Keynote: Jerome Pearson Memorial Lecture - Space Elevators as a Transformational Leap for Human Movement Off-Planet

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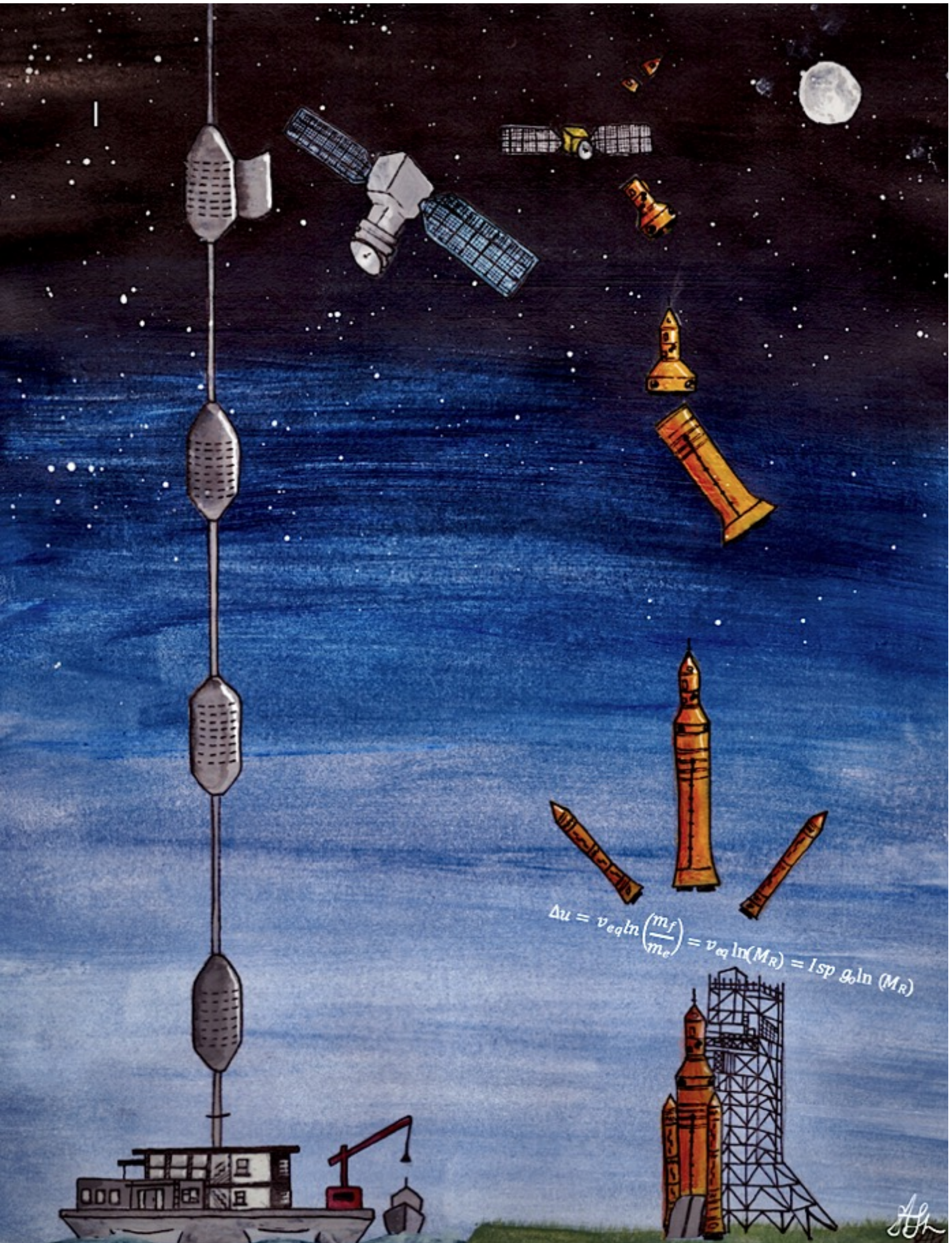

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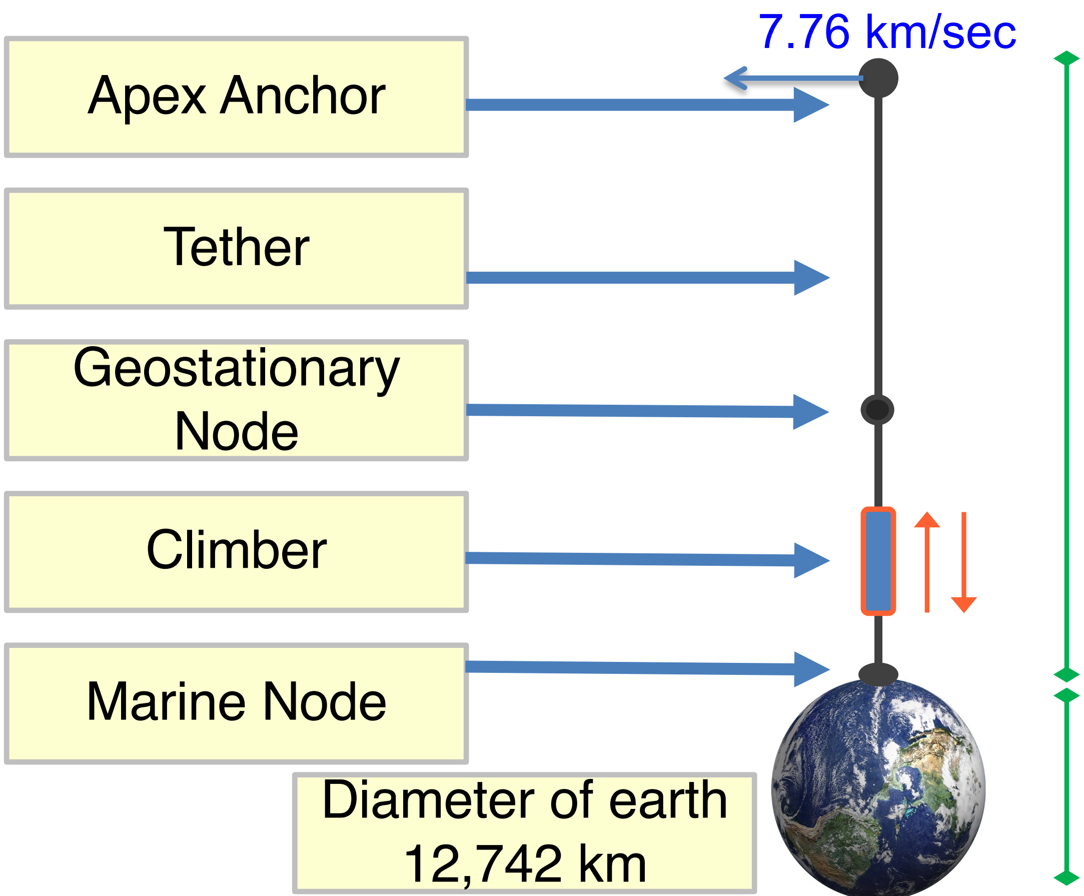
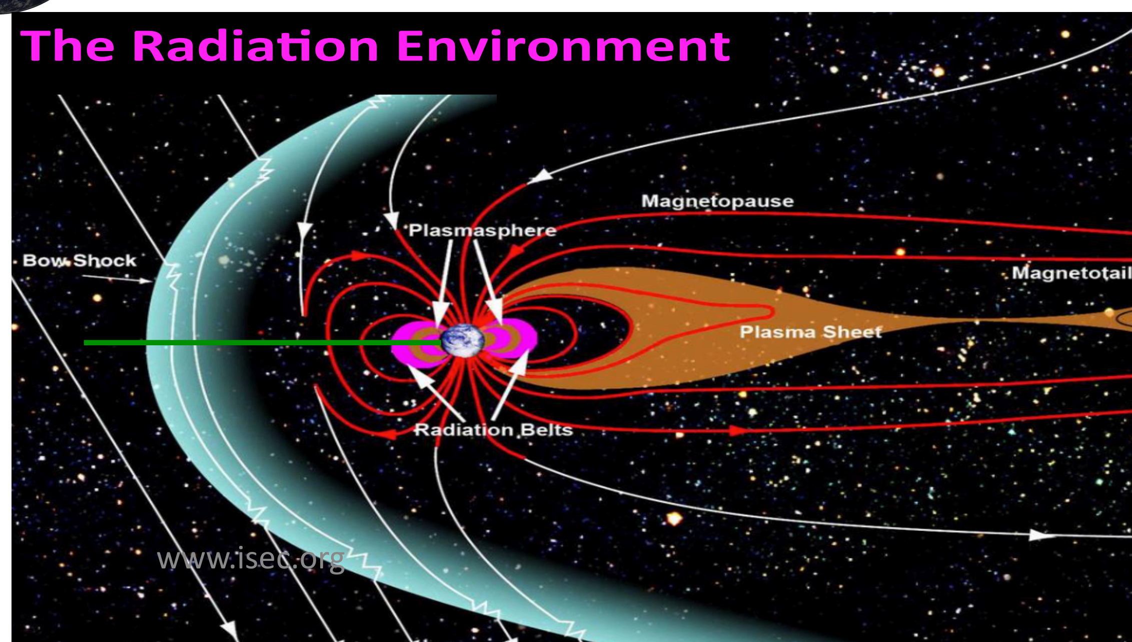
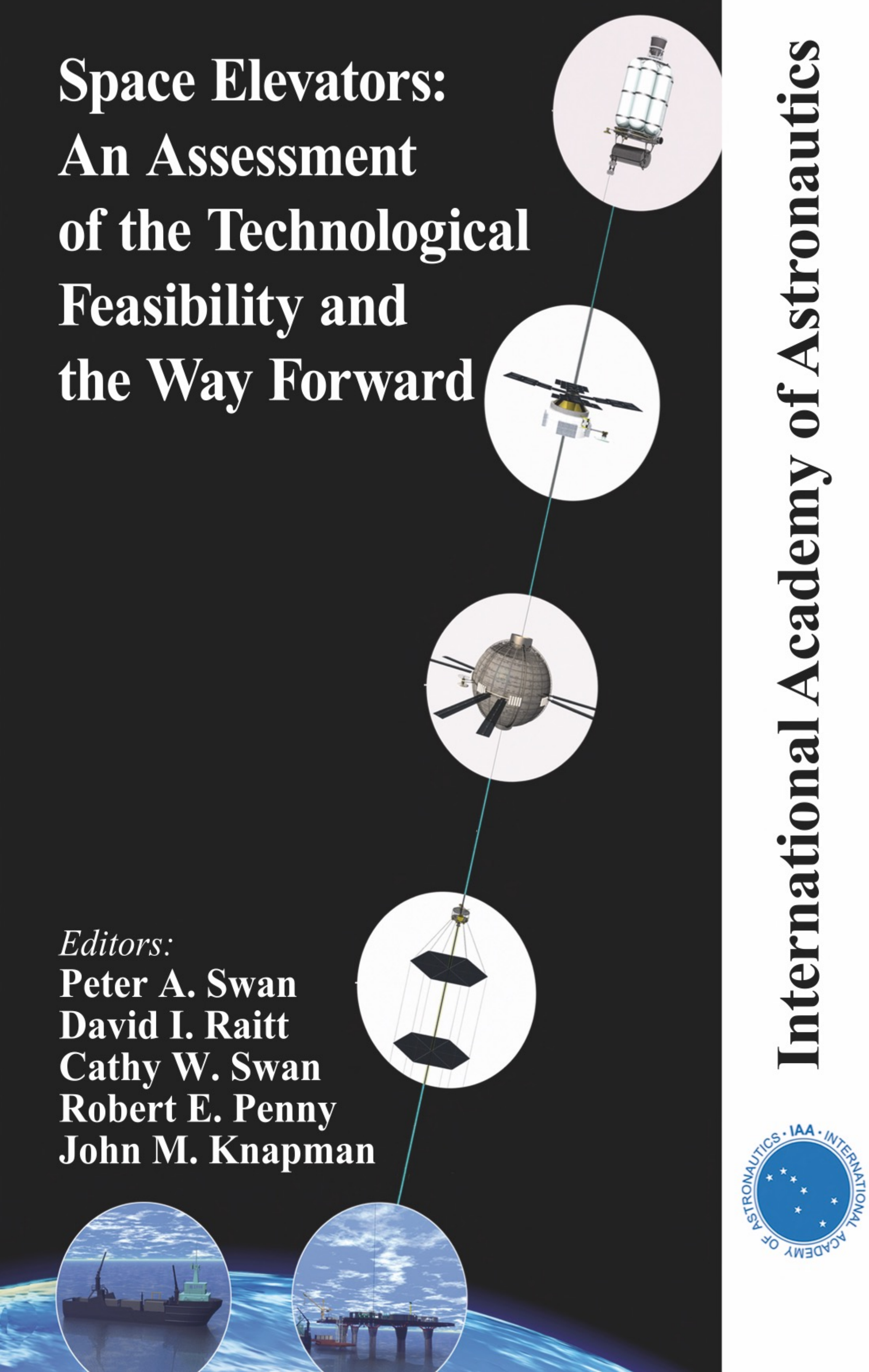
The Space Elevator







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- IAA four year study
- 45 space experts
- Started at Edwards' architecture
- 350 page major study report
- Conclusion:

