenario of expanding to 15 Space Elevators by 2060 which would provide a deliverable capacity of about 1,200 tonnes per day to geostationary orbit and beyond. This capacity level would be sufficient to meet most of the global electricity demand with Space Solar Power by 2060, just ten years after the Net Zero target of 2050, and then continue to provide more and more environmentally free baseline power to increase the electrification across the globe.

In addition, the potential benefits of Space Elevators for space exploration and sustainability make them a technology worth pursuing. Continued research and development and strategic partnerships between governments, private sector companies, and academic institutions can help overcome the technical, financial, and regulatory challenges and make Space Elevators a reality in the coming decades. The safety and reliability of Space Elevators, especially during the initial stages of deployment, will also play an important role and will create win-win conditions between rockets and Space Elevator.

6.6 Conclusion

In conclusion, the combination of SBSP and SE technologies has the potential to revolutionize the way we generate and deliver renewable energy to meet the growing global demand. Humanity's needs for 5,000 GW of baseline power around the globe by

2050 is driving the need for environmentally friendly power. The SBSP satellite constellation can meet that goal and help move humanity into the second half of this century with a robust source of energy which is continuous and does not disturb the atmosphere. The electrification of the total globe will be a tremendous advancement for development into the next century. An operational Space Elevator can provide a more efficient and cost-effective means of transporting SBSP satellite parts to GEO, allowing for more frequent space-based assembly and deployment of large-scale Space Solar Power satellites. If one thinks of permanent space infrastructure, one is transformed into a believer that a bridge to space is possible! These characteristics include daily, routine, safe, inexpensive with environmentally friend operations. As the demand increases for renewable energy and the need to reduce carbon emissions, developing and deploying these technologies will be essential to achieve global Net Zero targets. Overall, the advancement of Space Solar Power and Space Elevator technologies represents a promising avenue for sustainable energy and space exploration. The baseline for the Dual Space Access Strategy with both advanced rockets and Space Elevators is the solution.

Rockets will open up the SBSP community, while the Space Elevator will start supporting in 2036 and develop into the "heavy lifter."

Space Elevator Insights:

The combination of Space Based Solar Power and Space Elevator technologies has the potential to revolutionize the way we generate and deliver renewable energy to meet the growing global demand.

- The SBSP satellite constellation can meet that goal and help move humanity into the second half of this century with a robust source of energy which is continuous and does not disturb the atmosphere. The electrification of the total globe will be a tremendous advancement for development into the next century.
- An operational Space Elevator can provide a more efficient and cost-effective means of transporting Space Based Solar Power satellite parts to GEO, allowing for more frequent space-based assembly and deployment of large-scale satellites.

Section D: Critical Missions at/from GEO & Apex Anchor

D.1 Introduction: In 2020, when the Modern-Day Space Elevator emerged, the concept of an active transportation node at the Apex Anchor became obvious. The enhancement of the roles of an Apex Anchor showed how it has become a focal point for several significant missions around the "Logistics Center at the top of the Gravity Well." We must believe that Space Elevators are the transportation story of the 21st century. Reliable, routine, safe, and efficient access to space is close at hand. Space Elevators and their Galactic Harbours are an essential part of the global and interplanetary transportation infrastructure. The key here is that daily, green, routine, inexpensive, efficient, massive movement of payloads to GEO – and release from other locations along Space Elevators – will allow high speed launches to any location in our solar system.

D.2 Transformational Strength: Of the many transformational strengths of Space Elevators is a location for development, assembly, storage, as well as standard releases towards so many destinations. The term used in previous writings has been "Assembly at the Top of the Gravity Well." Of course, there is gravity (one over radius squared is a very small number), so essentially the drag of gravity is weak while total energy is extremely high – potential and kinetic are both "off the charts" compared to what rockets have been able to provide at that altitude.

One of the problems with some of Space Elevators' unique ideas is that proponents "get it," but others may not. Most recognize the value of GEO as this has been historically a very valuable location for commercial and government operations. However, the value of the Apex Anchor has not been appreciated as most thought of it as only the end mass to keep the tether taught. When you think Apex Anchors as launching pads opening up the solar system, many people "start to get it." When the Apex Anchor and GEO node are recognized as locations for normal human operations (storage, assembly, construction, habitats, and release pads) the value becomes immense. The title for those two locations should be something like factories at the top of the gravity well and beyond.

D.3 Top of Gravity Well: The idea is simple; raise payloads with solar energy to GEO (35,786 km) or Apex Anchor (100,000 km) altitudes and then assemble them in robotic factories. This leads to an operational capability which will release any size spacecraft, with appropriate rocket motors, to any location around the GEO belt and beyond. When released from the Apex Anchor, any planet can be reached in any inclination – daily and safely – all while being environmentally safe. The concept relies on the fact that Space Elevator operations will raise tether climber payloads of 14 tonnes to rotating locations at GEO or even higher to the Apex Anchor (with a potential energy of being at 100,000 km altitude and kinetic energy based on a velocity of7.76 km/sec). Each payload can then be assembled into a much larger mission spacecraft. At GEO, the assembly could lead to huge satellites such as Space Solar Power vehicles of greater than 2,000 tonnes each. Imagine the ability to build any size commercial, scientific, or governmental satellite at GEO without impacting the environment? At the Apex Anchor, the combination of massive energy given to any size scientific mission (with assembly) opens up the universe to anyone who has a factory at the Apex Anchor. Can you image enabling the dreams of scientists of having space systems that can be of any size and reach any solar system body? The enabling factor for both of these "enterprise zones" is a Space Elevator Transportation System with robotic assembly factories at GEO and the Apex Anchor.

Permanent transportation infrastructures ensure logistics are
straight forward and predictable:
RAISE IT, ASSEMBLE IT, and RELEASE IT.

D.4 Enterprise Zones: [Fitzgerald, 2021] Cargo flights can depart from the GEO port to any other location at GEO and from the Apex Anchor, to the Moon, Mars, or other destinations in the solar system. These cargo flight departures will be by "space carriers" (a prose extension of "air carriers"), or even container ships -- conducting logistic missions to their destinations. Think United, Delta, and British Airways, or Maersk, APL, and the like. As cargo delivery is the main theme, perhaps FedEx, UPS, or Amazon Prime should be visualized as enterprises at work within the GEO and Apex Enterprise Regions.

When humanity decides to do off planet activities, there will be a tremendous need for logistics support, movement of manufactured goods, as well as transporting people [especially at low cost and routinely]. The question on ISEC's table is: how can the strengths of Space Elevators' new and unique capabilities providing "train stations" at 35,786 km and 100,000 km altitudes enable missions of all types, while having little or no environmental effect on our planet?

The story told here is an enterprise story; driven by entrepreneurial forces we all know so well. The government's role is clear to those who know the import-export dynamics around the world today. Utilities such as power, illumination, and surveillance are also part of operations. Deliveries arrive on the Climber--from Planet Earth --and are retrieved from the Climber. The cargo must then be taken to either the transportation cargo craft or to a cargo integration center. These integration centers would be for storage, assembly, repair, construction and/or mission operations. Both the cargo craft and the integration center will be instrumental in conducting operations at both GEO and Apex Anchors.

Enterprise at GEO Node: The above mentioned activities will develop into full spectrum businesses similar to Earth's transportation enterprises. The "space carriers" operating at the Apex will not be learning transportation on the job. Their Earth based transportation experiences of moving cargo from here to there will be applied at the Apex. There will be fundamental changes to be sure; but their entrepreneurial efforts at the Apex will be transportation based. The only trick will be to adjust to space travel versus air or sea travel. An other major enterprise activity at GEO will be the assembly and deployment of additional Space Elevators.

Enterprise at Apex Anchor: Cargo spacecraft leaving the Apex Anchor will be properly loaded and secured with specialized thrusters affixed to support guiding the craft to its destination, and to stop when it gets there. The capability to raise all manner of space system components and segments 100,000 km using energy from the sun as a Green Road to Space – enables assembly of major space missions only dreamt of before. The inherent rapid release velocity (7.76 km/sec) at an Apex Anchor – and the ability to release every day of the year towards any destination, such as the Moon, Mars and even Pluto – opens the universe to humanity. These capabilities lead to the enabling of missions such as:

- A release point for interplanetary science missions with space systems of any size (assembled at the top of the gravity well) to any planet with daily windows.
- Interplanetary human missions (after development of full Operational Capability) with space systems of any size to any planet with daily windows. (see chapter 8)
- Interplanetary logistics, storage and resupply capability with "just in time delivery" (see chapter 8)
- Cis-Lunar logistics, storage and release for supply missions with "just in time delivery"
- Astronaut rescue staging area with storage of necessary rescue material such as oxygen, habitats, water, rocket fuel, power, and food. (As little as14 hours away)
- Planetary defense asteroid detection sensors, with multiple 100,000 km tethers on each side of the Earth (206,000 km baseline) for stereoscopic vision of incoming asteroids from the Sun or out of the asteroid belts. In addition, the storage of planetary defense spacecraft will enable rapid response to near-term threats within 24 hours. Flexibility of responses can be accomplished by storing (for rapid assembly) of various defensive segments of planetary protection space systems, depending upon the threat. (see chapter 7)

D.5 Permanent Space Access Infrastructure: The next two topics (chapters) will leverage the strengths discussed above and then developed into operational missions. Each of these can leverage all other facets of Space Elevators, but each will have its unique needs that must be fulfilled. These chapters and the topics of interest are: Planetary Defense and Interplanetary Exploration and Scientific investigations.

The next two chapters present potential missions that can "save the planet" and enhance the gathering of science throughout the solar system and beyond. These two ideas represent the vast future opportunities for missions that leverage a permanent space access infrastructure while teamed with advanced rockets. The future opens, only restricted by the ability to dream big enough.

Space Elevator Insights:

The inherent velocities at GEO and
Apex Anchor are natural for so many missions

- Assembly at GEO enables missions not restricted by the rocket equation leading to much more diverse missions, much bigger systems assembled there and remarkable supply, assembly, and build capabilities.
- Assembly at Apex Anchor enables lunar and interplanetary missions that are far more capable (bigger payloads and spacecraft) with high velocities that match exciting missions "out there." (as fast as 14 hrs to the Moon and 61 days to Mars with six releases per day)

Chapter 7 Planetary Defense

7.1 Study Importance

Humanity's existence on the Earth depends upon Planetary Defense systems and their timely deployment. The obvious threats are from medium to large asteroids that are destined to impact the Earth. There is a concern that the programs of record are emphasizing the longer-term threats and concentrating on defining and identifying them. This author believes the fact that several asteroids pass the Earth from the Sun side without being identified until after they have passed is of some concern. The first new concept proposed is a "finding them" issue that could be addressed by the new concepts of asteroid defense from the Apex Anchor. The second remarkable capability of Space Elevators is that a planetary defense garage could be placed at each Apex Anchor to ensure that assembly of stored components could be accomplished in a rapid manner and released within 24 hours to respond to these near Earth and recently identified threats. This combination of an ability to find them and then target them within hours is a major change in approach. It can ONLY be accomplished by having Planetary Defense garages at the Apex Anchors with operational support from the Earth ready to respond to near-term threats. Not only do we need to know and identify a threat's size, composition, and near-term danger to our planet, but we also need to be ready for a rapid response to threats that are now unknown. This chapter's purpose is to show that a rapid response for Planetary Defense missions, can be one that leverages the transformational strengths of Space Elevators. These strengths have tremendous potential to become an integral component of the global defensive plan:

- Storage of Planetary Defense mission hardware at the top of the gravity well
- Ready for immediate release from the Space Elevator's Apex Anchor, within a short time of warning, and
- The ability to release at high velocity (7,76 kms/sec) Planetary Defense mission hardware of an adequate size to reduce (eliminate) the threat.

7.2 Planetary Defense Coordination Office: The US Government created, in 2016 within NASA, a Planetary Defense Coordination Office. Its goal is to manage planetary defense-related activities across NASA. Their approach is to: search/detect/track, characterize, plan and coordinate, assess and mitigate objects approaching the Earth. [PDCO, 2022] A Jan 2020 Near-Earth Orbit (NEO) survey of asteroids found only 18.2% of 140-300m size and 18.4% between .30-1.00 km size out of a population estimated at 25,000. The survey found in addition, there have been several asteroids that have been identified after they have passed the Earth going away from us. These surprise asteroids lead to the recognition of a need for a "rapid response" capability to protect the Earth's inhabitants. There is a special need for a short response time for asteroids coming from behind the sun and not being detected (less than a month warning with a proper detection approach and for asteroids surprising us because of a change in direction from close approaches or collisions within the asteroid belt (only about three months of warning time upon detection).

