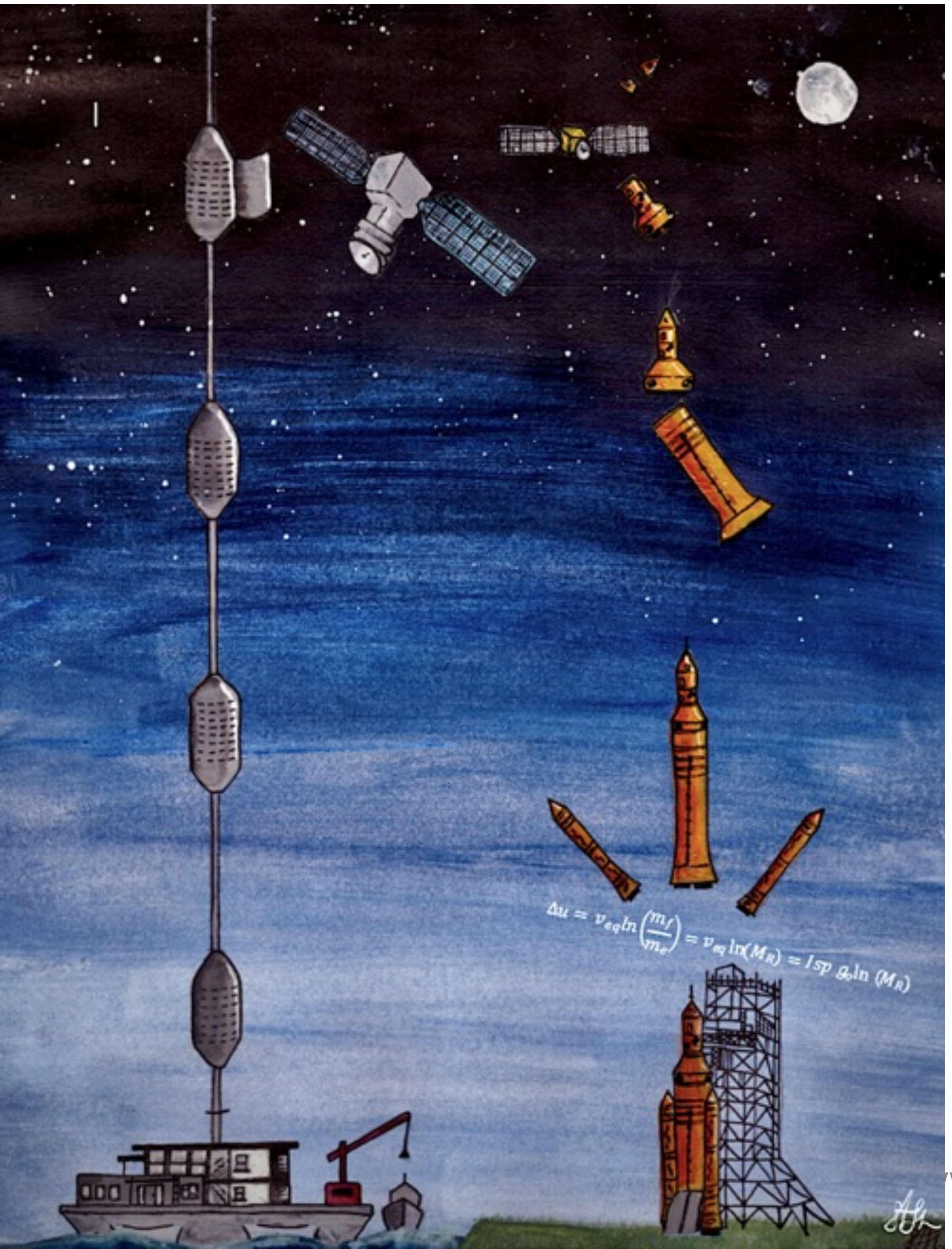
Dreaming Of Space:
Take a Space Elevator



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Co-editor, IAA Study, Space Elevator Feasibility
Former Chairman, Commission VI - IAA
Member, National Space Society
Professor Emeritus, Teaching Science and Technology, Inc.
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Past Industry Professor, Delft Technical University
Past Member, USAF Scientific Advisory Board [4 years]
Past Member, Army Science Board [10 years]
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A. Stanton Design

Space Elevator Vision and Approach

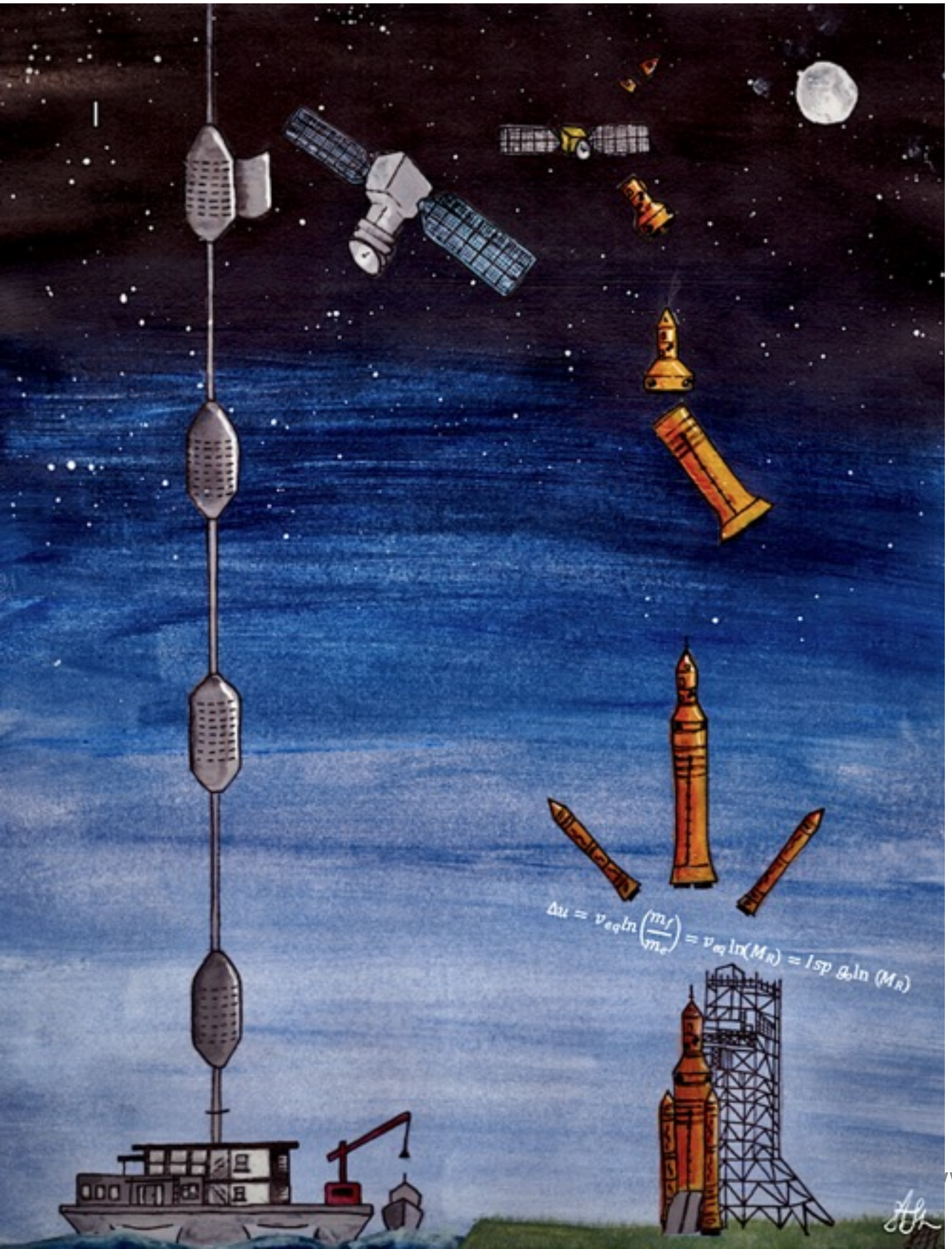
Vision: ***Space Elevators are the Green Road to Space while they enable humanity's most important missions by moving massive tonnage to GEO and beyond. This is accomplished safely, routinely, inexpensively, daily, and they are environmentally neutral.***

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.***

Modern Day Space Elevator



"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.