  The Space Elevator Seems Feasible

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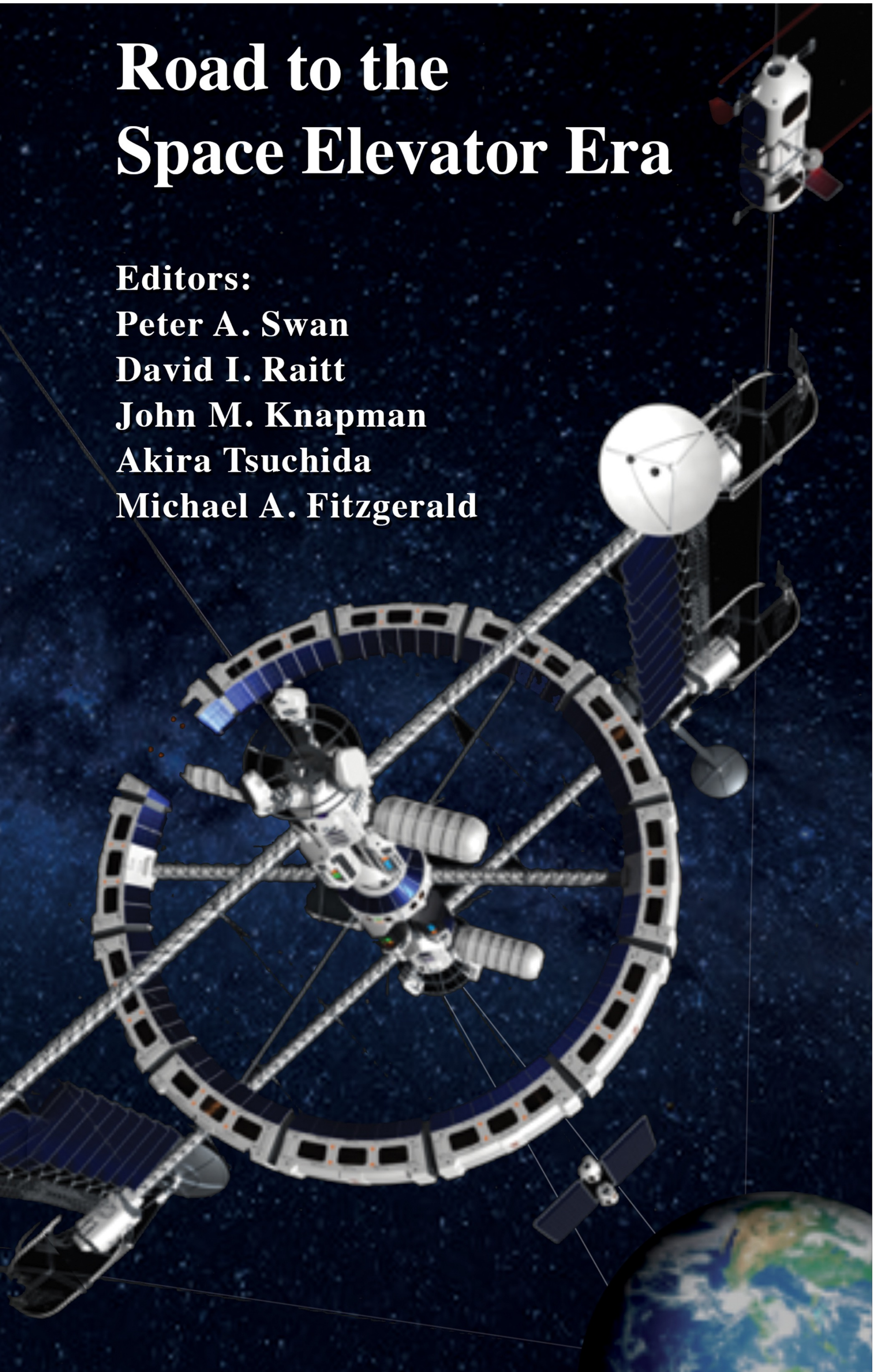

International Academy of Astronautics

- IAA four year study
- 30 + space experts
- Parallel with ISEC
- 200 page major study report
- Conclusion:

Technologies are beyond Preliminary Readiness Assessment

IAA · INTERNATIONAL ACADEMY OF ASTRONAUTICS

ISEC Studies

2022	Dual Space Access Architecture – just starting
2021	Design Considerations for the Space Elevator Climber-Tether Interface - in progress
2021	Space Elevators are the Green Road to Space
2020	Space Elevators are the Transportation Story of the 21st Century
2020	Today's Space Elevator Assured Survivability Approach for 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 a Space Elevator Earth Port
2014	Space Elevator Architectures and Roadmaps
2013	Design Considerations for a Space Elevator Tether Climber
2012	Space Elevator Concept of Operations
2010	Space Elevator Survivability, Space Debris Mitigation

Completed studies on www.isec.org in pdf format are free

	Other Study Reports
2019	The Road to the Space Elevator Era - IAA IAA = International Academy of Astronautics (https://iaaspace.org)
2014	Space Elevators: An Assessment of the Technological Feasibility and the Way Forward - IAA
2014	The Space Elevator Construction Concept – Obayashi Corporation (https://www.obayashi.co.jp/en/news/detail/the_space_elevator_construction_concept.html)

Transformational Leap

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

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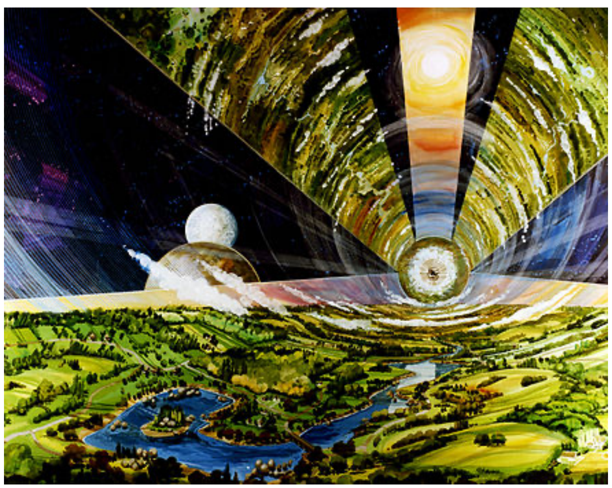
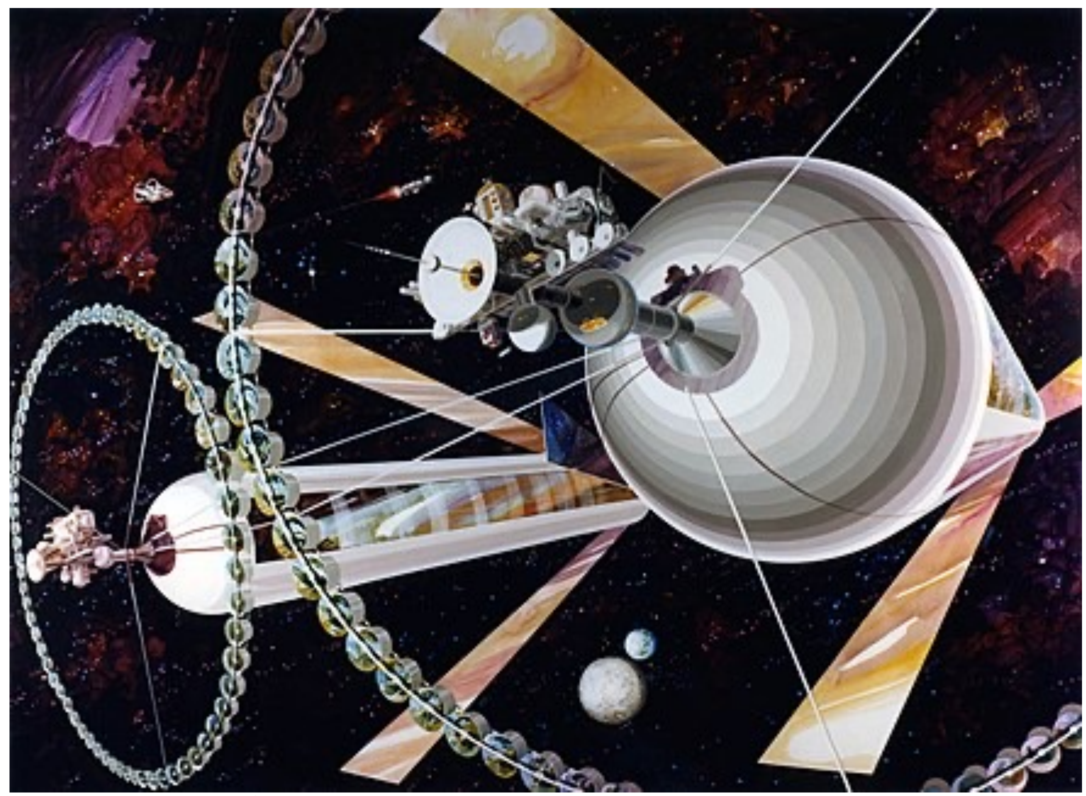
- *Dreamers*
- Space Elevator Vision
- Transformational Characteristics
- Dual Space Access Future
- Summary

NSS Vision

- NSS 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.”





But, who asks how much mass
Is required at the altitude of the Moon?

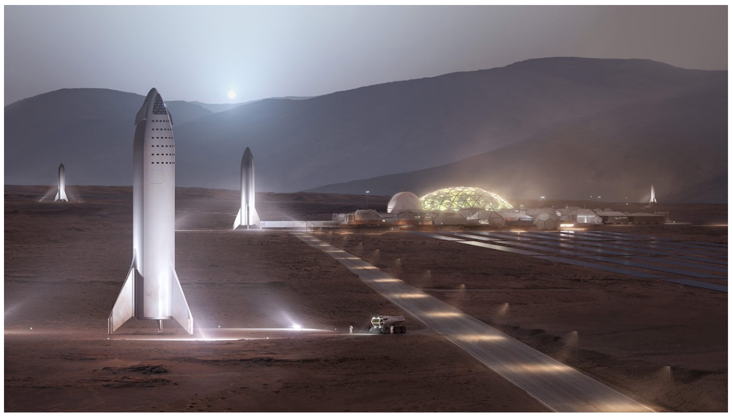
How about 10,500,000 tonnes?

Living and working in thriving communities beyond Earth – NSS

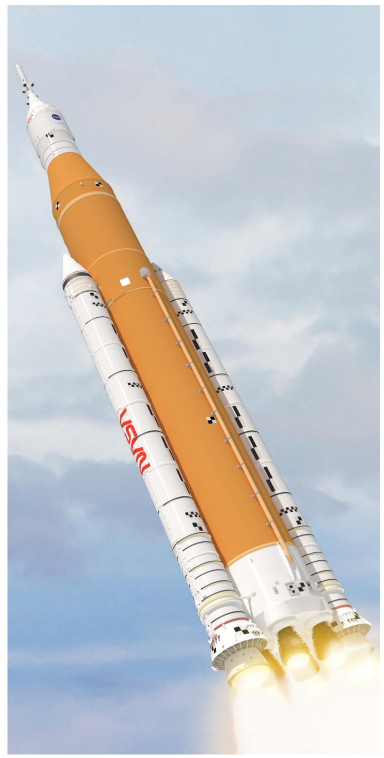
Dream Big!

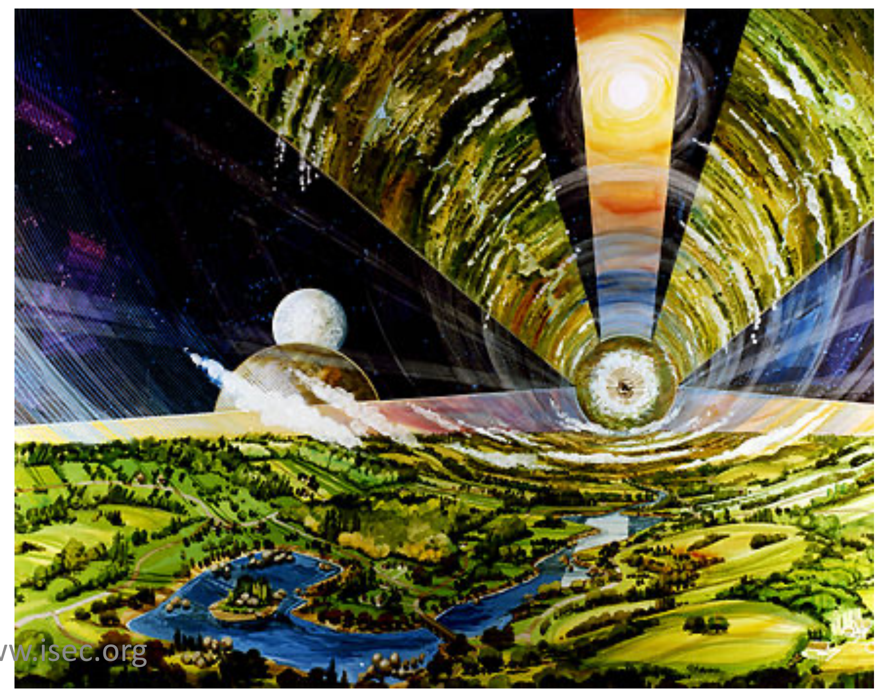
But How much mass to Orbit?

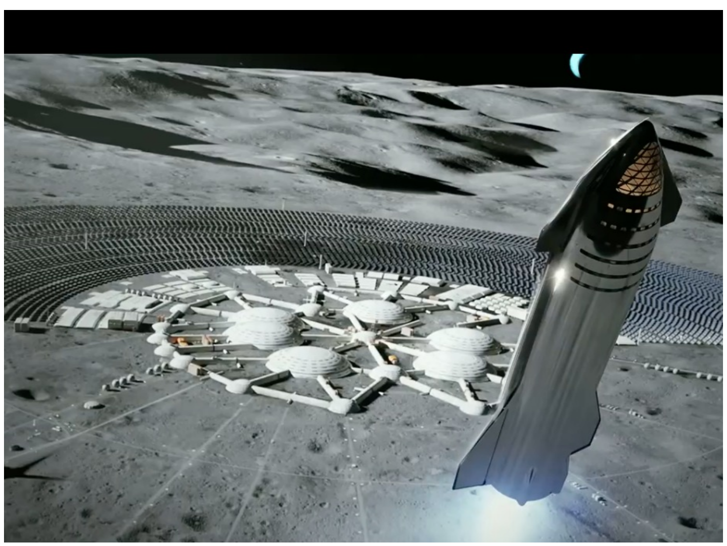
Image from Blue Origin website



Images from SpaceX website
1,000,000 tonnes to Mars surface







Images by NASA
and Rick Guidice

Images from SpaceX
500,000 tonnes to
Lunar surface
(Swan estimate)

Reference Missions:

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- Sun-Eath L-1 SunShade – 20,000,000 tonnes well beyond GEO

- Space Solar Power – 5,000,000 tonnes to GEO for 12% of Global Electrical need***
- Moon Village – 500,000 MT* - European “togetherness” towards a Moon Village suggests a massive support effort required.
- SpaceX Colony – 1,000,000 MT** – Mr. Musk has stated that he needs that amount of mission support on Mars.
- L-5 O’Neill Colony – 10,500,000 tonnes

* Estimate in Study Report “Space Elevators are the Transportation Story of the 21st Century