Figure 7.1: Large Asteroid

7.1.1 Threats to Civilization: When you first hear the words "Planetary Defense" you might think of a sci-fi movie with spaceships ready to defend Earth from aliens, and some Earthlings in spacesuits holding laser guns. This is simply not the case. Planetary Defense does involve defending Earth, but it does not involve aliens or any sort of attack. Planetary Defense entails detecting, monitoring, understanding, and mitigating dangerous near-Earth objects (NEOs). These various size objects are in our solar system, in the form of asteroids and comets. Whether or not an object is classified as a NEO depends on its orbit, size, and composition. An example of an NEO is an asteroid called Eros. [NASA, 2022] It has a length of about 10.5 miles (16.8 kilometers) and is large enough to be described as a threat to civilization.

Figure 7.2: An Illustration of a NEO Approaching Earth [Citizen Science, 2022]

7.1.2 NEO Threats: For the NEOs that may impact Earth, Planetary Defense involves preventing or mitigating their impact. Prevention involves deflecting or disrupting the NEO's characteristic orbit, and mitigation involves taking measures such as evacuation to protect people in cases where a NEO cannot be prevented from impacting Earth. Two principal factors impact the potential threat: warning time and size. Small and medium asteroids can be successfully deflected if given enough warning time. The larger ones, like EROS, require greater knowledge of identification characteristics and significant time to alter course. The NEO survey also found that there have been several asteroids that have been identified after they have passed the Earth as they were going away from us.

Figure 7.3: Tunguska River in Russia
[Tunguska, 2008]

One must note that if NEOs do hit Earth; they can be a real threat. The well-known one is the dinosaur killer event that occurred 66-million years ago. [CNN, 2022] In 1908, a large explosion occurred near the Podkamennaya Tunguska River in Russia (Figure 2), which flattened 830 square miles (2,150 square kilometers) of a forest. It is referred to as the Tunguska event, the largest impact event on Earth in recorded history.

Additionally, an event occurred on Feb 15, 2013, [Chelyabinsk, 2019] when an asteroid exploded over Chelyabinsk, Russia. The asteroid was about sixty-six feet long (20 meters) and the energy of its explosion was 6 to 33 times as much energy released from the atomic bomb detonated in Hiroshima during World War II. It is known as the third largest impact event in recorded history.

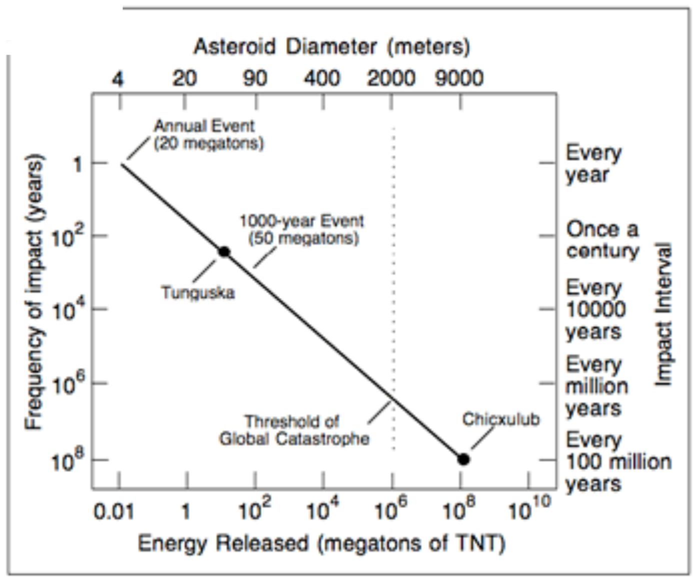


Figure 7.4: Asteroid Impact Chart [Asteroid, 2022]

Figure 7.4 illustrates the frequency of asteroid impacts with NASA estimating that an asteroid would have to be 96 Km wide to “completely and utterly wipe out the Earth”. [Asteroid Today, 2022]

7.2 Pre-Position Mission Equipment: The authors propose a more robust, real-time planetary defense system by pre-positioning defensive components of the Planetary Defense system at Apex Anchors of the Space Elevator system. Then, with the appropriate warning, the choice of mission hardware could be rapidly implemented as to what specific system is needed to counter the threat. The appropriate response spacecraft could then be assembled in the Planetary Defense (PD) garage at 100,000 km altitude and released with an appropriate orbit to rendezvous with the incoming threat in a timely manner. The authors contend that this rapid, pre-positioning approach is superior to the classic launch from aircraft or rockets in the following ways: a) it reduces the operational timeline from months to mere hours from detection to launch; b) the components would already be at 100,000 kms from Earth, stored inside the PD Garage; c) by attaching appropriately stored rocket motors to the desired threat reduction spacecraft, any orbit could be leveraged: and d) the initial velocity of 7.76 km/sec would ensure rapid transit towards the incoming asteroid or debris, thus hitting it at more of a distance from Earth.

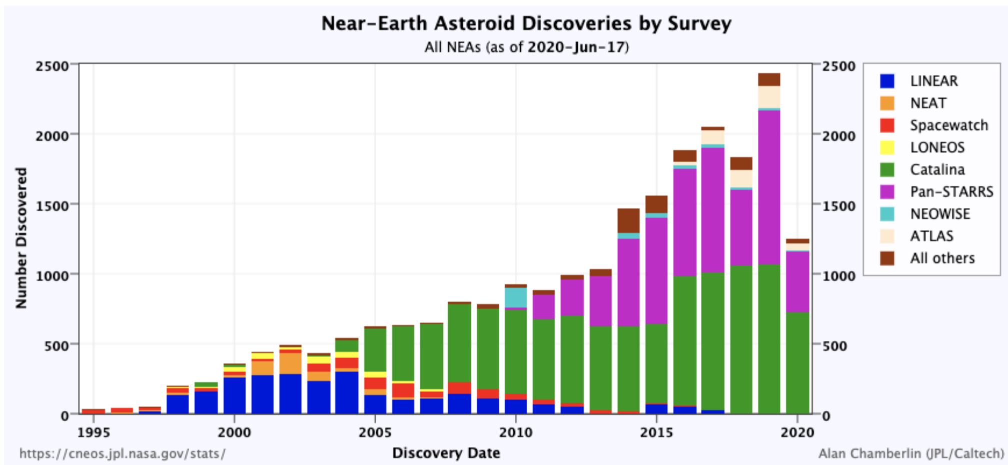


Figure 7.5, Near-Earth Asteroid Discoveries as of Jun2020 [NEO, 2020]

7.2.1 Network of Organizations: In the rare event that a NEO is projected to impact Earth, we need to be prepared to prevent it from happening or mitigate its impact. This does not mean you should start worrying and scare all your friends – there is a network of organizations and projects currently studying NEOs and working on preventive efforts. There are a large number of projects working on cataloging NEOs and also on warning systems to have in place in case of potential NEO impacts. [Val Klavans, 2021] One example is ATLAS, the Asteroid Terrestrial-impact Last Alert System (ATLAS), that discovered Comet ATLAS (C/2019 Y4 ATLAS). The ATLAS is comprised of a robotic astronomical survey and an early warning system for small NEOs, using two telescopes located in Hawaii. ATLAS is operated by the University of Hawaii's Institute for Astronomy. The Catalina Sky Survey (CSS) is another project in the process of discovering and cataloging comets and asteroids, focusing on potentially hazardous asteroids and their impact risks. CSS also is improving awareness of the known distribution of NEOs in our solar system. It is located at the Mount Lemmon Observatory in the Catalina Mountains, near Tucson, Arizona. CSS is conducted by the University of Arizona's Department of Astronomy in Tucson, Arizona. Near-Earth Object WISE (NEOWISE) is a mission extension of the Wide-field Infrared Survey Explorer (WISE), a NASA infrared space telescope. WISE was launched in 2009 and it had multiple mission extensions, first occurring in 2010. NEOWISE's focus is to search for NEOs, with an emphasis on asteroids that could collide with Earth. NASA's Jet Propulsion Laboratory and the California Institute of Technology manage operations for NEOWISE in Pasadena, California.

Figure 7.6: Hazards by the Numbers [Defend, 2022]

7.2.2 Expansion of Threat Arena.

It seems to the authors that the arena of short warning times has been undervalued. There are two cases that are dangerous to the Earth and our civilization that needs a rapid response for the defense of our planet. They are:

- Out from behind the Sun – Periodically the authors read about asteroids that have passed our planet without identification. These occur as we have a weak capability to notice medium-size asteroids that curve around the sun and rise towards the Earth's radius. The problem is that optical sensors on Earth do not work well when looking at the blinding light from the sun.
- Out of the asteroid belt – when two asteroids come close to each other, they can change orbit and go in any direction. The thought is that periodically a large asteroid would be thrown towards the Earth as it goes close by another asteroid and has its path altered. This could lead to a rapid flight through our orbit (estimate is three months flight time) and could be easily missed by our identification network not looking for this phenomenon.

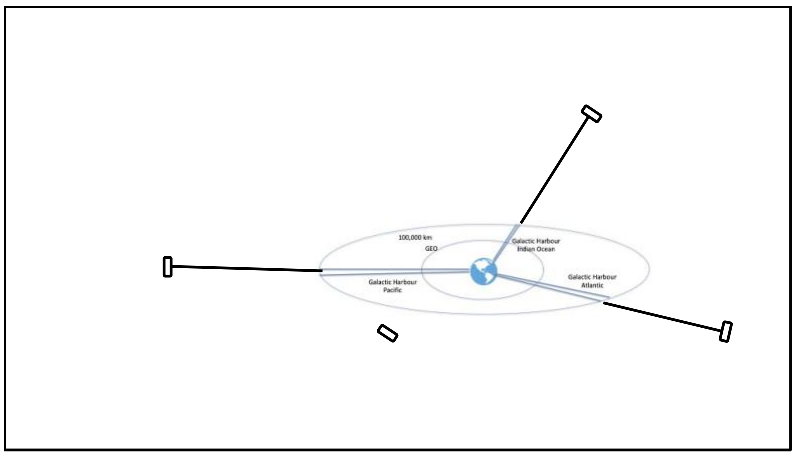


Figure 7.7: Apex Anchor Orientation

7.3 Rapid Response Threats:

Each of these rapid response threats would require rapid identification and then a rapid response. This leads to the transformational strengths of the Space Elevator which could be available by 2037, as planned. For example, [Surprise, 2022] on 25 Jul19 when an asteroid approach from Earth's blind spot, the team of astronomers at the Arecibo Observatory in Puerto Rico had just 30-minutes to collect as many radar readings as they could. There are two parts to this proposed enhancement to the current program: Identification of Out of the Sun and Out of the asteroid belt.

This first part will only be touched upon as it is a large topic all by itself. The concept is that sensors are located on a large baseline infrastructure that can stare at the edges of the sun and also with an outward focus (see Figure 7.8). This could be achieved with the placement of sensors at the Apex Anchor of the six Space Elevators suggested as the Initial Operating Capability by 2040. While facing the sun, it will have the ability to look for upcoming asteroids with a huge optical baseline and then change its focus towards the asteroid belt during the other half of the daily rotation. Additionally, the plan is to reach outside of Earth, namely back to Moon and to Mars. When there are settlements on the Moon and Mars, the proposed "Asteroid Busters" concept can also provide planetary protection to these settlements as well as to the Earth.

Additionally, China is building a far-reaching radar system for planetary defense.