A. Stanton Design

Transformational Leap

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

The Future is Here

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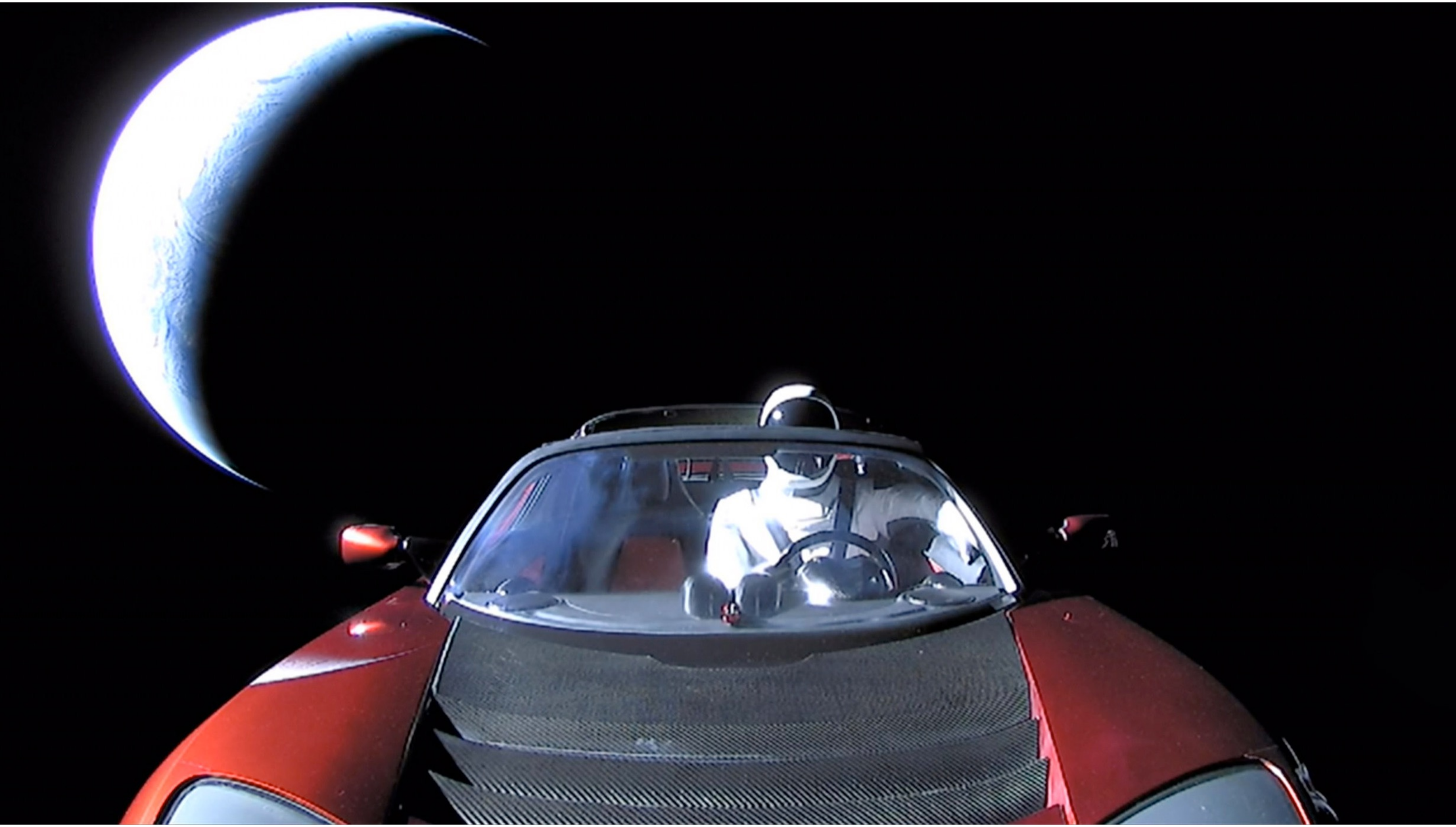
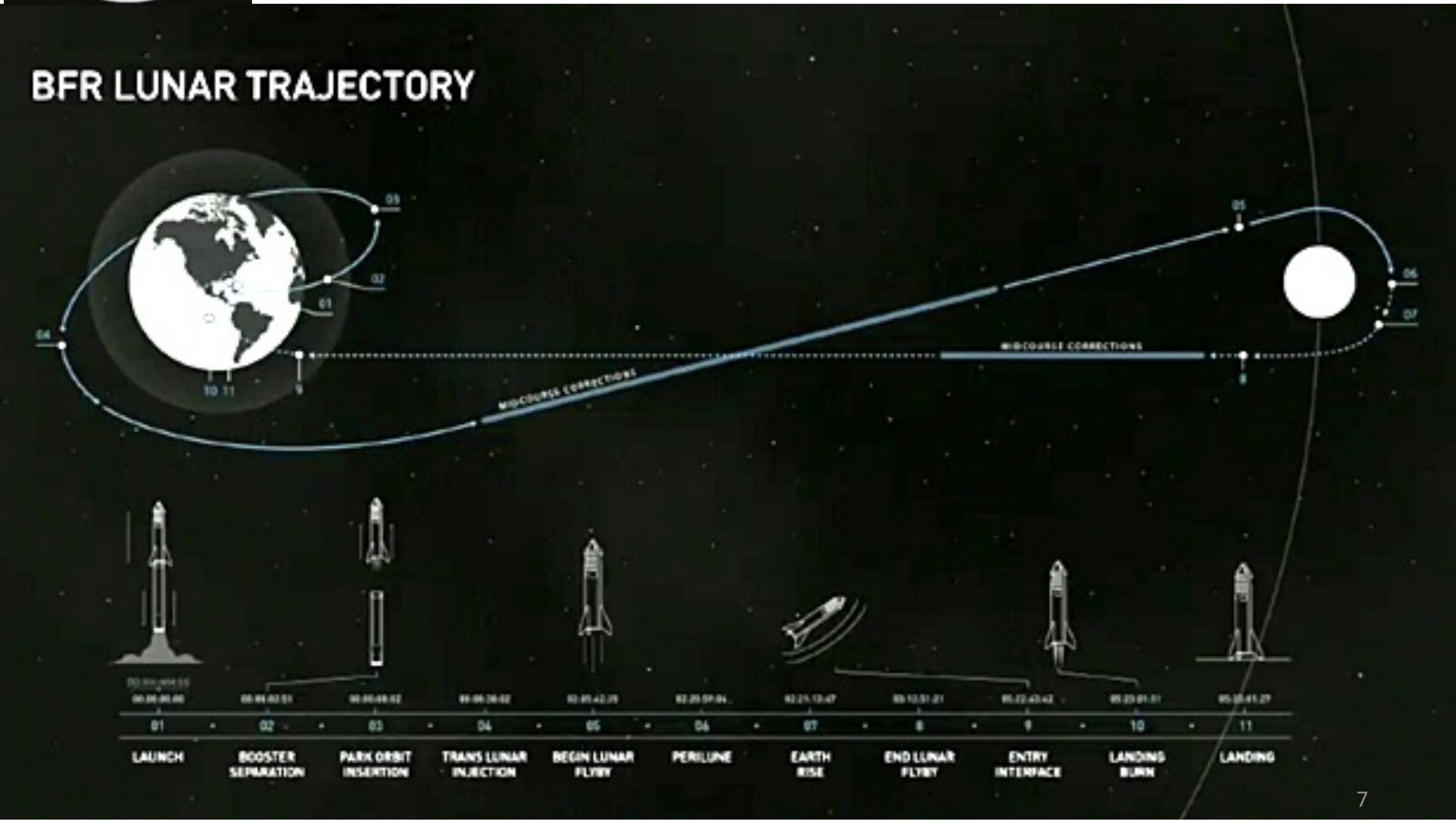


Dear Moon
On-Contract for 2023



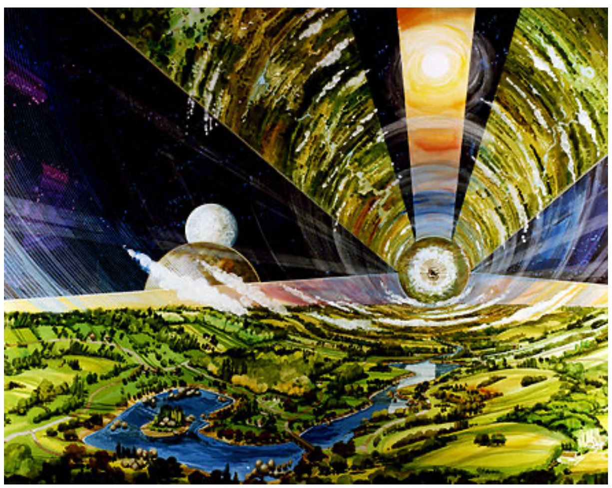
Dear Moon

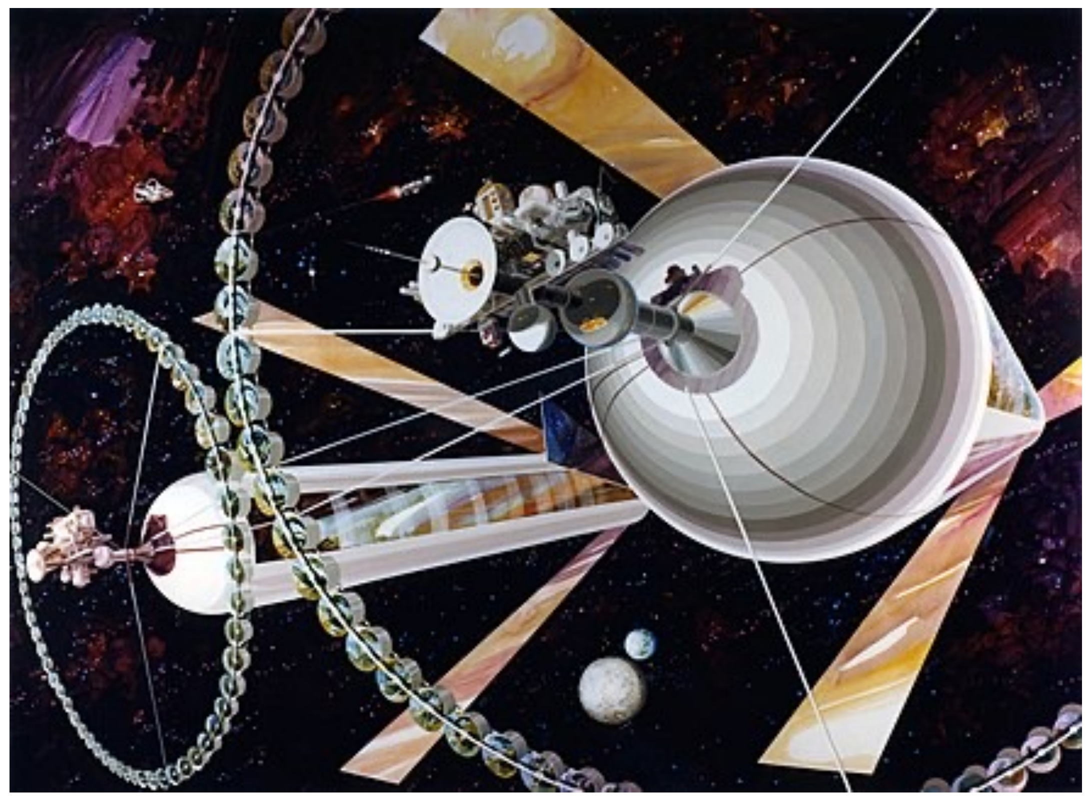
“Awe inspiring global universal art project”

- I choose to go to the Moon – with artists
- One week in space – 2023 with six to eight artists
- What will they see? Feel?
- What will they create?
- Yusaku Maezawa Japanese Entrepreneur (ZOZO, Inc.) painter, photographer, artist
- “Awe inspiring global universal art project”

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?

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

Living and working in thriving communities beyond Earth – NSS

Dream Big!

But How much mass to Orbit?