** Elon Musk, 21 July 2019, CBS Sunday Morning Interview

***Mankins, John, conversation with P. Swan

Transformational Leap

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
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- Dreamers
- *<u>Space Elevator Vision</u>*
- Transformational Characteristics
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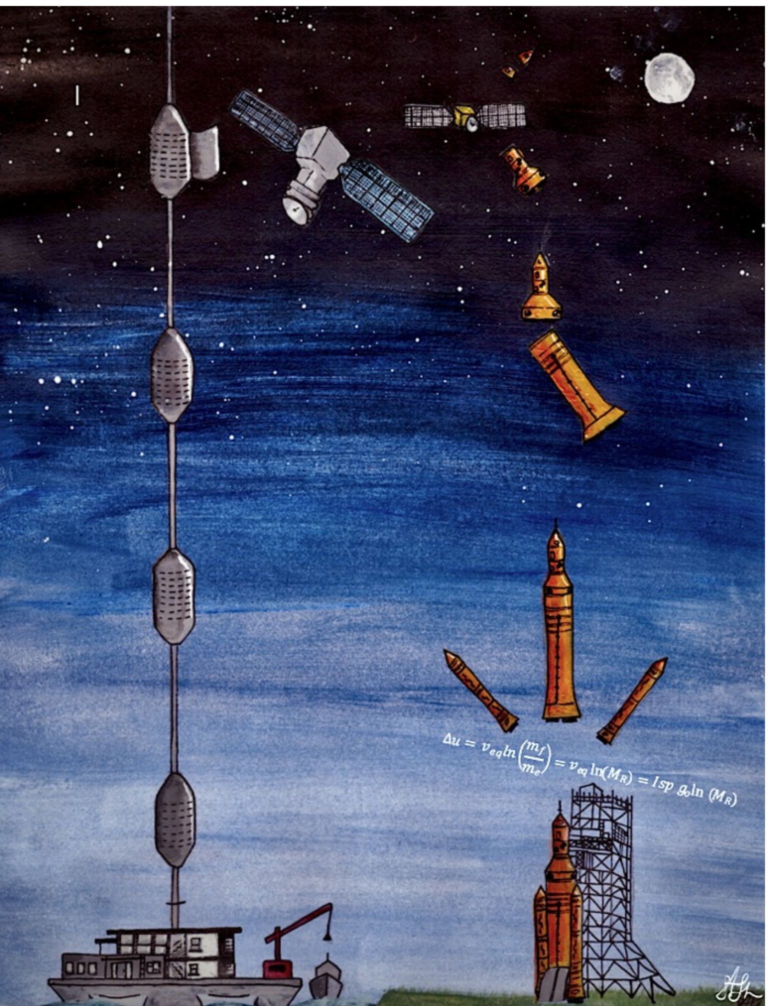
- Summary

Space Elevator Vision 2038 Timeline

New 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.*

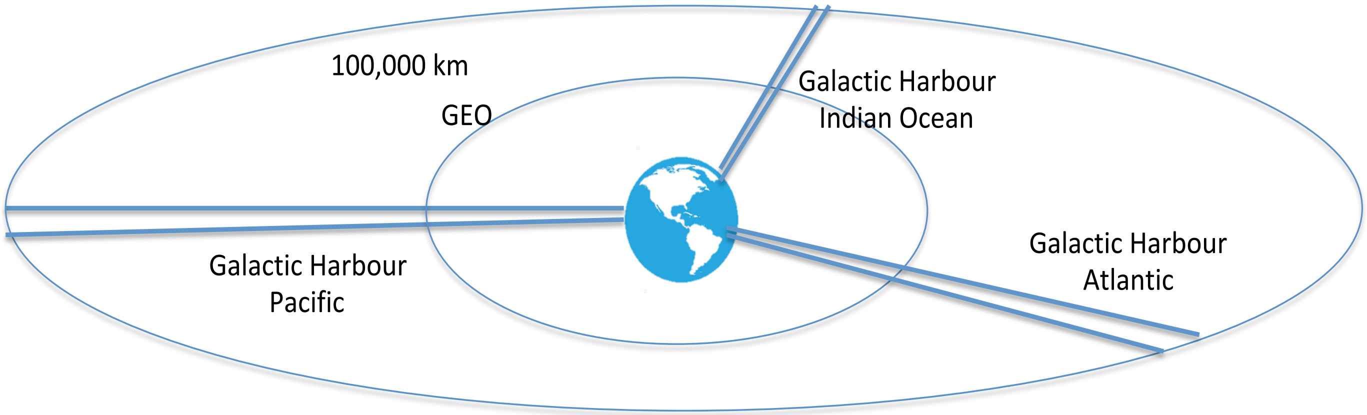


Approach: A permanent Dual Space Access Architecture relies on Space Elevator traditional strengths such as inexpensive, safe, daily, routine, with special characteristic of Earth friendly, and its ability to avoid the rocket equation. The rockets are complementary and cooperative to Space Elevators.

Rocket Strengths: (1) Operational today with future growth, (2) rockets reach multiple orbits, and (3) rapid movement through the radiation belts

Space Elevator Strengths: As permanent infrastructure they lead to daily, routine, environmentally friendly, and inexpensive departures towards mission destinations

Vision of Galactic Harbours – A Green Road to Space



Permanent Transportation Infrastructure lifting Massive tonnage by electricity to GEO and beyond, daily, routinely, inexpensively, and safely

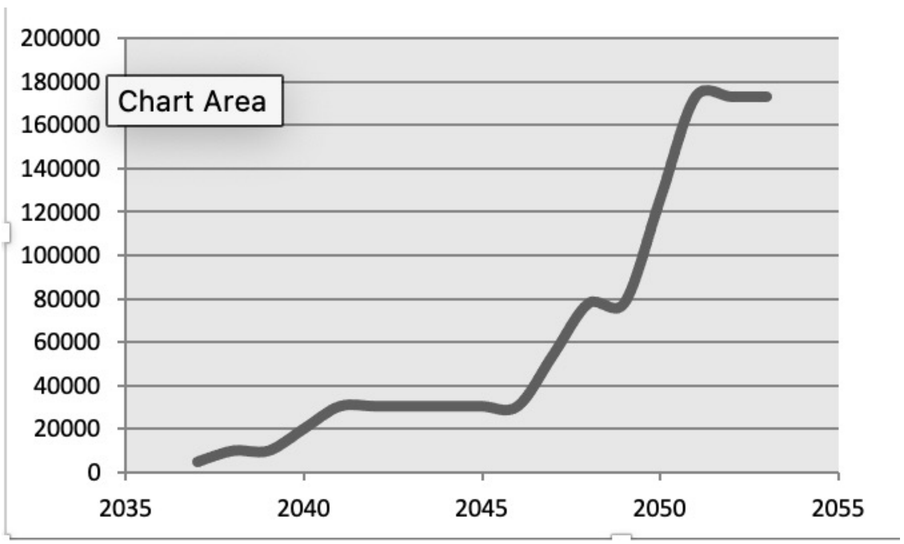
Three Galactic Harbours

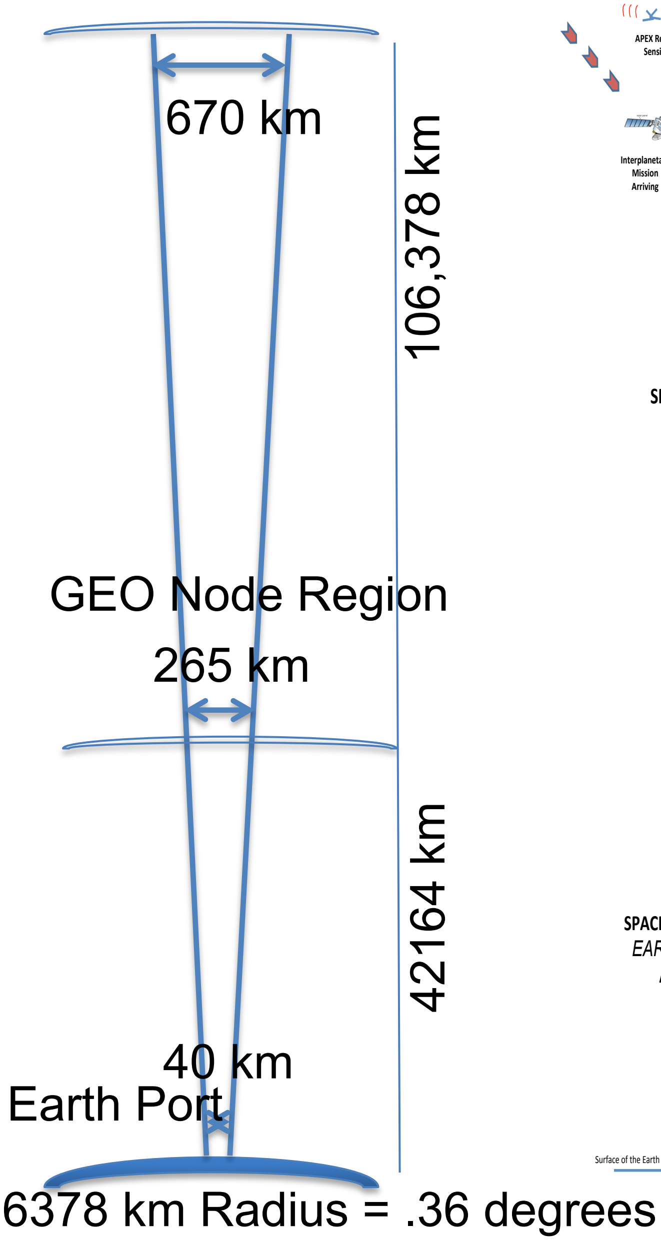
– 7 climbers a week/elevator

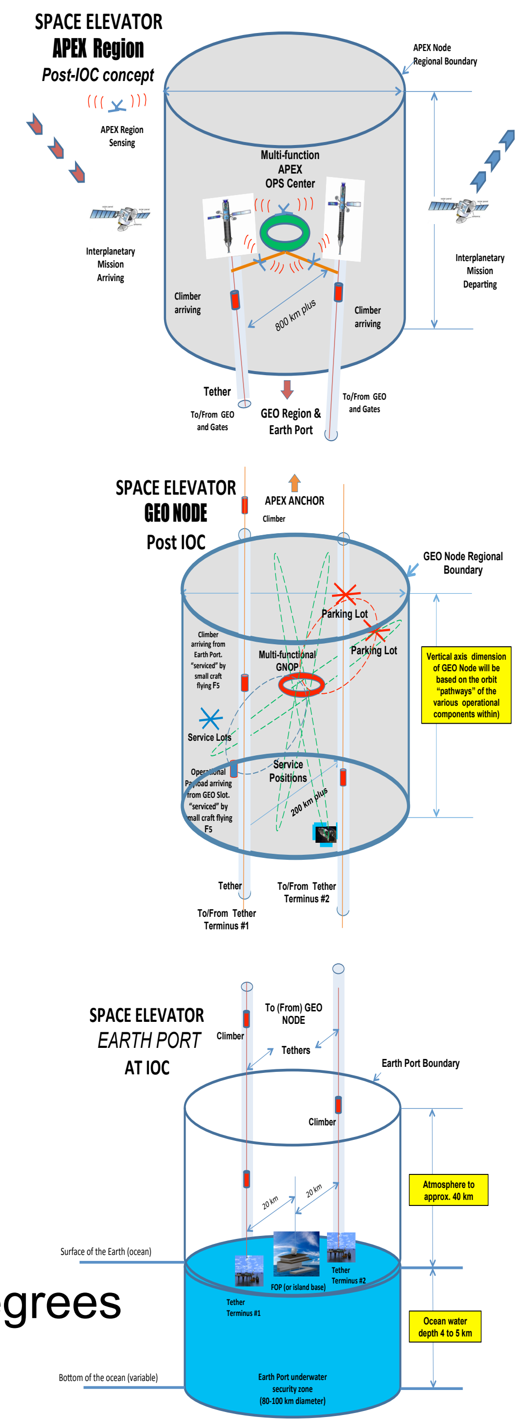
– 14 tonnes payload each, x2 x3
or 30,000 tonnes/yr

– expanding to 80 tonnes payload
each, or 170,000 tonnes/yr

Annual payload (tonnes/yr)







- Galactic Harbour includes two Space Elevators radially extending from Ocean surface to Apex Anchor for a permanent space access infrastructure.
- One reusable tether climber lift-off per day
- Three Regions, Earth Port – GEO – Apex Anchor, where commercial ventures will grow

Modern Day Space Elevator Transforming Space Access

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What is a Modern Day Space Elevator?

The term “A Modern Day Space Elevator” has evolved from a dream to a scientific engineering reality. The four major thrusts for the present Modern Day Space Elevator are:

- Space Elevators are ready to enter Engineering Development (Phase Two of development)
- Space Elevators are the Green Road to Space
- Space Elevators can join advanced rockets inside a Dual Space Access Architecture
- Space Elevator’s major strength as a permanent transportation infrastructure is movement of massive cargo to GEO and beyond enabling new enterprises along the way.

