D4.3 Modern Day Space Elevators Customer Design Drivers 2023 International Astronautical Congress, Baku, Azerbaijan

The term “Modern Day Space Elevator” describes how we have matured through eight Space Elevator architectures described by David Raitt in his Quest Magazine article (2021).

This session reflects well on the Jerome Pearson Memorial Lecture as it has taken his concepts to the next level.

Art by
A. Stanton

Jerome Pearson Memorial Lecture:

Jerome Pearson *(1938-2021)*

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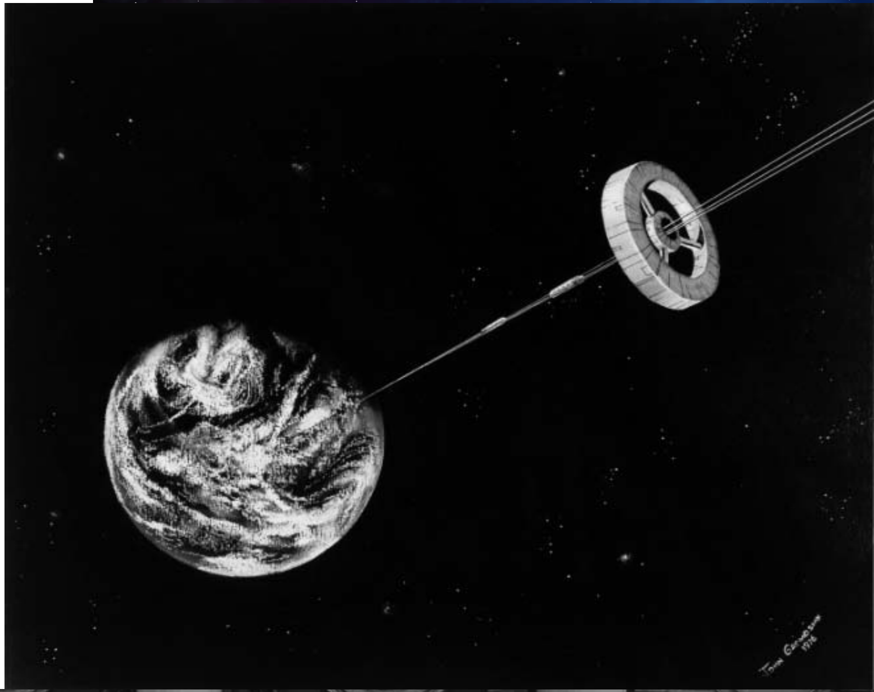
Today's Keynote Speech is named the Jerome Pearson Memorial Lecture as recognition of his impact within our space community. He is a co-inventor of the Space Elevator and a great supporter of the IAF and IAA over the last 45 years. Each year during this future technical session, the keynote speech will be named after him.



His 1975 article in Acta Astronautica and presentation at the 27th International Astronautical Congress in Anaheim, California (10-16 October 1976) presented the first engineering description of space elevators. His presentation was entitled – "Using the Orbital Tower to Launch Earth-Escape Spacecraft Daily."

Yuri Artsutanov and Jerome Pearson

Keynote: Jerome Pearson Memorial Lecture -
RESEARCH CHARACTERISTICS OF A PERMANENT SPACE ACCESS TRANSPORTATION INFRASTRUCTURE

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Peter Robinson

Tether Climber Systems Engineer
International Space Elevator Consortium
Fellow, The British Interplanetary Society

Peter A. Swan, Ph.D.

President and Member BoD, www.isec.org
International Space Elevator Consortium
Senior Vice President, Galactic Harbour Associates, Inc.
Faculty Associate, ASU – Osher Lifelong Living Institute
Fellow, American Institute of Aeronautics and Astronautics
Fellow, The British Interplanetary Society
Academician, International Academy of Astronautics
Co-editor, IAA Study, Space Elevator Feasibility

SpaceFlight June 2023

SpaceFlight

A British Interplanetary Society publication

Volume 65 No.6 June 2023 £5.99

Elevators rise

We have the technology

Starliner's July launch

ESA's Project Apollo?

Rocket Lab's Electron devolution

SpaceX's Starship lift-off to disaster

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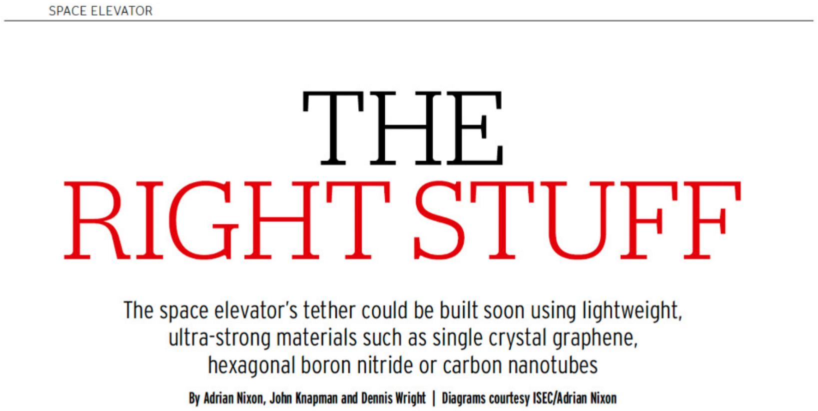
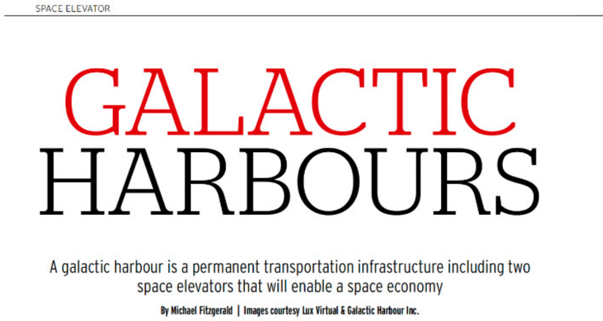


SPACE ELEVATOR

THE RIGHT STUFF

The space elevator's tether could be built soon using lightweight, ultra-strong materials such as single crystal graphene, hexagonal boron nitride or carbon nanotubes

By Adrian Nixon, John Knapman and Dennis Wright | Diagrams courtesy ISEC/Adrian Nixon



SPACE ELEVATOR

GALACTIC HARBOURS

A galactic harbour is a permanent transportation infrastructure including two space elevators that will enable a space economy

By Michael Fitzgerald | Images courtesy Lux Virtual & Galactic Harbour Inc.

SPACE ELEVATOR

Cooperation & competition

A dual space access strategy leverages the best of both space elevators and rockets for a greener road to space

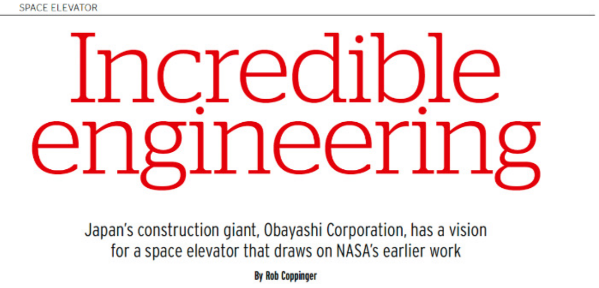
By Peter Swan

SPACE ELEVATOR

Modern day space elevators

The eighth space elevator architecture, as a permanent space transportatic system, has remarkable transformative capabilities

By Cathy Swan



SPACE ELEVATOR

Incredible engineering

Japan's construction giant, Obayashi Corporation, has a vision for a space elevator that draws on NASA's earlier work

By Rob Coppinger

Research into Transformational Leap

- ***Vision and Dreamers***
- Transformational Characteristics
- Research Topics
- Engineering Status
- Summary

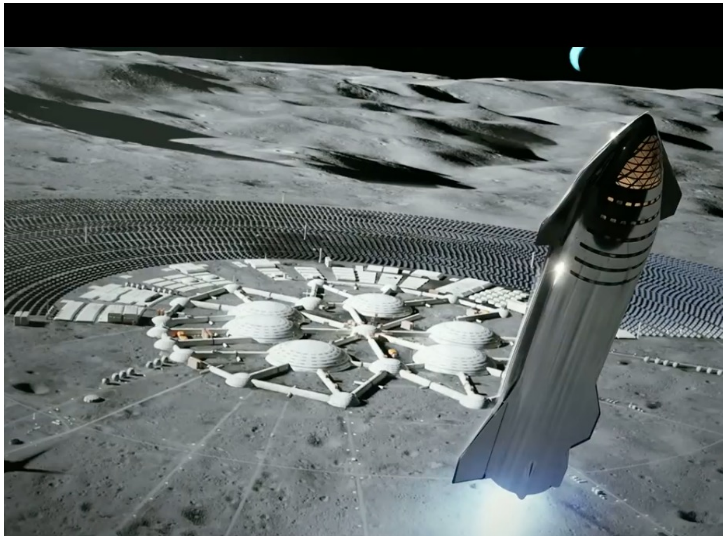
Living and working in thriving communities beyond Earth – NSS

Dream Big!

But How much mass to Orbit?

Images from SpaceX website

1,000,000 tonnes to Mars surface



Images from SpaceX

500,000 tonnes to Lunar surface

(Swan estimate)

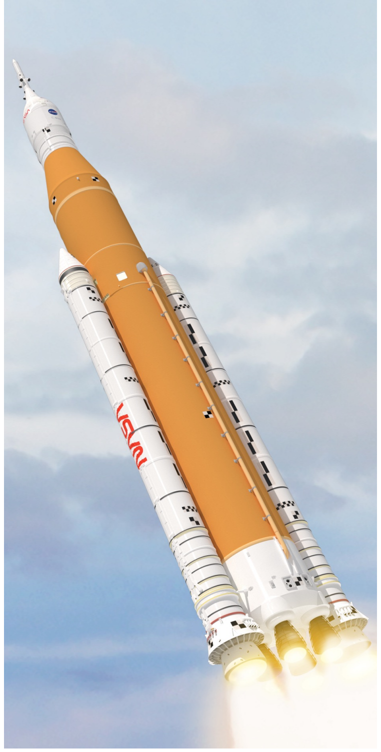
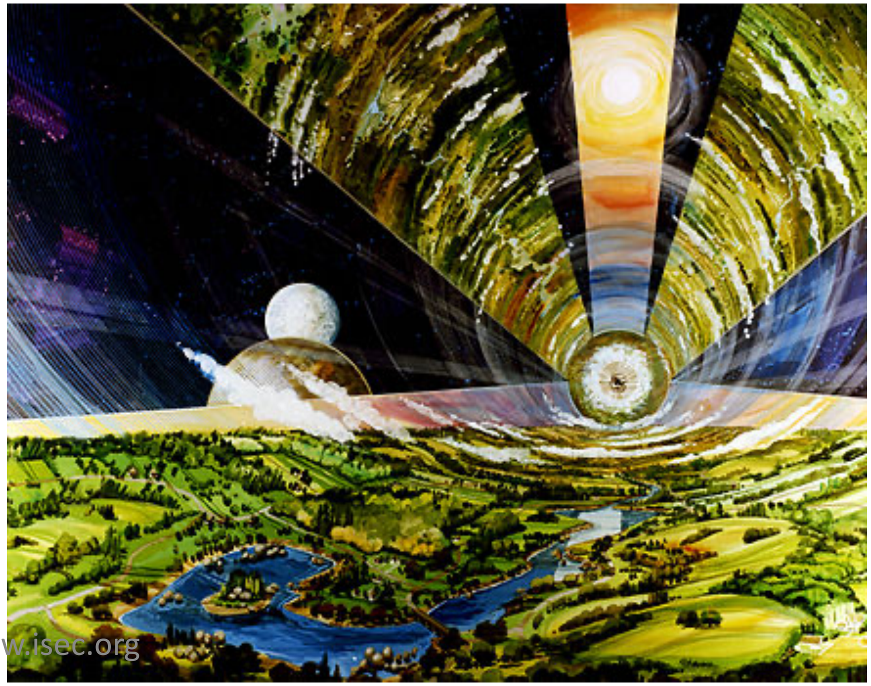


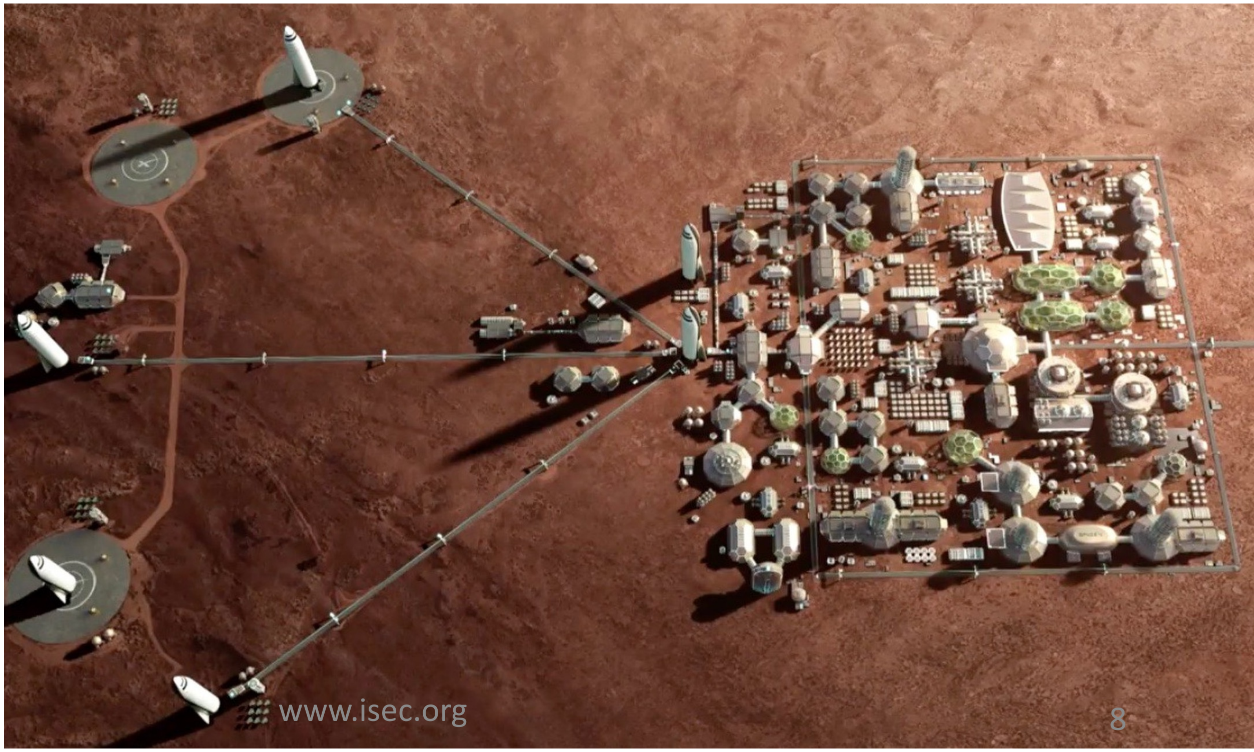
Image from Blue Origin website



Images by NASA and Rick Guidice

Mars Colony

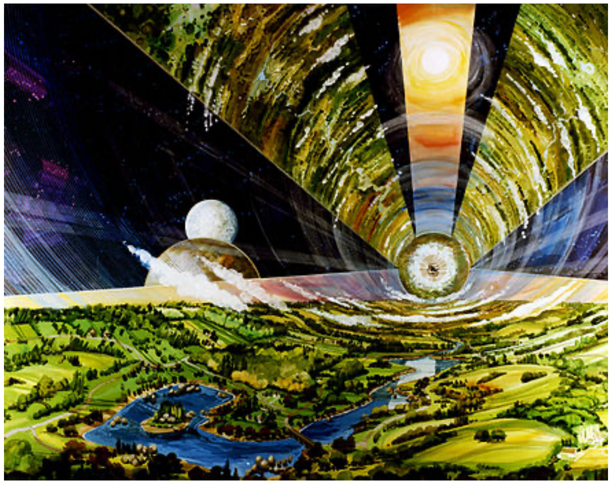
- I think there are really two fundamental paths. History is going to bifurcate along two directions. One path is we stay on Earth forever, and then there will be some eventual extinction event. I do not have an immediate doomsday prophecy, but eventually, history suggests, there will be some doomsday event. The alternative is to become a space-faring civilization and a multi-planetary species…*
- Mr. Musk stated that he needs 1,000,000 Metric Tons of support for his Colony.**

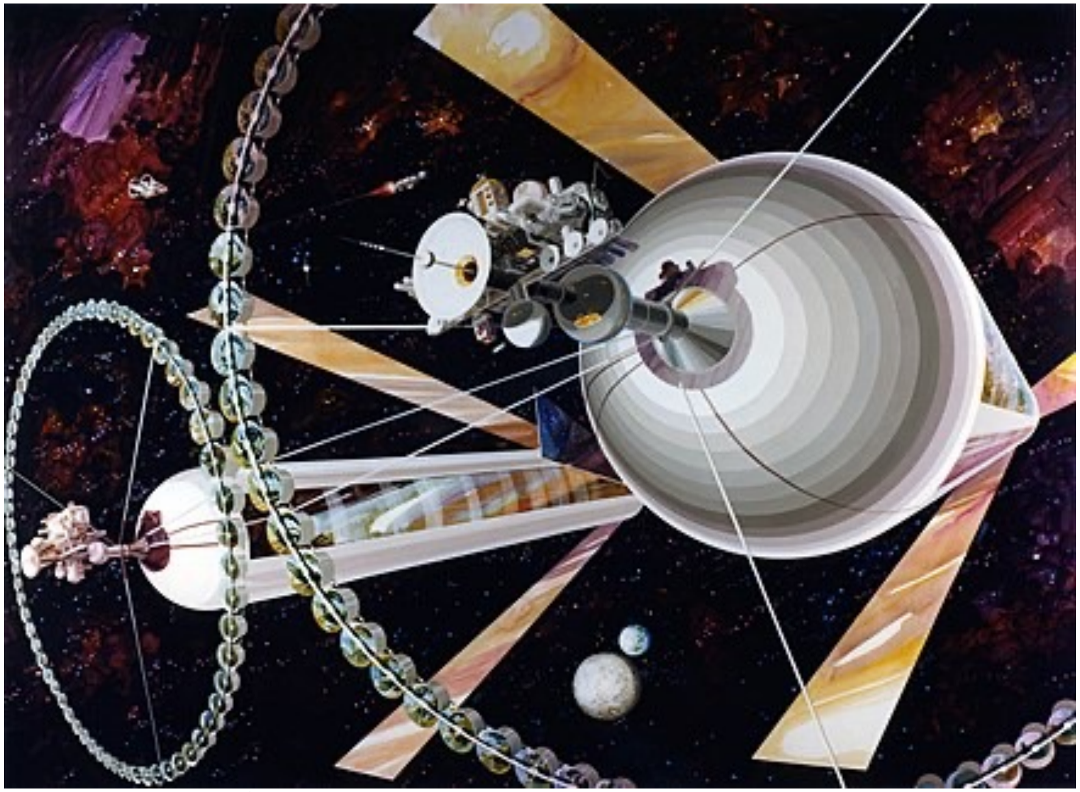


*Musk, Elon, "Making Humans a multi-Planetary Species," New Space, Vol 5, No 2.
**Musk, Elon., Quotation from CBS's Sunday Morning Show, 21 July 2019.