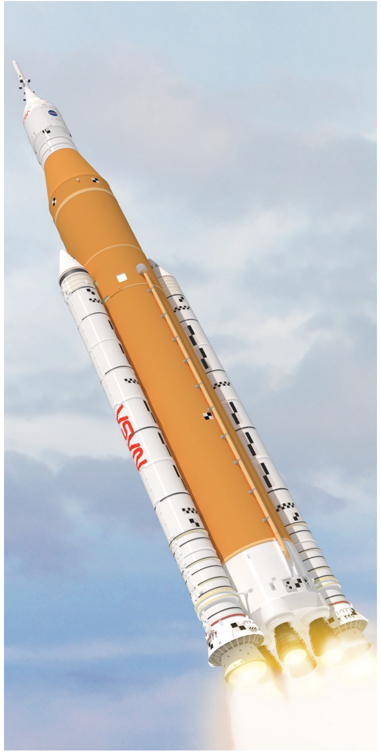
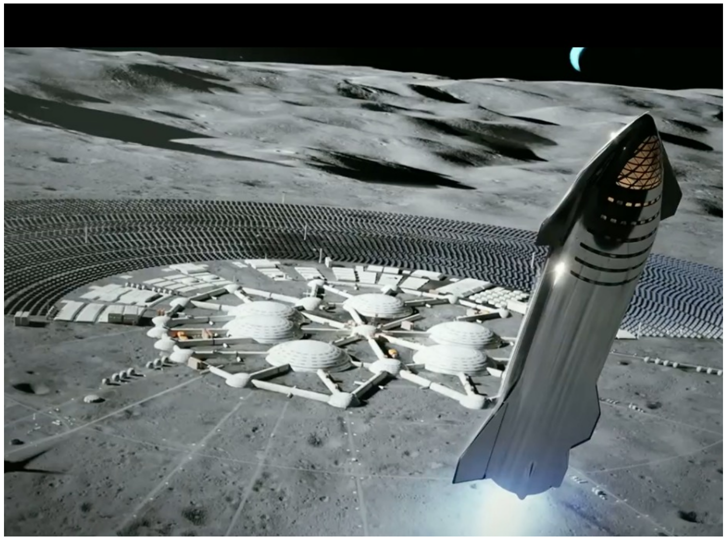
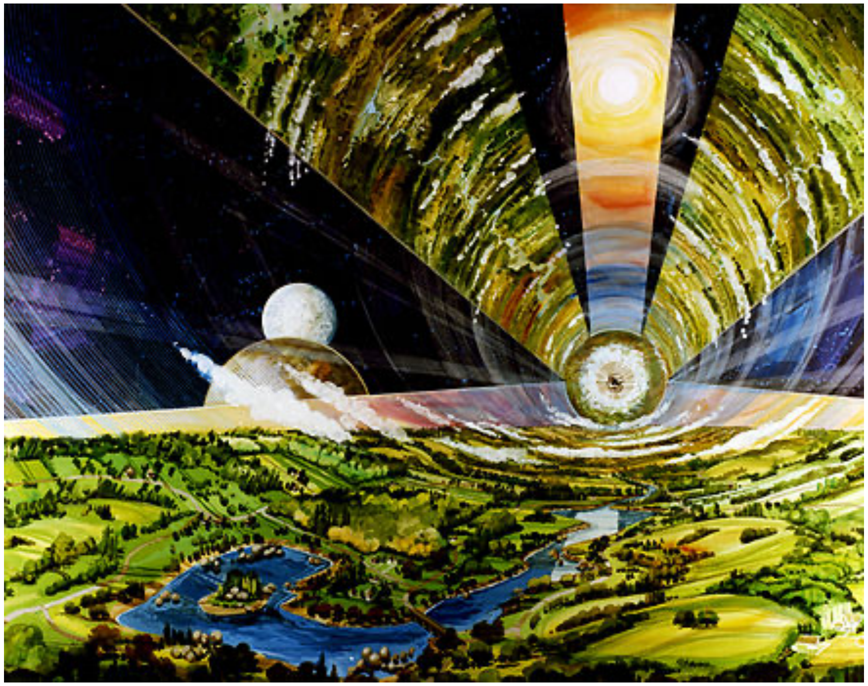


Image from Blue Origin website

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





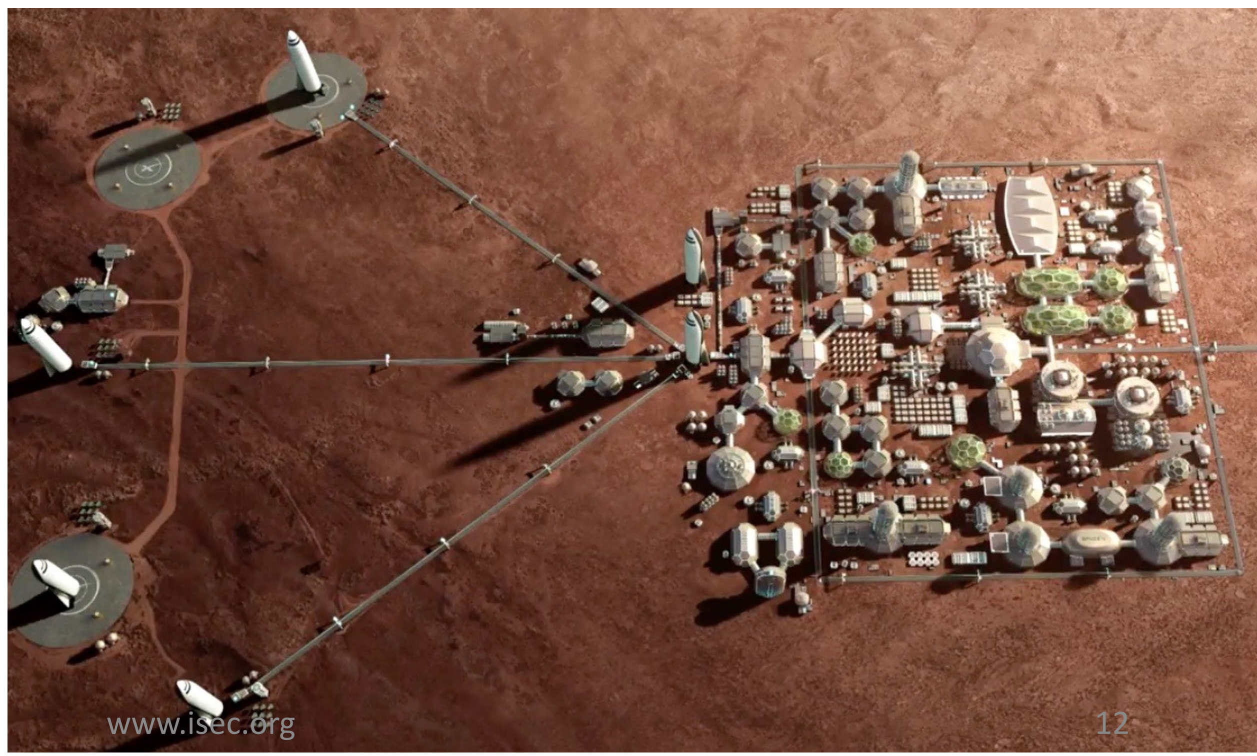
Images by NASA
and Rick Guidice

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

Mars Colony

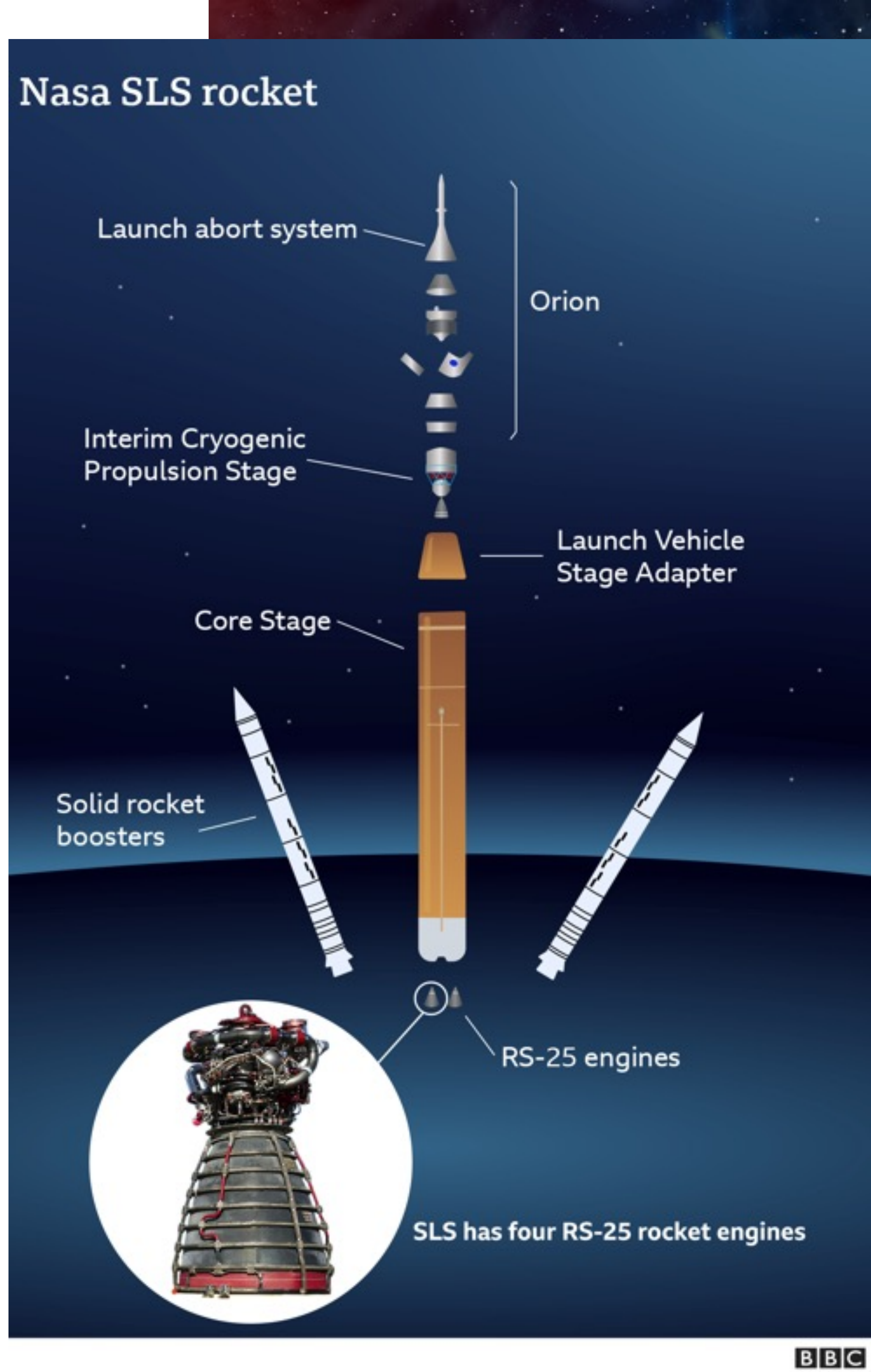
- I think there are really two fundamental paths. History is going to bifurcate along two directions. One path is we stay on Earth forever, and then there will be some eventual extinction event. I do not have an immediate doomsday prophecy, but eventually, history suggests, there will be some doomsday 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.



SLS Rocket - Government

- NASA's Space Launch System (2005 start design)
- $18 Billion Development
- $2 Billion per launch (excluding development)
- 45,000 kg to Moon
- NO (?) recoverable segments
- Designed to sit on pad for 180 days during launch scrubs.



BBC News

Competition

- Government vs Commercial
- Vision driven or funding driven
- Technologies are there, designing for environment is difficult.