Art by
A. Stanton

Transformational Leap

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- Dreamers
- Space Elevator Vision
- *Transformational Characteristics*
- Dual Space Access Future
- Summary

Transformational Characteristics

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, and with little environmental impact. Permanent transportation infrastructures called space elevators will enable missions by leveraging their strengths:

- Daily, routinely, safely, inexpensively
- Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments.
- Massive movement (30,000 tonnes/yr vs. approx.. rockets' 26,000 tonnes over 65 years)
- Green Road to Space ensures environmentally neutral operations
- High velocity (starting at 7.76 km/sec at 100,000 altitude enables rapid transits)
- Reduction of the need for Rocket Fairing Design limitations
- Assembly at the Top of the Gravity Well

Annual payload (tonnes/yr)

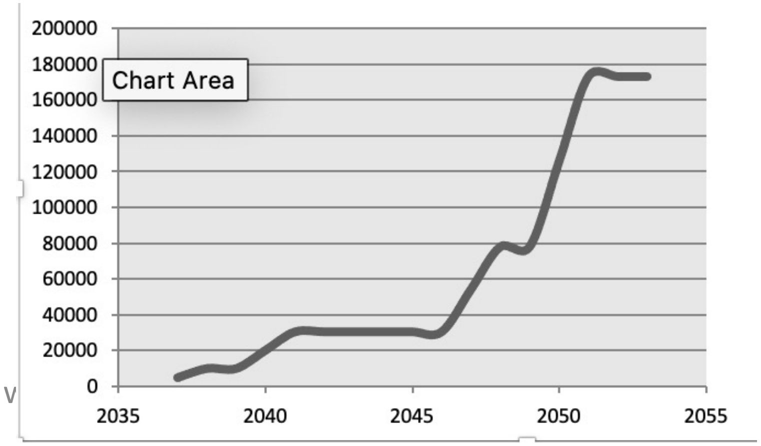
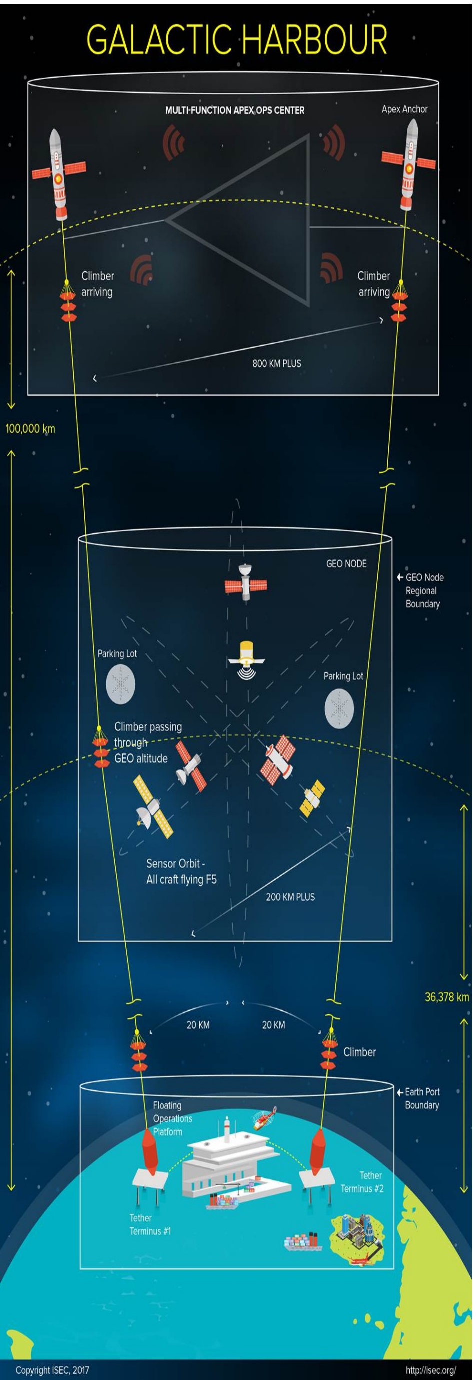


Figure 88. Massive Cargo Movement by Space Elevators (Swan "Dual Space Access Strategy Minimizes the Rocket Equation," Space Renaissance International 3rd World Congress 2021 – Congress Theses, Final Resolution and Papers. Pg 254-255.)

Strength One: *Daily, routinely, safely, and inexpensively*:



- Permanent access to GEO & Beyond - daily!
- "on-time delivery" a routine strength of space elevators' logistics
- To Mars - any day – an outcome from the Arizona State University & ISEC 2021 study.
- Lowest cost in the industry – think bridge across a river vs. one time events (boats)
- A Bus Schedule (next chart)

Bus Schedule for Interplantary Transportation
when departing from Galactic Harbour Apex Anchor

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/1/2035	Indian #1	Mars	87 days	9/26/2035	
7/1/2035	Pacific #1	Mars	86 days	9/25/2035	
7/1/2035	Pacific #2	Mars	84 days	9/22/2035	Fast

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/8/2035	Indian #1	Mars	81 days	4/14/2035	
7/8/2035	Indian #2	Mars	81 days	4/14/2035	
7/8/2035	Indian #1	Mars	80 days	4/13/2035	Fast

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Pacific #1	Mars	78 days	9/30/2035	Fast
7/15/2035	Atlantic #1	Mars	190 days	1/21/2036	
7/15/2035	Atlantic #1	Mars	182 days	1/13/2036	
7/15/2035	Atlantic #2	Mars	173 days	1/4/2036	
7/15/2035	Atlantic #2	Mars	164 days	12/25/2035	
7/15/2035	Atlantic #1	Mars	154 days	12/15/2035	

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #1	Mars	223 days	3/1/2036	

Bus Schedule, from Apex Anchor 2035 to Moon

Date	Departure	Destination	Flight Time	Arrival	Comments
every day	Indian #1	Moon	14 hours	+ 14 hours	
every day	Indian #2	Moon	14 hours	+ 14 hours	
every day	Pacific #1	Moon	14 hours	+ 14 hours	Fast
every day	Pacific #2	Moon	14 hours	+ 14 hours	
every day	Atlantic #1	Moon	14 hours	+ 14 hours	
every day	Atlantic #2	Moon	14 hours	+ 14 hours	

Bus Schedule to Mars*

*from study by ASU & ISEC – "Space Elevators are the Transportation Story of the 21st Century"

SETS Strength Two: *Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments:*

- “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.”*
- We must move … “the discussion from $/kg (which they call the language of rockets) to future key elements of economics and exchange of resources.”*

*Barry, K., Eduardo Pineda Alfaro, “Changing the Economic Paradigm for Building a Space Elevator,” Acta Astronautica, to be published in 2022.

Characteristics of Permanent Transportation Infrastructure

- Revolutionarily inexpensive to GEO [$100/kg to GEO]
- Commercial development similar to bridge building
- Routine [daily launches]
- Safe [no chemical explosions from propulsion]
- Permanent infrastructure 24/7/365/50 yrs. [bridge similarities]
- Massive loads with daily launches per elevator (30,000 tonnes per year to GEO & beyond (early operations))
- No shake-rattle-roll during launch
- "Big Green Machine" Little impact on global environment
- No consumption of fossil fuel.
- Does not leave space debris in orbit

Beats the Gravity Well in an environmentally friendly manner

SETS Strength Three: *Massive movement (30,000 tonnes/yr vs. approximately. 26,000 tonnes over 65 years by rockets)*

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

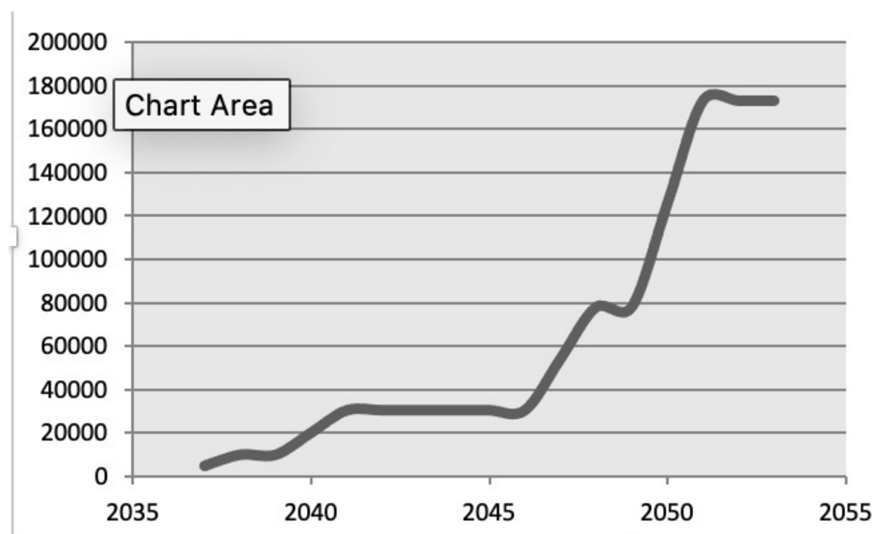
Note: Leo is 4% of launch pad mass
GEO, Interplanetary, Lunar 2% of pad
*Shuttle launch vehicle reached orbit as an operational satellite

Historic Movement
(1957 – 2020)

22,216 tonnes between 1957 and 2020.

Space Elevator expected
movement of mass
Initial Operations Capability (30,000 tonnes/yr)
Full Operations Capability (170,000 tonnes/yr)

Annual payload (tonnes/yr)



SETS Strength Four: *This Green Road to Space ensures environmentally neutral operations*

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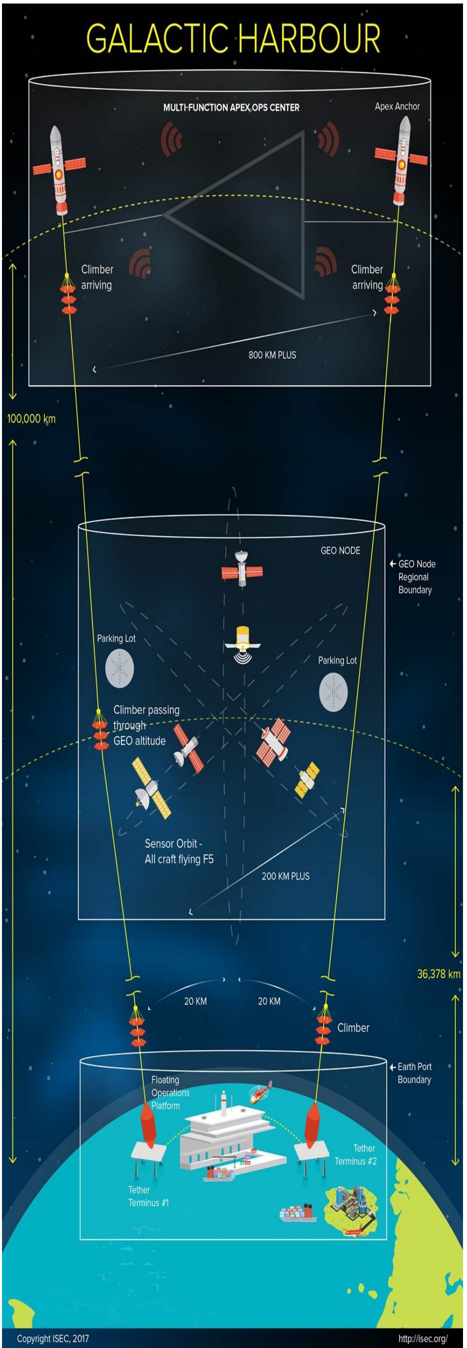
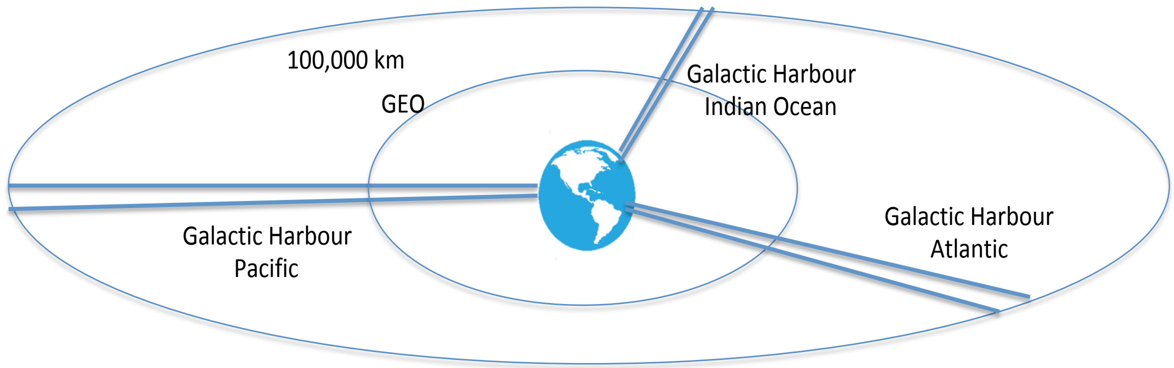


A Green Road to Space



Massive tonnage* raised by electricity to GEO and beyond, daily, routinely, inexpensively, safely, and in an Earth Friendly manner.

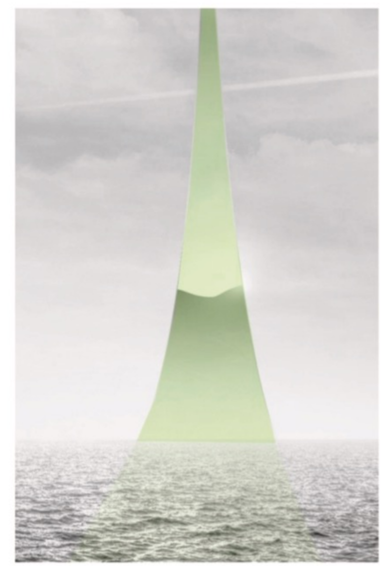
Space Elevators Beat the Rocket Equation
We Enable Dreams

*(30,000 tonnes/yr vs. approx.. rockets' 26,000 tonnes over 65 years)

Space Elevators are the Green Road to Space

- 18-month study at www.isec.org (pdf free)
  - Electricity from the Sun's energy raises cargo from the ocean's surface to GEO
  - Massive cargo delivered to GEO and beyond enables Earth-friendly missions such as Space Solar Power
- A robust permanent transportation infrastructure
  - Moving more cargo in a year (25,000 tonnes) to GEO and beyond (at Initial Operational Capability) than humanity has placed in orbit since 1957 (22,000 tonnes)
- Enables Space Solar Power requires -- To supply 12% of the global electrical demand in 2060 while stopping global warming