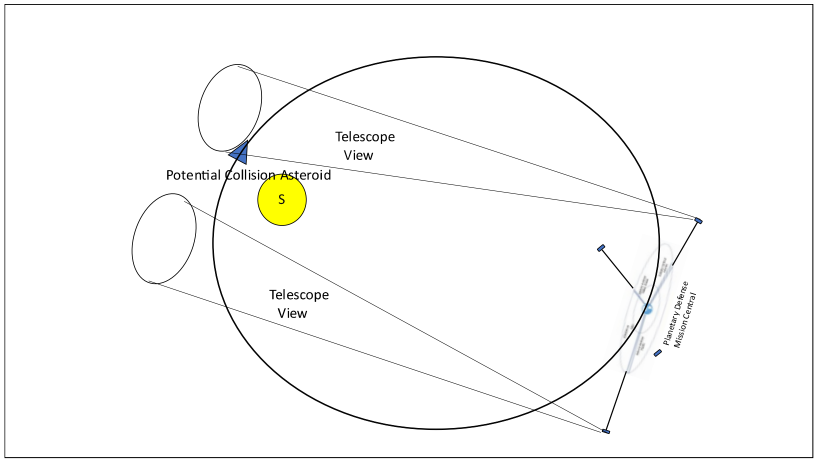


Figure 7.8: Surveillance Capability Towards the Sun

China has started construction on a new high-definition deep-space active observation facility to bolster planetary defense. The country's officials and scientists say it will help safeguard humanity against space rocks. The facility, designed to detect near-Earth asteroids that may be a threat to humanity, will be built in the country's Southwest Chongqing municipality. It is codenamed China Fuyan (or "compound eye"). The observation facility will feature more than 20 antennas, each of which will have a diameter of between 25 and 30 meters. These will work simultaneously to conduct high-definition observations of asteroids within 150 million kilometers of Earth. According to the Global Times, this will make it the world's most far-reaching radar system. [Young, 2022]

Currently, the US has a space surveillance network used to detect, track, catalog and identify artificial objects orbiting the Earth. However, it is not equipped to detect incoming bodies from farther out in space. [JSTOR, 2018] There is a proposal, called the Wide Area Space Surveillance System (WASSS) that would provide near continuous, real-time monitoring of insertion events, orbital maneuvers, and resident space objects (RSOs) in deep space. A constellation of satellites is proposed with multiple wide field-of-view sensors in an orbit that provides optimal viewing of prioritized regions of space. However, these satellites would be located at LEO.

7.3.1 Expansion of Additional Mission to Apex Anchor: The Galactic Harbour will be the volume encompassing the Earth Port, stretching up in a conical shape to include two Space Elevator tethers, and extending outwards to the Apex Anchor as shown in Figure 7.9. An additional mission can be added to the Apex Anchor which would be planetary defense. The facilities located at the apex anchor would allow storage of components of an asteroid defense mission satellite and then assembly of the proper rocket with a proper defensive approach within a short time. In addition, when released in the proper direction, the planetary defensive mission spacecraft would have an inherent velocity of 7.76 km/sec at an altitude of 100,000 km (low gravity does not affect velocity once released).

To prepare for the defense of the planet, the Planetary Defense space segments will enter the Galactic Harbour at the Earth Port and traverse up to the Apex Anchors "Garage." With this concept of Galactic Harbors comes the recognition that a system's approach to Planetary Defense will require complementary capabilities, rocket portals and Galactic Harbour infrastructures, each with their own strengths and shortfalls. The Apex Anchor is the perfect location as the home for the "Planetary Asteroid Busters." It is envisioned that the Space Elevator System will have three Galactic Harbours yielding six Space Elevators. This would provide less than 24hrs response time at Initial Operating Configuration (IOC) (one tether) and less than 8hrs at Final Operating Configuration (FOC) (three Galactic Harbours).

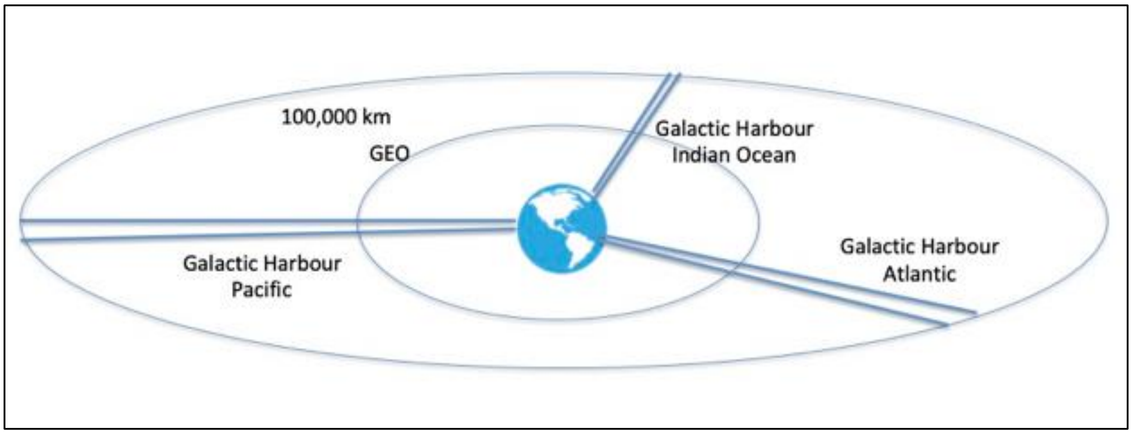


Figure 7.9: Galactic Harbour Orientation

It is envisioned that the "Garage" would hold multiple "asteroid busters" that can be configured and assembled as required by the threat. The controlling authority would be a "Planetary Defense Control Center," which can be located anywhere on Earth or if populated, the Apex Anchor itself. This capability would provide a rapid response of defensive systems since the Asteroid "Busters" would be pre-positioned within the Apex Anchor's "Garage" and then configured to respond to the threat within one Earth rotation day.

7.3.2 VASIMR:

Time-to-Target is a critical parameter as it provides the window to successfully engage an incoming asteroid. NASA has a concept, called the VASIMR Plasma Engine (See Figure 7.10).

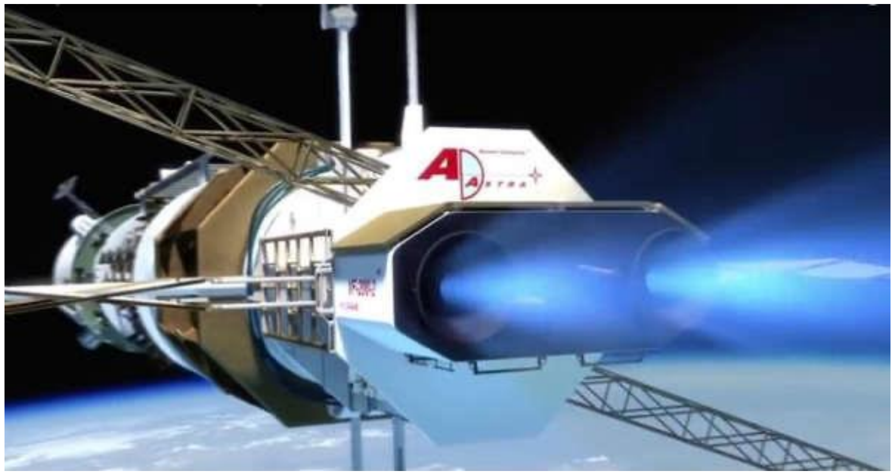


Figure 7.10: NASA's VASIMR Plasma Engine [bing, 2022]

The advantage of a Plasma Engine is the speed that can be achieved. VASIMR is capable of "constant power throttling," which allows in-flight mission-optimization of thrust and specific impulse to enhance performance and reduce trip time. For example, it can reach Mars in six weeks or approximately 42-days. [Diaz, 2013] It is estimated that a plasma engine could achieve speeds of 123,000mph! [Diaz, 2010] (plus starting at 15,000 mph from Apex Anchor release) This capability allows a reaction for an asteroid coming out of the Sun, if it is prepositioned in LEO or has a rocket stored and ready to launch with short warning time. This capability could be greatly enhanced by storing it along with the "Asteroid Buster" at the Apex Anchor, thus providing significant reduction in response time.

Additionally, the Apex Anchor can provide the following for Planetary Defense:

1. Additional surveillance capabilities are located within the Apex Anchors.
2. Higher orbital speeds since Apex Anchor is traveling around 7.76 km/sec.
3. The "Planetary Busters" can be significantly lower in mass since they are not suffering from the rocket equation to raise them to 100,000 km and 7.76 km/sec.
4. A "Planetary Defense Control Center" could control and then fire a barrage of 3-4 planetary defense mission spacecraft, thus increasing the chances of success.

7.4 Operational Concept of aa Apex Anchor Planetary Defense System (AAPDS):

This "Asteroid Busters" control center can be located anywhere with its mission to integrate all orbital trajectories of large objects that could threaten the Earth. For those asteroids that threaten the Earth, the **AAPDS** would take appropriate action. A key point to make is that the control center does not have to be heavily staffed as most systems would be automated. Upon notice of an occurring threat, the staff could be increased as appropriate.

It is envisioned that there would be four major missions for the **AAPDS:**

1) First is to coordinate global searches and identification of potential threats to Earth. During this continuous operation, the team will develop and practice responses to a variety of threats – coordinating global responses as well as focusing upon the Apex Anchor capability responses.
2) Second, and most important, is to be able to remotely deliver, configure and control a set of rockets at the Apex Anchor of the Space Elevator. The control station on Earth would be able to remotely configure, assemble, and launch a "barrage" of rockets at the intended target in a rapid manner, similar to military defensive capabilities. Since their release point is at 100,000Km (62,137mi) from Earth the travel distance (as well as beating the gravity well restrictions) to the threat is significantly reduced while the inherent speed will also shorten the trip.
3) Third, if the threat was located soon enough, would be "asteroid deflection" so the asteroid would miss the Earth entirely. Early arrival at the potential threatening asteroid is a dominant factor in the planning for effective defense of the Earth.
4) Fourth, if the asteroid was not detected far enough out, the mission would be "asteroid destruction" so the remaining pieces would not pose a threat to the Earth. When the situation becomes grave, the whole power of the Earth's countries' capabilities must be implemented. Thus, multiple capabilities MUST be stored at the multiple Apex Anchors to ensure sufficient response to major threats.
5) A key point to note is that if the rockets are going to miss the target or it was determined not to be a successful impact, the control station can remotely reconfigure the rockets and send another barrage rapidly to the target in a matter of minutes to hours.

7.4.1 Equipment Required:

The **AAPDS** would be a widely distributed system comprised of the following major parts: Factory, Headquarters, Operations Control Center, and the Galactic Harbour (Earth Port, Tether, Climber, and Apex Anchor) responsible for transporting, configuring, and deploying the "Asteroid Busters" from the Apex Anchor's "Garage."

The **AAPDS** would have two major components. The first would be a deep space tracking capability and the second would be an Asteroid "Buster" capability. Both capabilities would be remotely deployed to the Apex Anchor. The following is a short description of the equipment (hardware and software) required for **AAPDS**.

7.4.2 Systems Backbone

Figure 7.12 provides an overview of the backbone required for a Planetary Defense System.

Communications Backbone: A key aspect of this backbone is the remote capability to deliver, configure and deploy the "Asteroid Buster" from the control station.

7.4.3 Major Steps to Prepare Asteroid Protection from Apex Anchors:

Space Surveillance: A key component for Planetary Defense is the detection of incoming asteroids in time to divert them from striking Earth. There are numerous ground-based surveillance systems that can be tied to the Apex Anchor to give a much better deep-space detection capability. In addition, if these were located on one of the two Apex Anchors in each of the three Galactic Harbors (100,000 Km from Earth) they would provide a significant deep-space surveillance capability.