NASA Driven Design

Commercial Driven Design

NASA Image, USA Today,

Lunar Facilities Serviced by SpaceX

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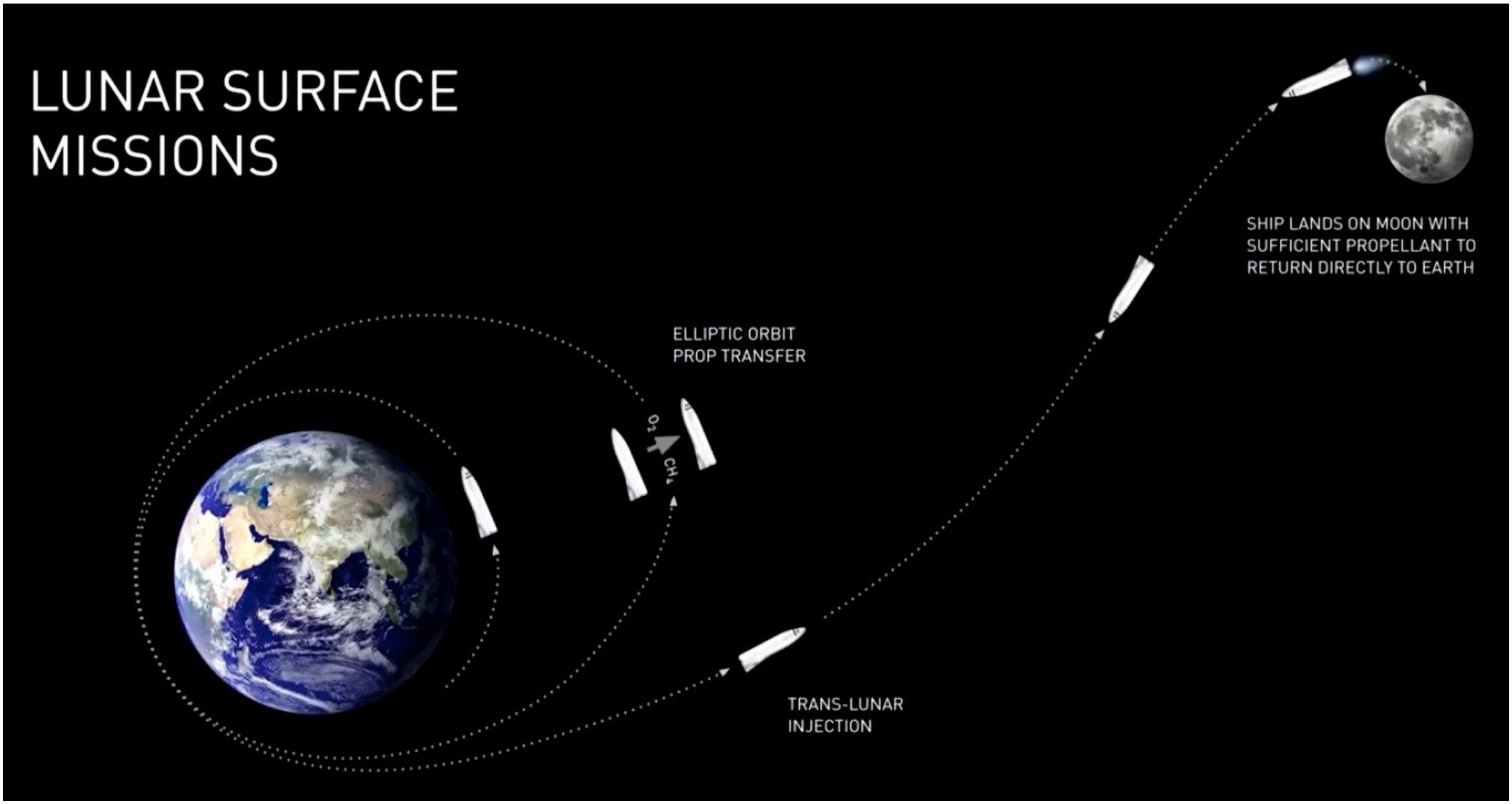
To/From Lunar Surface One-refuel



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

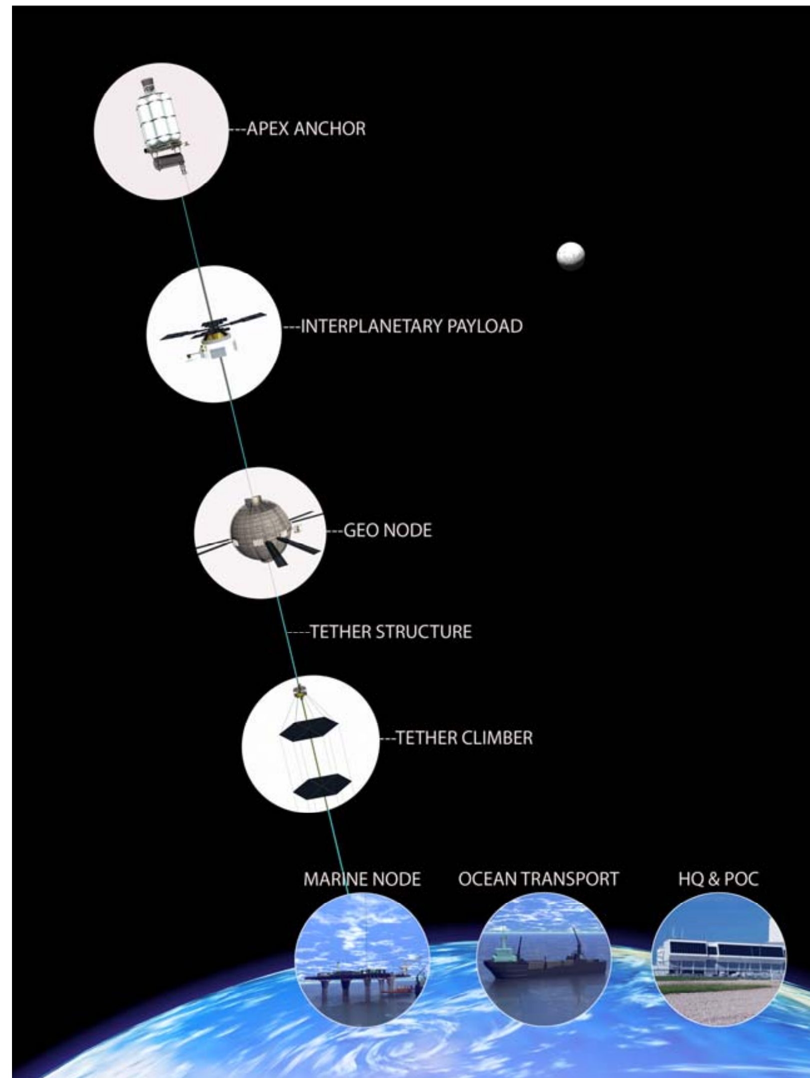
** Elon Musk, 21 July 2019, CBS Sunday Morning Interview

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

What Humanity Needs for For Movement off-planet?

They are Space Elevator Strengths

- Revolutionarily inexpensive (< $100/kg)
- Routine: 24/7/365/50 yrs.
- Permanent Infrastructures
- Safe
- No shake-rattle-roll during launch
- Commercial development similar to bridges
- Massive payloads [14 to 70 metric tons]
- Opening up design options for space systems
- Fewer volumetric restrictions for launch
- Easy delivery to GEO within a week
- Recovery and repair of satellites
- Little impact upon the global environment
- Does not leave launch debris in orbit
- Flexibility for orbital releases:
- Variety of operations for
    - releasing or capturing satellites,
    - refueling of space systems,
    - construction of habitats with housing



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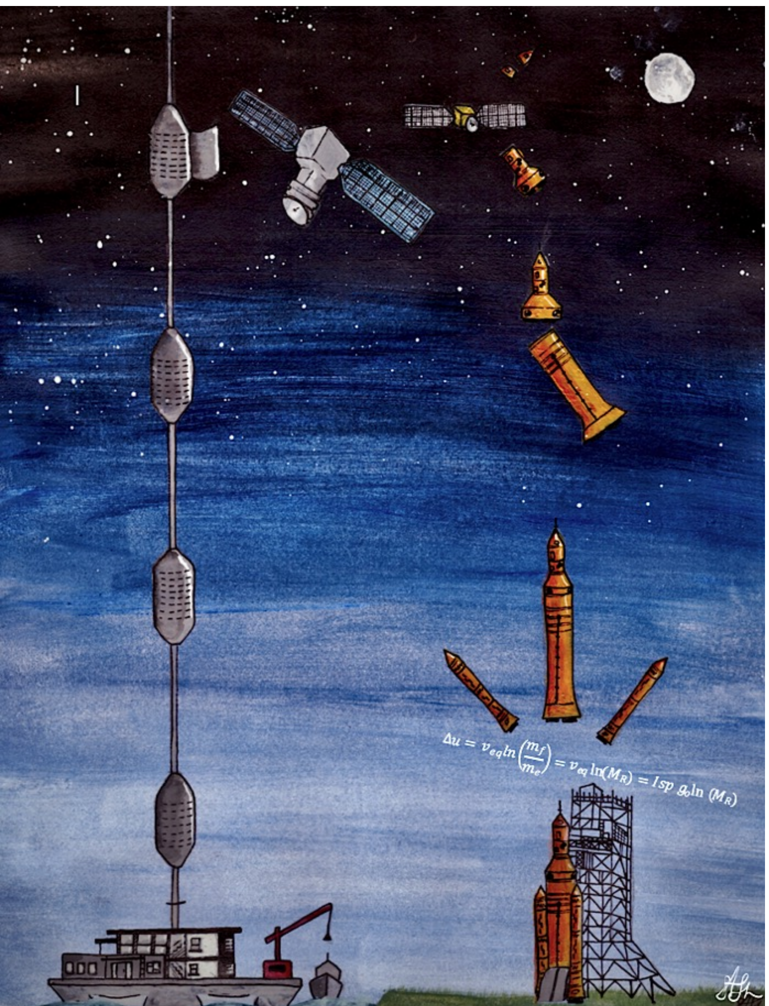
Space Elevator Vision and Approach