Space Elevators:
The Green Road to Space



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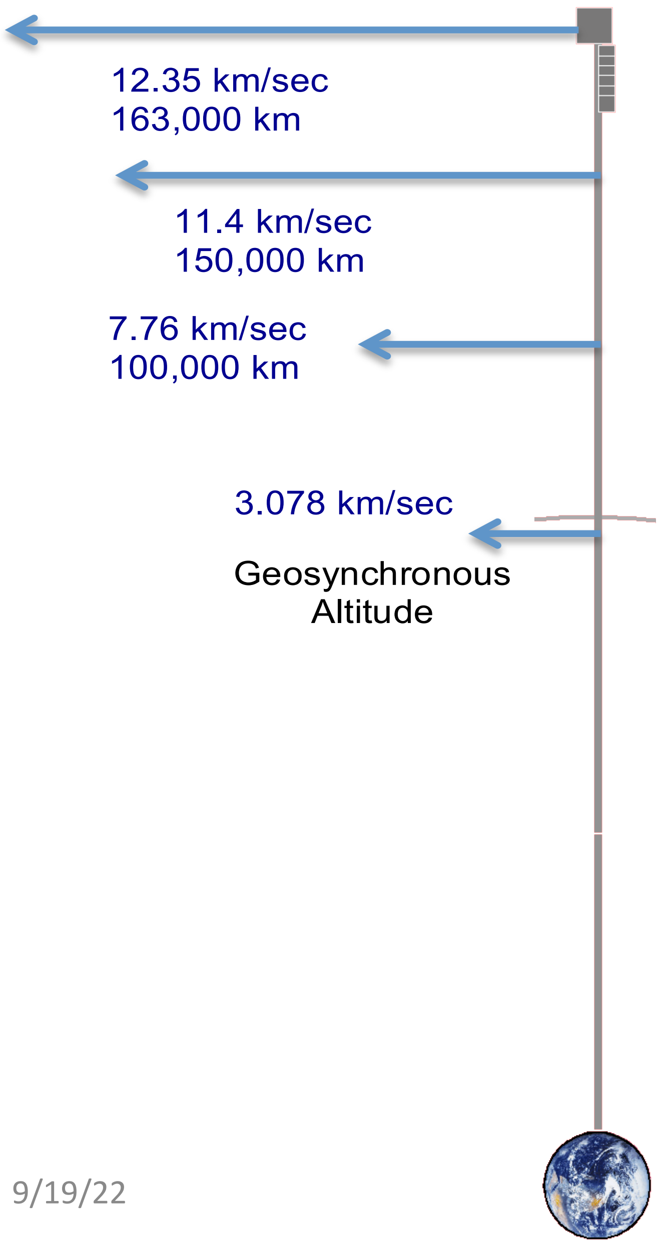
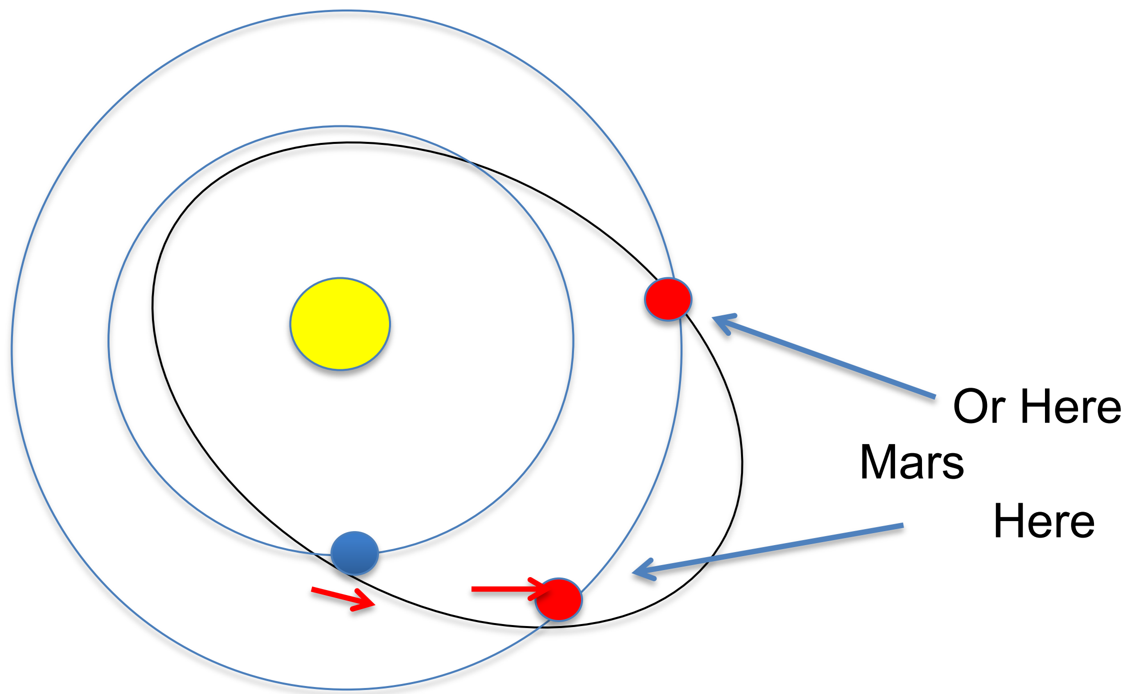
A Primer for Progress in Space Elevator Development

SETS Strength Five: *High velocity (starting at 7.76 km/sec at 100,000 km altitude) enables rapid transits*



- This new vision of Galactic Harbour architectures will change the "thinking" for off-planet migration – How fast can we go?
- At 100,000 km altitude, there is no significant gravity pull to limit departures
- At 100,000 km altitude, there is tremendous velocity (7.76 km/sec) enabling beyond Mars
- With longer Space Elevators, the whole solar system opens up and even escape from the sun is possible (without thrusting from rocket fuel).

Case One: Fastest Approach



Concept: Our spacecraft enters the ellipse, “not at perigee,” but on the side of the ellipse centered as one foci at the Sun and outer portion matching Earth and Mars locations.

SETS Strength Six: Reduction of the need for Rocket Fairing Design limitations

- Think controlled explosions to initiate rocket flight and then rapid acceleration with atmospheric disturbances as well as abrupt shocks as stage separation occurs thorough out flights. These forces are focused upon the fairing region as the flight continues.
- The fairing of rockets have always restricted the design considerations for spacecraft. The volume is small and constrained, thus forcing compromise in the design of satellites.
- The Space Elevator has large spaces to deposit logistics cargo without draconian design requirements. In addition, the ride is very passive as it accelerates with electric motors and has very few forces during flight.

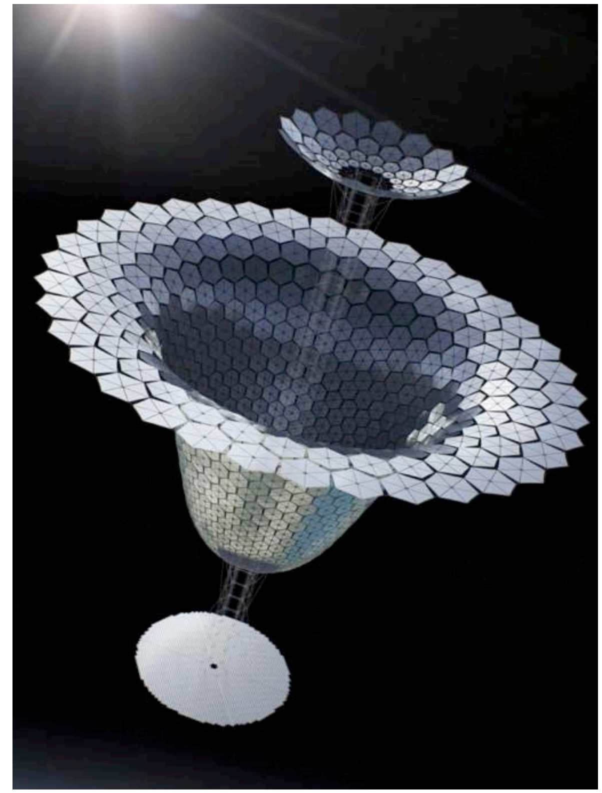
SETS Strength Seven: Assembly at the Top of the Gravity Well

- One of the basic problems with our science missions of the past (and near-term future) is that they had to be built on the ground and then tremendous resources had to be expended to reach our destinations fighting gravity all the way.
- Can you image robotic assembly at 100,000 km altitude after the segments of the payload, spacecraft and rockets have been raised by electrical energy?
- Or at the GEO Region within an assembly/repair/build Facility?
- Assembly at the Apex Anchor results in Gravity has been beaten! This means that the Green Road to Space lifts all the components of huge planetary (Cis-lunar) missions to an robotic facility with a daily schedule for release in a routine, inexpensive and safe operational approach. When the various segments of the mission spacecraft reach the Apex Anchor, they have gained tremendous potential energy (associated with a height of 106,378 km) and kinetic energy (associated with a velocity of 7.76 km/sec) allowing them to race across our solar system after assembly.
- This statement combines the facts that the speeds at release are impressive (7.76 km/sec) and alignment towards any solar system object can be each day. The key here is that additional rocket motors can be raised and assembled to adapt to the inclination differences, additional speeds for gravity assists timing, and rendezvous slowdowns as appropriate at destinations.

An Example of Near Term Needs Requiring Assembly at GEO

- "Space solar power can solve our energy and greenhouse gas emissions problems. Not just help, not just take a step in the right direction, but solve."
- Promise: Eliminate 100's (1,000's?) of Coal Burning Plants by providing 12% of 2060 Earth's population.
- "I need 5,000,000 tonnes."*

Mankins, John, The Case for Space Solar Power, Virginia Edition Publishing Co. Dec 2013.
*Private conversation with Dr. Peter Swan Oct 2019



Each Alpha Mark IIIA is 9,800 tonnes (to GEO) - For output of 2 Gwatt continuous power

Note: several other designs are lighter, but produce less energy.

Transformational Leap

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- Dreamers
- Space Elevator Vision
- Transformational Characteristics
- *Dual Space Access Future*
- Summary

Dual Space Access Architecture

Rockets to Open up the Moon and Mars with Space Elevators to supply and grow the colonies. In addition, Rockets would delivery prototypes and initial operational Space Solar Power Satellites, while Space Elevators would fill out the constellations with the heavy lifting.

Image by Amelia Stanton

Combination of delivery approaches: Will greatly enhance the missions of the future. Maturing customer demand for huge masses to support important missions will make the value of space elevators obvious.

Rocket Strengths: (1) Operational today with future growth, (2) rockets reach multiple orbits, and (3) rapid movement through the radiation belts

Collaboration and Cooperation

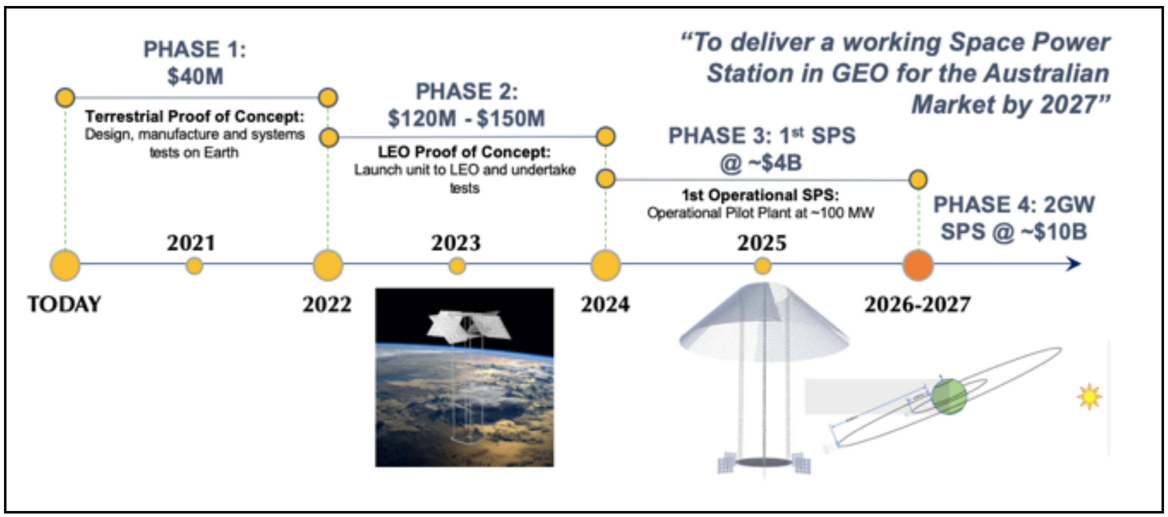
Space Elevator Strengths: As permanent infrastructure they lead to daily, routine, massive, environmentally friendly, and inexpensive departures towards mission destinations

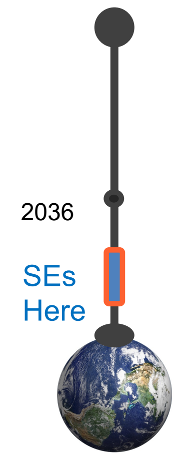
Minimizing the Rocket Equation Limitations

Rockets to initiate SSP's prototypes with Space Elevators to supply and grow the Constellation.

Likely and possible for rockets to deploy the first SPS systems.

- Incredibly useful earth-to-orbit systems for deploying new space technologies, opening up new activities
- Deliver the initial prototypes to LEO for testing and the initial GEO production satellites for operational testing.





Space elevators are needed for high-throughput, massive hardware deployment.

- Consistent, continuous movement of freight to GEO and beyond
- Enable space technology deployment at scale for high impact
- Fills out the constellations by moving massive amounts of cargo

Transformational Leap

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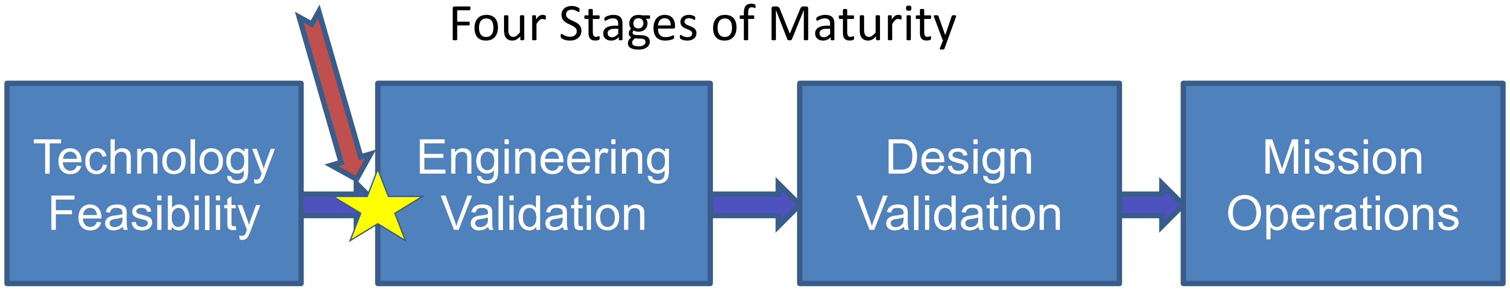
- *<u>Summary</u>*

The Space Elevator has Entered Engineering Validation!

Development starts here
Four Stages of Maturity



1. The ISEC team has been assessing the technology feasibility situation since 2008.
2. Recently the team has begun an open dialog with members of industry, academia, and others who could be the deliverers of developmental solutions.
3. Industry (especially) will show how the needed technologies are being matured and when they could be dependably available.
4. These readiness assessments were the Phase One exit criteria.