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?

The Future is Here

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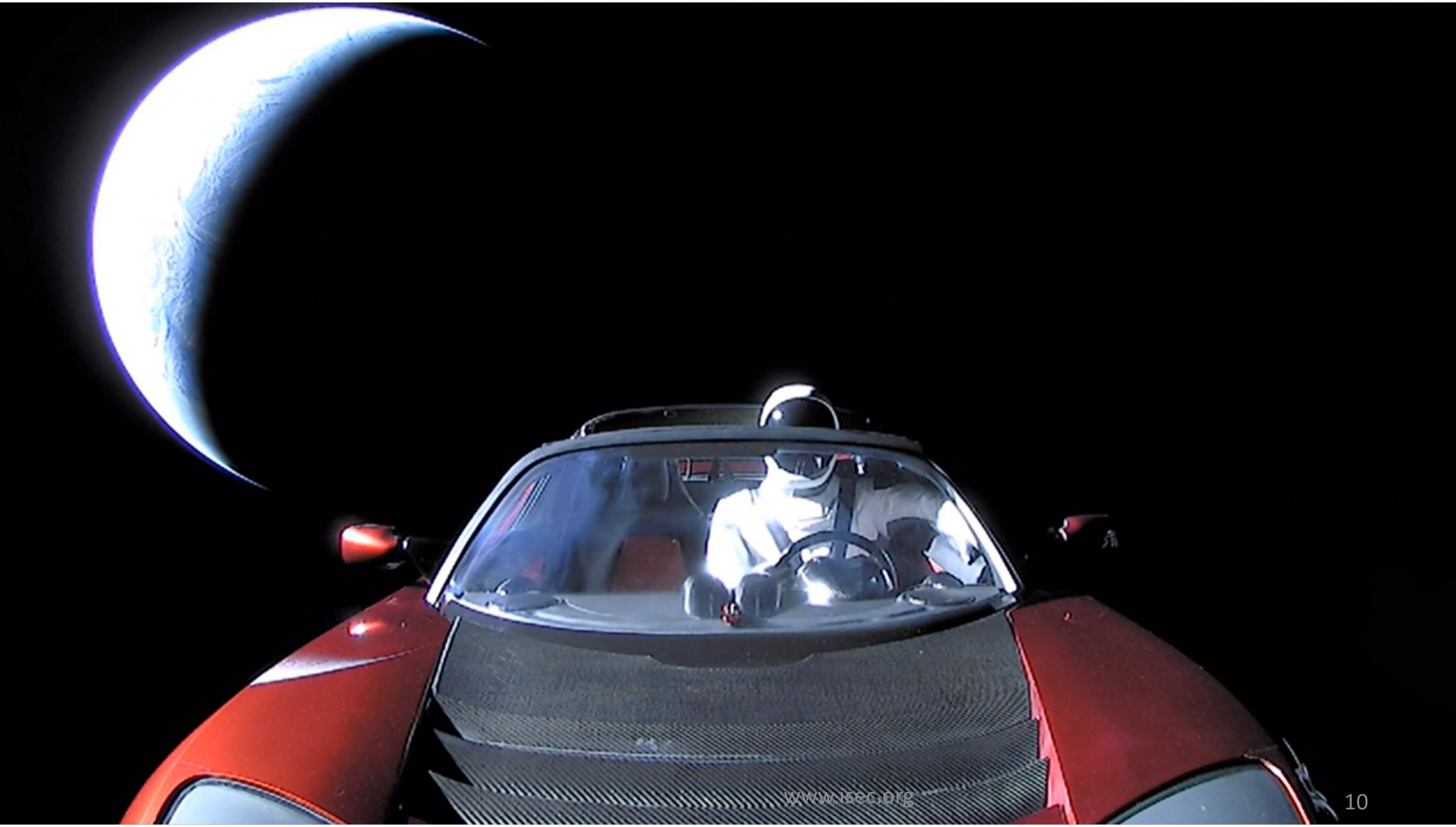


Our Dream - Humanity Moves off-planet

- "Mr. Bezos described a dreamy, ambitious vision of the future: a trillion people in space, living not on moons or planets, but bucolic space colonies in a style… Mr. Bezos said. 'We are going to build a road to space, And then amazing things will happen.'"
- 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."
- Elon Musk's vision: Mr. Musk has outlined his vision for establishing a human colony on Mars
  - One million colonists in his lifetime
  - for people that can afford a $200,000 ticket price.
  - fully reusable transportation system
  - 100 people and 80 days to get to Mars – maybe as little as 30 day

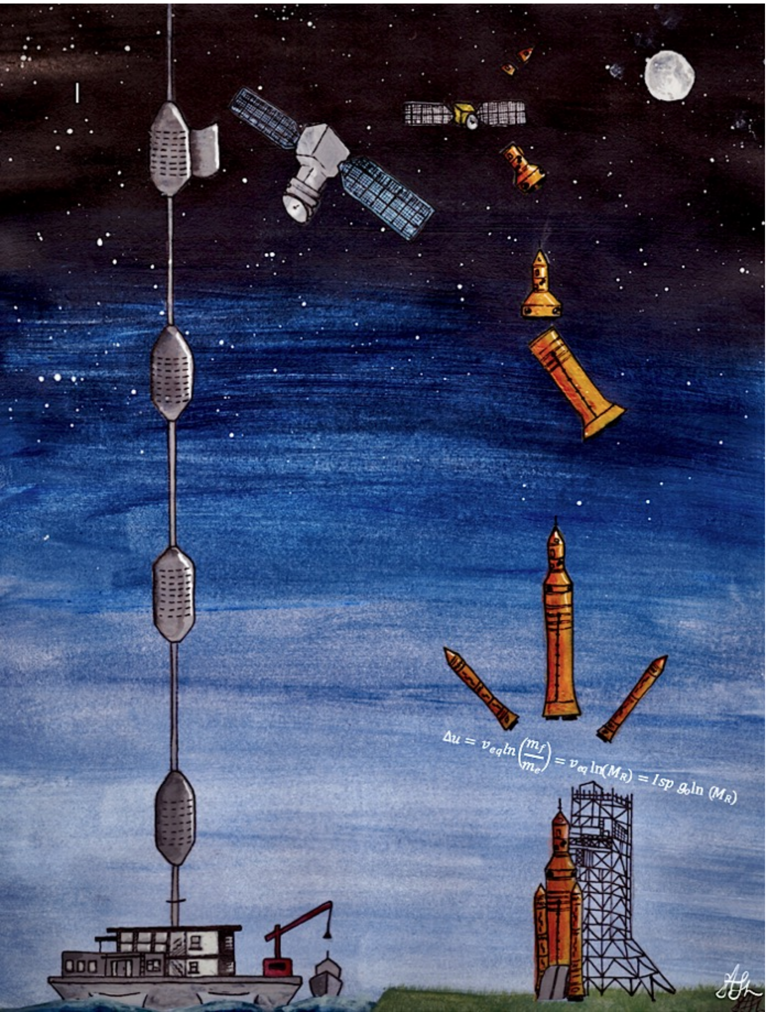
Space Elevator Vision and Approach

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. Rockets are complementary and cooperative to Space Elevators.

Rocket Strengths: Operational today with future growth, rockets reach multiple orbits, and they have rapid movement through the radiation belts

Space Elevator Strengths: ***As permanent space transportation infrastructure, they will lead to daily, routine, environmentally friendly, massive movement of cargo and inexpensive departures towards mission destinations throughout the solar system.***



Interplanetary Vision

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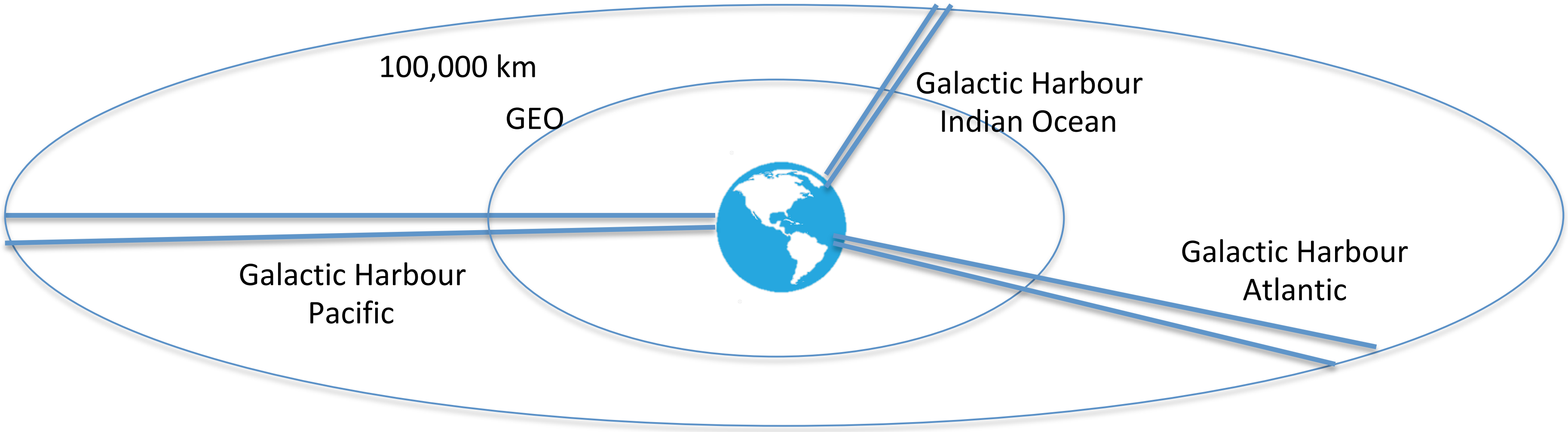

Promise to Planetary Scientists: Any scientific payload mass To any destination in the solar system with daily launches available.

Vision of the Future: On to Moon and Mars with Rockets then Space Elevators to supply and buildup the colonies

Modern Day Space Elevator

A. Stanton Design

"A Modern Day Space Elevator" has evolved from a dream to a scientific engineering reality.

The four major thrusts 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.

Research into Transformational Leap

- Vision and Dreamers
- ***Transformational Characteristics***
- Research Topics
- Engineering Status
- Summary

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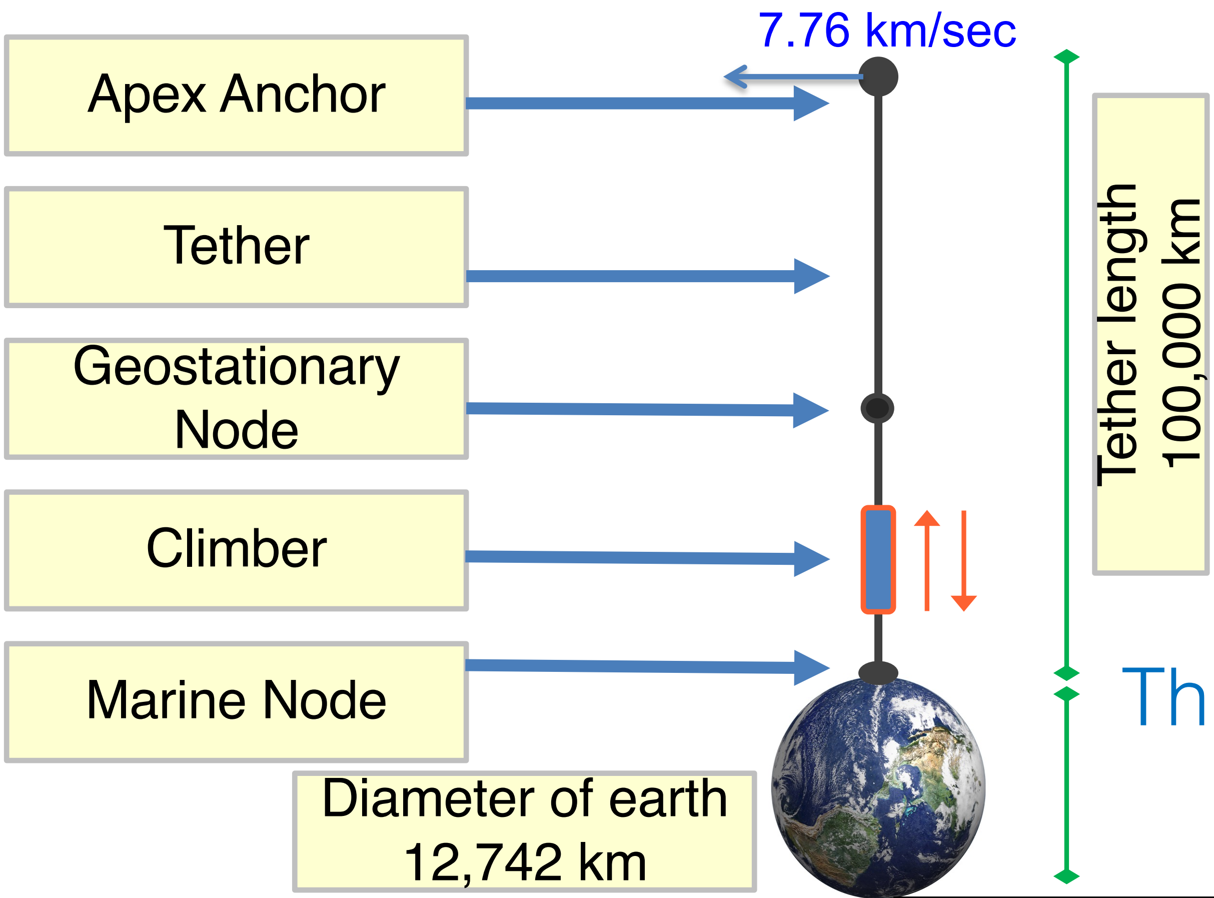
Space Elevators