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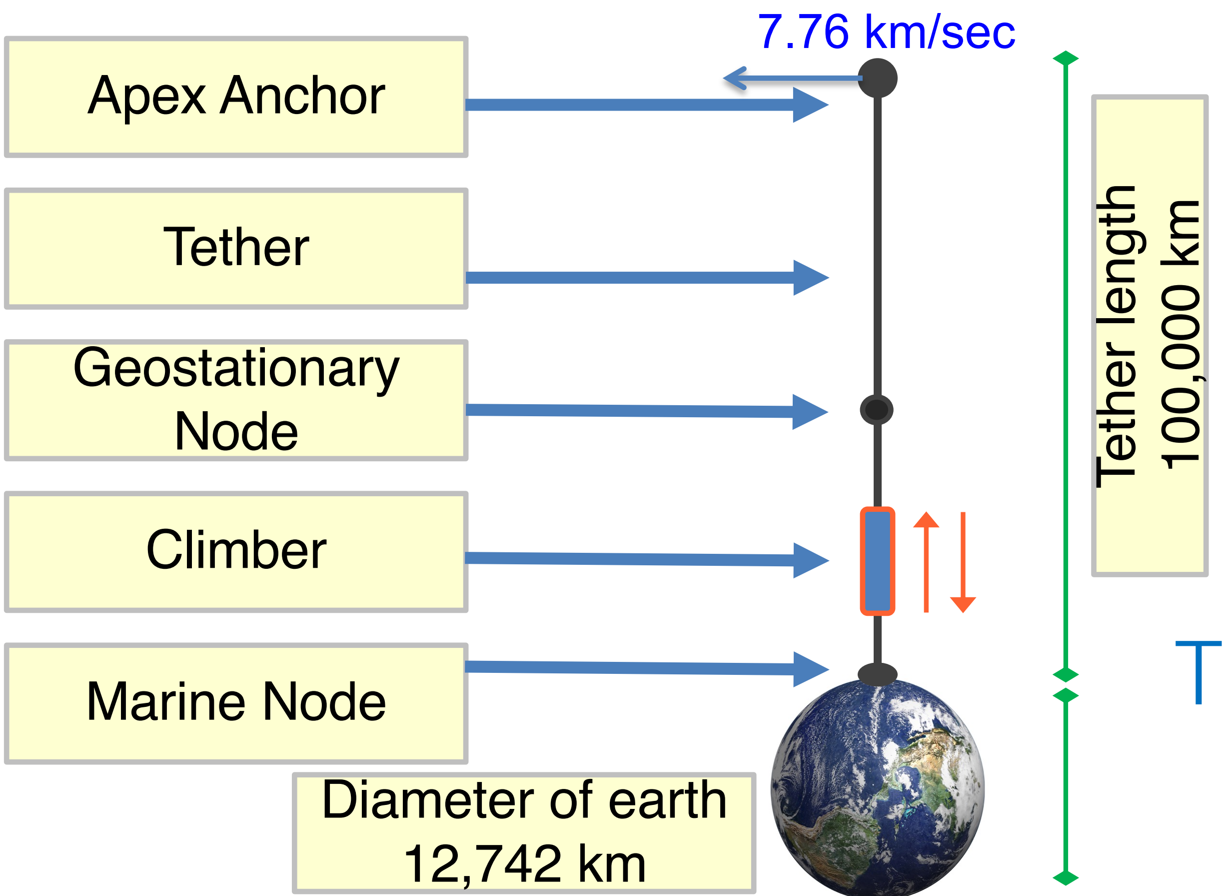
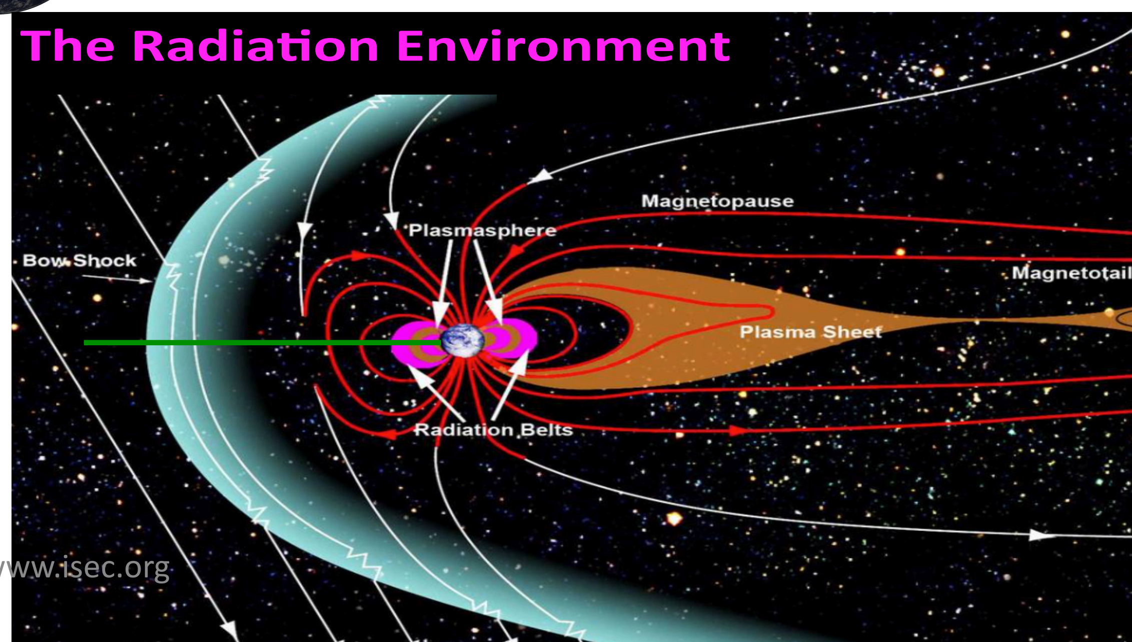
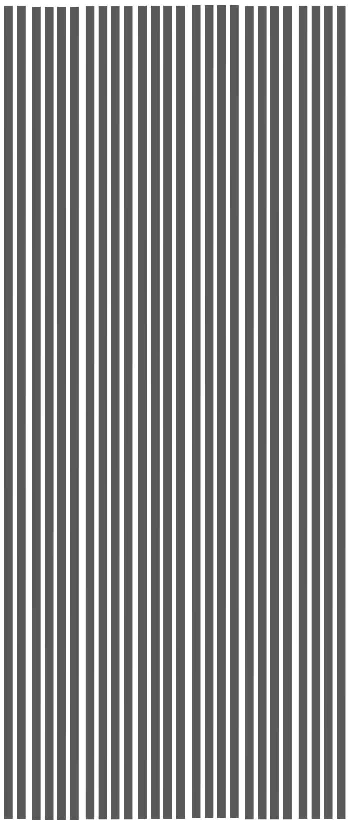


The Space Elevator



Graphene has the strength to make the space elevator tether



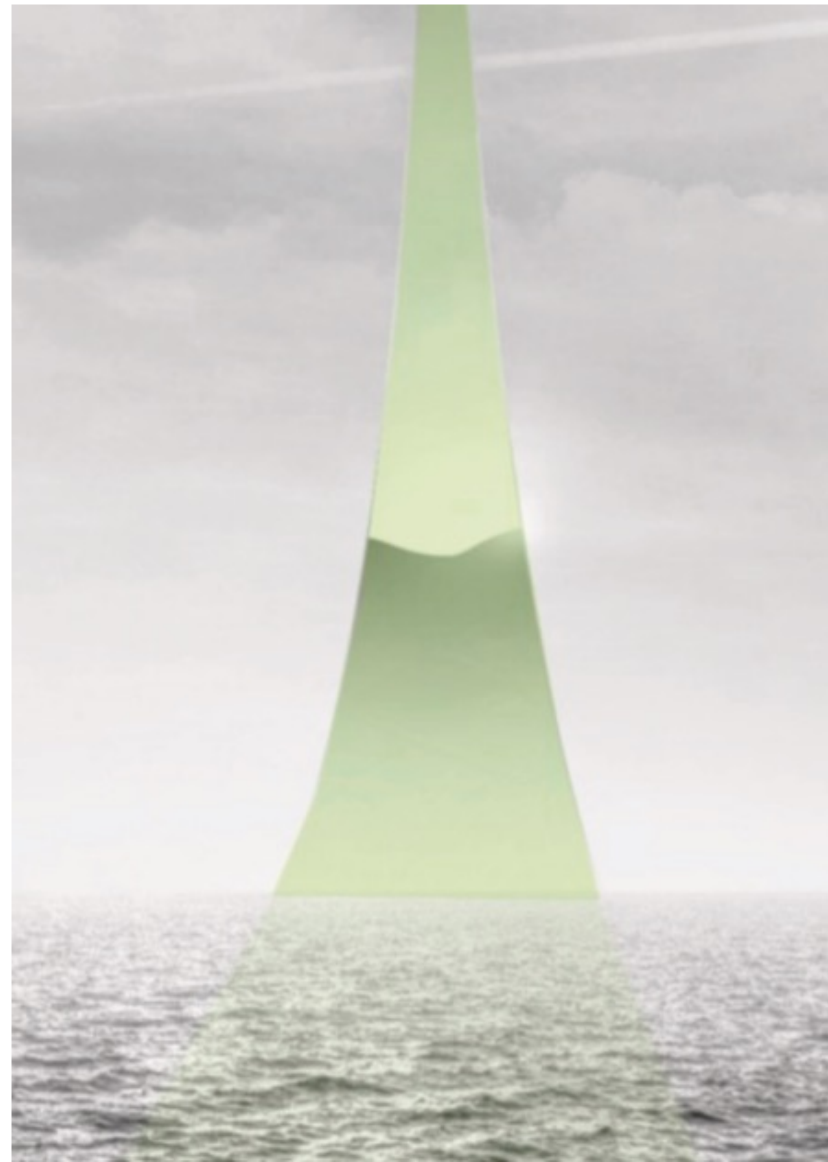
100 million metres long

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



Transformational Leap

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Why SEs? - 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

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

Rocket Equation
an Example

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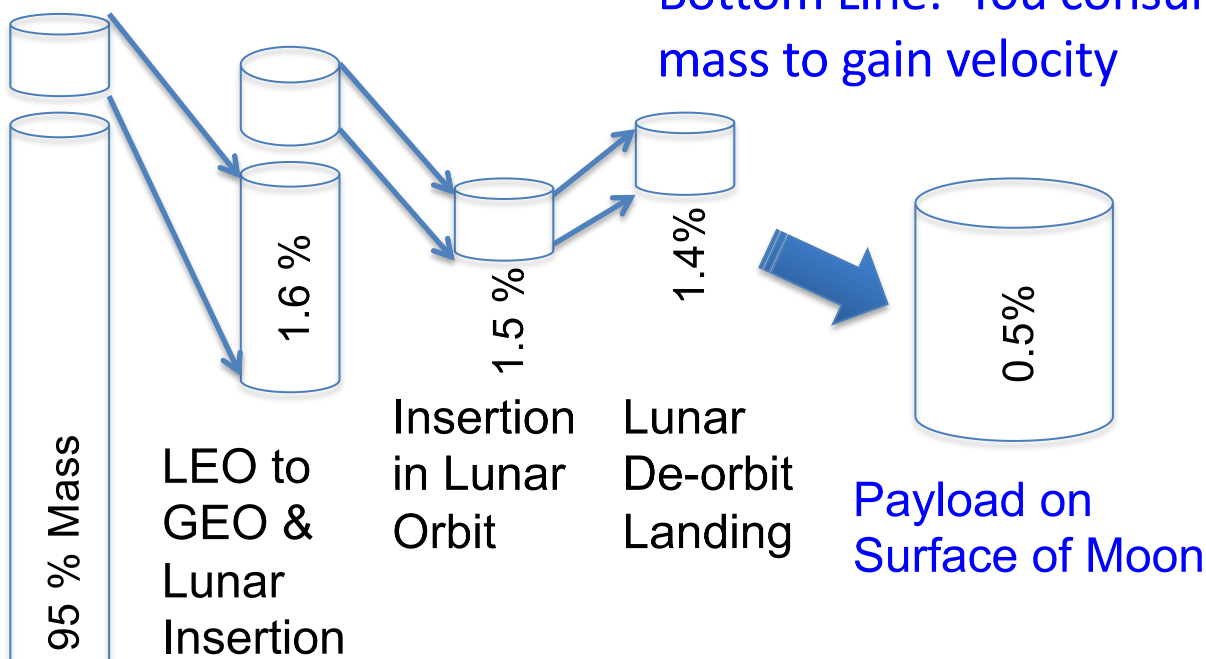
Bottom Line: You consume your pad mass to gain velocity