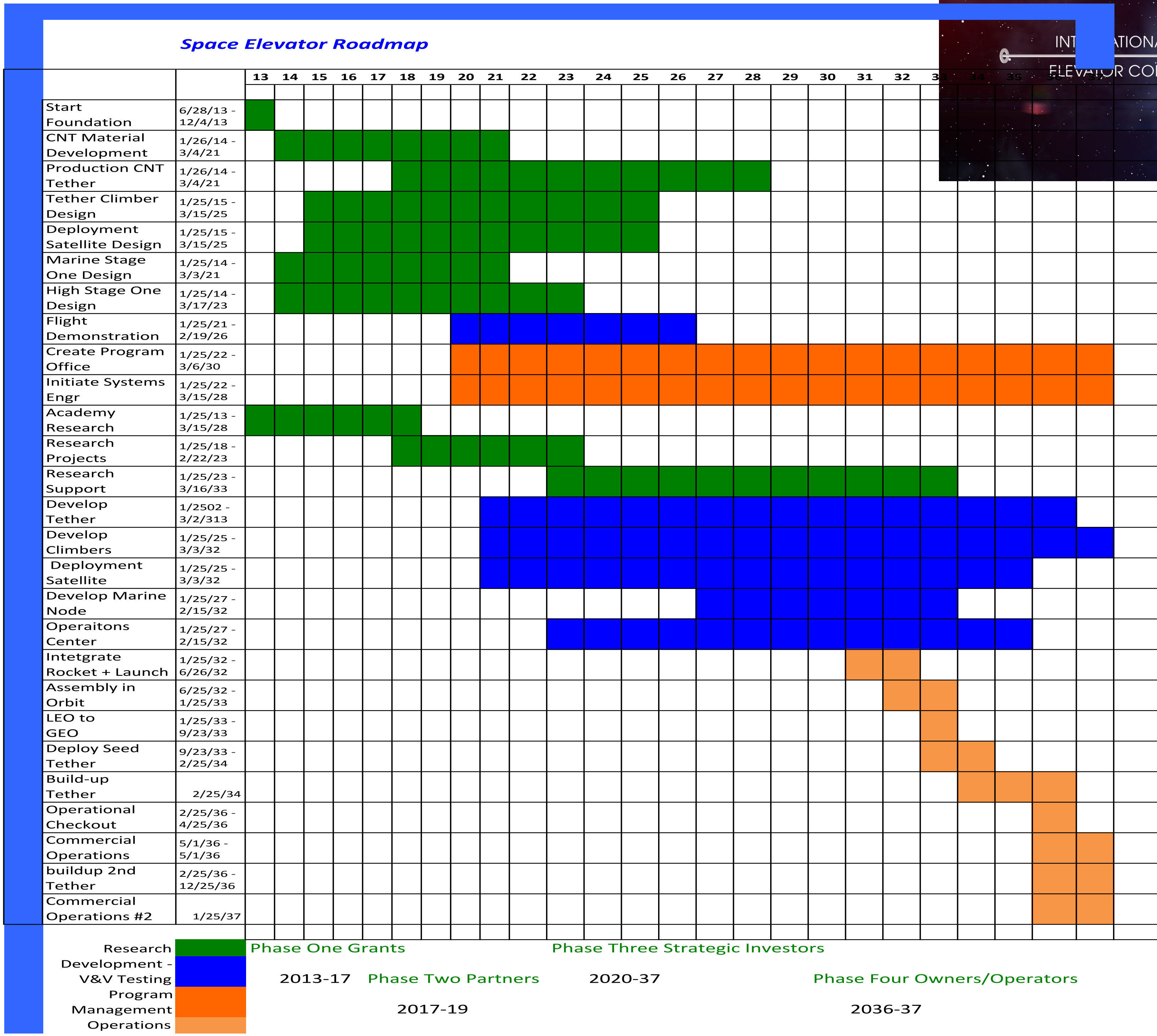


Figure 11- 1. Space Elevator Roadmap A

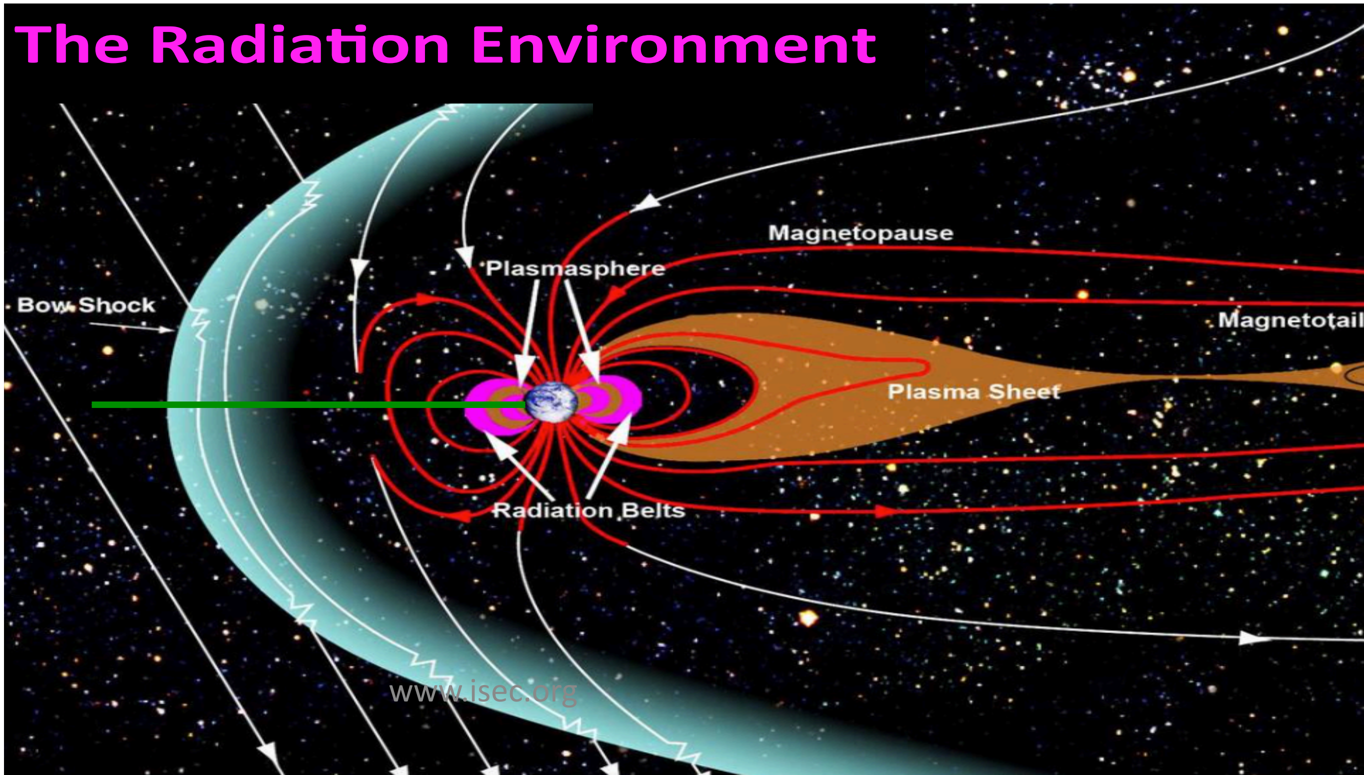
Why Space Elevators? Because we Must!

- Fulfills the Dreams of Many
- Raises Massive Cargo using Solar Energy
  - Green Road to Space
  - Permanent Infrastructure for GEO & Beyond
  - Daily, Routine, Safe, and Inexpensive
  - Early Operations: 30,000 tonnes per year
- Space Elevators are a Simple Elegant Solution to the Rocket Equation. - They avoid it!

Backup Charts

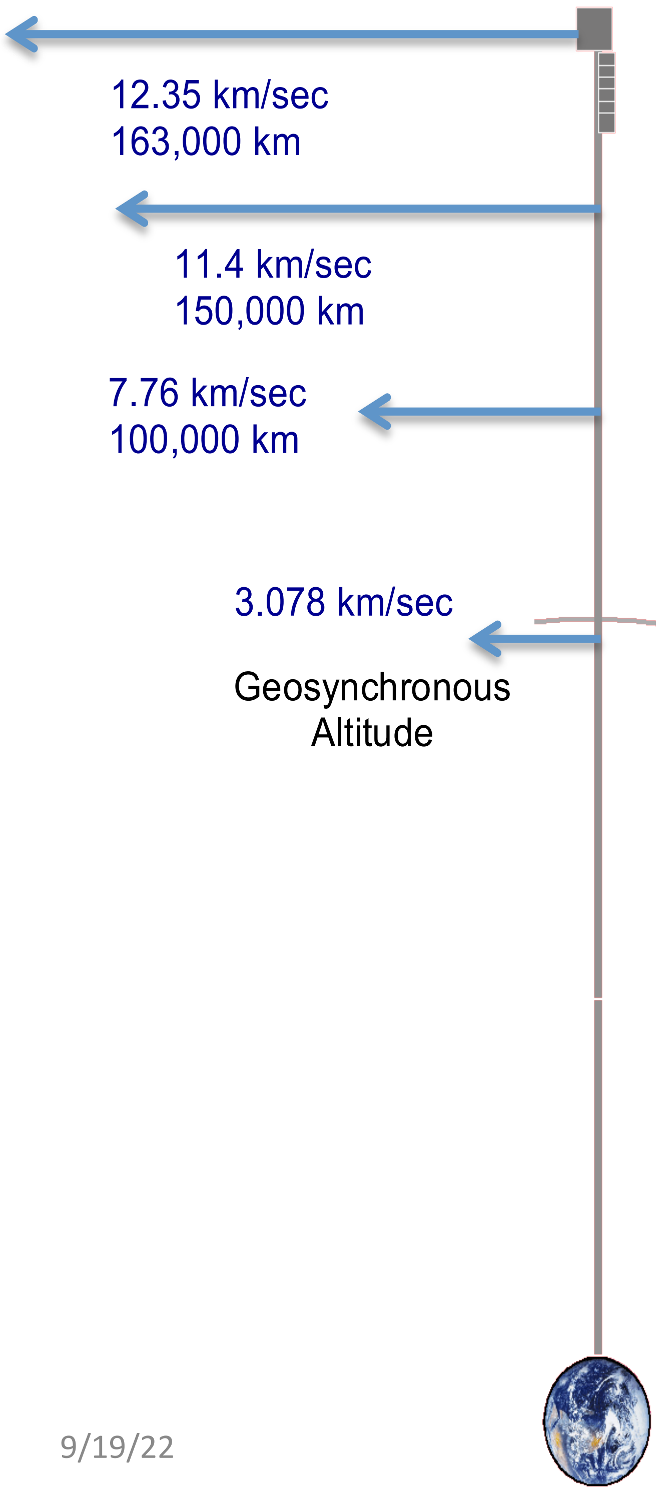
Earth Radius
6,378 Km

Space Elevator
100,000 km
In green



Transformational Leap

- Dreamers
- Space Elevator Vision
- *Arizona State University joint study "to Mars"*
- Transformational Characteristics
- Dual Space Access Future
- Summary



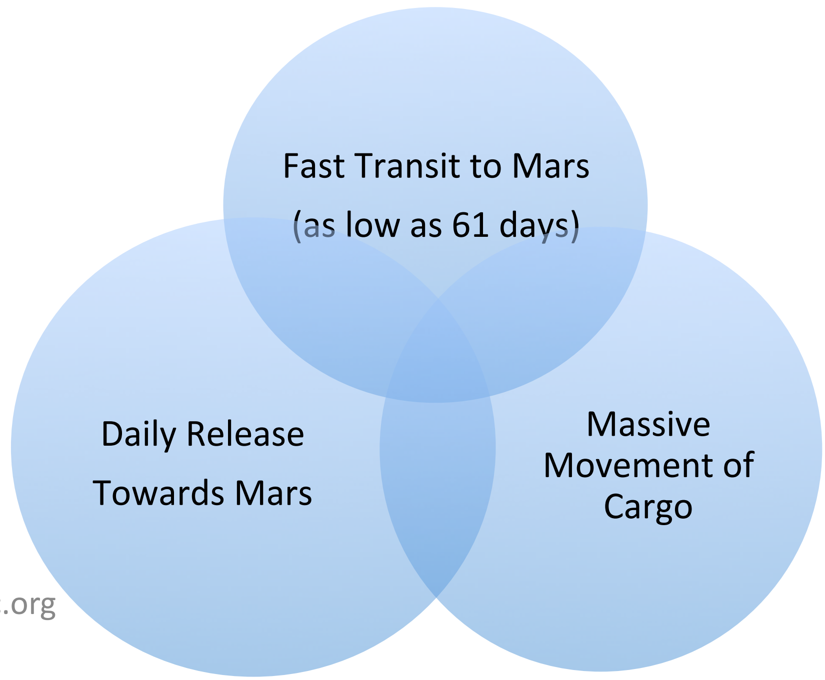
Revolution Coming

- This new vision of Galactic Harbour architectures will change the "thinking" for off-planet migration – How fast can we go?
- At 100,000 km altitude, there is no significant gravity pull to limit departures
- At 100,000 km altitude, there is tremendous velocity (7.76 km/sec) enabling beyond Mars
- With longer Space Elevators, the whole solar system opens up and even escape from the sun is possible (without thrusting from rocket fuel).