Think “bridge” to space



7.76 km/sec

Apex Anchor

Tether

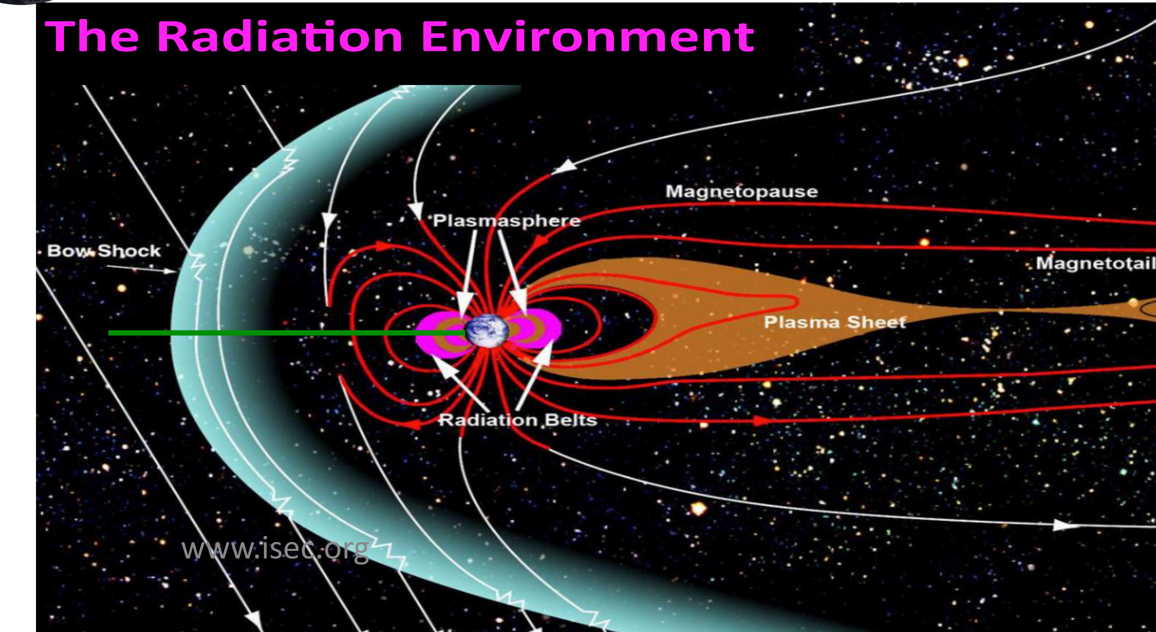
Geostationary Node

Climber

Marine Node

Diameter of earth 12,742 km

Tether length 100,000 km



The Radiation Environment

www.isec.org

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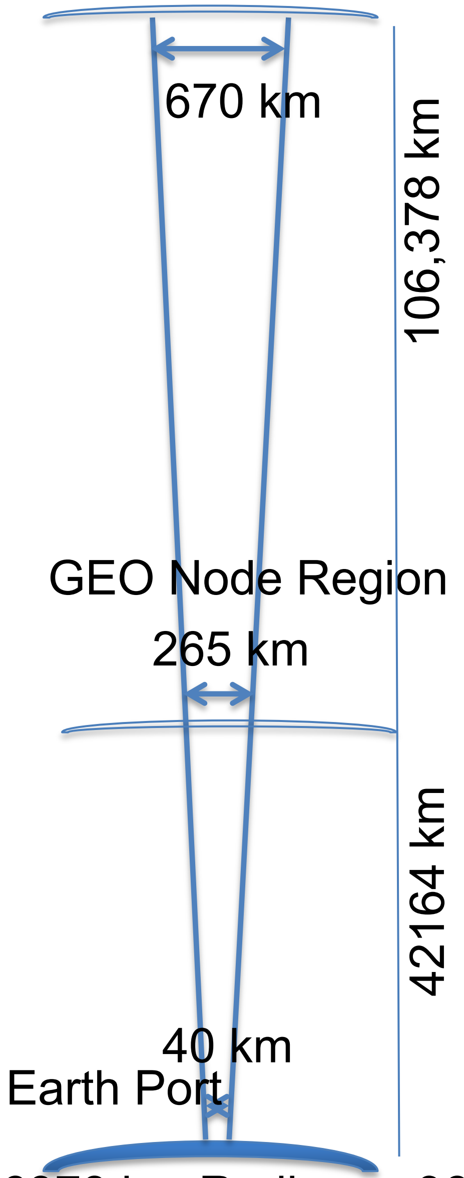
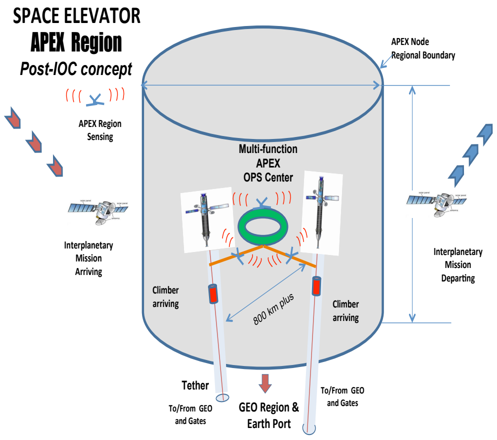
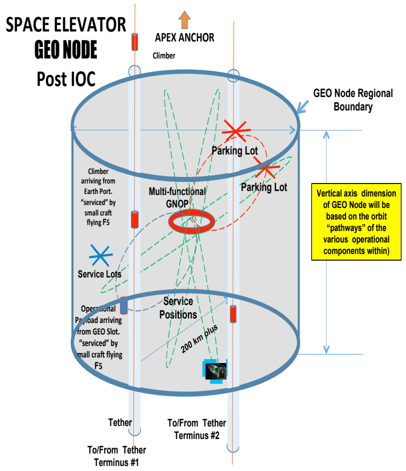
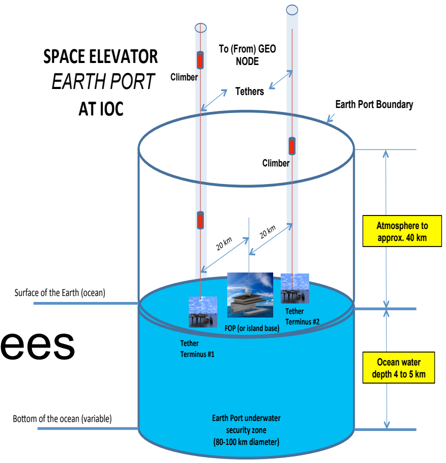
Apex Anchor Region









- 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

Characteristics of Transportation Infrastructure (think trains/bridges)

- Revolutionarily inexpensive to GEO [$100/kg to GEO]
- Unmatched Efficiency [70% delivery statistic]
- 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

Reference Missions: (customer demands)

Note: Humanity has only orbited about 26,000 tonnes during our history

- 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
- Planetary Sun Shades – 20,000,000 tonnes to E-S L1 for 2% temperature reductin

* 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

Unmatched Efficiencies Dwarfs Advanced Rocket Deliver Statistics

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- Space Elevators have an "Unmatched Efficiency" of liftoff to GEO and beyond.
- Rockets deliver 2% of the launch mass to GEO altitude and 0.5% of launch mass to the surface of the Moon (or Mars).
- Space Elevator efficiency is in the range of 70% of its liftoff mass arrives at its destination (with the remaining 30% surviving in the form of a reusable tether climber).

The answer to:

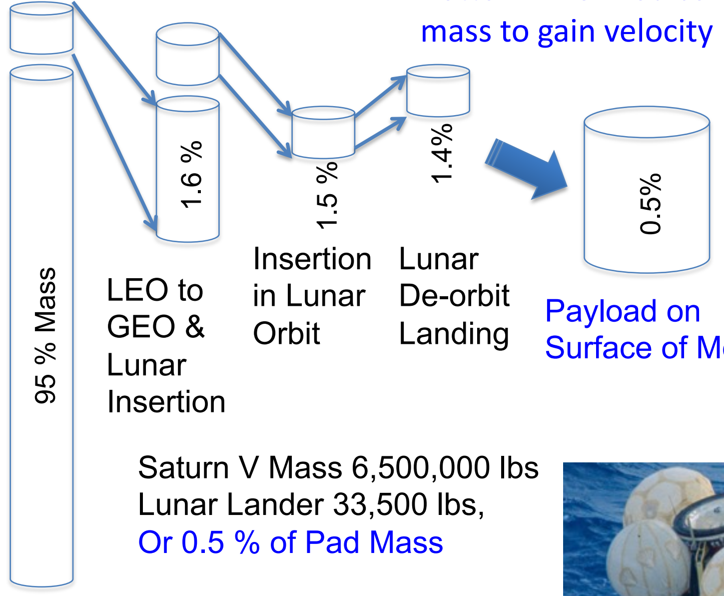
Why Space Elevators?

Unmatched Efficiency for moving mass to space on a permanent transportation space system:

70% vs. 1% to the Moon

Rocket Equation

Bottom Line: You consume your pad mass to gain velocity



95 % Mass

1.6 %

1.5 %

1.4%

0.5%

LEO to GEO & Lunar Insertion

Insertion in Lunar Orbit

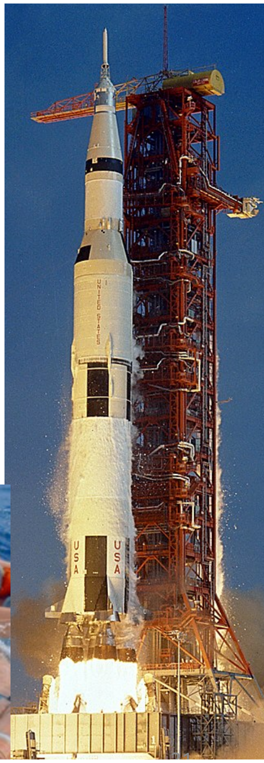
Lunar De-orbit Landing

Payload on Surface of Moon

Pad Mass At Liftoff

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

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



3/3/2022

How to Avoid the Rocket Equation

How does a single space rocket transportation infrastructure hope to aggressively move off planet when they only deliver one half of one percent of the initial mass on the pad to their destination on the lunar (Mars) surface?

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	1.4
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

Space Elevator Pad Mass – 14 tonnes payload (6 tonnes reusable climber)
Delivery Mass to GEO or Apex Anchor – 14 tonnes payload, reuse climber
Six Space Elevators - or 14 x 6 = 84 tonnes per day > 30,660 tonnes/year
With Mature Space Elevators (79 tonnes per day) . 170,000 tonnes/year

Percentage to Destination = 70% with reusable climber

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

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 space transportation infrastructures, called space elevators, will enable missions by leveraging their strengths:

- Daily, routinely, safely, inexpensively
- Unmatched Efficiencies
- Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments
- Unmatched Mass Movement (30,000 tonnes/yr)
- Green Road to Space ensures environmentally neutral operations
- Unmatched 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

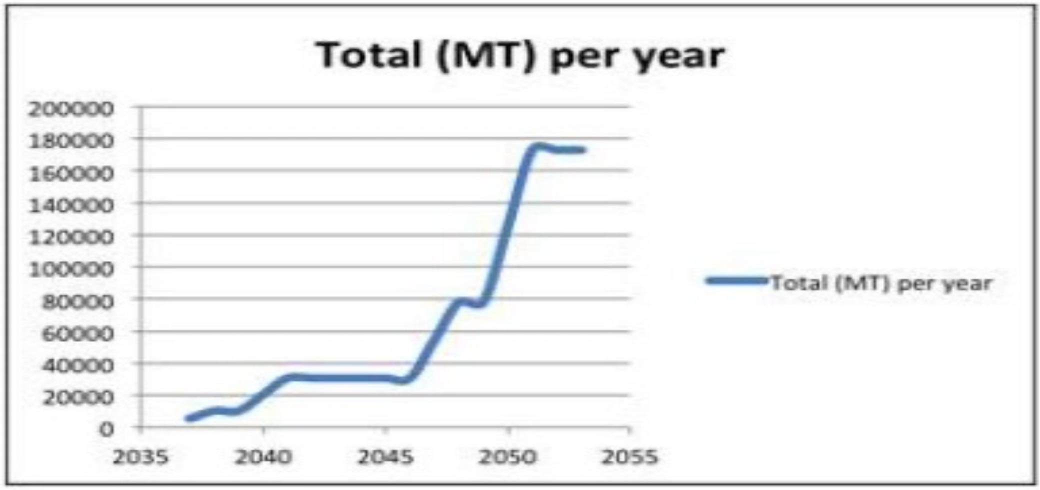


Figure 88. Massive Cargo Movement by Space Elevators (Swan "Dual Space Access Strategy Minimizes the Rocket Equation," Space Renaissance International 3rd World Congress 2021 – Congress Theses, Final Resolution and Papers. Pg 254-255.)

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

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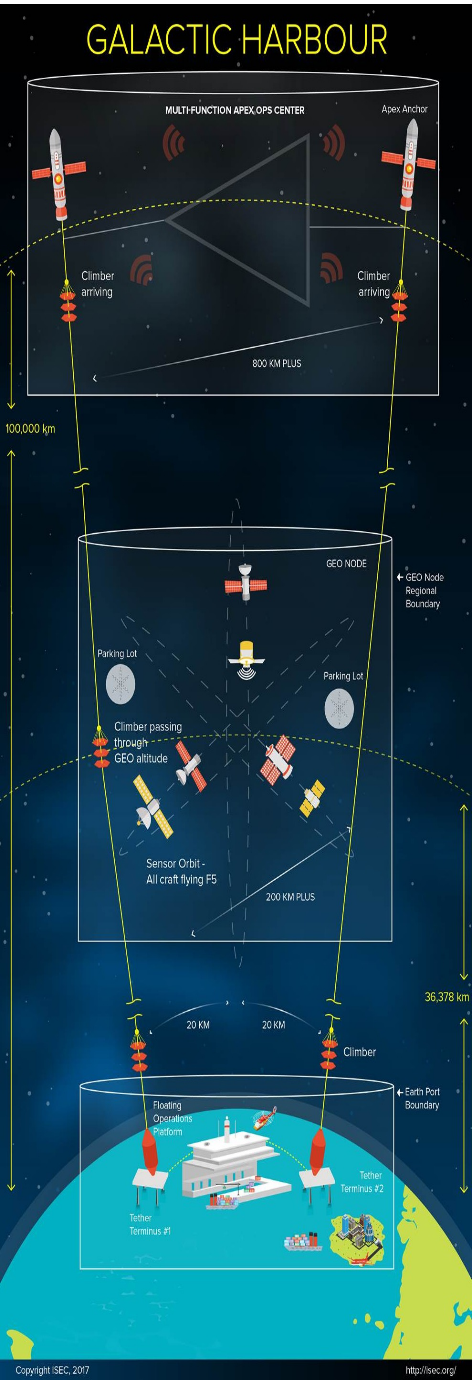

- Permanent access to GEO & Beyond - daily!
- "on-time delivery" a routine strength of space elevators' logistics
- To Mars - any day – an outcome from the Arizona State University & ISEC 2021 study.
- Lowest cost in the industry – think bridge across a river vs. one time events (boats)
- A Bus Schedule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

Think Logistics with Permanent Transportation Infrastructure

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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: *Unmatched Massive movement (30,000 tonnes/yr)*

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

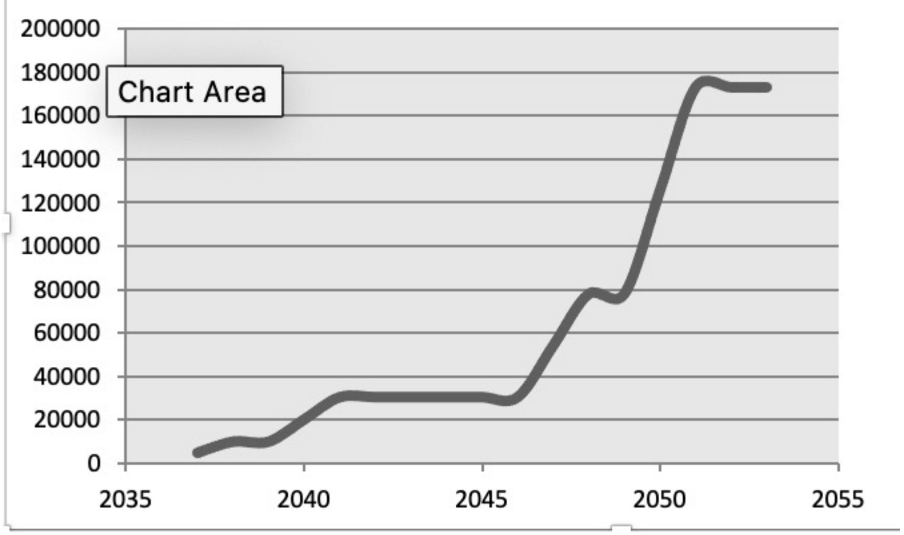
Note: Leo is 4% of launch pad mass
GEO, Interplanetary, Lunar 2% of pad
*Shuttle launch vehicle reached orbit as an operational satellite

Historic Movement
(1957 – 2020)

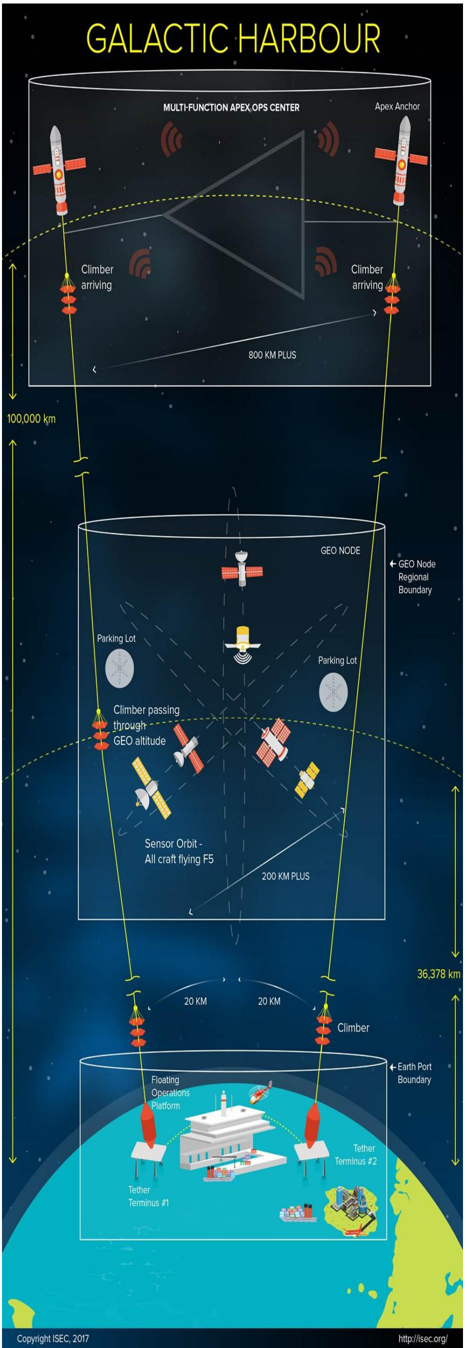
22,216 tonnes between 1957 and 2020.