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

Pad Mass
At Liftoff

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

Apollo – half percent to Lunar Surface

Problem – Mass Deliver Percentage

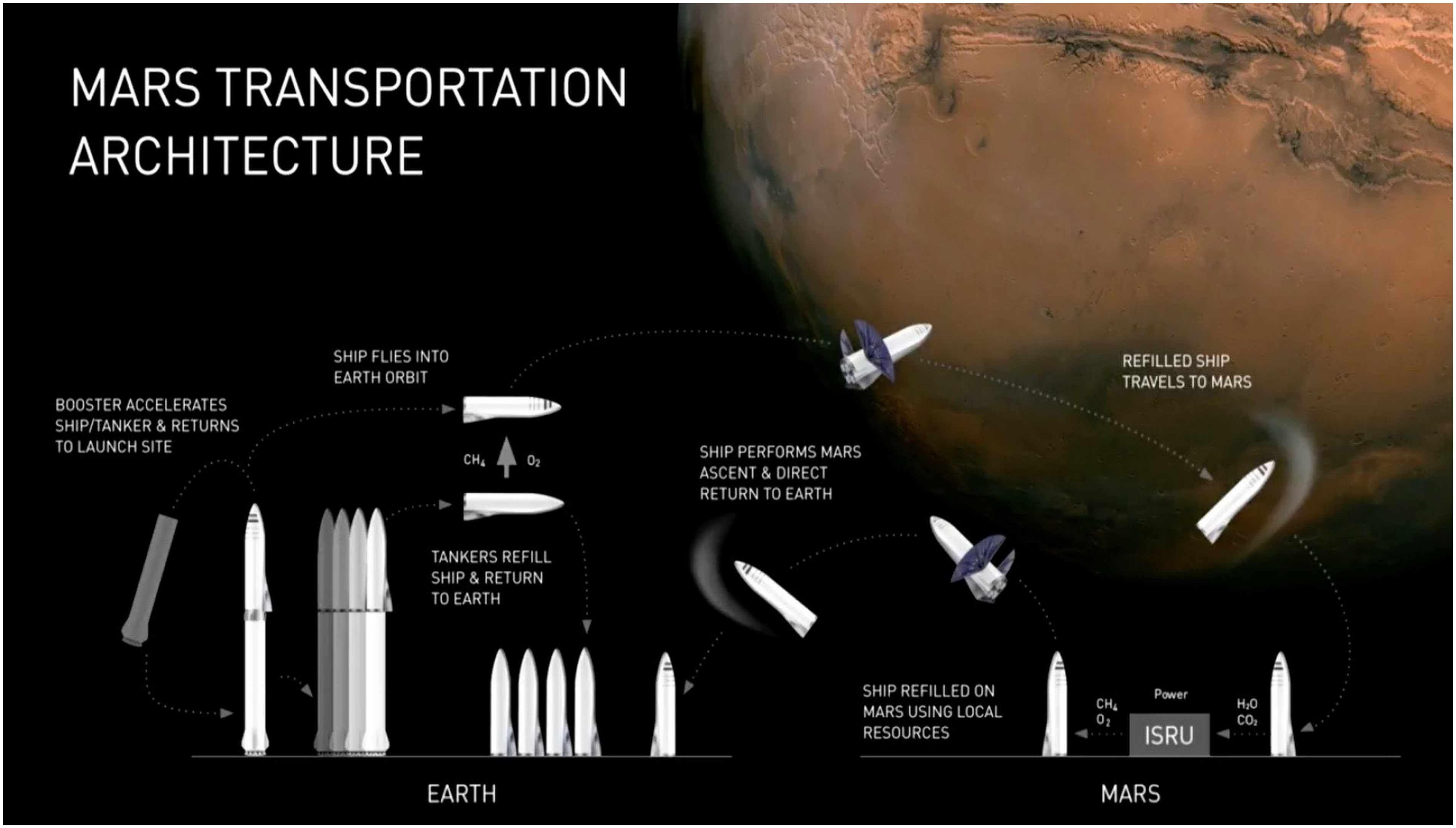
Launch Vehicle	*Mass on Pad (kg)*	*Mass Delivery*	*%*
Apollo Saturn V	3,233,256	Lunar lander = 15,103	0.5
		ocean landing = 5,557	0.17
Atlas V	590,000	to GEO = 8,700	1.5
Falcon Heavy	1,420,788	to GEO = 26,700	1.9
Starship	4,000,000	to GEO = 21000	0.5
New Glenn	1,323,529	to GEO = 13,000	1

Percentage to Orbit by Rockets

Mission	Launch Vehicle	Total Mass at Pad (kg)	Mass at LEO Orbit	% to LEO Orbit	Mass at GTO Orbit	% to GTO Orbit	Comment
STS - Columbia	Space Transportation System	2,041,000	80,700	0.040	2270	0.1	Columbia is payload of STS note; $1.6 B / launch - for GTO, ComSat in Shuttle bay
Spacecraft	StarShip	5,000,000	100,000	0.020	21000	0.4	Needs refueling to leave LEO, for GEO no refuel
	NEW Glenn	1,323,529	45,000	0.034	13000	1	
Apollo	Saturn V	3,233,256	140000	0.043	41000	1.3	Tli vs. GEO
	Saturn V	3,233,256		0.005			To lunar surface
	Saturn V	3,233,256		0.002			Returned to Earth's ocean
	CZ-5-522	630,000	20,000	0.032	11000	1.7	
	Atlas V	590,000	18,500	0.031	8700	1.5	
Spacecraft	Ariane 5	737,000	20,000	0.027	10000	1.4	
	Soyuz	310,000	7,000	0.023			
	Soyus 2-1b Fregat	308,000	8,500	0.028	3000	1	
	StarShip	4,000,000	100000	0.025	21000	0.5	Starship to GEO, no refueling
	Falcon Heavy	1,420,788	63800	0.045	26700	1.9	
			ave	0.032		1.5	

Remember, the rocket equation does NOT have factors for cost nor reusability. The reuse of rocket segments is remarkable and lowers cost and increases Efficiency…. But it does not deliver more mass to orbit as percentages.

SpaceX
Systems Approach



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?

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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

Transformational Characteristics

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Annual payload (tonnes/yr)

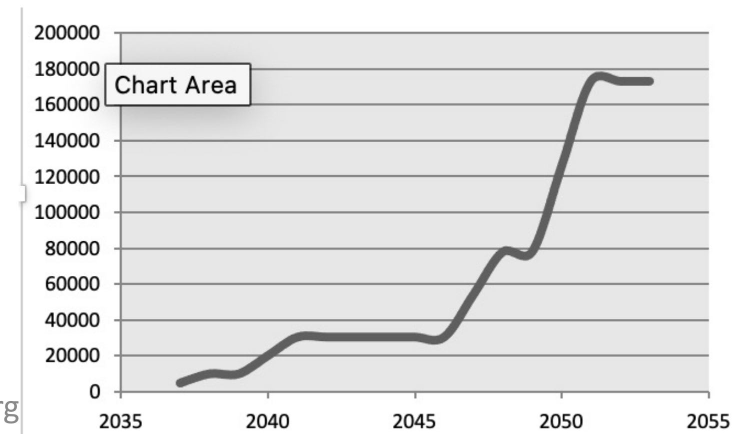
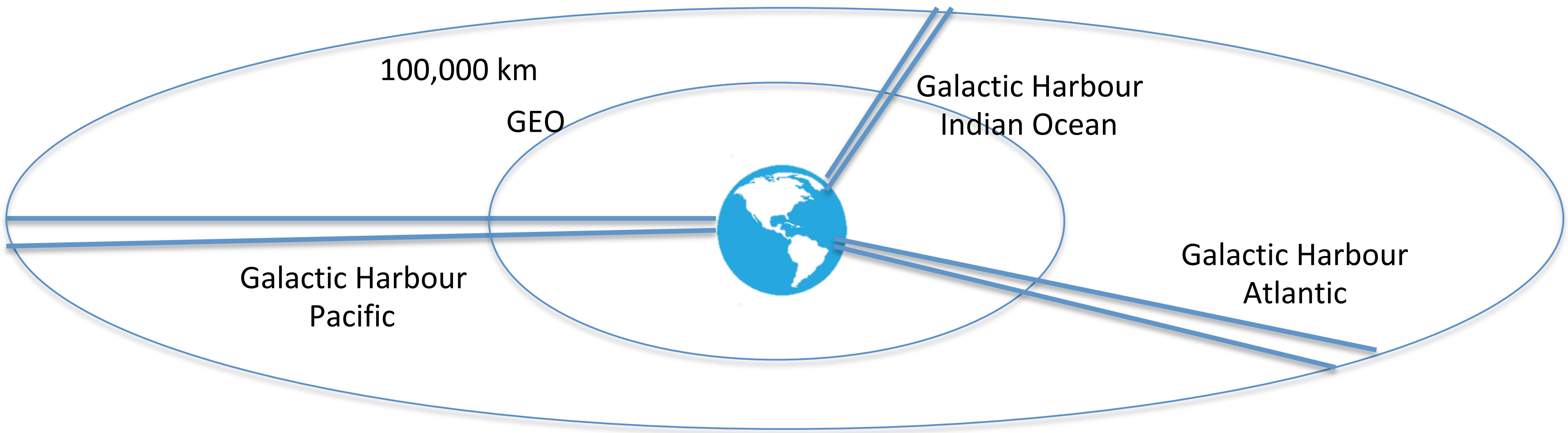


Figure 88. Massive Cargo Movement by Space Elevators (Swan "Dual Space Access Strategy Minimizes the Rocket Equation," Space Renaissance International 3rd World Congress 2021 – Congress Theses, Final Resolution and Papers. Pg 254-255.)