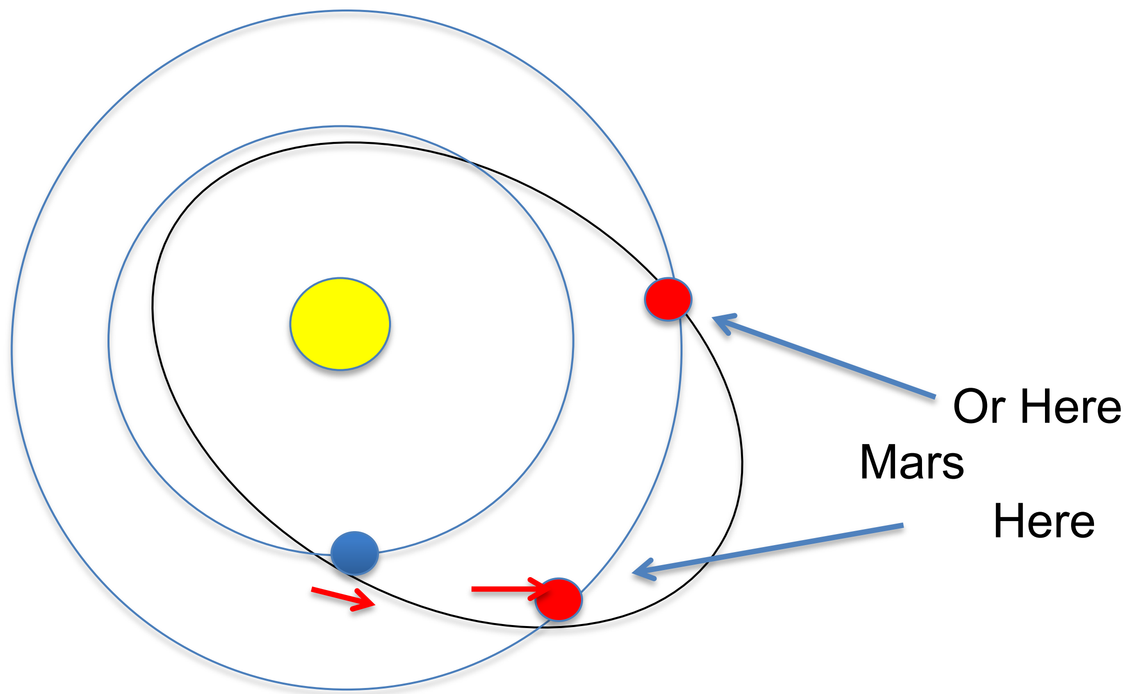
Enable Interplanetary Mission Support

The unique characteristic of Space Elevators is a rapidly moving Apex Anchor (7.76 km/sec) enabling remarkable opportunities for off-planet missions. This combination of three major strengths will ensure constant support to missions beyond Geosynchronous altitude. Strengths:

- Rapid Transit to Mars (61 days best with many between 80 to 100 days)
- Release every day towards Mars (no waiting for 26 month window)
- Massive tonnage of mission support equipment (170,000 tonnes per year with a mature system)



Case One: Fastest Approach

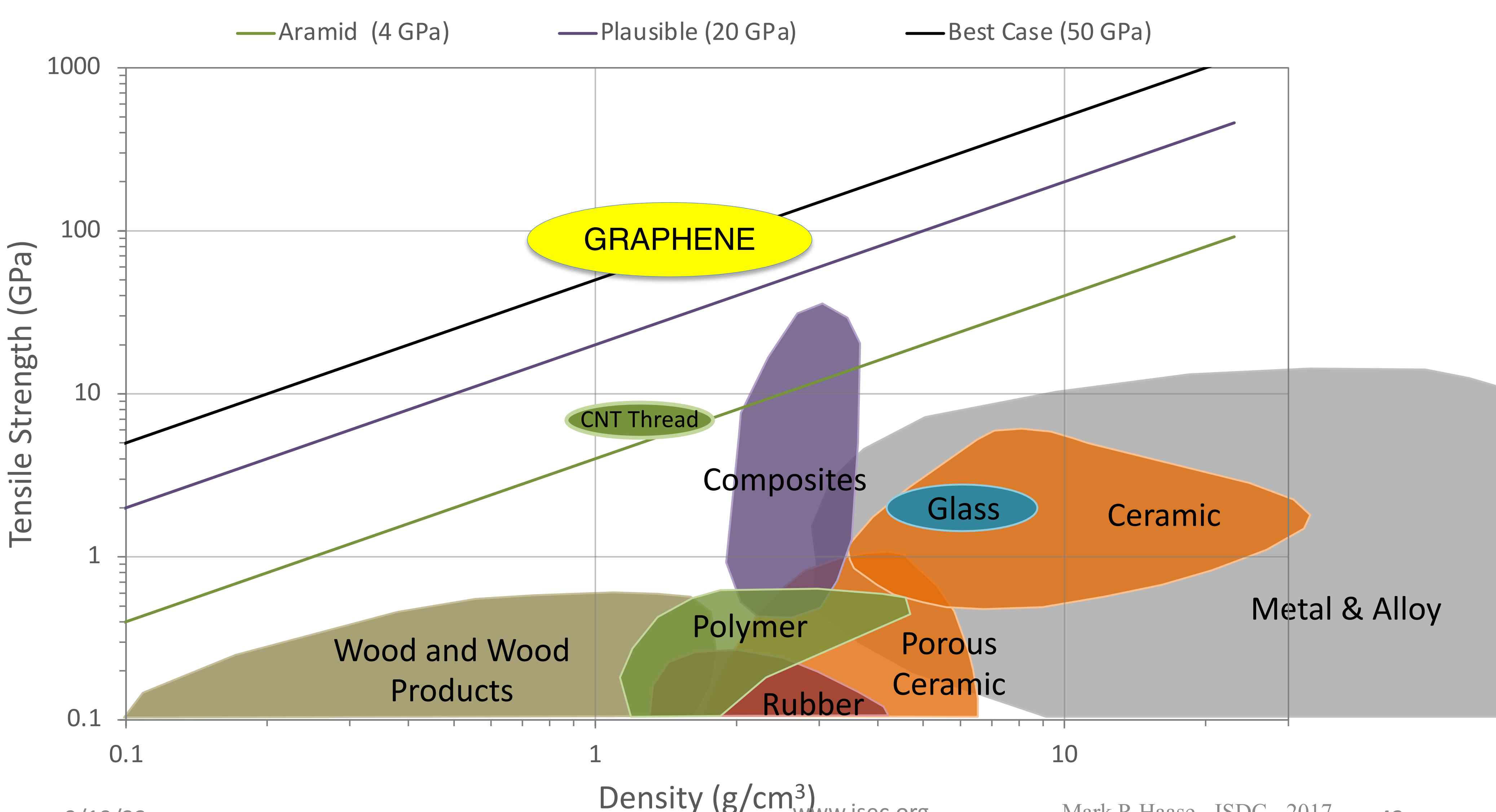


Concept: Our spacecraft enters the ellipse, “not at perigee,” but on the side of the ellipse centered as one foci at the Sun and outer portion matching Earth and Mars locations.

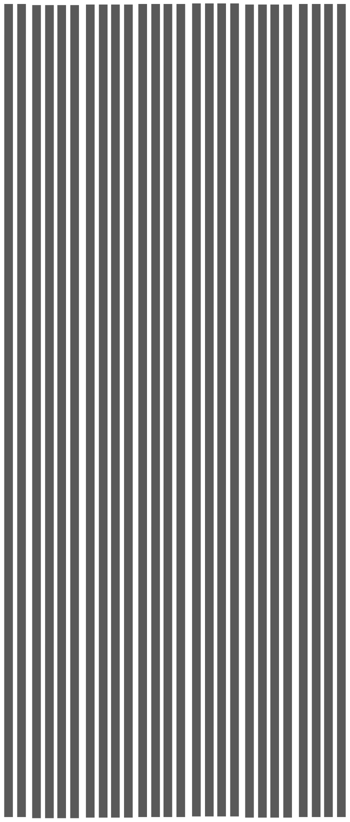
Tether candidate materials

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

YES: Graphene is strong enough to be a candidate tether material



Graphene has the strength to make the space elevator tether



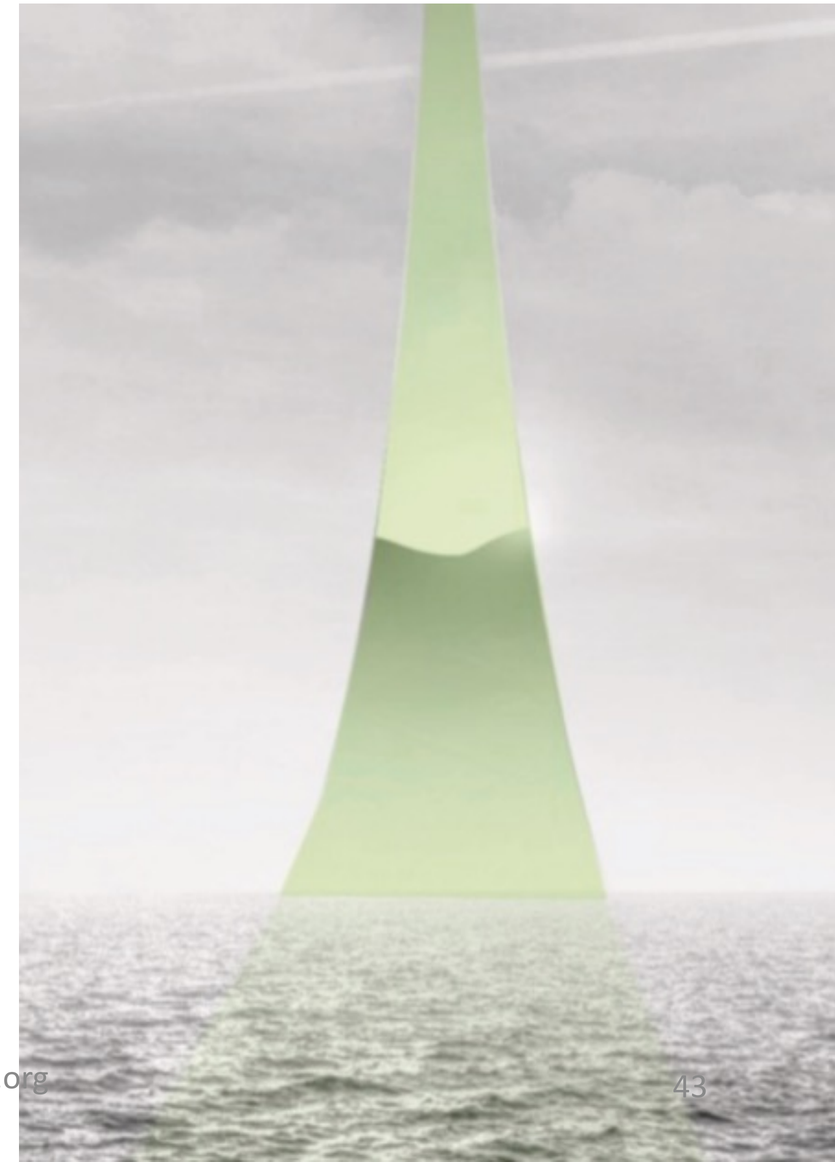
100 million metres long

1m wide

12,333 layers of
single crystal graphene
4 microns thin near Earth

The thickness tapers with the
maximum at GEO
(35,786km from Earth's surface)
being 14 microns

This will support a 20 tonne climber



General Graphene roll to roll (R2R) production line operational with a capacity of 100,000 m^2/year.

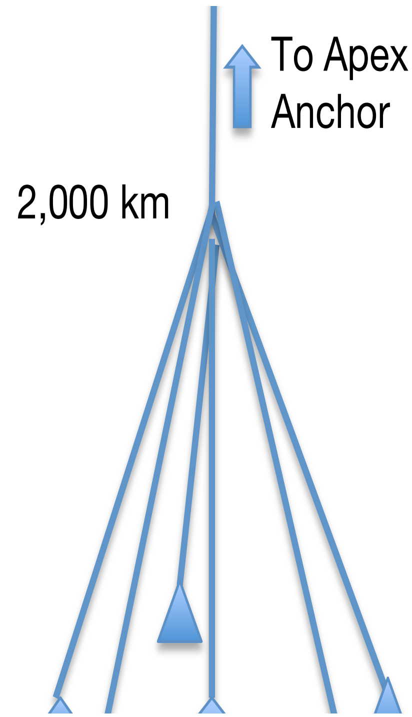
Image Credit: General Graphene

Source:
Anon, 2022. *The journey from CVD graphene innovation to commercialisation*. [online] innovationnewsnetwork.com. Available at: < https://www.innovationnewsnetwork.com/journey-cvd-graphene-innovation-commercialisation/17349/> [Accessed 29 May 2022].

Operating Safely in Debris Environment

Two Reports and seven pg summary in “Start Now” work book.

- 2010 "Space Elevator Survivability, Space Debris Mitigation."
- 2020 "Today's Space Elevator Assured Survivability Approach for Space Debris.”



"Space debris mitigation is an engineering and management problem with definable quantities such as density of debris and lengths/widths of targets." Space Debris is NOT a show stopper!

Three parallel Activities.

- Passive – multi-leg, tether design,
- Active – move tether, protection, repair climber
- Collaboration – knowledge sharing, active involvement in tracking, coordinate with owners,

Space Debris is a Manageable Challenge for Space Elevators

TOPICS to be Addressed:

Debris alert ➔ Warning needs

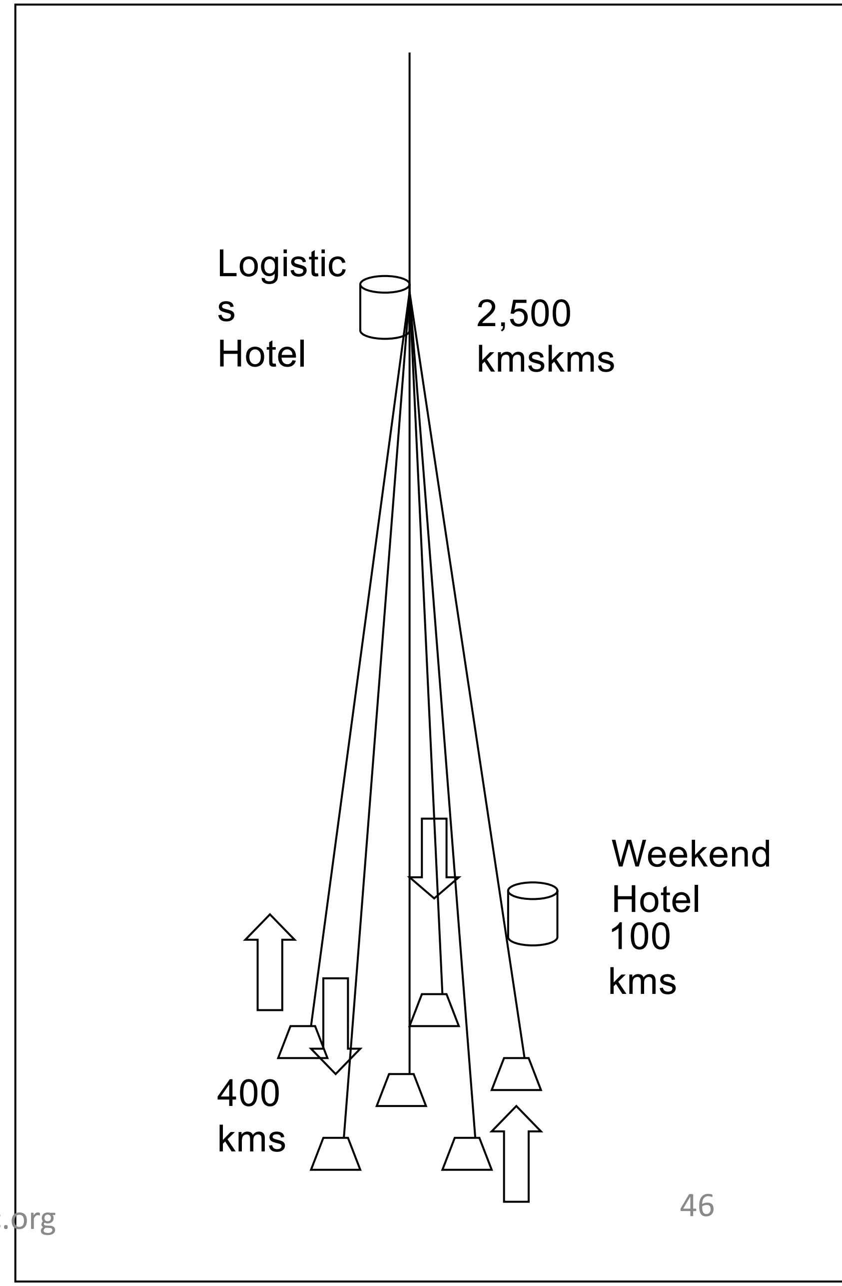
Debris sizing ➔ as a threat variant

Space Elevator Tether Movement ➔ passive defense

The Sentry System ➔ an Architecture adjunct for protection

System Recovery ➔ Post debris-event actions

Space Debris Adjunct (Mitigation) -- The Space Elevator will establish an op's relationship with space debris mitigation systems. The space debris "chair" will be charged with providing awareness, warning, active defense, passive defense, and (if needed) recovery after a debris event.