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

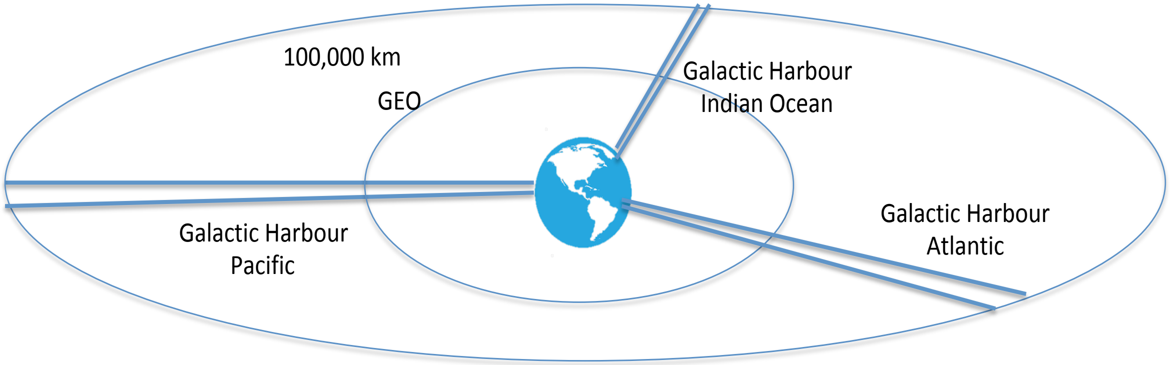
Annual payload (tonnes/yr)



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



A Green Road to Space



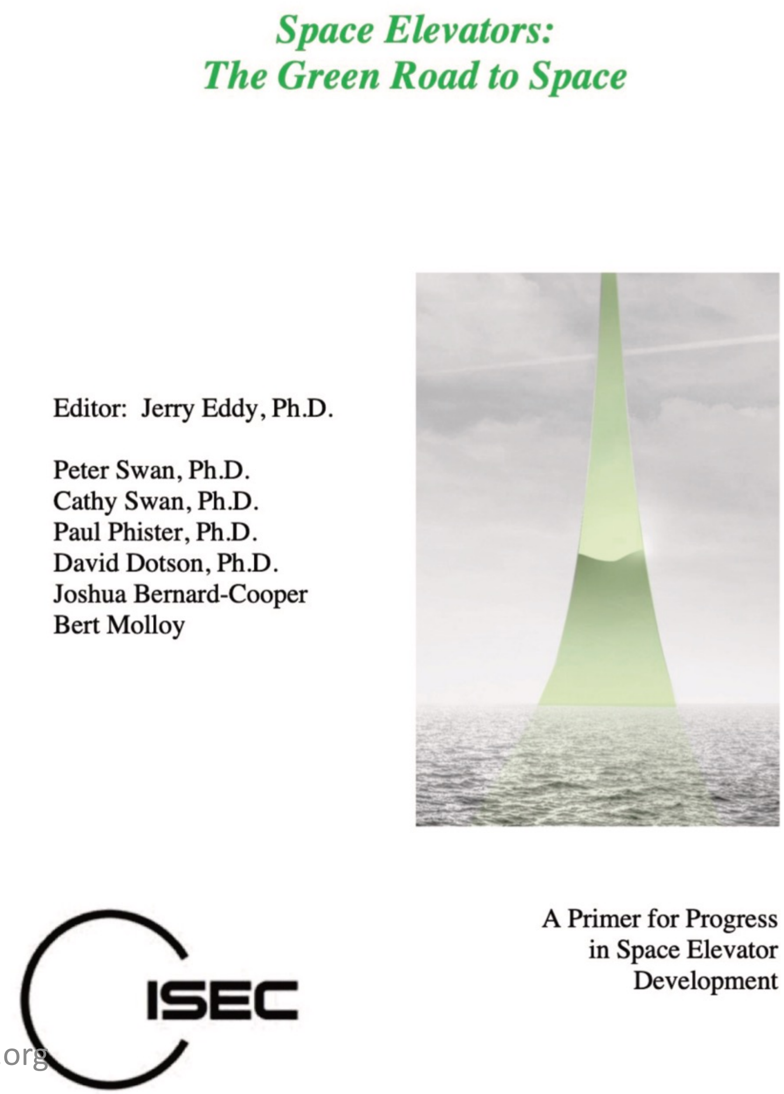
Massive tonnage* raised by electricity to GEO and beyond, daily, routinely, inexpensively, safely, and in an Earth Friendly manner.

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

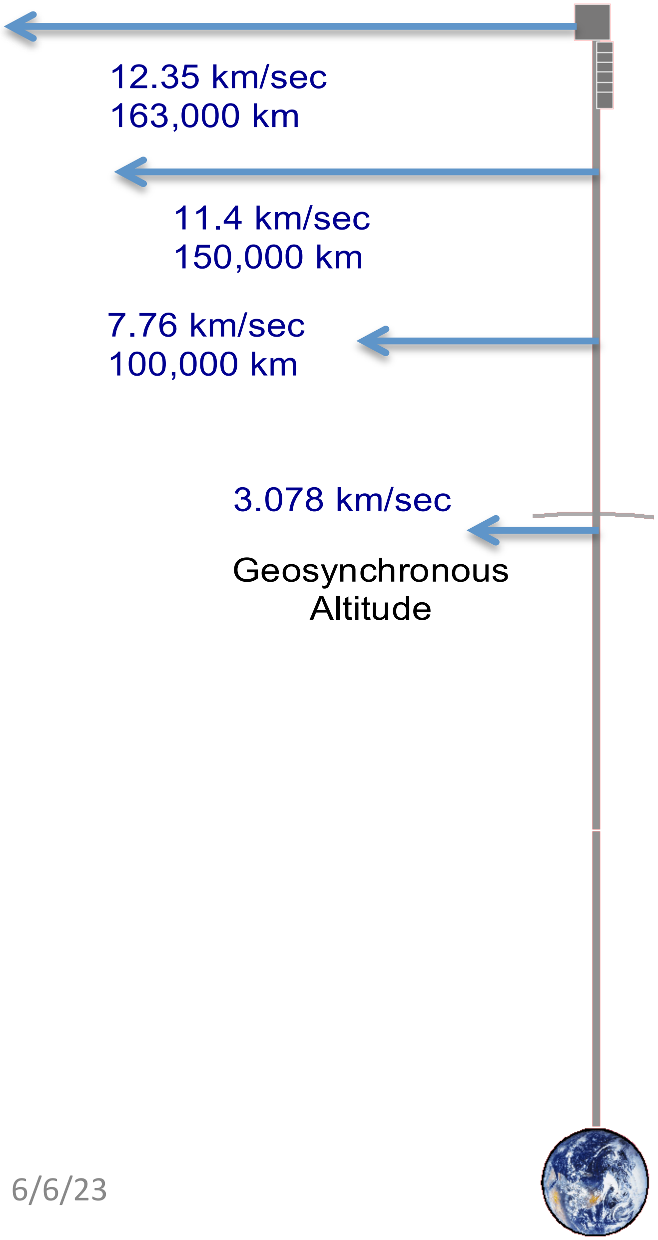
Editor: Jerry Eddy, Ph.D.

Peter Swan, Ph.D.
Cathy Swan, Ph.D.
Paul Phister, Ph.D.
David Dotson, Ph.D.
Joshua Bernard-Cooper
Bert Molloy

A Primer for Progress
in Space Elevator
Development

ISEC

SETS Strength Five: *Unmatched 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).

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.

Voyagers Today

Launched 1977 – 46 years ago
Speed today - velocity of 15 km/s (V2) 17 km/s (V1)
Launch mass – 815 kg (V1) 721 kg (V2)
AU's from Earth – 154 (V1) 124 (V2)
Interstellar Space – Aug 2012 (V1) Nov 2019 (V2)

Proposal: Space Elevators have:

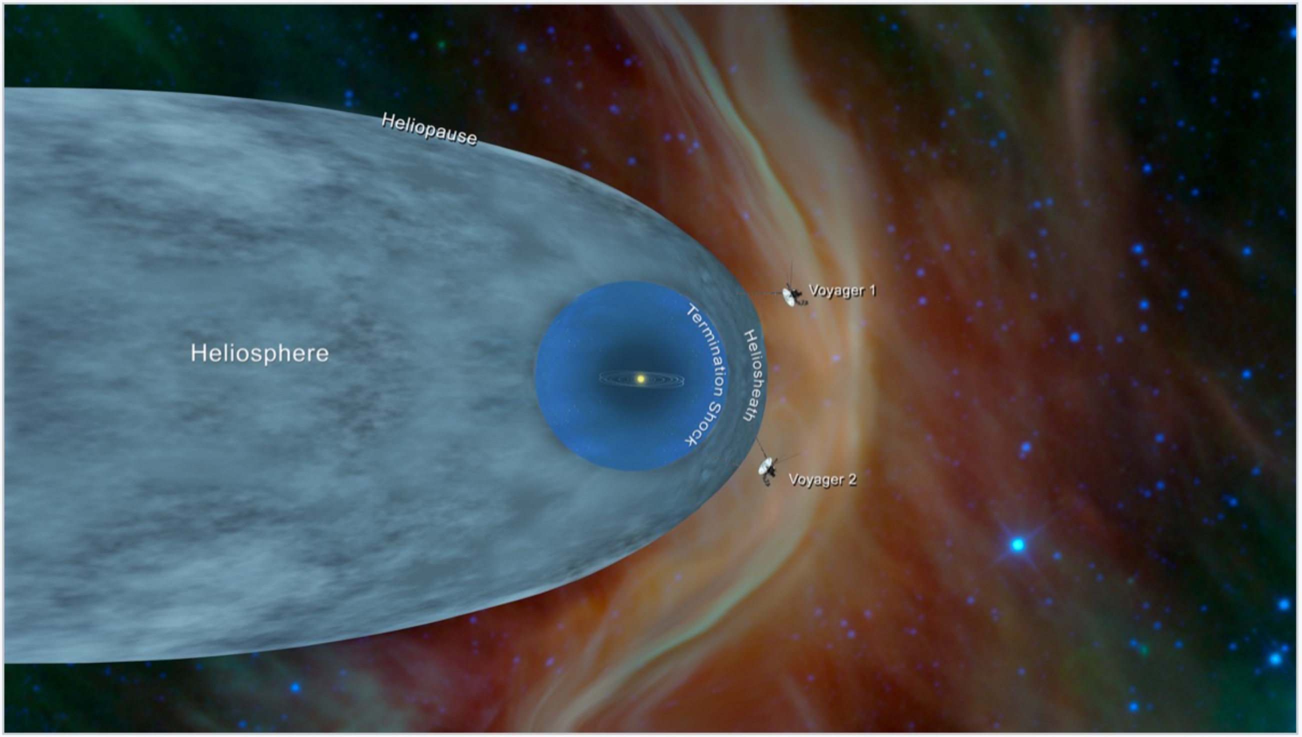
Unmatched Efficiencies
Unmatched Velocities
Unmatched Lift Capacities

Why: They have a
Permanent space
Transportation system

Voyager mass to launch vehicle mass = 0.001
Efficiency of less than 1/10 of one percent

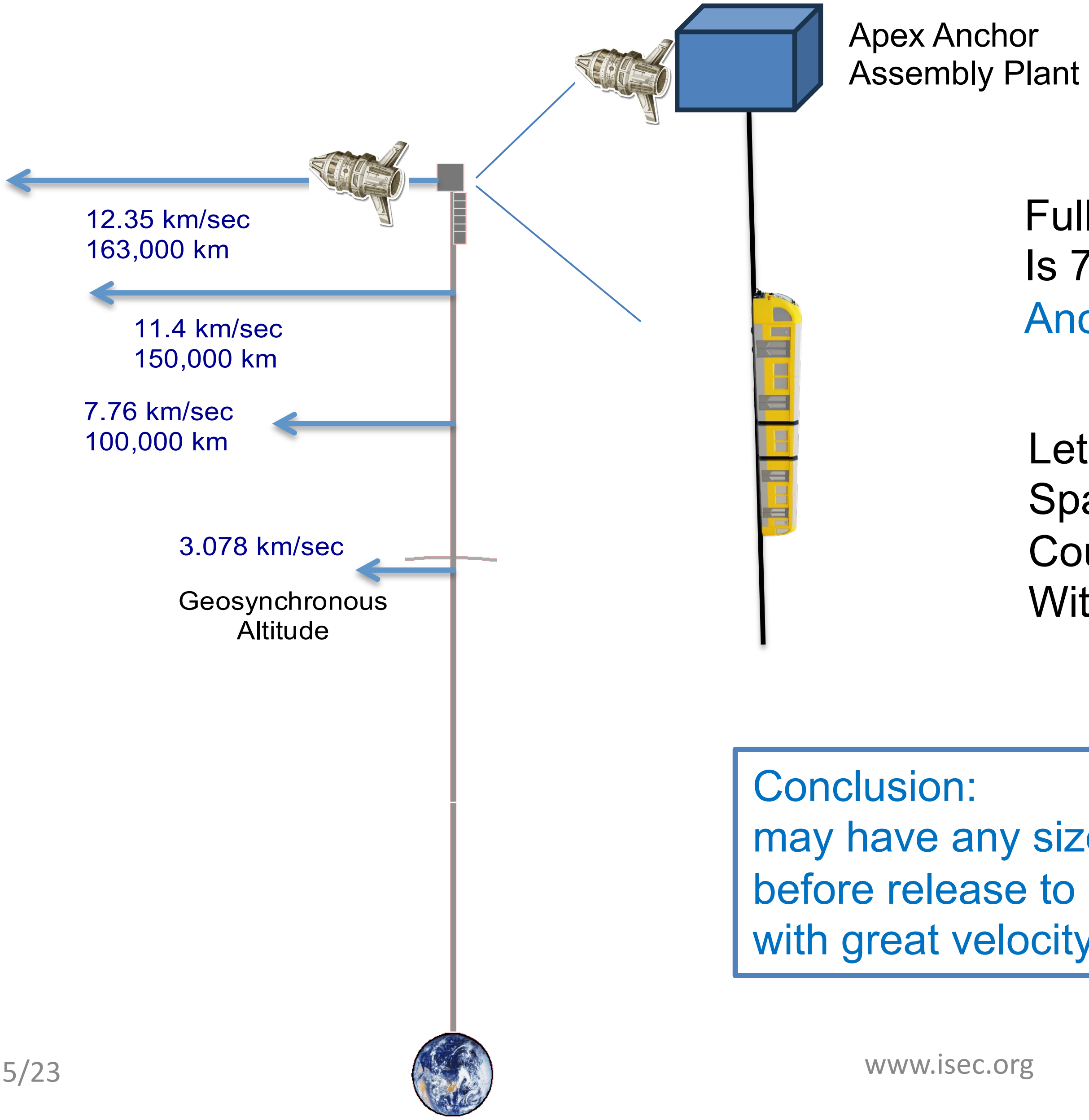
Space Elevators = 70%

From NASA's website



Voyager 1 crossed the heliopause, or the edge of the heliosphere, in August 2012.
Voyager 2 crossed the heliosheath in November 2018.[6][42]

Assembly above Gravity Well



Fully Operational Capacity
Is 79 tonnes per day to Apex Anchor Assembly Plant (2048)

Lets say an Interstellar
Spacecraft ready to release
Could weigh 28,835 tonnes
With one year of daily lifts

Conclusion: The interstellar scientist may have any size space system assembled before release to beyond the solar system with great velocity.