Interplanetary Vision



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

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

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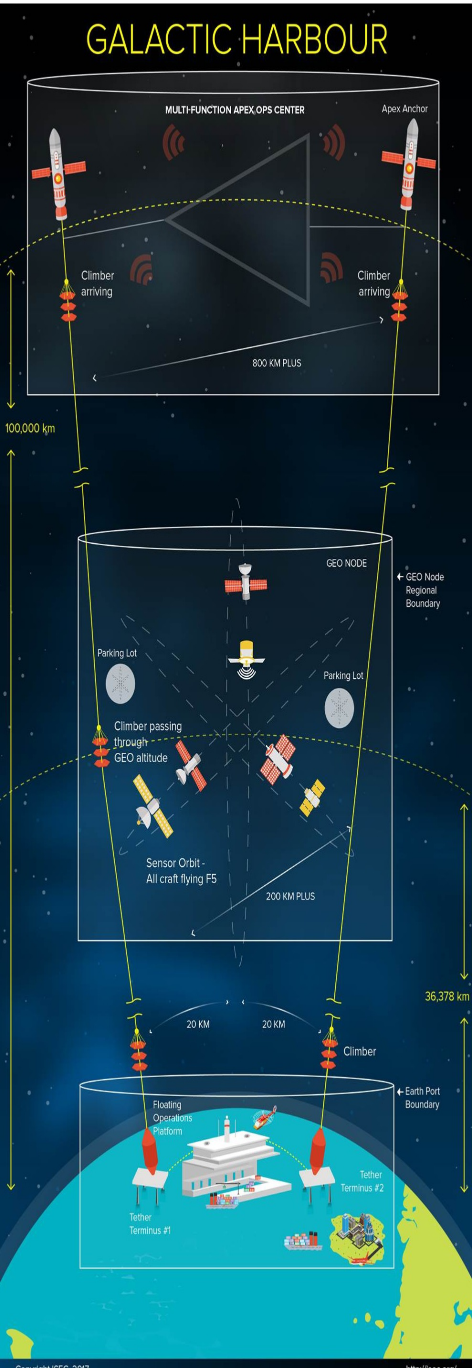

- Permanent access to GEO & Beyond - daily!
- “on-time delivery” a routine strength of space elevators’ logistics
- To Mars - any day – an outcome from the Arizona State University & ISEC 2021 study.
- Lowest cost in the industry – think bridge across a river vs. one time events (boats)
- A Bus Schedule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

Bus Schedule to Mars*

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	

*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

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
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- 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

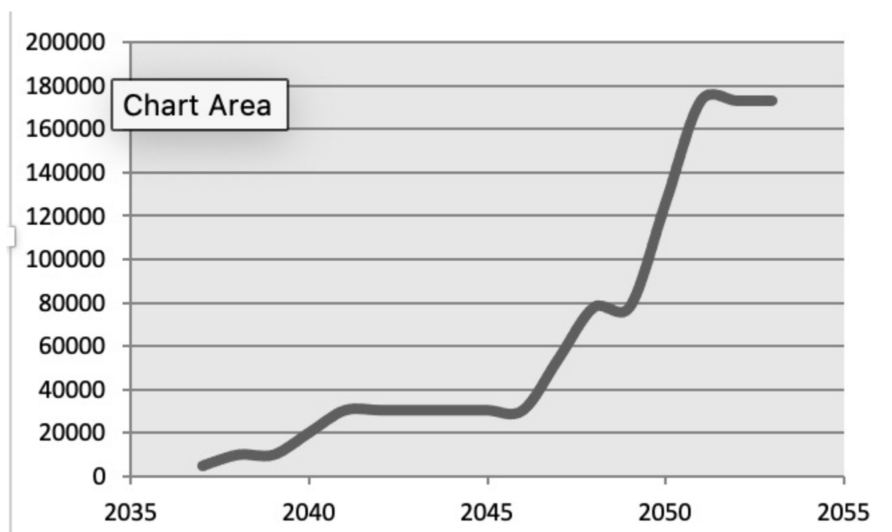
Note: Leo is 4% of launch pad mass
GEO, Interplanetary, Lunar 2% of pad
*Shuttle launch vehicle reached orbit as an operational satellite

Historic Movement
(1957 – 2020)

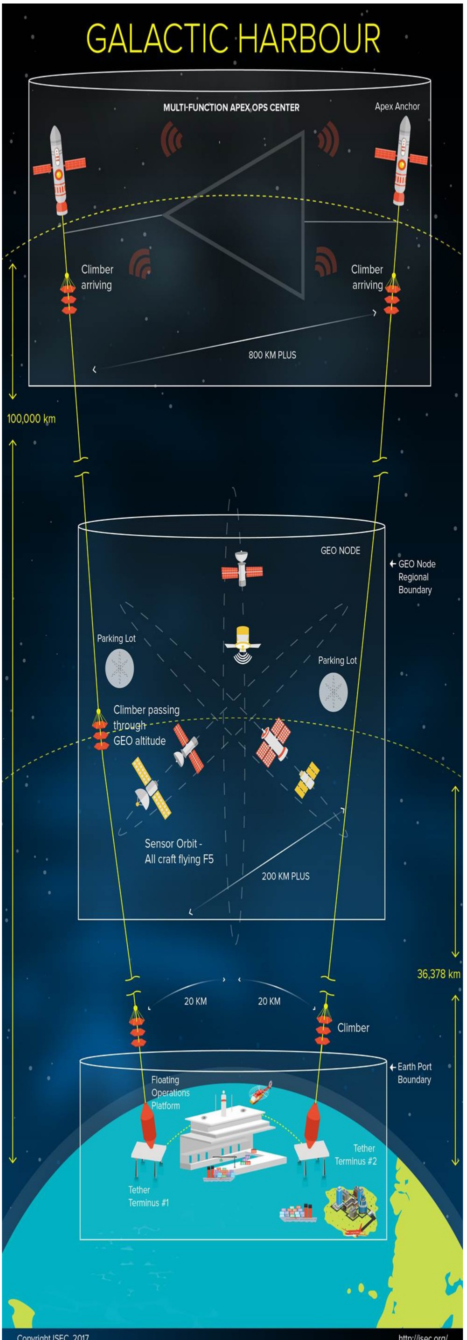
22,216 tonnes between 1957 and 2020.

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

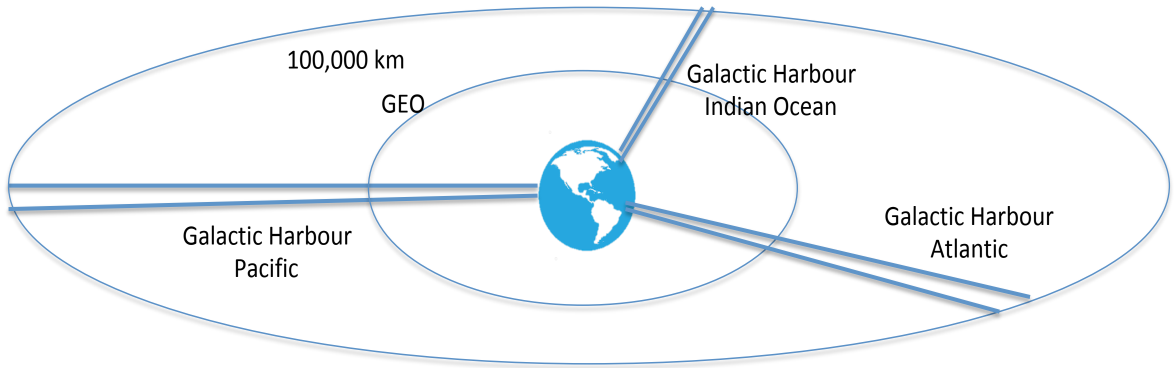
Annual payload (tonnes/yr)



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



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)

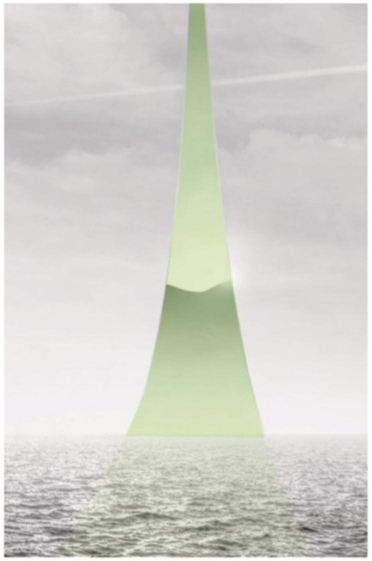
Space Elevators are the Green Road to Space

- 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.

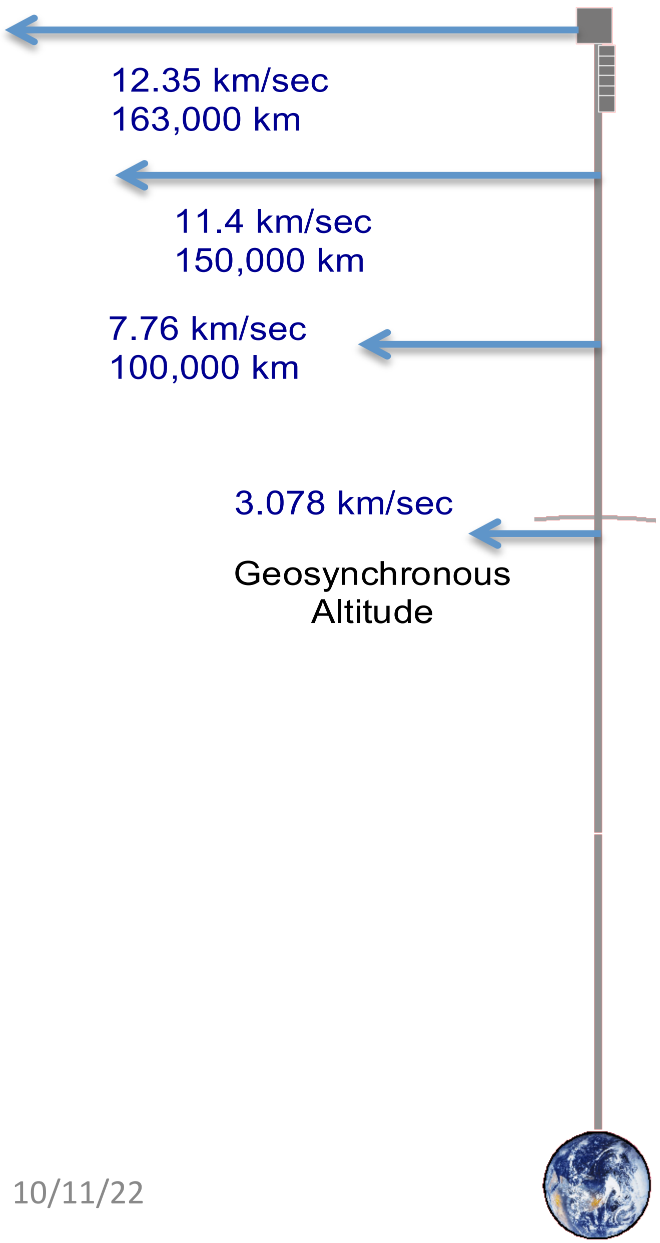
Peter Swan, Ph.D.
Cathy Swan, Ph.D.
Paul Phister, Ph.D.
David Dotson, Ph.D.
Joshua Bernard-Cooper
Bert Molloy