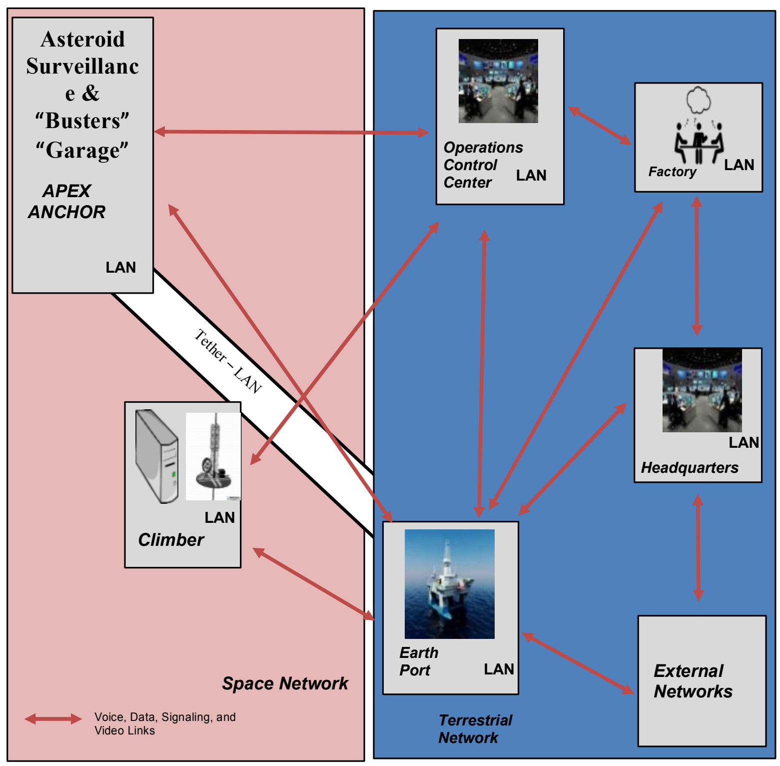


Figure 7.12: Planetary Defense Backbone

Asteroid "Buster" Prepositioned at Apex Anchor: The main mission for Planetary Defense is the actual "asteroid Buster" that will be deployed and impact the incoming asteroid long before it reaches the Earth. It is envisioned that the Asteroid "Buster" will have a flexible configuration in order to be able to "bust" various size asteroids that could impact the Earth. For example, payload delivered at impact: 500 lb. (227 Kg) for small asteroids, 1000 lbs. (454 Kg) for medium asteroids and 1500 lb. (680 Kg) for large asteroids. It is envisioned that the Asteroid "Buster" would be remotely configured within the "Garage" to meet the incoming threat. This would provide the capability to deliver a payload for low-mass (75-meter asteroid), medium-mass (150-meter asteroid) or a large-mass (>200-meter asteroid).

The Asteroid "Buster" will have three major sections, namely: engine, fuel, payload. There is nothing unique about the makeup of the "buster", so it can be procured using existing processes. However, the design criteria for an Apex Anchor Asteroid Buster will include the need to be flexible. The concept is to store the major segments at the Apex

Anchor in the Garage and then assemble the Asteroid Buster after the identification of the threat and released towards the target within 24 hours.

A pre-determined number of Asteroid "Busters" can be pre-positioned in the Apex Anchor's "Garage." It will require no Earth based rocket launches to deliver the "Busters" to the Apex Anchor as they would be delivered by the Space Elevator system. Then when released, they will be above the gravity well, can respond within 24 hours, and will have starting velocity of 7.76 km/sec, with potential to add rocket motors to increase the speed, change inclination, and correct trajectories. The Asteroid "Buster" concept is extremely flexible and must be responsive to a wide variety of threats. The system is pre-positioned and can be configured to meet a wider variety of threats (low, medium, high). Additionally, the system can dispense a salvo of "Busters" to ensure successful impact, whereas under the DART concept if there is a miss, they have to launch another DART which takes time.

7.5 Summary: Humanity's continued existence on the Earth depends upon Planetary Defense systems and their timely deployment. The threats are from medium to large asteroids that are destined to impact the Earth in the future. To be effective, the complex infrastructure, from operations center to supply logistics to supply the Apex Anchor Asteroid Buster garages, needs to be able to search/detect/track, characterize, plan and coordinate, assess and mitigate objects approaching the Earth. Note that these same functions can be used to monitor the Moon and Mars Colonies for protection. The current response time, based upon Earth departures, is not quick enough to effectively negate a true asteroid impact on the Earth if the threat is close to the Earth when detected. The two special cases are "out of the sun" and new collision orbits from the asteroid belt. What is required is a rapid response capability to protect the Earth's inhabitants. A solution is proposed that will create a more flexible, real-time planetary defense system by pre-positioning components of the Planetary Defense system at the Apex Anchors of the Space Elevator system. With this capability, a more appropriate negation could be achieved. This rapid, pre-positioning approach is superior to the classic launch from aircraft or rocket mode in the following ways: a) it reduces the operational timeline from months to mere hours from detection to launch; b) the components would already be at 100,000 kms, stored inside the PD Garage; c) by attaching appropriately stored rocket motors to the desired threat reduction spacecraft, any inclination and speed could be leveraged: and d) the initial velocity of 7.76 km/sec would ensure rapid transit towards the incoming asteroid or debris, thus hitting it at more of a distance from Earth than a rocket launch could. Having stored Asteroid Busters above the gravity well has tremendous advantages over trying to organize, load a rocket, and then schedule a launch in a timely manner. The survival of our species demands that the planet's defense leverages the best technologies available.

Space Elevator Insights:

Pre-Positioning of Planetary Defense Equipment at Apex Anchors

This rapid, pre-positioning approach is superior to the classic launch from aircraft or rocket mode in the following ways:

a) Dual telescopes scanning identified risk zone around the sun for early detection could give up to 30 day warning when today there is no warning.

b) Reduces the operational timeline from months to mere hours from detection to launch because the components would already be at 100,000 kms, stored inside the Planetary Defense Garage – assemble chosen segments and rocket motors and then launch!

c) In addition, by attaching appropriately stored rocket motors to the desired threat reduction spacecraft, any inclination and speed could be leveraged with daily launch and initial velocity of 7.76 km/sec ensuring rapid transit which would hit the threat at more of a distance from Earth than a rocket launch.

Chapter 8: Case study: Interplanetary Revolution

8.0 Unmatched Velocity & Mass: Can you imagine a large space system leaving Earth in excess of 12.35 km/sec which ensures escape from our Sun? How about if it had an extra 10 km/sec assist from a slingshot release from the Apex Anchor, with the ability to gain another 15 km/sec by doing gravity assists along the way. The total concept being discussed is fast enough to reach any of our 7 planets with reasonable timelines. It could also leave our solar system and approach meaningful destinations "out there" within a reasonable time (100 AUs in 19 years). In addition, there is more for the scientist seeking answers within our solar system and the interstellar arena – how about the ability to send muti-tens of tonnes along this path in a huge space system with fuel for rendezvous and landing along the way? How does this work? You assemble a large spacecraft above the gravity well of the Earth, add velocity to it by spinning it around the Earth and then release it with extra velocity from a giant slingshot. An extra-long Space Elevator (163,000 km) could achieve these goals by 2038. This story should be told as part of future opportunities for space exploration, planetary sciences, and interstellar studies. [Note: Voyager increased by 15 km/sec with a gravity assist when entering Jupiter's field at 10 km/sec, then leaving at 25 km/sec.]

8.1 Quick look at history: The history of interplanetary satellite investigations of our solar system has been marvelous with images and science returned that have altered scientific "facts!" Of course; more data, close-up data collection, images from a distance and then up close – and then of course different views and platforms have changed the path of planetary sciences. Satellites have impacted not only planetary sciences but the understanding of our "Earth's" growth. It seems that every day we are finding another exo-planet or discover water at new locations – or better yet – collecting in-situ science from long duration in space, on planets or from the Moons clustering around our 8 planets (of course, also Pluto and Ceres.) And then there are the few who have escaped our solar system. The problem has always been - the bigger the ellipse or hyperbolic orbits, the less of a satellite mass can be accommodated as

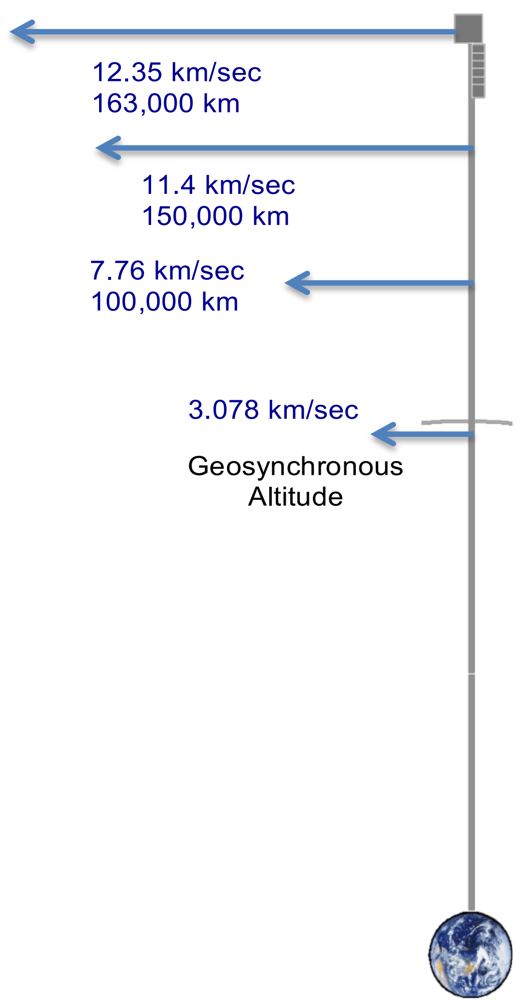


Figure 8.1: Velocity at Altitudes

the problem needs massive energies to deliver small spacecraft.

8.2 The Current Problem – Rocket Approach: The community of planetary scientists has a remarkable achievement record visiting all of our planets, including Pluto. This series of successful missions is enviable when you consider the phenomenal restrictions placed upon the scientists. Our history of planetary sciences has always been costly, not often enough, and far too many restrictions on scientific payloads – not enough power to go around – not enough science "time" for the instruments, ridiculously low mass budgets and of course the thermal, power and heating requirements that have to be shared across all scientific instruments and spacecraft operations including communications. In addition, the cost of developing space survivable equipment for long duration missions is far beyond the simple experiments that can be accomplished on Earth. These restrictions tend to limit size, shape, power needs and thermal protection; thus, leading to extra complexity, lengths of development and of course cost. However, there is great news for the planetary scientist! The ability to assemble any size space system at the Apex Anchor leads to a remarkable capability to send large mission space systems to distant targets with extremely high velocity on almost any day of the year.

8.2.1 Near Term – a potential breakthrough: The soon to appear Starship will provide amazing opportunities for planetary scientists with "ride-share" type missions to the Moon and Mars. These commercially available space transportation opportunities will open those destinations in the next few years for so much science that it will amaze the scientific community. As hitching a ride to Starship locations will be remarkable, the science collection will become routine for these commercial missions. Starship will hopefully embrace the concept and provide remarkable cargo capability in the near future with other large commercial launch vehicles following their example. The assumption is that the planetary scientists should be contracting for ride sharing opportunities during the initial (no humans) trips to both the Moon and then to Mars. This sharing of ride opportunities should:

- During their testing period – multiple rides in the near term with return to the Earth (planned at least)
- Lunar flights will provide opportunities with rapid flights and return to Earth
- The ride share capability to the surface of the Moon will provide amazing opportunities for science collection, and even return to the Earth during the SpaceX lunar lander testing. Of course, Blue Origin and others are not far behind on these opportunities with their new contracts for Lunar landers.
- With the actual depositing humans on the surface of the Moon, there will be opportunities to have not only scientific data collection, but data analysis assisted by human presence.
- Then of course, will be the SpaceX flights to Mars; first no humans and then test flights with small numbers of players, and then large numbers who will develop

settlements. These flights will also provide room for science payloads at commercial prices.

The beauty of having frequent flights of large vehicles with large payload bays is that there will always be room for science payloads if negotiated with the research organization at commercial delivery prices. In the near future, the ride shares will be to predetermined locations – where the testing program takes them. However, they will have mass, volume, and power available for the science community. Remember, it is all controlled by the draconian rocket equation

8.2.2 Mid-Term: In the future, there will be remarkable room in these massive vehicles so sharing could occur. In the future, the Starship could take spacecraft to various locations along their path to their own destinations and drop them off for new and exciting locations – almost anywhere in the solar system. These ideas will lead to a massive increase in scientific data collection across our solar system.