Spacecraft image -- Image by brgfx on Freepik

19 years to reach 100 AU With Huge S/C

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

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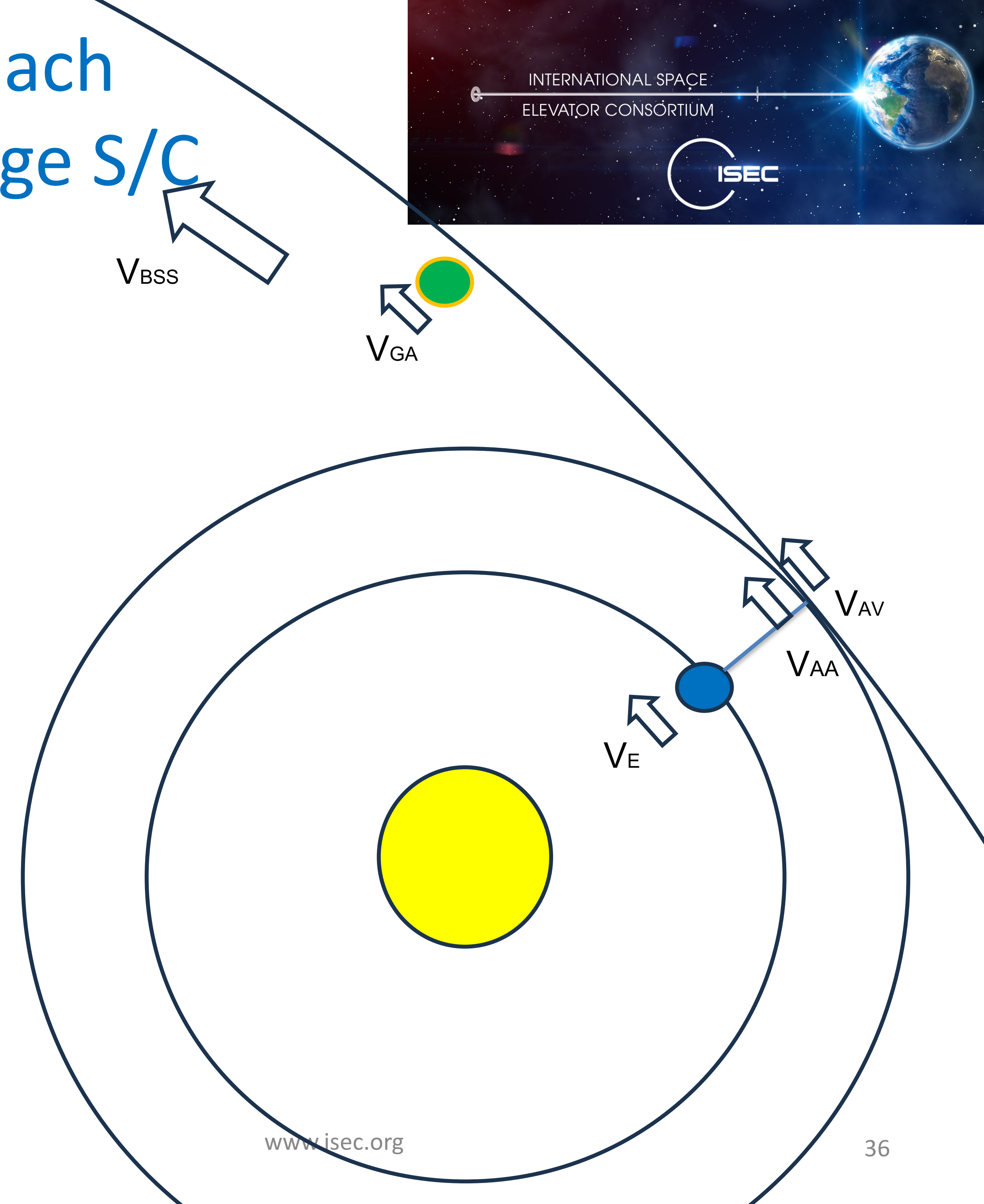
	Type of Velocity	km/sec
V_{BSS}	Velocity beyond Solar System	25.25
V_{GA}	Velocity with Gravity Assist	15
V_{AV}	Added Velocity at Tip	10
V_{AA}	Velocity at Apex Anchor	12.35
V_E	Velocity of Earth	30
V_{SS}	Velocity to Escape solar system	42.1



Research into Transformational Leap

- Vision and Dreamers
- Transformational Characteristics
- ***Research Topics***
- Engineering Status
- Summary

Research Topics

- Analysis of Preliminary Technological Feasibility – completed
- Analysis of Mission Supportability
  - Design of Support to GEO and Apex Anchor missions
- Analysis of Lift Efficiency and Capacity
  - Design of Space Elevator as Transportation System
  - Design of Tether Climber
  - Design of Tether
- Analysis of Stability and Lifetime

ISEC Studies

Table 1, Study Summaries, ISEC

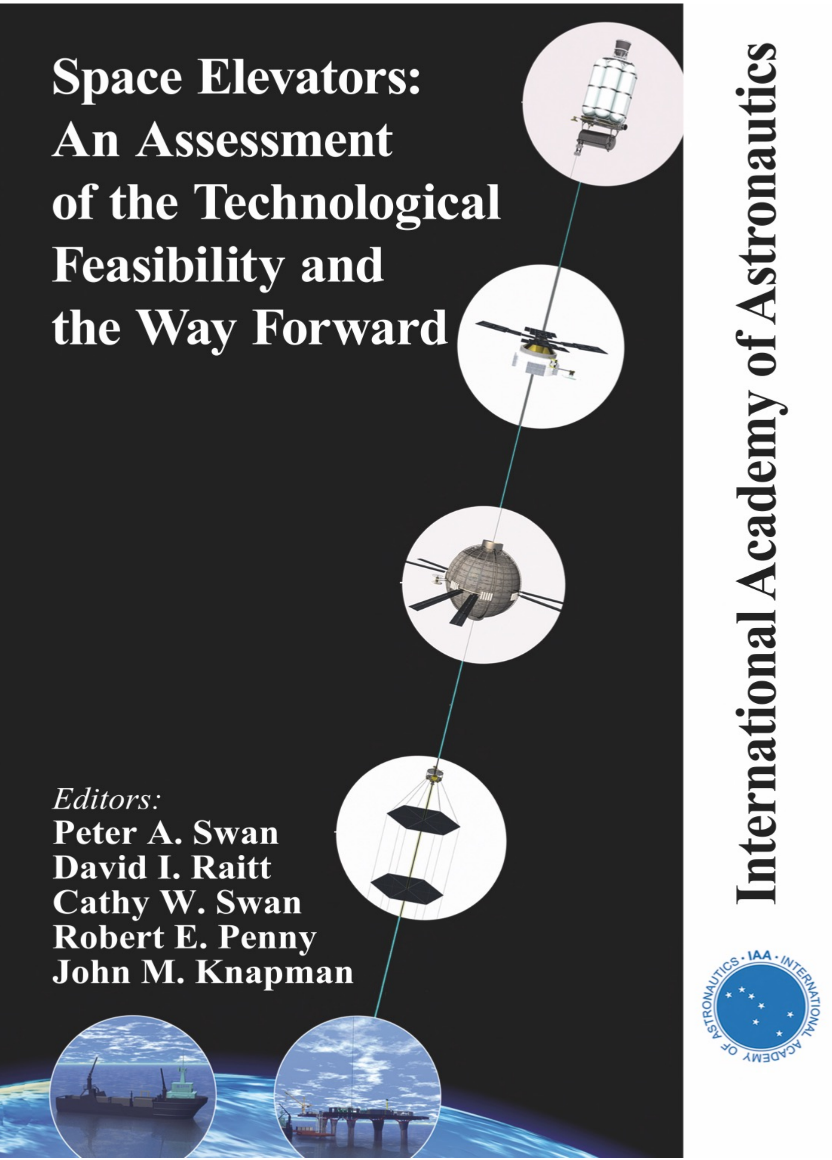
Year	*Title of ISEC Yearly Study Reports (www.isec.org/studies)*
2021	Design Considerations for the Space Elevator Climber-Tether Interface of the Space Elevator- just starting in progress
2021	Beneficial Environmental Impacts of the Space Elevator - in workSpace Elevators are the Green Road to Space
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)

Analysis of Preliminary Technological Feasibility

“Space Elevators are Feasible.”



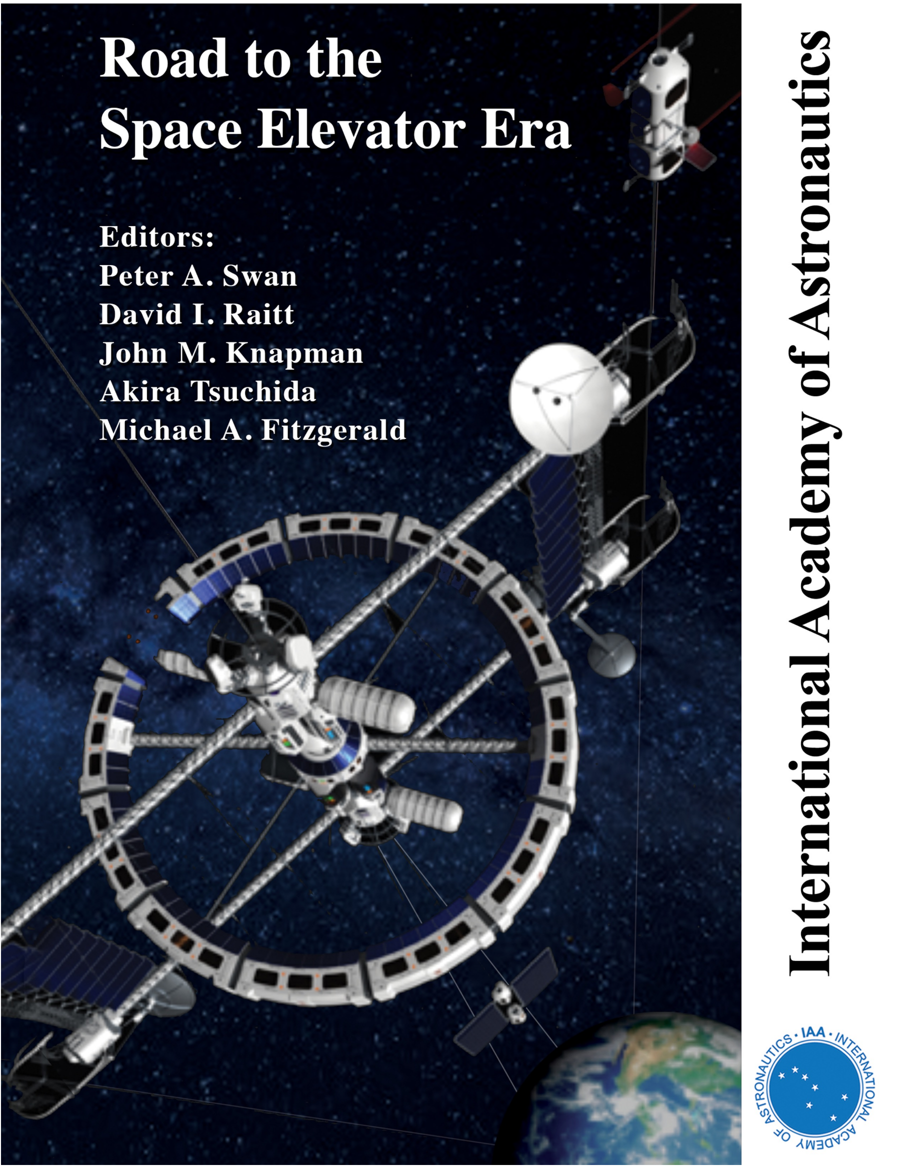
Space Elevators: An Assessment of the Technological Feasibility and the Way Forward

Editors:
Peter A. Swan
David I. Raitt
Cathy W. Swan
Robert E. Penny
John M. Knapman

International Academy of Astronautics

2014

2019



Road to the Space Elevator Era

Editors:
Peter A. Swan
David I. Raitt
John M. Knapman
Akira Tsuchida
Michael A. Fitzgerald

International Academy of Astronautics

www.

Research into Transformational Leap

- Vision and Dreamers
- Transformational Characteristics
- Research Topics
- ***Engineering Status***
- Summary

Spacecraft for Space Elevator

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

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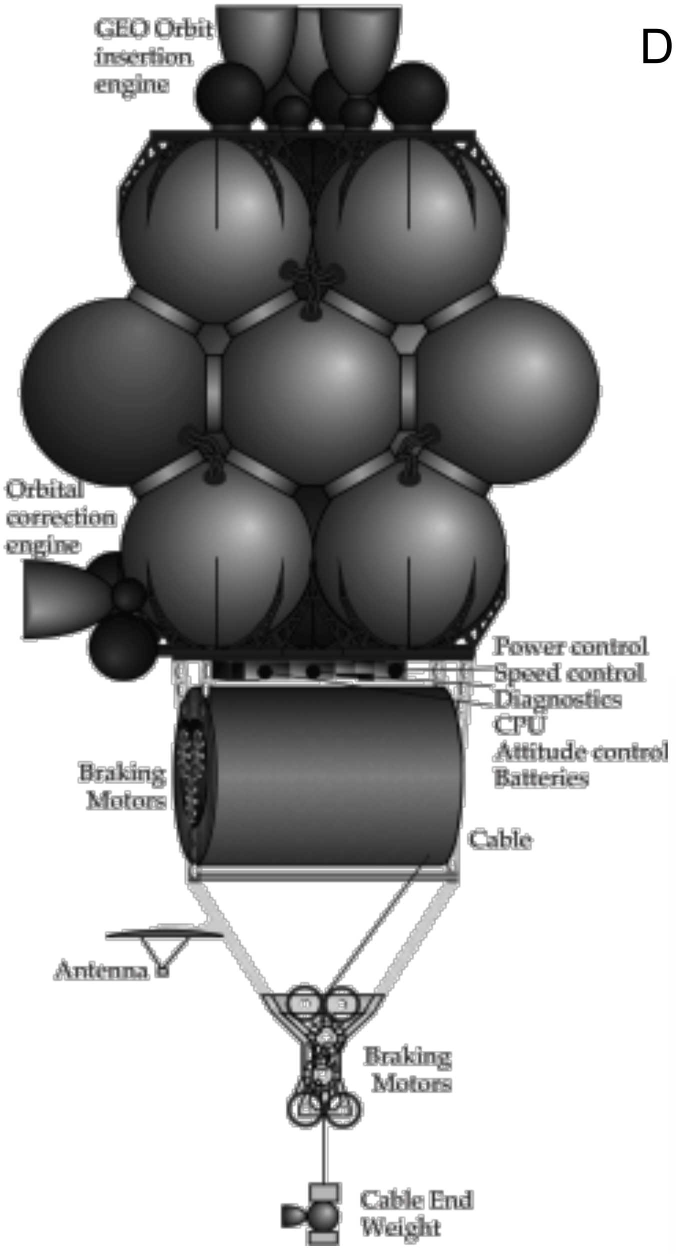
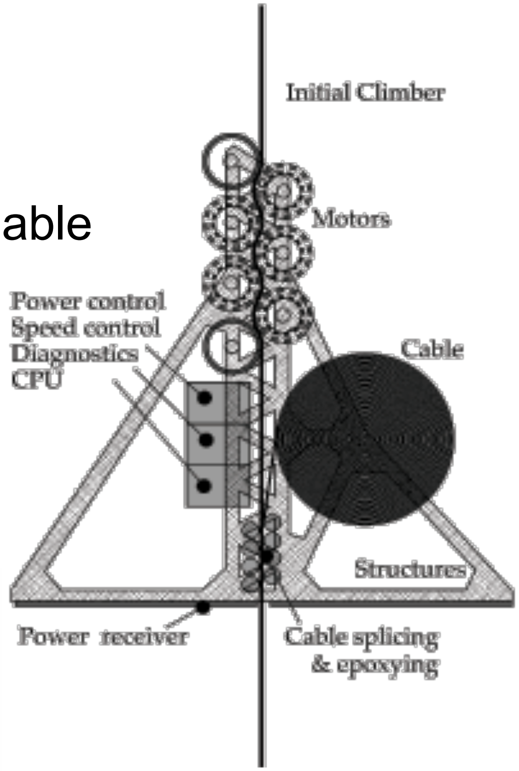
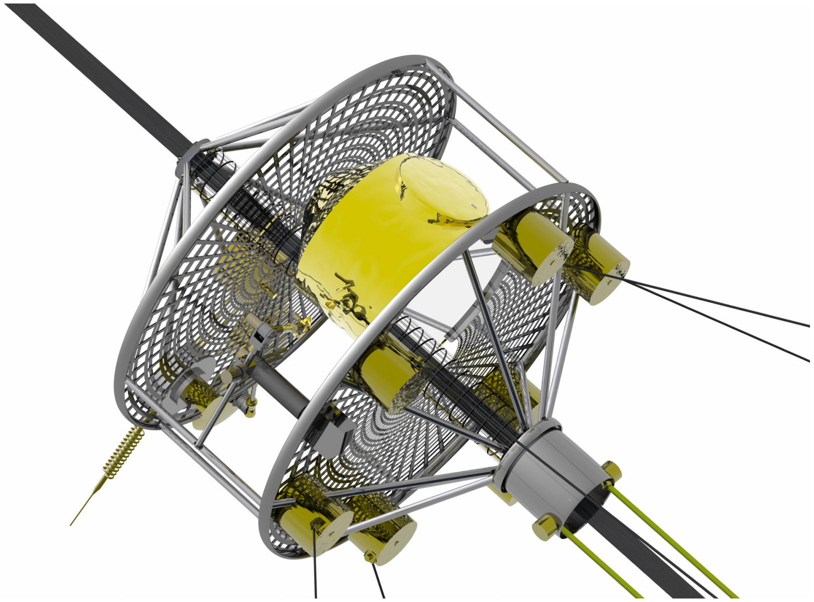