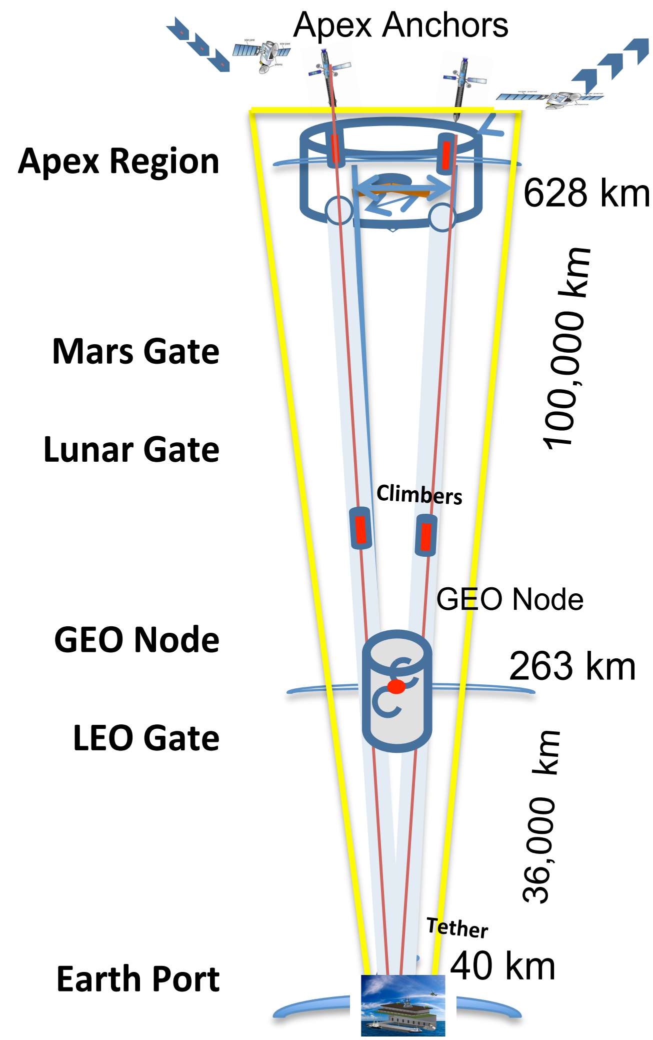


ISEC Approach

- Executive Summary of 2010 Report stated: To assess the risk to a space elevator, we have used methodology from the 2001 International Academy of Astronautics (IAA) Position Paper on Orbital Debris:
- "The probability (PC) that two items will collide in orbit is a function of the spatial density (SPD) of orbiting objects in a region, the average relative velocity (VR) between the objects in that region, the collision cross section (XC) of the scenario being considered, and the time (T) the object at risk is in the given region."

$$PC = 1 - e^{(-VR \times SPD \times XC \times T)}$$

- Using this formula, we calculate the Probability of Collision for LEO, MEO, and GEO. Our focus is on LEO -- as fully two thirds of the threatening objects are in the 200-2000 km (LEO) regime. Our analyses show:
- 2001 Position Paper On Orbital Debris, International Academy of Astronautics, supported by NASA, 24.11.2000. download for free from www.isec.org



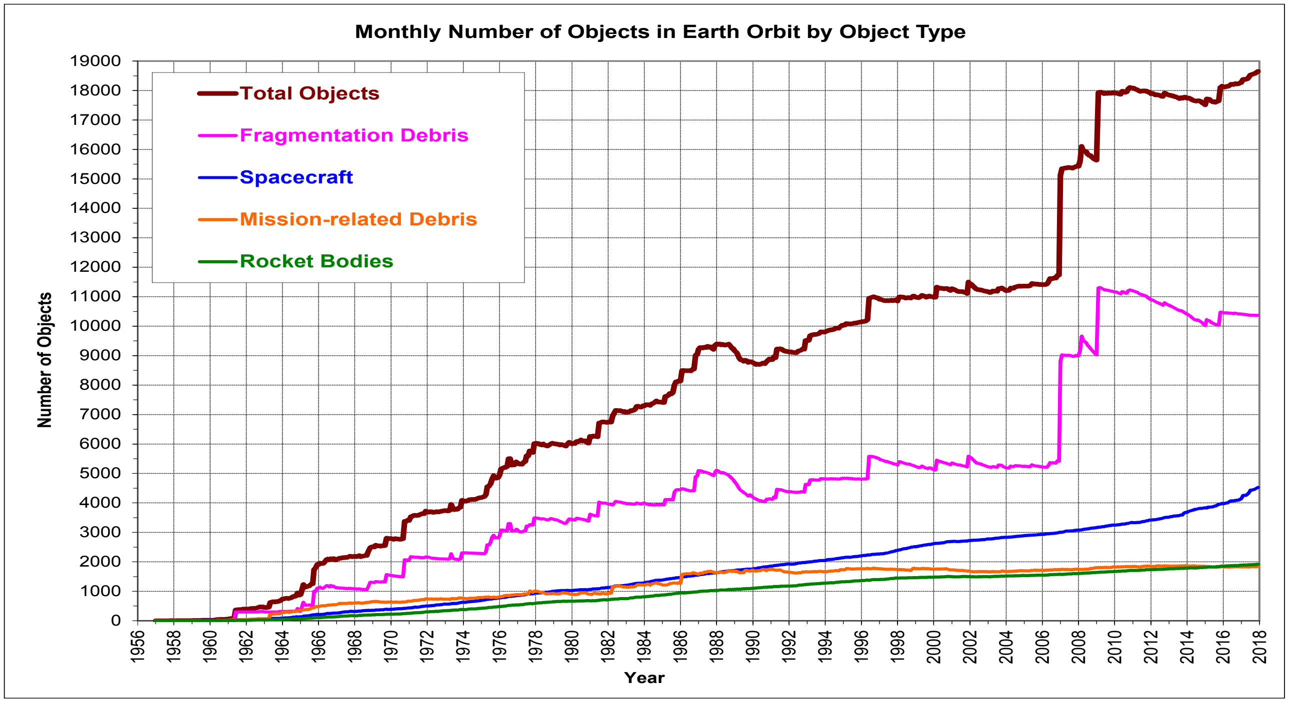
Summary for Future

Item	*2010*	*2019*	*2030 Est.*	*Comment*
Total Tracked Debris by NASA	15378	19137	38,000	Assume comm constellations will add many space objects
Threats in GEO region	Not significant	Not significant	Not significant	Good operational proceedures a must.
Threat in MEO region	Not Significant	Not Significant	Not Significant	Good operational proceedures a must.
Untracked, small (<10 cm) debris will impact a Space Elevator in (LEO 200-2000 km), on the average;	Once every ten days	Once every 7.5 days	Once every 4 days	Design for tether anc movement planned to account for this - with continuous repair
Tracked debris will impact the total LEO segment (200 – 2000 km) if no actions are taken.	Once every 100 days or multiple times a year	Once every 75 days or several times a year	Once every 40 days or every two months or so	Note, this assumes there is no active movement of trackec objects or of the tether
Tracked debris will only impact a single 60 km stretch of LEO space elevator, on the average	Every 18 years with every 5 years in peak regions	Every 14 years with every 4 years in peak regions	Every 7 years with every 3 years in peok regions	Note, this assumes there is no active movement of trackec objects or of the tether

Conclusion

- As a result, the conclusion stays the same: - for 2009, 2018 and 2030
- Space debris mitigation is an engineering problem with definable quantities such as density of debris and lengths/widths of targets. With proper knowledge and good operational procedures, the threat of space debris is not a show-stopper by any means. However, mitigation approaches must be accepted and implemented robustly to ensure that engineering problems do not become a catastrophic failure event.
- And there are always the engineering solutions for some of the challenges. Many people have suggested architectural designs to help the issue. Here are some of them:
- Eliminate the major debris in orbit (this is a must - and there are many people around the world who believe this must be started soon to ensure no future challenges to normal spaceflight - this is NOT a space elevator issue alone, but one for all spaceflight.)
- design an emergency response that sends tether from GEO downward when the tension jump signals a major change resulting from sever.
- provide an emergency lowering of tether from 2,000 km upon sever in the highest probability areas (LEO high density orbits)
- provide multiple legs from 2,000 kms and below. [I actually like that one - see image below]

Space Debris Sept 2018



Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

Orbital Debris Quarterly News

Item	***2010***	***2019***	***2030 Est.***	***Comment***
Total Tracked Debris by NASA	15378	19137	38,000	

Sep 2018 Orbital Debris Quarterly News(NASA Johnson Center office)

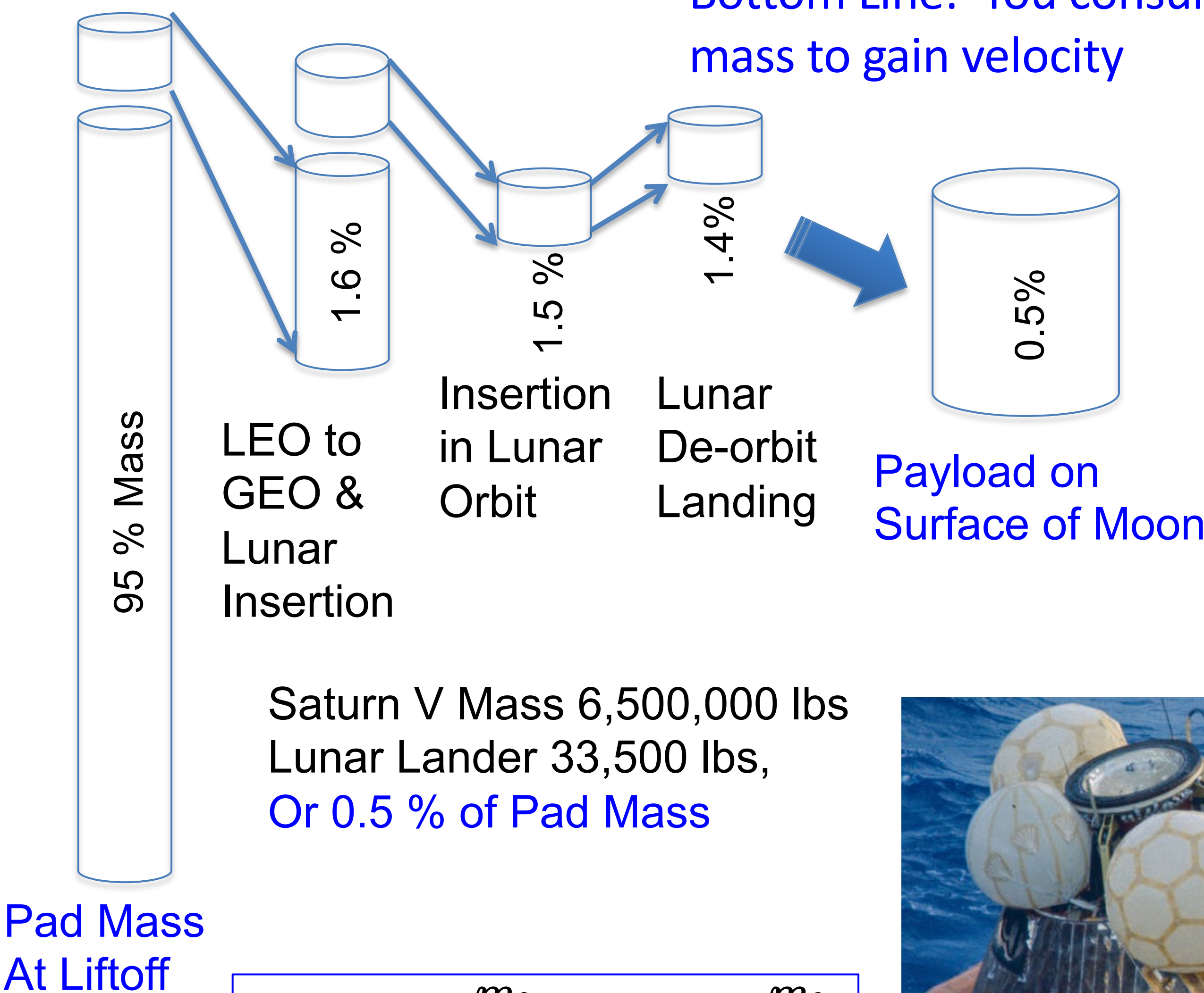
SATELLITE BOX SCORE
(as of 04 July 2018, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads*	Rocket Bodies & Debris	Total
CHINA	312	3652	3964
CIS	1520	5069	6589
ESA	82	57	139
FRANCE	64	488	552
INDIA	89	117	206
JAPAN	173	111	284
USA	1663	4737	6400
OTHER	887	116	1003
TOTAL	4790	14347	19137

* *active and defunct*

Rocket Equation
an Example

Bottom Line: You consume your pad mass to gain velocity



Saturn V Mass 6,500,000 lbs
Lunar Lander 33,500 lbs,
Or 0.5 % of Pad Mass

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

Conundrum of Rockets

Space Elevators answer the Conundrum of Rockets

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

Delivery statistics to GEO would be up from 2% of rocket pad mass to 70% by Space Elevators per event – also delivered in an Earth Friendly Manner