8.3 A Revolution: However, the problem is still mass, velocity and cost. Even with the situation eased by the volume, frequency and commercial processes, the rocket equation is still dominant. In order to really open up the solar system – and especially interstellar missions – the only option is Space Elevator Apex Anchor releases. There are two principal advantages (in addition to all of the previously recognized strengths (characteristics) of Space Elevators:

- Unmatched Velocities: After raising the spacecraft to the Apex Anchor, the inherent velocity depends on the altitude (Initial Operational Capability – 100,000 kms, and future dedicated science mission Space Elevator – 163,000 kms). This enables rapid flights to all the planets (40 days to Mars and 200 days to Neptune, and of course 14 hours to the Moon) and even escape from the solar system. In addition, there are additional approaches to increasing the speeds (see explanations below in section 8.4).
- Unmatched Spacecraft size, mass, and delivery statistics: A major characteristic of Space Elevators is that you may efficiently raise mass (70% of lift mass to the Apex Anchor) without disturbing the environment (Green Road to Space). In addition, there is capability to place large masses at the top of the tether by bringing them up in incremental payloads and then assembling them. This results in the capability to assembly large spacecraft with massive rocket motors over time enabling the scientists and settlers to place mass where needed. Envision early plans of 14 tonnes per day to the Apex Anchor for 365 days on a science dedicated Space Elevator. Once delivered, the assembly would occur in parallel to lifts in a low "g" environment (approx. 0.2 g). Next would be the release of a 5110 tonnes science spacecraft towards their designation for delivery of cargo or science mission satellites.

8.3.1 Summary:

The solar system and interstellar scientists may have any size space system assembled before release with great velocity toward their destination. In addition, with the same concept, settlers and explorers may have supplies in large quantities delivered to their designated locations.

8.3.2 Space Elevator Strengths to Support Interplanetary missions: In addition to the unmatched strengths described above, there are a few more that improve the needs to explore beyond the Earth. They are:

- As the Space Elevator is to be a transportation system, significant characteristics include daily, routine, safe, efficient, and inexpensive delivery. Can you image a space access system that actually has a schedule and can be expected to deliver when required?
- A significant strength of a transportation system is low costs – very much similar to the transition from a boat crossing a river until the bridge replaces it – massive savings in operations.
- Planetary science payloads that are lifted on the Space Elevator would recognize that it is the Green Road to Space as it does not burn fuel in the atmosphere nor leave debris in LEO or along the way.
- The size of the payloads, and the "shake-rattle-roll" is forgotten as the raising of the tether climber is done with wheels driven by electricity and can accommodate most sizes of future payloads.

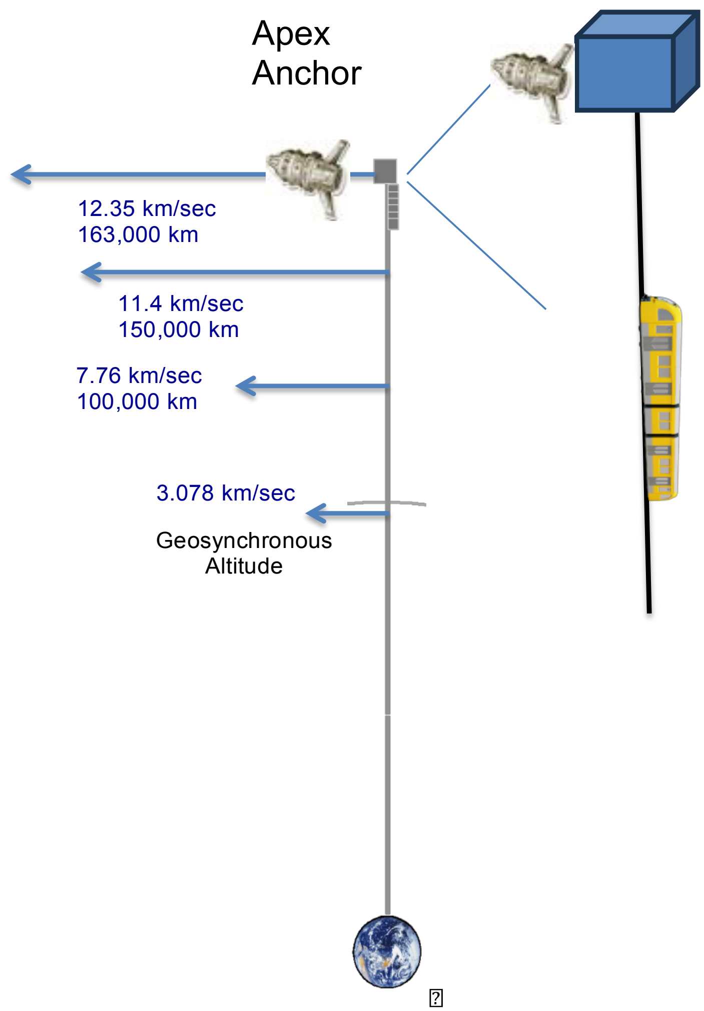


Figure 8.2: Apex Anchor Assembly at Top of Gravity Well

	Type of Velocity	km/sec
VBSS	Velocity beyond Solar System	25.25
VGA	Velocity with Gravity Assist	15
VAV	Added Velocity at Tip	10
VAA	Velocity at Apex Anchor	12.35
VE	Velocity of Earth	30
VSS	Velocity to Escape solar system	42.1

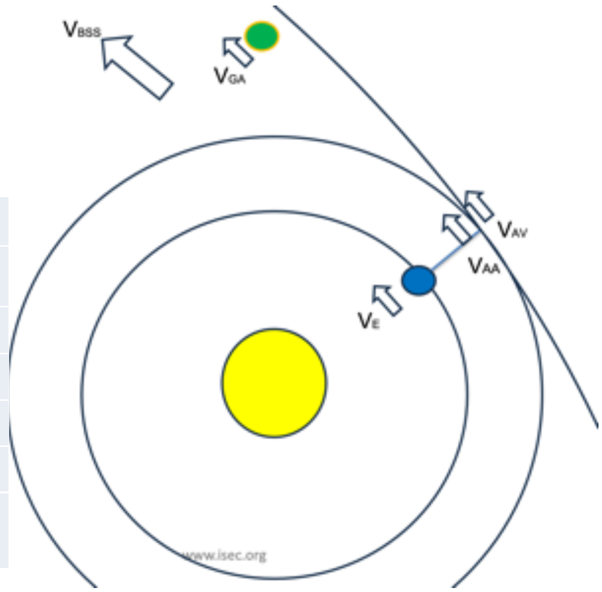


Figure 8.3: Velocities to Escape Solar System

8.3.3 Summary: The Interplanetary and Interstellar communities will recognize that Space Elevators have remarkable transformational strengths, which will enable the planetary science community to have space systems of almost any size to be assembled above the gravity well and then launched with great velocity.

8.4 Interstellar Velocity Description: The problem in the past has always been mass on the top of the rocket – how fast? In addition to massive rockets using up 99% of the mass to gain enough velocity to reach our planets, then they leveraged the concept of gravity assist. The Space Elevator is proposing that there is a way to gain vast amounts of velocity while having a massive scientific spacecraft.

The puzzle for interplanetary and for interstellar is to gain enough velocity (relative to the sun) to reach vast distances in reasonable times. The image above shows the suggested approach for interstellar flights (reaching one of our 7 planets becomes less of a problem). The first velocity necessary to understand is escape from the Sun – 42.1 km/sec to leave the solar system. The next one is our initial ride – velocity of the Earth with respect to the Sun – 30 km/sec. This results in a needed velocity of 12.1 km/sec added to 30 to escape the solar system. First, we understand the length of the tether (163,000 km altitude) results in a velocity of 12.35 km/sec. This gives us 42.35 km/sec or just a little more than we need to exit the solar system. There are long distances "out there, so extra velocity is desired to reduce the time of travel to any desired destination. Next, we use a 'slingshot' maneuver with additional hardware at the Apex Anchor gives 10 km/sec more. [Peet, 2021] And lastly, we incorporate as many gravity assists with massive planets as we can arrange. The example is the Voyager flight by Neptune for a velocity assist of 15 km/sec. The total is then 25.5 km/sec velocity when leaving the solar system without burning rocket fuel for speed. (of course, with our generous mass combined to create the spacecraft, there will be room for rocket motors of significance to increase velocity, slow down for rendezvous or landing at destination. The remarkable conclusion is that using the Space Elevator and the inherent strengths of velocity and assembly of mass at the top will enable massive science missions to interstellar space and within our solar system.

8.5 Conclusions:

8.5.1 Dual Space Access Architecture: With the advanced rockets such as Starship and New Glenn there will be major improvement in the delivery of science payloads for interplanetary scientists. Moving mass under commercial "ride-share" will give remarkable opportunities for science. However, they are still limited by mass and velocity to reach the other planets or even interstellar. When you leverage the Dual Space Access Strategy, the results will be remarkable.

8.5.2 Space Elevator Characteristics: Space Elevators have phenomenal characteristics that will enable the interstellar and interplanetary communities. Two dominant characteristics are unmatched velocities from the Apex Anchor and the ability to assemble massive spacecraft at the top of the gravity well.

8.5.3 Response: Space Science Enthusiasm will skyrocket as the future unfolds with both advanced rocket capability for lifting large science projects in the near term and then the revolution inherent with the characteristics of Space Elevators. In addition, the interstellar community will recognize the remarkable reach of leaving the Earth's gravity field with massive payloads and high velocities.

Space Elevator Insights:

In order to really open up the solar system – and especially interstellar missions, the only option is Space Elevator Apex Anchor releases with two dominant characteristics.

- Unmatched Velocities: enables rapid flights to all the planets (40 days to Mars and 200 days to Neptune, and of course 14 hours to the Moon) and even escape from the solar system.
- Unmatched Spacecraft size, mass, and delivery statistics by assembling the interplanetary space system above the gravity well.

Section E: Conclusions and Recommendations

E1.0 Significant Insights: A summary of the chapter by chapter insights on the various Space Elevator characteristics are shown.

Section A: Why Space Elevators? *Unmatched Efficiency* -- Unmatched Efficiency of delivery to the customer is provided with a permanent space transportation infrastructure. Glaring examples: Space Elevators deliver 70% of the climber mass starting at the Earth Port to GEO while rockets only deliver 2% to GEO of their pad mass.

Chapter 1: *The Modern-day Space Elevator will be transformational as a permanent space access infrastructure*: a) Space Elevators are ready to enter Engineering Development, b) Space Elevators are the Green Road to Space, c) Space Elevators should join advanced rockets inside a Dual Space Access Architecture Strategy, and d) Space Elevators, as transportation core, attract and logistically support massive future enterprises.

Chapter 2: *Space Elevators will open space for humanity while saving the planet from global warming*: A first step into our future must be to build Space Elevators. A leap into this bright future for humanity by using individual launches alone is counter productive. There must be a permanent transportation infrastructure that can move massive logistics to GEO and beyond with environmentally friendly operations.

Section B: *What else do you achieve with a permanent transformational transportation infrastructure, besides massive delivery of logistics? The answer has so many levels leading to Space Elevators to move logistics:* a) Daily departures allows logisticians the opportunity to plan for "on time delivery" of products to various destinations on and around Mars, b) Rapid delivery (as short as 61 days) allows the delivery of important logistics when required, c) Environmentally friendly operations improves our world while delivering massive logistics to customers at GEO and beyond and d) Unmatched delivery statistics – 70% to GEO and beyond.