Deployment Spacecraft
& Future Apex Anchor

Buildup Climber with Cable

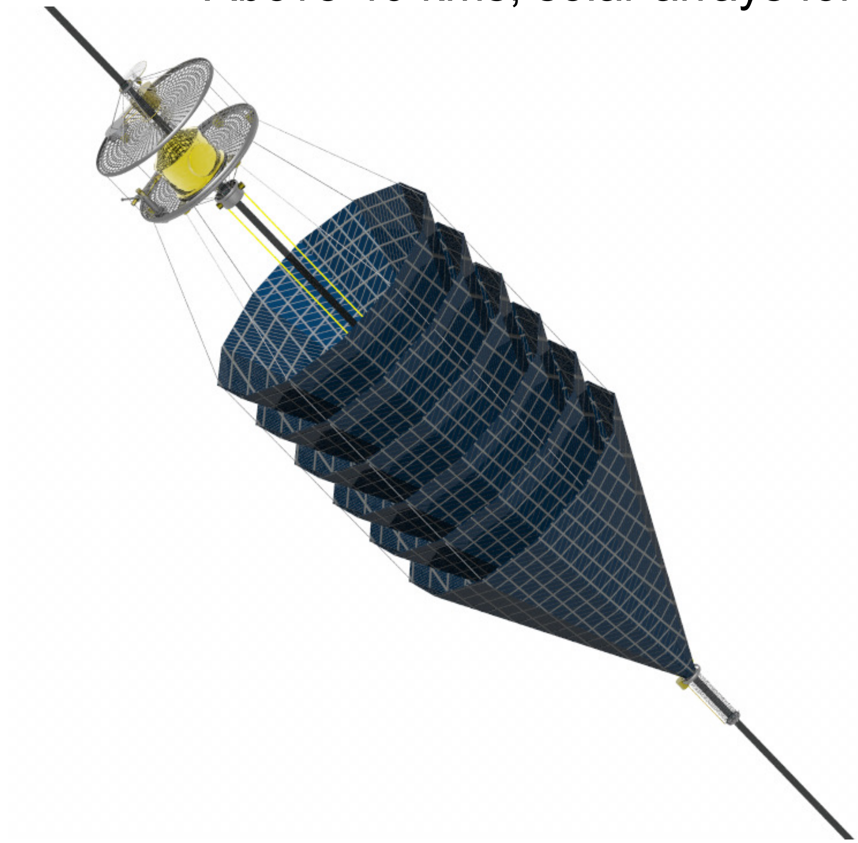


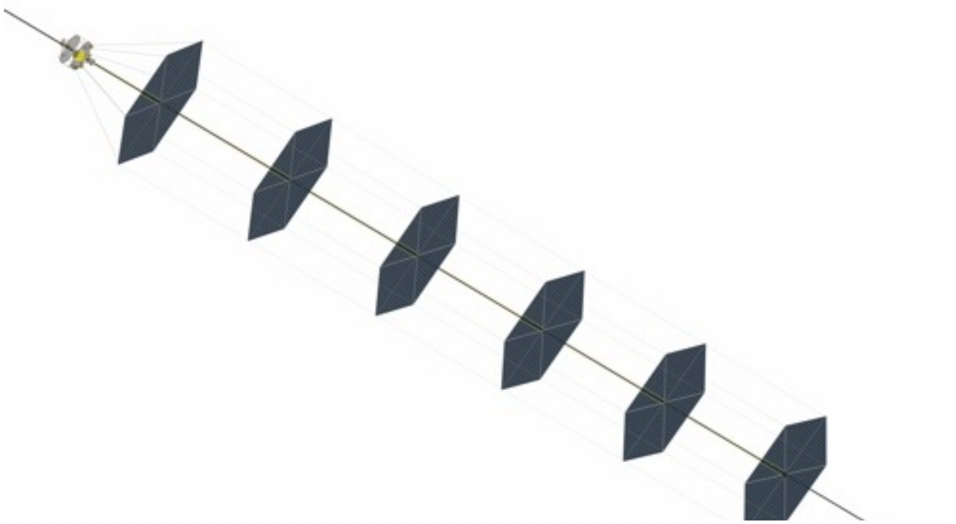
Baseline Tether Climber

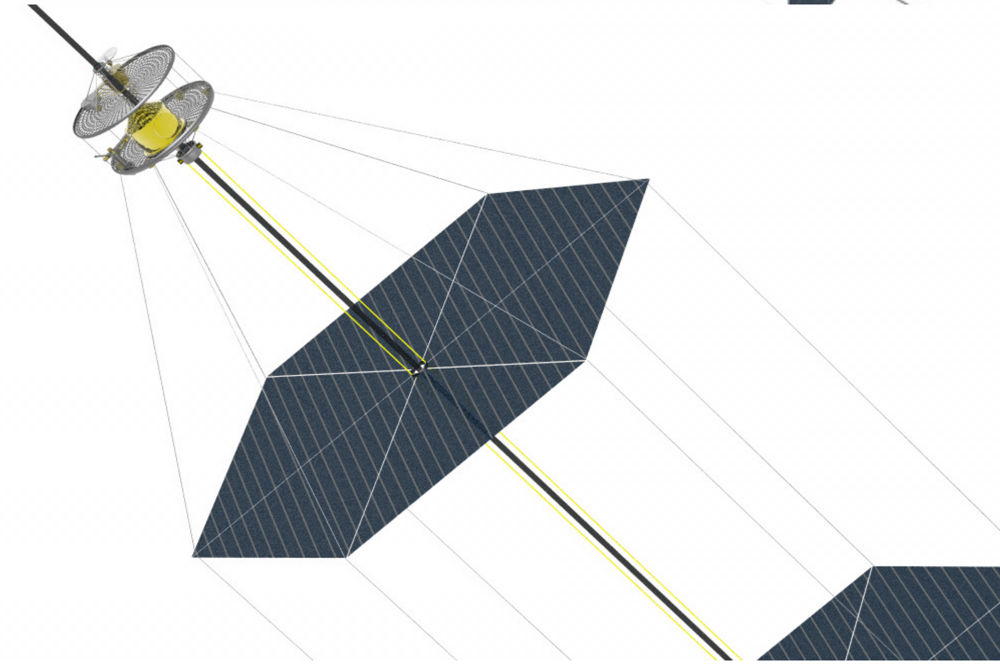


Tether Climber

First 40 kms protected through atmosphere
Above 40 kms, solar arrays for power

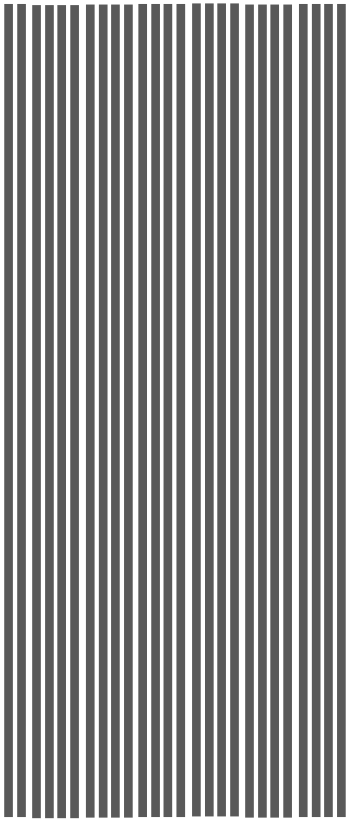






Images by chasedesignstudios.com

Graphene has the strength to make the space elevator tether



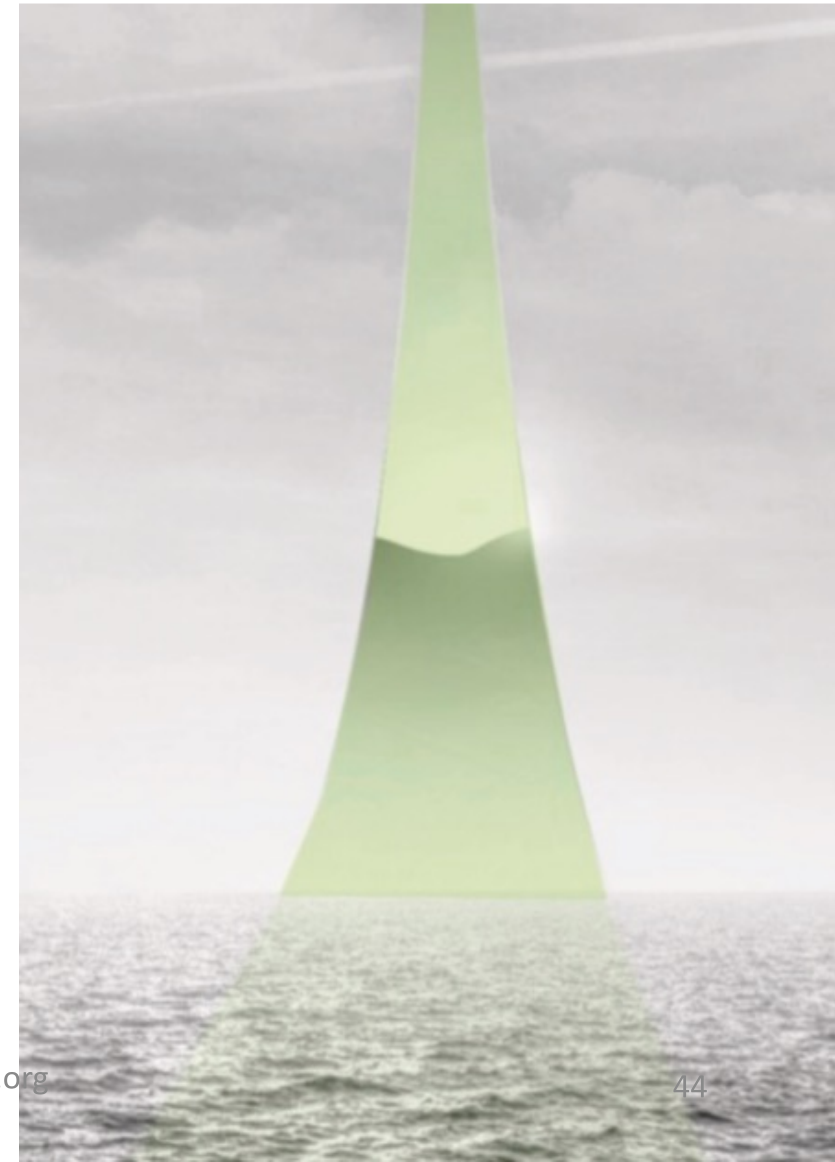
100 million metres long

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



Tether candidate materials

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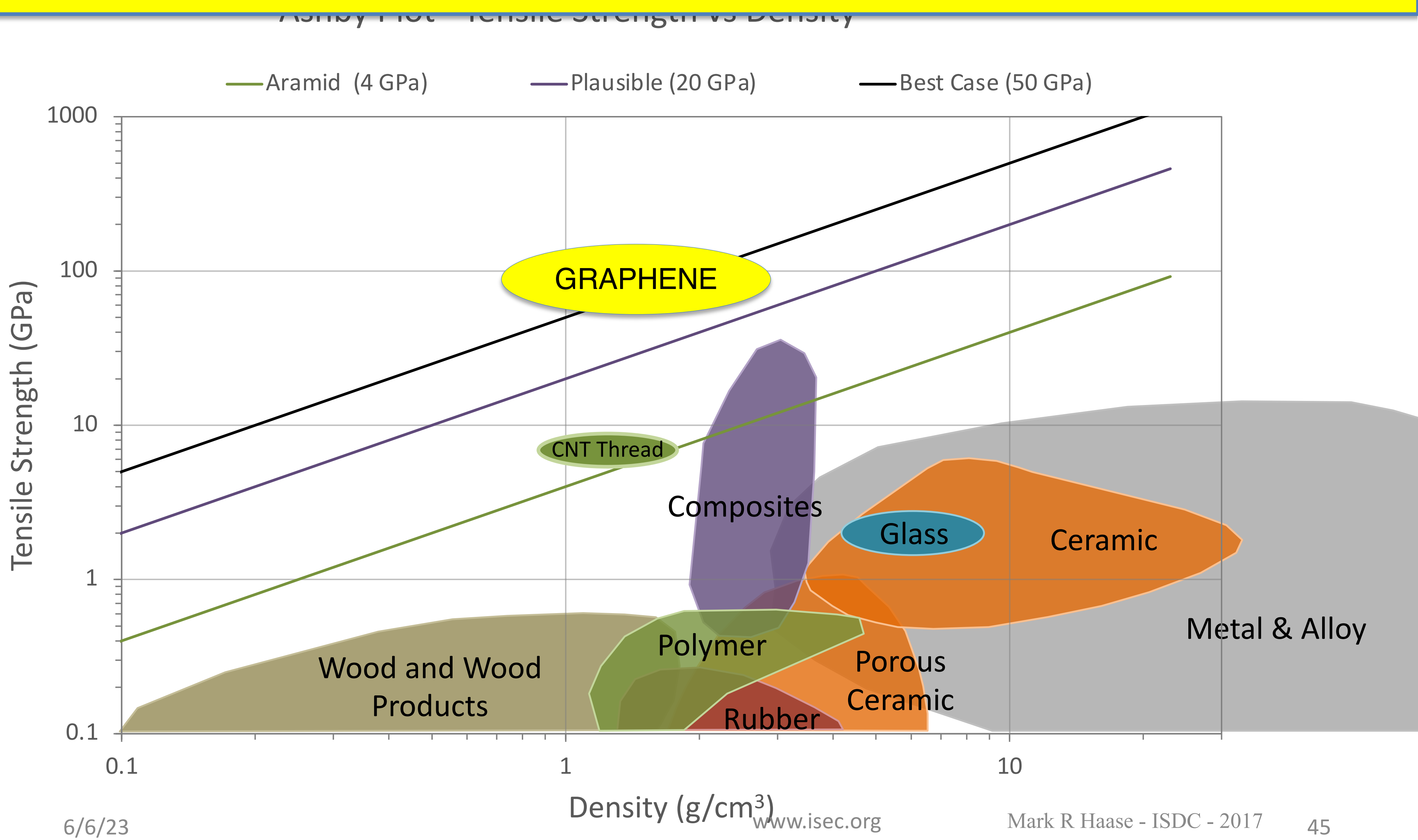
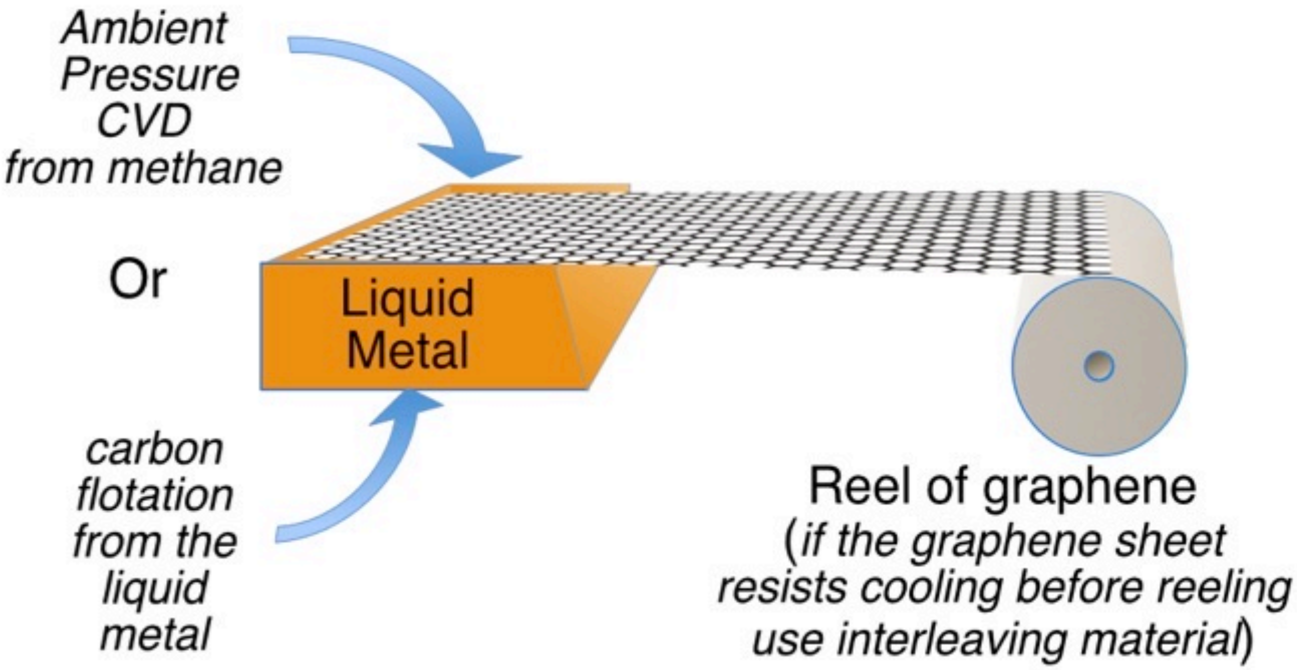
YES: Graphene is strong enough to be a candidate tether material



Graphene: A new continuous process

Principles for making continuous single crystal sheet graphene



Ambient Pressure CVD from methane

Or

carbon flotation from the liquid metal

Reel of graphene
(*if the graphene sheet resists cooling before reeling use interleaving material*)

I published the hypothesis to test it amongst the world’s top graphene scientists. (While retaining key intellectual property)

This hypothesis has not been invalidated to date.

https://investorintel.com/market-analysis/making-graphene-2d-materials-liquid-

Graphene: A new continuous process

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

Nixene Journal
Vol 6 iss 6

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].

Image Credit: General Graphene

LG Electronics Inc – Industrial Scale Graphene Sheets

Industrial scale manufacture of graphene
Speeds of m/min and kilometre lengths

ISEC

Graphene roll to roll manufacture Image credit: LG

LG can make CVD sheet graphene at:

- Speed of 1 metre per minute
- Lengths up to 1 kilometre
- On copper foil 400 mm wide

Graphene roll to roll transfer to polymer film, Image credit: You Tube and CharmGraphene

Charmgraphene can make CVD sheet graphene at:

- Speed of 2 metres per minute
- Lengths up to 1 kilometre
- On copper foil 300 mm wide

Source:
https://nano.market/news/graphene/charmgraphene-starts-mass-producing-cvd-graphene-using-a-roll-to-roll-process/
https://www.youtube.com/watch?v=NcTPjBIAbGE [Accessed 29th May 2022]

NixeneJournal

Tether manufactured on earth, assembly in orbit

INTERNATIONAL SPACE
ELEVATOR CONSORTIUM
ISEC

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How big is a reel of single crystal graphene 1m wide 100,000km long? (One continuous layer of tether)

20 mm core
1000 mm wide
300 mm Diameter

How much would it weigh?

77 kg

Density of graphene 0.77mg m^{-2}
https://www.nobelprize.org/nobel_prizes/physics/laureates/2010/advanced-physicsprize2010.pdf

Dr Peter Clark helped with the calculations
https://www.linkedin.com/in/peter-clark-30ab9221/

Is a tether made from single crystal graphene feasible?

Current commercial nanoplate graphene cannot be used to make a tether.

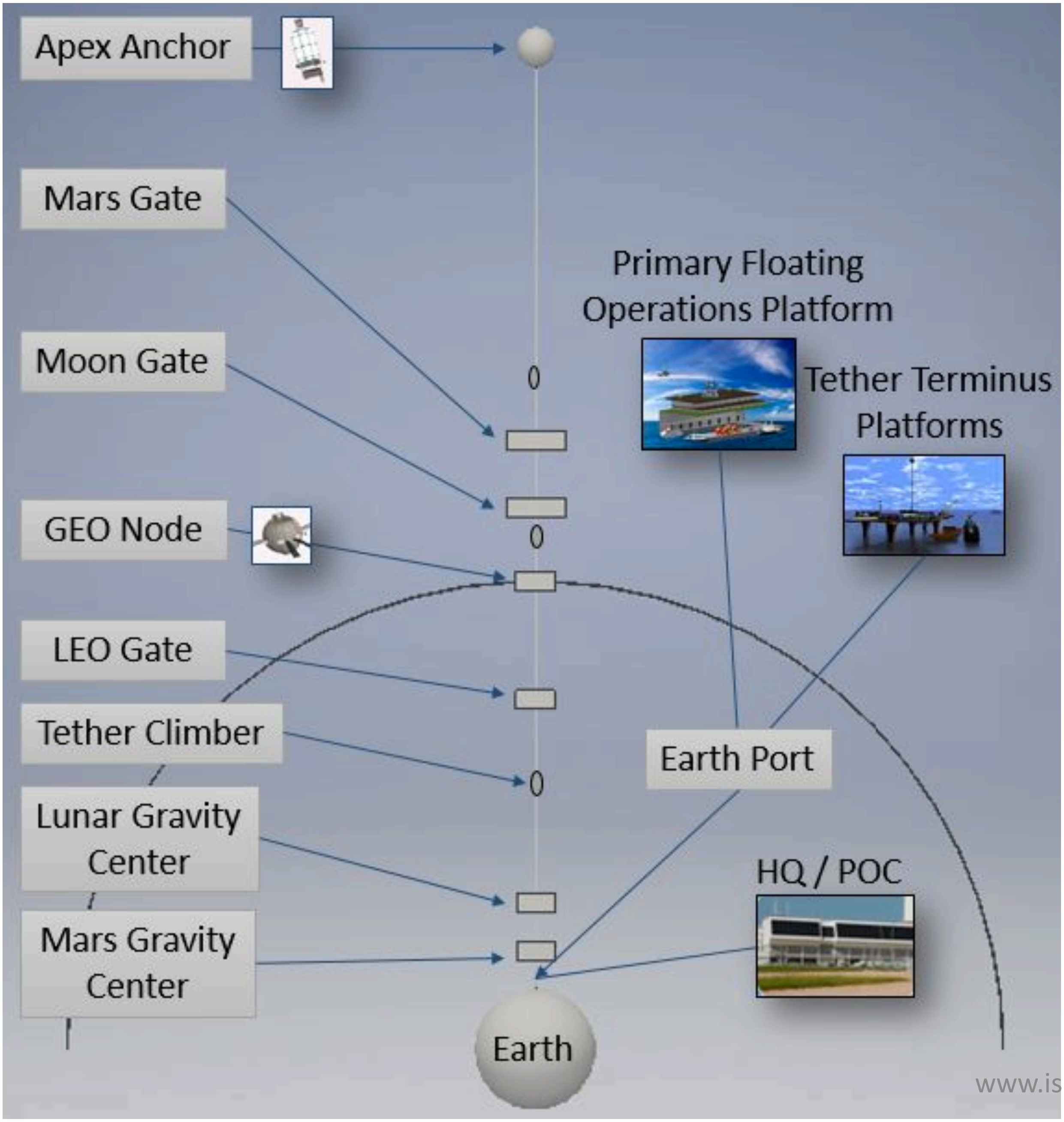
However, 500mm of single crystal graphene has been made 13 years after graphene first isolated.

Layered single crystal graphene is yet to be made but we know how to do this and the material is already being called Nixene

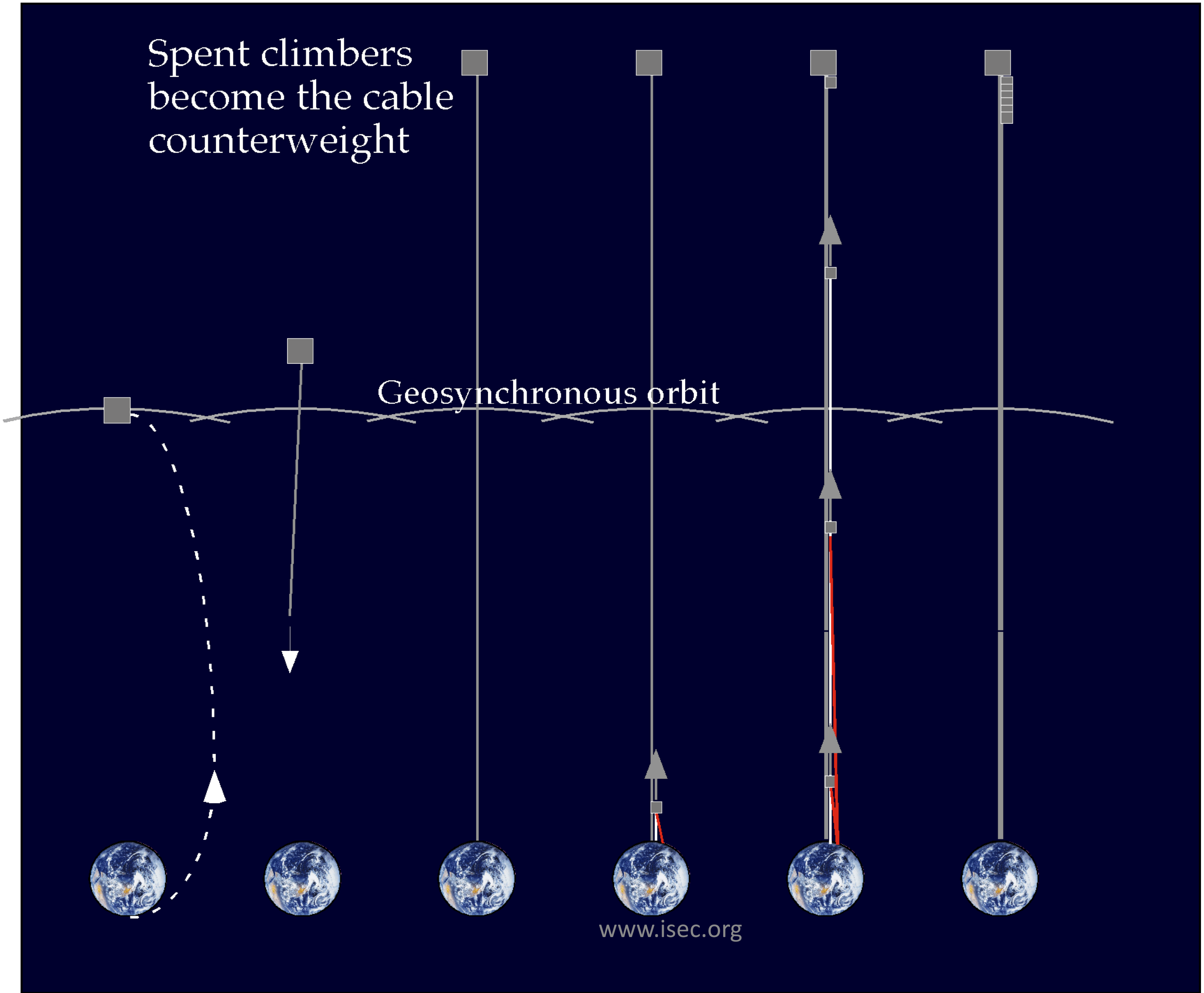
YES

Graphene tether material really is possible within our lifetimes.

System Overview

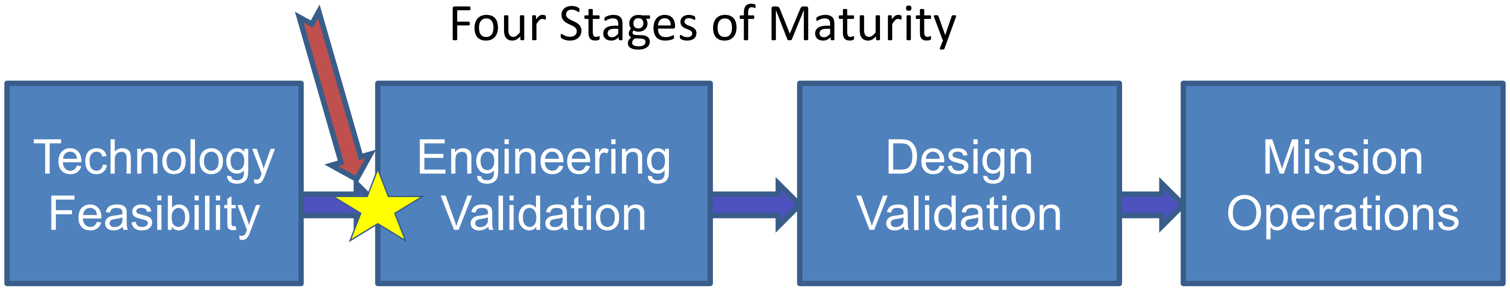


Deployment Overview



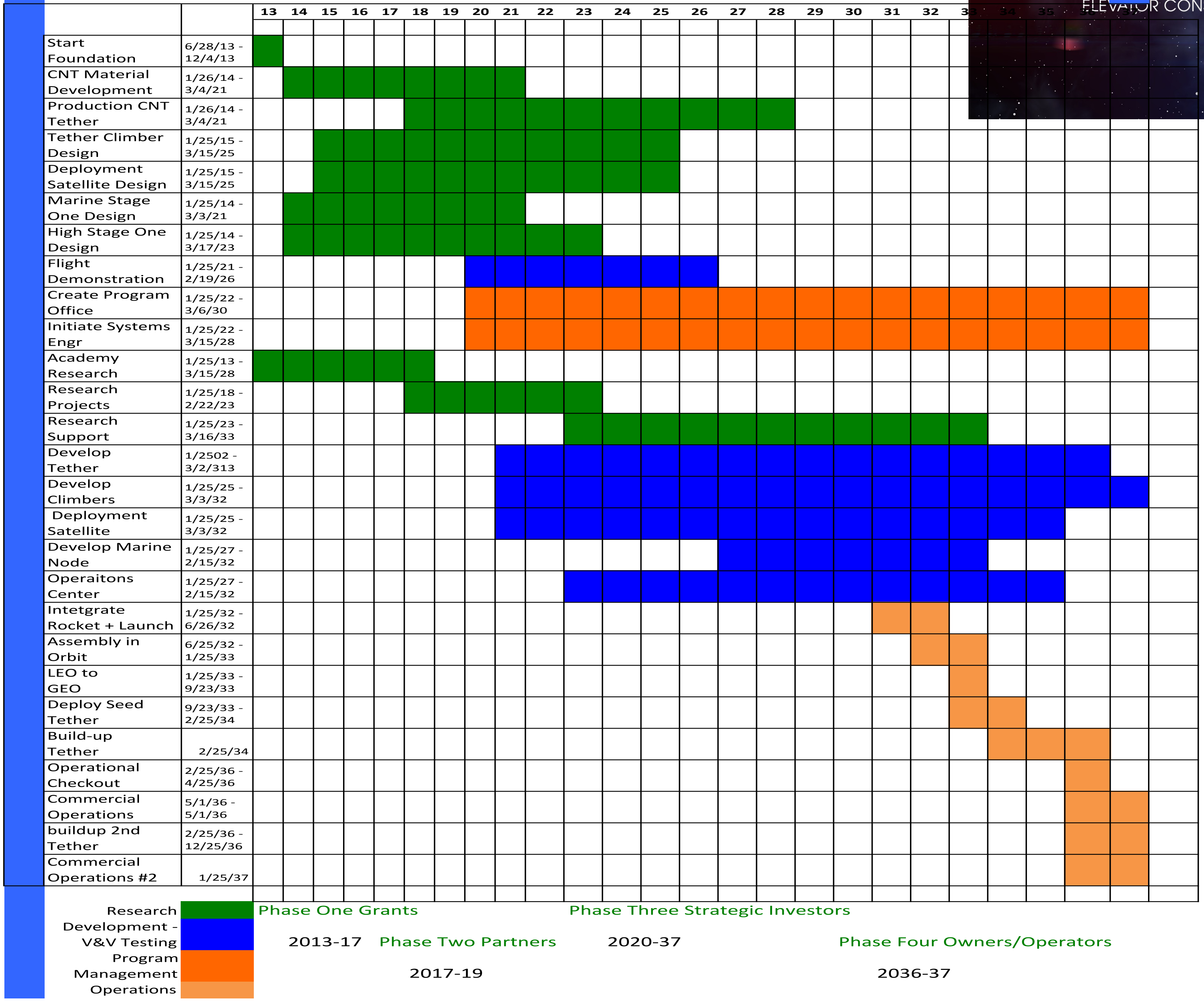
The Space Elevator has Entered Engineering Validation!

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.