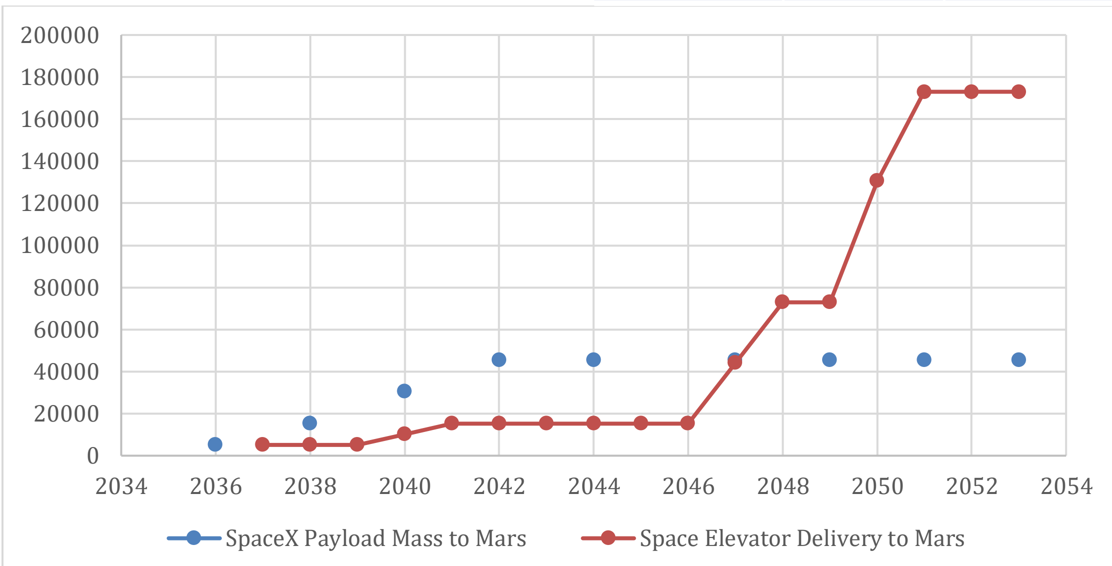
Chapter 3: *Space Elevators have many strengths; but the most remarkable ones relate to their being permanent space transportation infrastructures:* Move massive cargo - Daily (On Schedule) - Routinely ("just in time") - Efficiently (70% delivery statistic) - Environmentally friendly operations - Safely (think trains)

Chapter 4: *Space Elevator and Advanced Rockets tonnes to GEO and Beyond in Dual Space Access Architecture:*

Table E.1, Comparison

Figure E.1: Comparison by year

	Starships	Space Elevators
Daily Departures	3	6
Rapid Delivery	8 months to Mars – 26 month wait	range 61 to 400 – every day
GEO Delivery statists	21 tonnes at 0.5 % pad mass	14 tonnes at 70% of pad mass



Section C: *The problems of Humanity's future power requirements, the cooling of the Earth, and Global Climate Change have all focused a need for satellite-based solutions:* a) The power needs will double within the next 25 years, the ramping up of the global temperature is frightening, and major disturbances in weather are showing up in surprising locations, and b) It seems that long term answers to these dangers require massive satellite projects initiated in the near future.

Chapter 5: *The rising temperature around the globe has increased the awareness of the need to evaluate satellite solutions. The idea of a Sunshade has tremendous validity in that there is a direct relationship between blocked sun and temperature lowering on the receiving planet*: The concept of a planetary sunshade is relatively simple. Like an umbrella on a hot day, an object placed between the Sun and the Earth will reduce the amount of incoming solar energy and, therefore, the temperature of the Earth. There are two ways to construct a megaproject such as the sunshade in space: build it on and loft it from Earth or use space resources to build it outside of Earth's gravity well. Both approaches have benefits and drawbacks

Chapter 6: *The combination of Space Based Solar Power and Space Elevator technologies has the potential to revolutionize the way we generate and deliver renewable energy to meet the growing global demand*: a) The SBSP satellite constellation can meet that goal and help move humanity into the second half of this century with a robust source of energy which is continuous and does not disturb the atmosphere. The electrification of the total globe will be a tremendous advancement for development into the next century, and b) An operational Space Elevator can provide a more efficient and cost-effective means of transporting Space Based Solar Power satellite parts to GEO, allowing for more frequent space-based assembly and deployment of large-scale satellites.

Section D: *The inherent velocities at GEO and Apex Anchor are natural for so many missions*: Assembly at GEO enables missions not restricted by the rocket equation leading to much more diverse missions, much bigger systems assembled there and remarkable supply, assembly, and build capabilities. Assembly at Apex Anchor enables lunar and interplanetary missions that are far more capable (bigger payloads and spacecraft) with high velocities that match exciting missions "out there." (as fast as 14 hrs to the Moon and 61 days to Mars with six releases per day)

Chapter 7: *Pre-Positioning of Planetary Defense Equipment at Apex Anchor:* This rapid, pre-positioning approach is superior to the classic launch from aircraft or rocket mode in the following ways: a) it reduces the operational timeline from months to mere hours from detection to launch because the components would already be at 100,000 kms, stored inside the Planetary Defense Garage; and, b) by attaching appropriately stored rocket motors to the desired threat reduction spacecraft, any inclination and speed could be leveraged with daily launch and initial velocity of 7.76 km/sec ensure rapid transit ensuring that it would hit the threat at more of a distance from Earth than a rocket launch.

Chapter 8: *In order to really open up the solar system – and especially interstellar missions, the only option is Space Elevator Apex Anchor releases with two dominant characteristics:* a) Unmatched Velocities: enables rapid flights to all the planets (40 days to Mars and 200 days to Neptune, and of course 14 hours to the Moon) and even escape from the solar system, and, unmatched spacecraft size, mass, and delivery statistics by assembling the interplanetary space system above the gravity well.

E2.0 Major Conclusions: A summary of the major conclusions are:

E.2.1: Dual Space Access Architecture Leverage the Best of Advanced Rockets and Space Elevators: This study, conducted by the International Space Elevator Consortium, presents new perspectives on the Space Elevator, and compares it with advanced rockets to lead to a Dual Space Access Strategy for improving the human condition and for human movement off planet. This Dual Space Access Strategy is one that leverages the cooperation and coordination of Advanced Rockets and Space Elevators while satisfying the needs of these customers.

E.2.2: Unmatched Efficiencies lead to Space Elevators Beating the Rocket Equation: 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 concept is really restricting movement off planet with only 4% to LEO, 2% to GEO, and a woefully small percentage for delivery to the Moon, Mars' orbit, much less Mars' surface. The Space Elevator solves that rocket 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.

E.2.3: Unmatched Massive Logistics Support: Space Elevators will open the heavens for humanity, because they can move massive logistics off our planet with unmatched velocities and quantity of mass. The development of a permanent space transportation infrastructure is proposed with several significant transformational characteristics. The remarkable future of humanity living and working off planet will demand significant tonnage delivered off planet. The future can be astounding because they can deliver megatons of logistics support that can save the planet’s atmosphere by enabling a space solar power constellation of 2,000+ tonne satellites and provide a robust, daily, green approach for humanity to move off planet. A first step into our future must be to build Space Elevators.

E.2.4: Individual Conclusions: The ISEC has shown that there must be major changes in the approach for humanity's migration off-planet. Some of these changes include:

- Change of vision for interplanetary movement when delivery of mass is inexpensive, timely, environmentally friendly, daily, and supportive. This new vision of Space Elevator architectures will change the thinking for off-planet migration - We CAN bring it with us!
- Movement off-planet will require complementary capabilities -both rocket portals and Space Elevator infrastructures - each with their own strengths and short-falls. Inserting payloads into Low Earth Orbits and moving people through the radiation belts rapidly are strengths of rockets while massive movement in a timely, routine, inexpensive and Earth friendly manner are the strengths of Space Elevators. In addition, to initiate Space Elevator developments, rockets will be needed to deliver initial phases to GEO.

- An interesting insight in parallel with this analysis says that planetary scientists can be offered as much mass as they require for any of their missions. There will be zero restrictions for scientific instruments going to any place in the solar system - including the survival from the shake, rattle, and roll of rocket launches. If you cannot include it in one 14 metric ton payload capable tether climber, you can assemble parts at the Apex Anchor and release them once a day towards any destination.
- An intriguing proposal is to lower the Earth's temperature by lowering the amount of energy that is impacting the Earth's upper atmosphere with a sun shade.
- In 2020, when the Modern-Day Space Elevator emerged, the concept of an active transportation node at the Apex Anchor became obvious. The enhancement of the roles of an Apex Anchor showed how it has become a focal point for several significant missions around the "Logistics Center at the top of the Gravity Well."
- Humanity's existence on the Earth depends upon Planetary Defense systems and their timely deployment. The concept proposed is to show that a rapid response for Planetary Defense missions can be one that leverages the transformational strengths of Space Elevators: storage of Planetary Defense mission hardware above the gravity well, with quick assembly, and then release from the Space Elevator's Apex Anchor, with a high velocity (7,76 kms/sec), within 24 hours.
- Can you imagine a massive space system leaving Earth with an excess of 12.35 km/sec which ensures escape from our Sun? How about if it had an extra 10 km/sec assist from slingshot release from the Apex Anchor, with the ability to gain another 15 km/sec by doing gravity assists along the way. The total concept being discussed is fast enough to reach any of our 7 planets with reasonable timelines. It could also leave our solar system and approach meaningful destinations "out there" within a reasonable time (100 AUs in 19 years).

<u>The Major Conclusion</u>: <u>Why Space Elevators?</u>
Because they have Unmatched Efficiency, Unmatched velocities and Unmatched movement of mass to GEO and beyond.

E.3.0 Recommendation:

Immediately Initiate Development of Space Elevators!

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Appendices

A – International Space Elevator Consortium
B –Space Elevator Body of Knowledge
C – ISEC & IAA Studies
D -- Chapter 5 - Throughput Projection of Galactic Harbour [Swan, 2020b]

Appendix A International Space Elevator Consortium

Who We Are

The International Space Elevator Consortium (ISEC) is composed of individuals and organizations from around the world who share a vision of humanity in space.

Our Vision

Space Elevators are the Green Road to Space while they enable humanity's most important missions by moving massive tonnage to GEO and beyond. This is accomplished safely, routinely, inexpensively, daily, and they are environmentally neutral.

Strategic Approach: Dual Space Access Architecture

Rockets to open up the Moon and Mars with Space Elevators to supply and grow the colonies. In addition, Space Elevators will enable Green Missions such as, Space Solar Power and L-1 Sun Shade. This compatible and complementary approach with future rockets is not competitive while leveraging the strengths of both inside a Dual Space Access Architecture.

Our Mission

The ISEC promotes the development, construction and operation of a space elevator infrastructure as a revolutionary and efficient way to space for all humanity.

What We Do

- Provide technical leadership promoting development, construction, and operation of space elevator infrastructures.
- Become the "go to" organization for all things space elevator.
- Energize and stimulate the public and the space community to support a space elevator for low cost access to space.
- Stimulate science, technology, engineering, and mathematics (STEM) educational activities while supporting educational gatherings, meetings, workshops, classes, and other similar events to carry out this mission.

A Brief History of ISEC

The idea for an organization like ISEC had been discussed for years, but it wasn't until the Space Elevator Conference in Redmond, Washington, in July of 2008, that things became serious. Interest and enthusiasm for a space elevator had reached an all-time peak and, with Space Elevator conferences upcoming in both Europe and Japan, it was felt that this was the time to formalize an international organization. An initial set of directors and officers were elected and they immediately began the difficult task of unifying the disparate efforts of space elevator supporters worldwide. ISEC's first Strategic Plan was adopted in January of 2010 and it is now the driving force behind ISEC's efforts. This Strategic Plan calls for adopting a yearly theme to focus ISEC activities. Because of our common goals and hopes for the future of mankind off-planet, ISEC became an Affiliate of the National Space Society in August of 2013. In addition, ISEC works closely with the Japanese Space Elevator Association.

Our Approach

ISEC's activities are pushing the concept of space elevators forward. These cross all disciplines and encourage people from around the world to participate. The following activities are being accomplished in parallel:

- Yearly conference – International space elevator conferences were initiated by Dr. Brad Edwards in the Seattle area in 2002. Follow-on conferences were in Santa Fe (2003), Washington DC (2004), Albuquerque (2005/6 –smaller sessions), and Seattle (2008 to the present). Each of these conferences had multiple discussions across the whole arena of space elevators with remarkable concepts and presentations.
- Yearlong technical studies – ISEC sponsors research into a focused topic each year to ensure progress in a discipline within the space elevator project. The first such study was conducted in 2010 to evaluate the threat of space debris. The products from these studies are reports that are published to document progress in the development of space elevators. They can be downloaded at www.isec.org.
- International Cooperation – ISEC supports many activities around the globe to ensure that space elevators keep progressing towards a developmental program. International activities include coordinating with the two other major societies focusing on space elevators: the Japanese Space Elevator Association and EuroSpaceward. In addition, ISEC supports symposia and presentations at the International Academy of Astronautics and the International Astronautical Federation Congress each year.
- Publications – ISEC publishes a monthly e-Newsletter, its yearly study reports and an annual technical journal [CLIMB] to help spread information about space elevators. In addition, there is a magazine filled with space elevator literature called Via Ad Astra.
- Reference material – ISEC is building a Space Elevator Library, including a reference database of Space Elevator related papers and publications. (see section before this on references) www.isec.org
- Outreach – People need to be made aware of the idea of a space elevator. Our outreach activity is responsible for providing the blueprint to reach societal, governmental, educational, and media institutions and expose them to the benefits of space elevators. ISEC members are readily available to speak at conferences and other public events in support of the space elevator. In addition to our monthly e--Newsletter, we are also on Facebook, Linked In, and Twitter.
- Legal – The space elevator is going to break new legal ground. Existing space treaties may need to be amended. New treaties may be needed. International cooperation must be sought. Insurability will be a requirement. Legal activities encompass the

legal environment of a space elevator - international maritime, air, and space law. Also, there will be interest within intellectual property, liability, and commerce law. Starting work on the legal foundation well in advance will result in a more rational product.

- History Committee – ISEC supports a small group of volunteers to document the history of space elevators. The committee's purpose is to provide insight into the progress being achieved currently and over the last century.
- Research Committee – ISEC is gathering the insight of researchers from around the world with respect to the future of space elevators. As scientific papers, reports and books are published, the research committee is pulling together this relative progress to assist academia and industry to progress towards an operational space elevator infrastructure.

ISEC is a traditional not-for-profit 501 (c) (3) organization with a board of directors and four officers: President, Vice President, Treasurer, and Secretary. inbox@isec.org / www.isec.org

Appendix B Space Elevator Body of Knowledge

Recently, a visitor to our International Space Elevator Consortium (ISEC) conference was quoted as saying, "You have a remarkable body of knowledge at www.isec.org. He was referring to the efforts of many scientists, engineers, and project/program professionals over the last 8 to 10 years. The leap in quality and currency shows that the Space Elevator is indeed twenty years beyond Dr. Edwards' breakthrough accomplishment saying "it can be done." What is amazing are the conclusions from this body of knowledge:

1. Space Elevators are ready to initiate a developmental program
2. The tether material has been produced in the laboratory for the needed strength (150 GPa) and continuous length (1 meter per minute production) (note; not both capabilities at once - yet). This 2D material will be ready for the development team.
3. Space Elevators enable Missions off-planet with robust cargo movement as a complementary access to space with rockets.
4. Space Elevators are environmentally friendly in operations and enable Space Based Solar Power to eliminate hundreds of coal burning plants.

ISEC is particularly proud of its latest year-long study entitled "Space Elevators are the Transportation Story of the 21st Century." This study report places Space Elevators into the near future and shows how they support critical missions. One such mission is the enabling of Space Based Solar Power. This mission will lead to a much cleaner global environment by eliminating hundreds (or thousands) of coal burning plants. The report also shows how to support Mars colonies and Lunar villages by supplying their cargo. In addition, this report illustrates research accomplished by ISEC with Arizona State University showing the strengths of Space Elevators for interplanetary missions. Can you imagine 61 days to Mars? How about daily departures to Mars (no 26 month wait)? In addition, Space Elevators enable a tremendous benefit with massive cargo movement (170,000 tonnes per year to GEO and beyond). All this is accomplished with the Space Elevator architecture as a complement to rockets. This Dual Space Access Architecture (rockets and Space Elevators) is complementary and compatible - not competitive.

Body of Knowledge – Modern Day Space Elevator
The principal source for the following information is at **www.isec.org**.

A) ISEC Studies: Latest engineering, management, operations, and developmental issues addressed in year-long studies conducted by Space Elevator experts. Download all 16 of these ISEC study reports in pdf for free at **www.isec.org**. See Appendix C.

B) International Academy of Astronautics and Obayashi Corporation Studies: In addition, there were three other major studies conducted on the modern Space Elevator; by the International Academy of Astronautics and the Obayashi Corporation. See Appendix C.

C) References and Citations are listed by major topic (over 750 titles available).

D) Videos: Recently, the modern Space Elevator has been discussed within webinars that are accessible on ISEC website as well as YouTube. Two recent ones are: Space Elevator 101 and Dreaming of Space, Take an Elevator.

E) Any questions can be forwarded to info@isec.org.

Appendix C Studies of ISEC & IAA

List of International Space Elevator Study Reports Available on www.isec.org or purchase from www.lulu.com

Year	*Title*
2024	**Underway, Apex Anchor Strengths and Characteristics**
2023	**Dreaming of Space: Leverage Dual Space Access Architecture Advanced Rockets and Space Elevators**
2022	**The Climber-Tether Interface of the Space Elevator**
2021	**Space Elevators: The Green Road to Space**
2020	**Space Elevators are the Transportation Story of the 21st Century**
2020	**Today's Space Elevator Assured Survivability Approach Space Debris**
2019	**Today's Space Elevator, Status as of Fall 2019**
2018	**Design Considerations for a Multi-Stage Space Elevator**
2017	**Design Considerations for a Software Space Elevator Simulator**
2016	**Design Considerations for Space Elevator Apex Anchor and GEO Node**
2015	**Design Considerations for Space Elevator Earth Port**
2014	**Space Elevator Architectures and Roadmaps**
2013	**Design Considerations for Space Elevator Tether Climbers**
2012	**Space Elevator Concept of Operations**
2010	**Space Elevator Survivability, Space Debris Mitigation**
	and
2017	**Space Elevator: A History**

International Academy of Astronautics Studies (with participation from ISEC)

Year	*Title*
2019	The Road to the Space Elevator Era
2014	Space Elevators: An Assessment of the Technological Feasibility and the Way Forward
IAA	International Academy of Astronautics - sponsor of these four-year studies www.iaaweb.org
go to:	Virginia Edition Publishing Company, Heinlein Prize Trust https://www.heinleinbooks.com/book-store

Appendix D: Throughput Projection of Galactic Harbour

[most of the words from Swan, 2020b]

For Humanity to successfully and robustly move off planet, the question is:

What is the throughput of Galactic Harbours?

1 Introduction: When designing large complex space systems, there is a process that develops engineering projections of customer needs and then compares to infrastructure capabilities. This chapter will show that Space Elevator and Galactic Harbour development will follow historic approaches with an initial capability striving for "what can be done" within the first few years and then building towards customer requirements. Using the actual 2018 rocket launches as an initial capacity of lift-off to orbit, and estimating the total throughput reaching orbit during that year, the results were 114 launches with an average of eight metric tons yields a total of about 1,000 metric tons during the year. In comparison, SpaceX estimates that he will need 1,000,000 metric tons[2] to support his Mars Colony - or 1,000 years at today's launch rate.

However, if one were to develop a transportation infrastructure that can satisfy future customer needs while doing it for less money, routinely (daily), safely, in an environmentally friendly manner, and with massive movements of payloads -- in other words, the Galactic Harbour strengths could satisfy the customers' needs. This Galactic Harbour transportation infrastructure, as shown in the first image, provides very strong support of current and projected customer mission needs for GEO and beyond. If you think about past transportation infrastructures, they tend to start out small (individual point to point movement of cargo) while rapidly expanding towards the customers' needs and wishes. First, infrastructures increase the capability of each individual entity; and then, copy it until there are several transportation systems competing within a given marketplace. This model of previous transportation infrastructure growth will be used to show that increasing individual capabilities first, and then multiplying the number of infrastructures, is probably the model that will be followed by Galactic Harbours. In the airline industry, for example, they first improved the airplane to haul cargo and people that then lead to multiple airline companies competing for business. These historic infrastructures have shown that:

If you build it, and then improve it, they will come!

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[2] [Musk, 2019]Musk, Elon., Quotation from CBS's Sunday Morning Show, 21 July 2019.

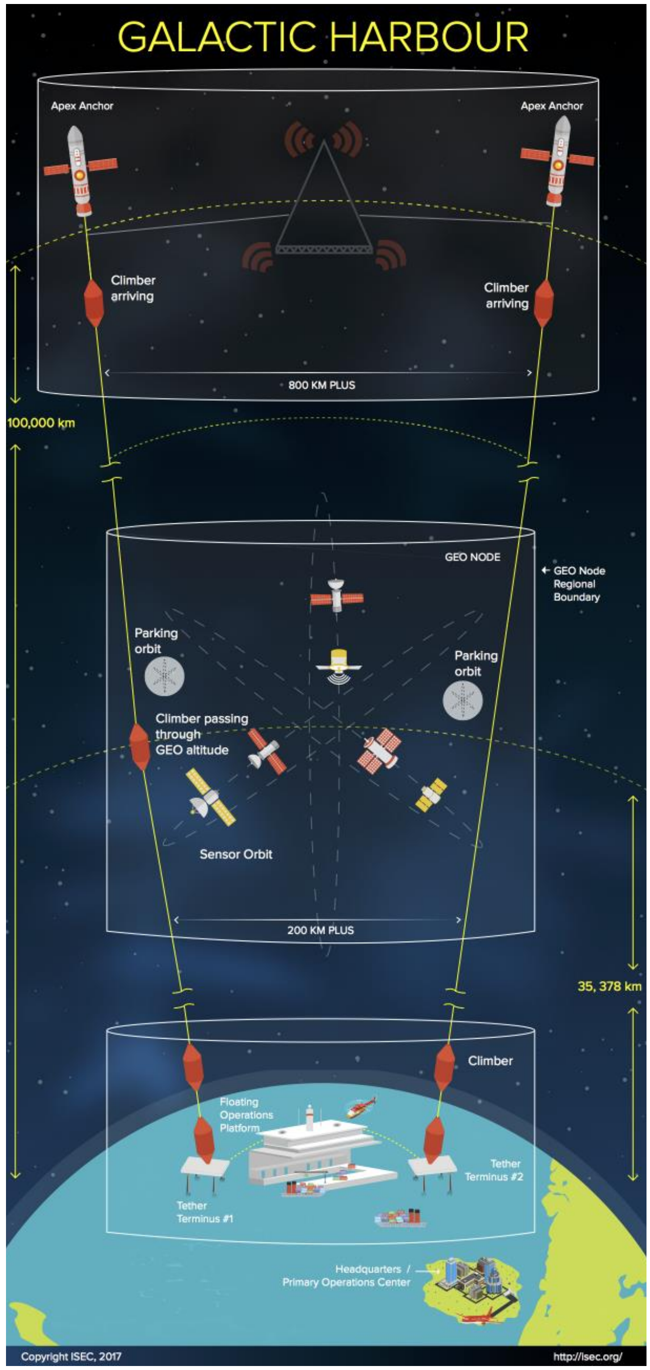

Figure 1 Galactic Harbour

It is also extremely important to realize that the decade of the 2020's is going to be the initial period of movement off-planet. NASA, ESA, China, Russia and other countries are announcing their programs to go to the Moon and/or Mars. Russia has announced a plan to go to a Martian Moon and operate robots on the Martian surface as their first approach to movement off-planet. Recently, they have joined China in planning for a research station at the Lunar South Pole. The decade of the 30's will be remarkable with respect to interplanetary missions and cargo required to be delivered. This revolution across the space arena is active and aggressive. The new mass movement off-planet will add tremendous demands to our global lift-off capabilities.

2 Growth of Galactic Harbours:

This chapter is looking in a futuristic manner to quantify the potential throughput of Space Elevator infrastructures around the world. Someone will build the first Space Elevator and then create a backup Space Elevator immediately so we do not ever become captured by gravity again. This pair of Space Elevators has come to be called the Galactic Harbour. It is a combination of transportation infrastructure and business enterprises leveraging new capabilities. This is the creation of a capability (first and second Space Elevator) and then improving the capability over time. As the material of the tether grows stronger, mission successes will lead to increased customer demands. As such, this first Space Elevator will be created, duplicated, and then multiplied -- resulting in competing transportation infrastructures around the world. The number of Galactic Harbours will expand naturally. As described in Chapter Two's Vision, the number of Galactic Harbours will expand naturally. The competitive aspect of transportation infrastructures will lead to two and then three

Galactic Harbours - first with Initial Operational Capabilities and then growing to Full Operational Capabilities. This vision for the 2035-2055 time period will be quantified and explained within the rest of this chapter. However, the authors believe this will only be the initial push for a robust capability to space with mid-century fostering growth towards six Galactic Harbours enabling robust movement off-planet.