Space Elevator Roadmap



		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Start Foundation	6/28/13 - 12/4/13	🟩																									
CNT Material Development	1/26/14 - 3/4/21		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																	
Production CNT Tether	1/26/14 - 3/4/21						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩										
Tether Climber Design	1/25/15 - 3/15/25			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩													
Deployment Satellite Design	1/25/15 - 3/15/25			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩													
Marine Stage One Design	1/25/14 - 3/3/21		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																	
High Stage One Design	1/25/14 - 3/17/23		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩															
Flight Demonstration	1/25/21 - 2/19/26								🟦	🟦	🟦	🟦	🟦	🟦	🟦												
Create Program Office	1/25/22 - 3/6/30								🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Initiate Systems Engr	1/25/22 - 3/15/28								🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Academy Research	1/25/13 - 3/15/28	🟩	🟩	🟩	🟩	🟩	🟩																				
Research Projects	1/25/18 - 2/22/23						🟩	🟩	🟩	🟩	🟩	🟩															
Research Support	1/25/23 - 3/16/33											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Develop Tether	1/2502 - 3/2/313									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Develop Climbers	1/25/25 - 3/3/32									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Deployment Satellite	1/25/25 - 3/3/32									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Develop Marine Node	1/25/27 - 2/15/32															🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Operaitons Center	1/25/27 - 2/15/32											🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Intetgrate Rocket + Launch	1/25/32 - 6/26/32																			▨	▨						
Assembly in Orbit	6/25/32 - 1/25/33																				▨	▨					
LEO to GEO	1/25/33 - 9/23/33																					▨					
Deploy Seed Tether	9/23/33 - 2/25/34																					▨	▨				
Build-up Tether	2/25/34																						▨	▨	▨		
Operational Checkout	2/25/36 - 4/25/36																								▨		
Commercial Operations	5/1/36 - 5/1/36																								▨	▨	
buildup 2nd Tether	2/25/36 - 12/25/36																								▨	▨	
Commercial Operations #2	1/25/37																								▨	▨	

Research 🟩
Development - V&V Testing 🟦
Program Management 🟧
Operations ▨

Phase One Grants 2013-17
Phase Two Partners 2017-19
Phase Three Strategic Investors 2020-37
Phase Four Owners/Operators 2036-37

Figure 11- 1. Space Elevator Roadmap A

The Earth Port's Floating Operations Platform

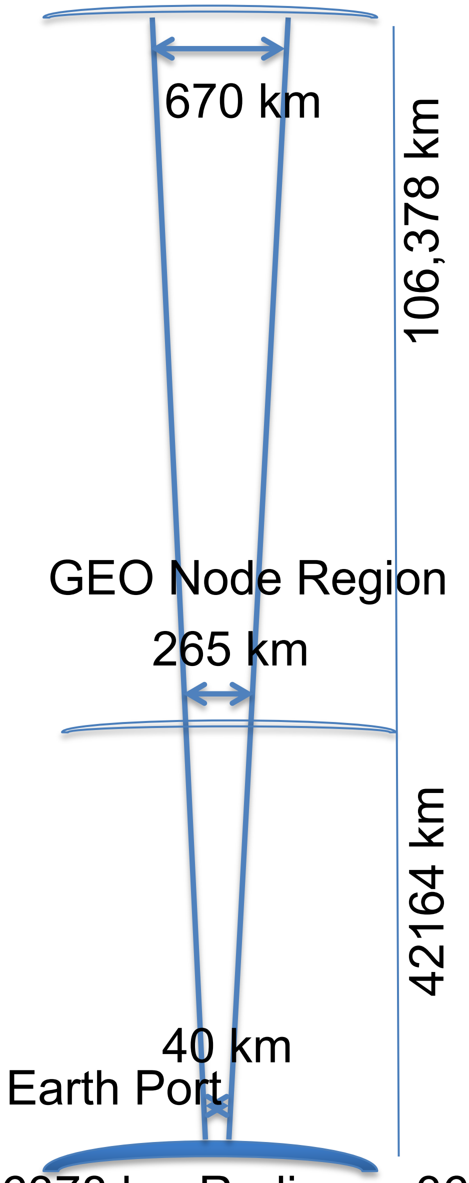
(As Presently Envisioned)

Mid Ocean cargo handling and crew housing with modern capabilities for operations, communications, and relocation.

- Container shipments handling
- Semi-submersible design for stability
- Ocean going barges and helicopter operations enlarges support footprint

Modern Day Space Elevator

Apex Anchor Region



670 km

106,378 km

GEO Node Region

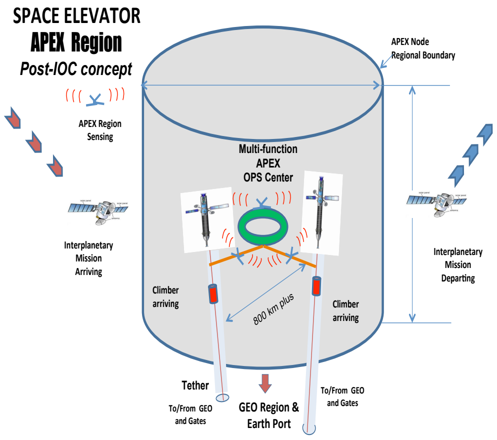
265 km

42164 km

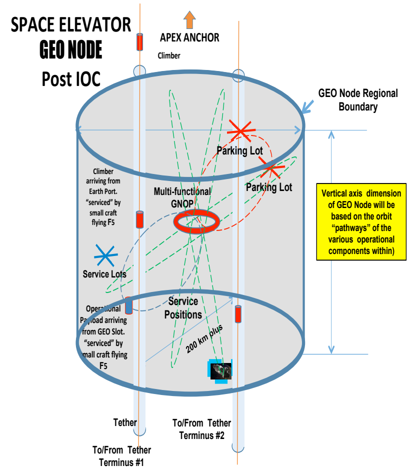
40 km

Earth Port

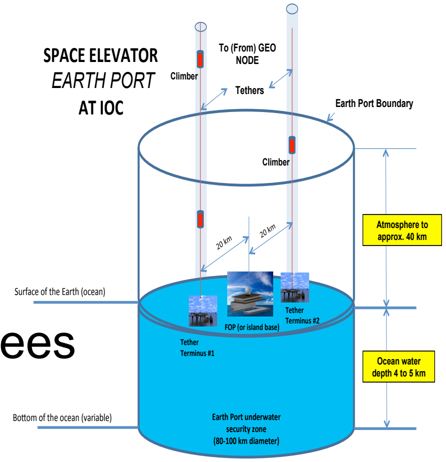
6378 km Radius = .36 degrees



SPACE ELEVATOR
APEX Region
Post-IOC concept



SPACE ELEVATOR
GEO NODE
Post IOC



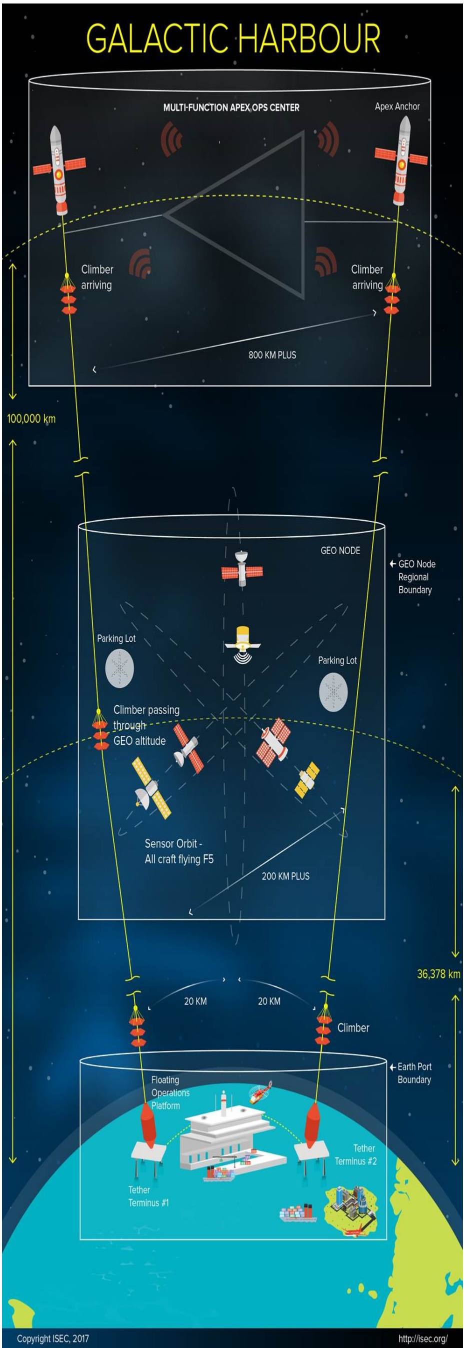
SPACE ELEVATOR
EARTH PORT
AT IOC

- 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, powered with solar power with 1-meter wide tether
- Three Regions,
  Earth Port – GEO – Apex Anchor
  Where commercial ventures will grow

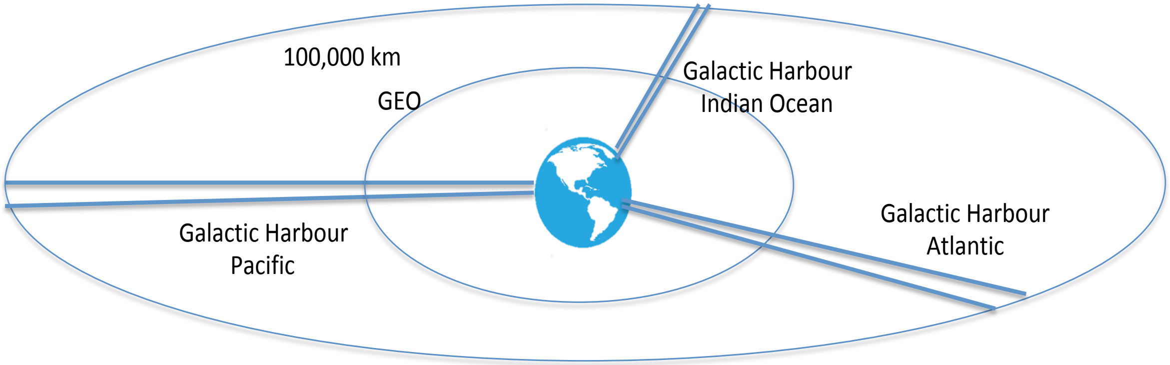
Research into Transformational Leap

- Vision and Dreamers
- Transformational Characteristics
- Research Topics
- Engineering Status
- ***Summary***

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



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)

Reference Missions:

- 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

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

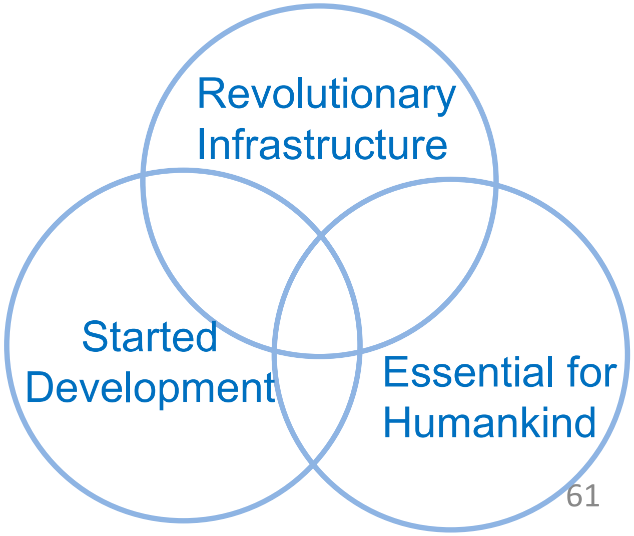
Space Elevator Strengths: As permanent infrastructure they lead to daily, routine, massive, environmentally friendly, and inexpensive departures towards mission destinations

Minimizing the Rocket Equation Limitations

Visions of Many Demand Space Elevators Start NOW!

- Space Elevators can Enable the needs and visions of many!
- They provide massive cargos to GEO and beyond
- SE are the Green Road to Space
- Dual Space Access Strategy is a collaborative approach
- A testing and demonstration development program for Space Elevators has started

Art by
A. Stanton


Revolutionary Infrastructure

Started Development

Essential for Humankind

Why Space Elevators? Because we Must!

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC

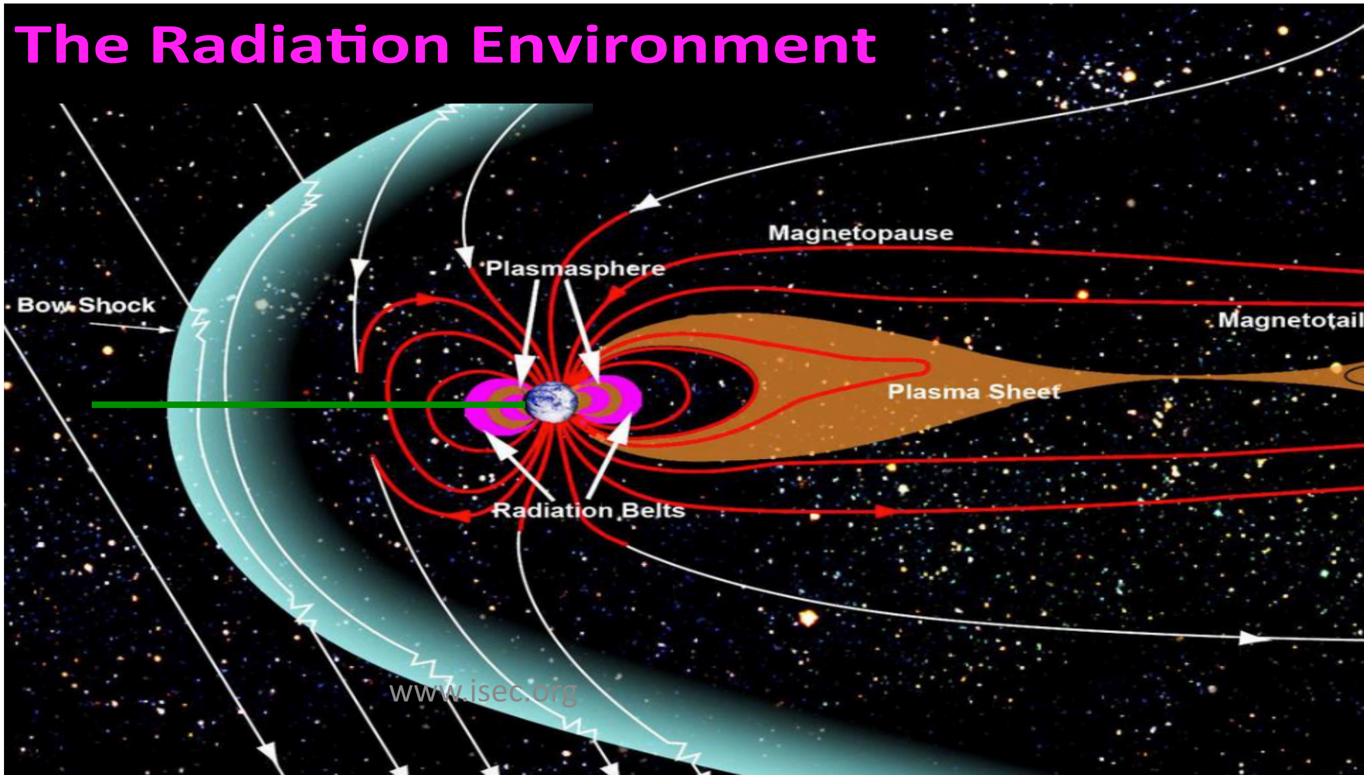
- Fulfills the Dreams of Many
- Raises Massive Cargo using Solar Energy
  - Green Road to Space
  - Permanent Infrastructure for GEO & Beyond
  - Daily, Routine, Safe, and Inexpensive
  - Early Operations: 30,000 tonnes per year
- Space Elevators are a Simple Elegant Solution to the Rocket Equation.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

How the Space Elevator Grew into a Galactic Harbour?

Backup Charts

Earth Radius
6,378 Km

Space
Elevator
100,000 km
In green



Eleven Videos Explaining Modern Day Space Elevators

Modern Space Elevator Explanations	***Speaker***
Dreaming of Space? Take a Space Elevator	Pete Swan
Why Space Elevators and Customer Demands/Visions?	Pete Swan
Architectural Features of Galactic Harbours	Michael Fitzgerald
Green Road to Space Leads to Environmentally Friendly Lifts	Jerry Eddy
Space Solar Power Enabled by Space Elevators	David Dotson
Economic Benefits of Space Elevators	Kevin Barry
Graphene is Last Puzzle for Development	Adrian Nixon
Dual Space Access Architecture – Complementary to Rockets	Pete Swan
Tremendous Body of Knowledge about Space Elevators	Dennis Wright

All videos at: https://www.isec.org/ready-to-go

Several more videos and podcasts are or will be up on site.