During the Seattle ISEC International Space Elevator Conference in August of 2015, the International Academy of Astronautics study group #3-24 met. This group's product, at the end of four years with input from 47 global Space Elevator experts, resulted in a study report entitled "Road to the Space Elevator Era."[3] This included participates from Japan, USA, UK, Ukraine, France, Portugal, Russia, China, Canada and Brazil. The team agreed to use, as much as possible, consistent terminology for their report. This general list of terminology is shown on the ISEC website – www.isec.org. The throughput of individual Space Elevators was estimated by the team creating common terminology. In the lexicon for Space Elevators, the following are in play for this study report, consistent with global understanding of the terms:

- Space Elevator (SE) - single tether of 100,000 km length
- Initial Operational Capability (IOC) - estimated capacity of 14 Metric Tons of cargo each day.
- Full Operational capability (FOC) - estimated capacity of 79 Metric Tons of cargo per day for a mature Space Elevator with human passengers as well as cargo.
- Galactic Harbour (GH) - Transportation Infrastructure with robust enterprises along the 100,000 km with dual Space Elevators.

When one emulates the growth of historic transportation infrastructures around the world, a parallel pattern comes into focus:

- First a single Space Elevator
- Next the back-up Space Elevator becomes a robust partner
- Creation of a Galactic Harbour around the first two Space Elevators
- Next comes a second Galactic Harbour with one and then another Space Elevator.
- Followed by a third pair of Space Elevators inside another Galactic Harbour
- As engineering knowledge improves for tether materials and climber structures, throughput increases significantly towards an FOC capability.
- This transition of IOC to FOC throughput grows the transportation infrastructures towards very robust support for interplanetary missions.

When one looks at this century's maturation of the Space Elevator, there are many studies that have laid out the estimated carrying capacity of both the initial and

[3] 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

more mature Galactic Harbours. Some of the specific studies and papers that establish the projection of carrying capability are:

Table 1, Projection of Capacity and Schedule

Year	Sponsor	Study Title	Through-put MTs and Start Date
2020	ISEC	Space Elevators: the Green Road to Space	14 in 2036 (IOC) & 79 in 2050 (FOC)
2020	ISEC	Space Elevator: the transportation story of the 21st century	14 in 2036 (IOC) & 79 in 2050 (FOC)
2019	ISEC	Today's Space Elevator	14 in 2036 (IOC)
2019	IAA	Road to Space Elevator Era	14 in 2036 (IOC) & 79 in 2050 (FOC)
2014	IAA	Space Elevators: An Assessment of the Technological Feasibility and the Way Forward	14 in 2036 (IOC)
2013	Obayashi	The Space Elevator Construction Concept	79 in 2050 (FOC)

IAA - International Academy of Astronautics, ISEC - International Space Elevator Consortium, Obayashi - The Obayashi Corporation

Taking that flow of development, one would have something similar to the following:

- Operations Date (IOCs)
  - 2037 - First IOC operational tether
  - 2038 - Second tether becoming a first Galactic Harbour
  - 2040 - Second Galactic Harbour
  - 2041 - Third Galactic Harbour
- Operations Dates (FOCs)
  - 2047 - First Galactic Harbour with one FOC Space Elevator and one IOC Space Elevator
  - 2048 - First Galactic Harbour with two FOC Space Elevators
  - 2050 - Second Galactic Harbour with two FOC Space Elevators
  - 2051 - Third Galactic Harbour with two FOC Space Elevators

In addition to the definition of terms (SE, GH, IOC, FOC), the estimated schedule has been projected. This was first shown in the ISEC 2019 Study Report (Today's Space Elevator). This schedule estimates the growth of capability and schedule as described in the last series of discussions. This projected schedule shows major steps in the development of this new transportation infrastructure called Galactic Harbours.

Table 2, Space Elevator Possible Schedule[4]

Event Occurring between two dates	***Early***	***Estimated***
Material for Tether shows required Characteristics	2019	2021
Material developed for Space Elevator Tether	2023	2029
Major Segments Validation Testing	2024	2030
Integrated Orbital Testing (Low Earth Orbit)	2031	2032
Launch of Deployment Satellite	2032	2034
Deployment of Space Elevator	2033	2036
Buildup of Space Elevator to Initial Operations Capability	2037	2040
Initial Operations	2037	2040
Second Space Elevator operational	2038	2041
Galactic Harbour Operational (IOC capacity)	2037	2040
Second Galactic Harbour Operations (IOC capacity)	2039	2042
Third Galactic Harbour Operations (IOC capacity)	2040	2043
First Galactic Harbour with Full Operations Capability (with People)	2047	2057
Second Galactic Harbour with Full Operations Capability (with People)	2048	2057
Third Galactic Harbour with Full Operations Capability (with People)	2049	2057

3 Throughput of Space Elevators:

After this recognition of previously established carrying capacity and operational dates, capability grows within the Global space access transportation Infrastructure as shown by the next chart. This development from a single IOC Space Elevator to three Galactic Harbours with the full capability estimated to handle humans and cargo illustrates the remarkable revolution in lift-off capability to support interplanetary missions to multiple destinations. The increase in capability over time is shown in the next chart.

[4] Swan, Peter, Michael Fitzgerald, "Today's Space Elevator," ISEC Study Report, lulu.com, 2019.

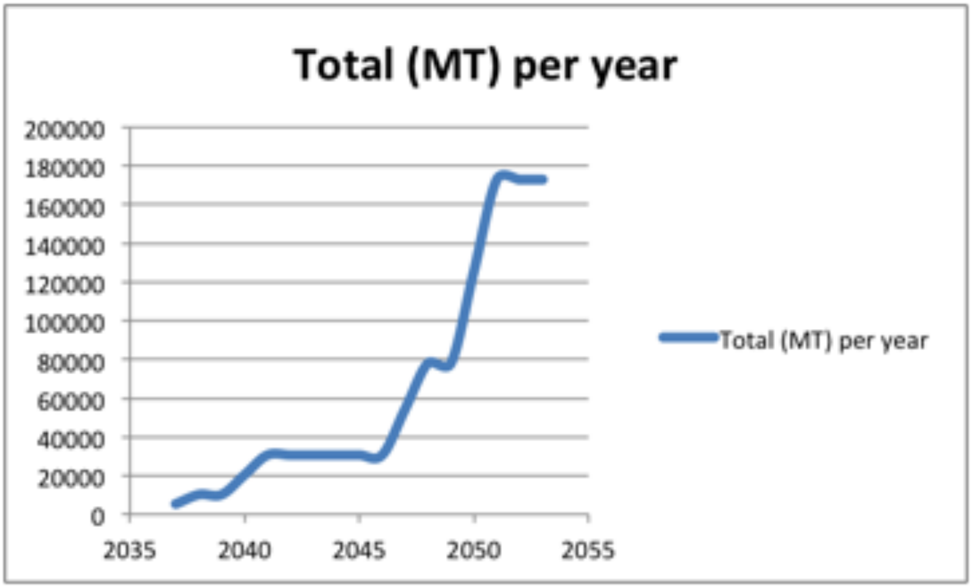

Figure 2, Galactic Harbour Throughput

When one looks at the table that created the previous chart, it looks like this:

Table 3 Total Throughput by Year

Year	# IOC SEs	# FOC SEs	# GHs	MT per IOC	MT per FOC	Total (MT) per day	Total (MT) per year
2036	0	0	0				
2037	1	0	1	14		14	5110
2038	2	0	1	14		28	10220
2039	2	0	1	14		28	10220
2040	4	0	2	14		56	20440
2041	6	0	3	14		84	30660
2042	6	0	3	14		84	30660
2043	6	0	3	14		84	30660
2044	6	0	3	14		84	30660
2045	6	0	3	14		84	30660
2046	6	0	3	14		84	30660
2047	5	1	3	14	79	149	54385
2048	4	2	3	14	79	214	78110
2049	4	2	3	14	79	214	78110
2050	2	4	3	14	79	344	125560
2051	0	6	3		79	474	173010
2052	0	6	3		79	474	173010
2053	0	6	3		79	474	173010

The growth is amazing when one thinks of the limited capability of current rockets (one year's launch capability is less than 1,000 MTs) with the first year of a single Space Elevator operations giving 5110 MT/year to GEO and beyond. This rapidly grows to six times that for three Galactic Harbours each with two IOC Space Elevators (30,660 MT/year). However, when one grows to an FOC capability in each Space Elevator for three Galactic Harbours, the numbers are remarkable and mission enabling (173,010 MT/year).

5 Conclusions:

This throughput explanation showed that the potential movement of mass off-planet by Galactic Harbours will enable the achievement of major missions hindered by the limited delivery statistics capabilities of the past. This Space Elevator permanent transportation infrastructure will satisfy customer needs while being compatible and complementary to the growing rocket portals. Each will have strengths to support various customers; however, the movement of cargo for complex and massive undertakings is a natural strength of the Galactic Harbours. This will have complementary transportation portals and infrastructures can ensure success in the different missions and destinations desired by future movement off-planet.

Leveraging a previous chart the delivery times for the three Reference Missions are shown. This tends to put the whole picture into focus. The demands are huge for these critical reference missions and their destinations. FOC Galactic Harbours are needed as soon as possible to support humanity's dreams.

Table 4, Galactic Harbour Fulfillment of Reference Missions

Reference Mission	***Metric Tons to Destination***	***Galactic Harbour IOC Fulfillment Time (yrs)***	***Galactic Harbour FOC Fulfillment Time (yrs)***
Space Solar Power	5,000,000	150	29
Mars Colony	1,000,000	33	6
Moon Village	500,000 estimated	17	3

Leverage Dual Space Access Architecture - Advanced Rockets and Space Elevators

During this multi-author 24-month long study, Space Elevator concepts grew towards cooperation with advance rockets. The strategy for the future is simple: leverage the strengths of both rockets and Space Elevators in a complementary approach. Here are some insights that became apparent during this ISEC Study

Why Space Elevators?
Unmatched Efficiency of delivery to the customer provided by a permanent space transportation infrastructure. Space Elevators deliver 70% of the mass at the Earth Port to GEO, the Moon and on to Mars, while rockets deliver only 2% of their pad mass to GEO.

Modern-Day Space Elevators will be transformational as a permanent space access infrastructure, called the Green Road to Space, inside a Dual Space Access Strategy.

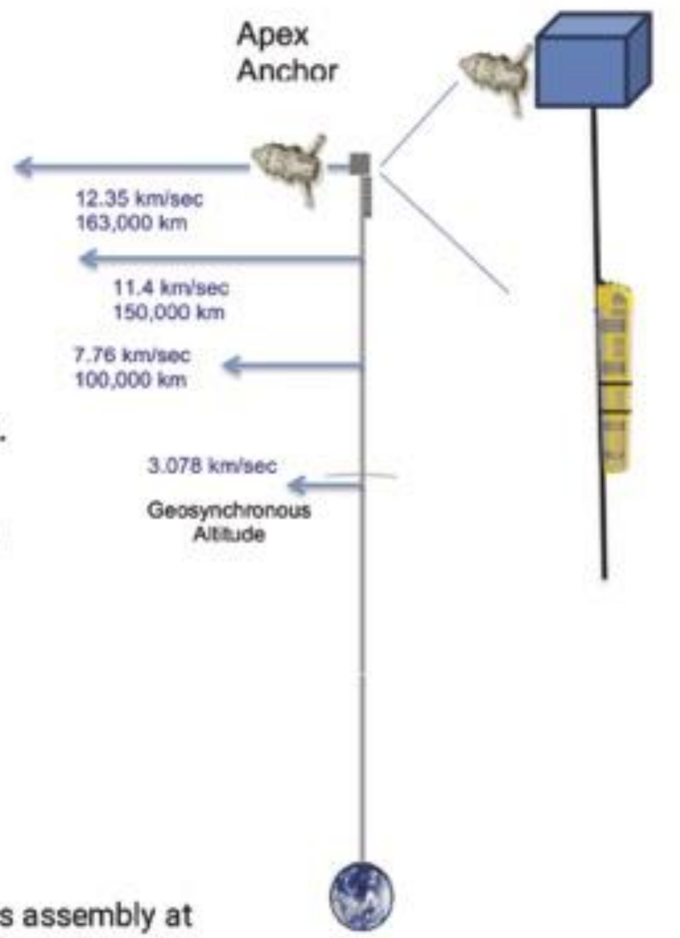

Image shows assembly at the Apex Anchor, above the gravity well, then release at extreme velocities.

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