A Primer for Progress in Space Elevator Development

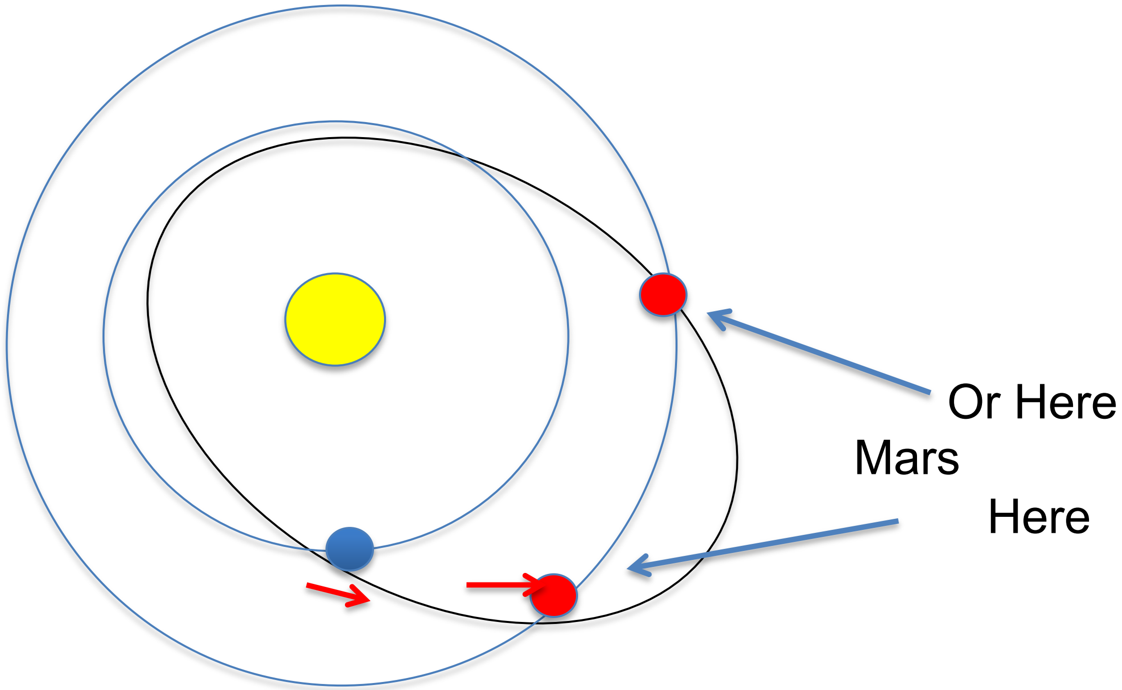
ISEC

SETS Strength Five: *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

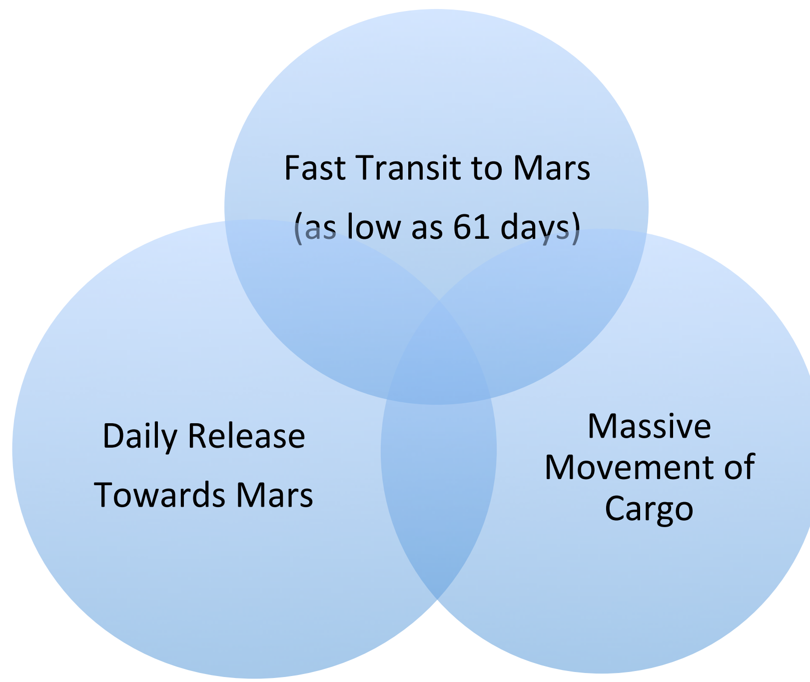


Concept: Our spacecraft enters the ellipse, “not at perigee,” but on the side of the ellipse centered as one foci at the Sun and outer portion matching Earth and Mars locations.

Special Strengths
A New Concept

The unique characteristics of Space Elevators with a rapidly moving Apex Anchor (7.76 km/sec) enable 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 80 to 100 days)
- Release every day towards Mars (no wait for 26 month)
- Massive movement of mission support equipment (170,000 tonnes per year when system mature)



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.

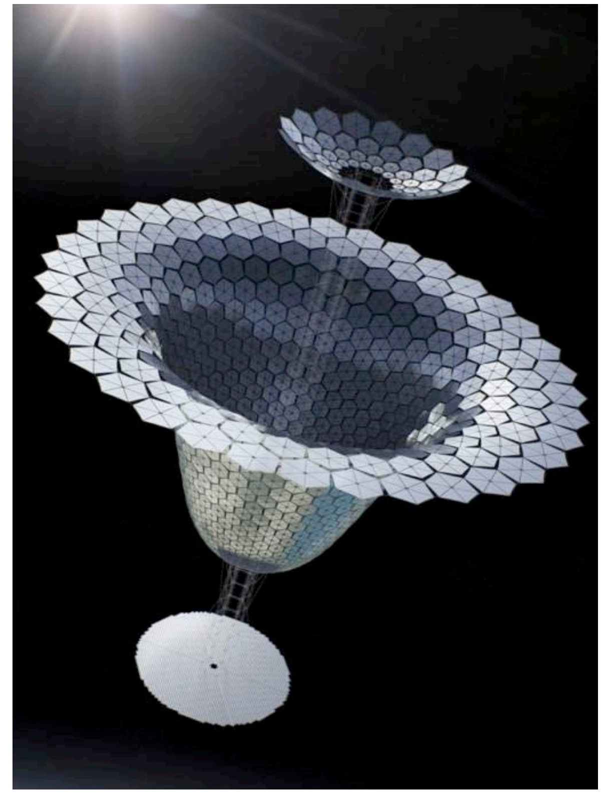
SETS Strength Seven: Assembly at the Top of the Gravity Well

- 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

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC

- Dreamers
- Space Elevator Vision
- Transformational Characteristics
- <u>Dual Space Access Future</u>
- Engineering Status
- 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

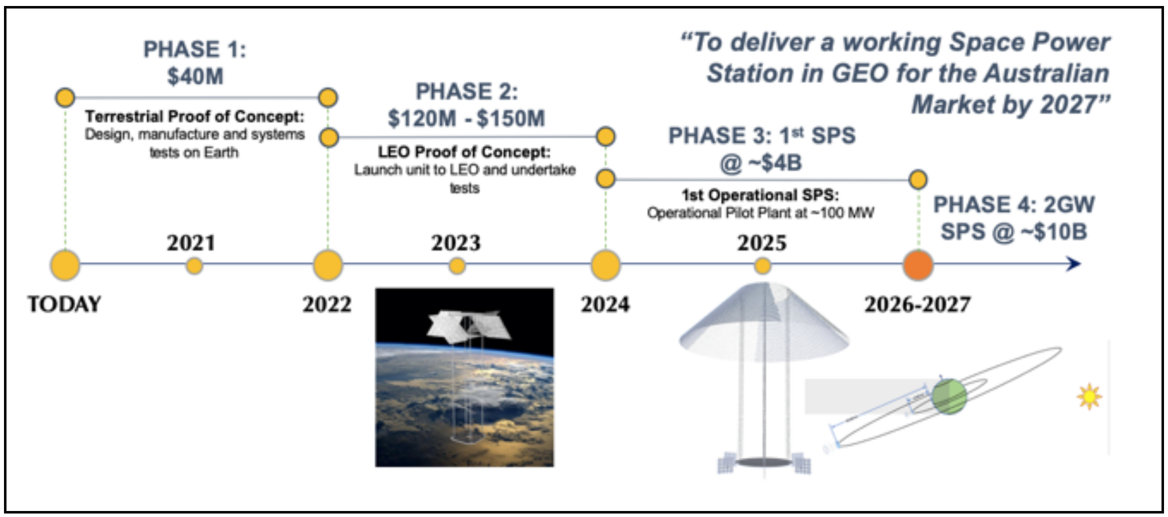
Space Elevator Strengths: As permanent infrastructure they lead to daily, routine, massive, environmentally friendly, and inexpensive departures towards mission destinations

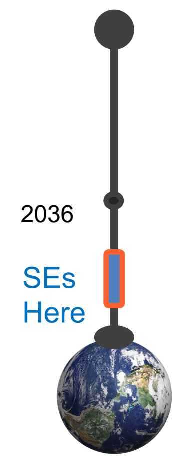
Minimizing the Rocket Equation Limitations

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

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

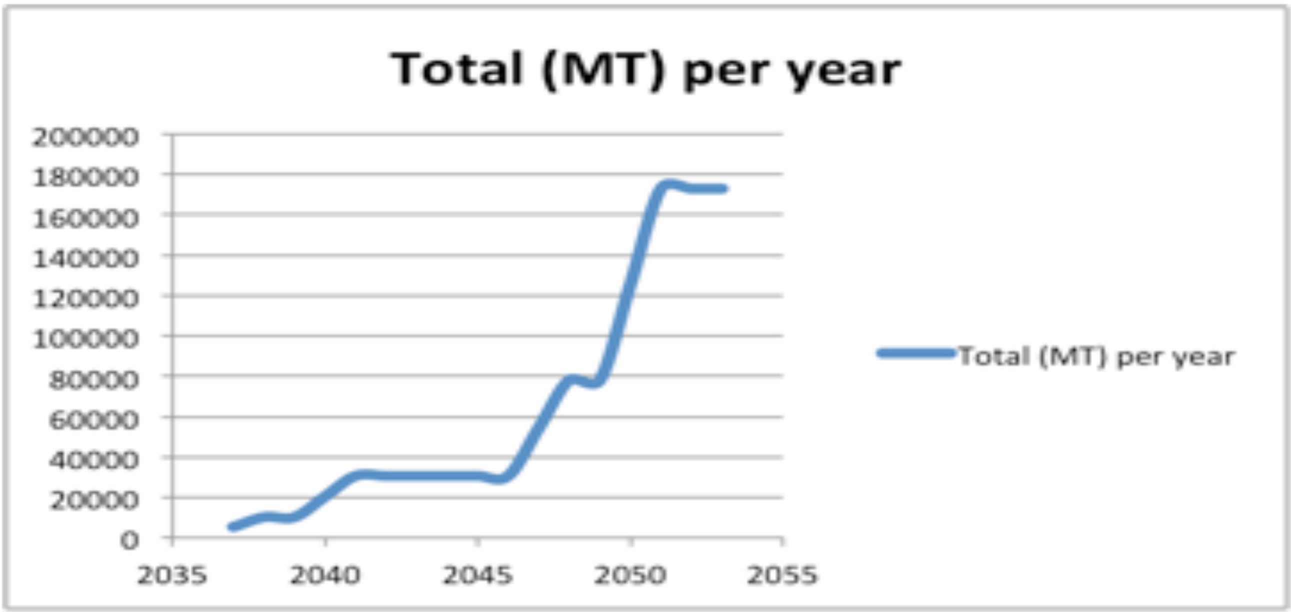
Massive Movement

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)
Only 22,216 tonnes to orbit.

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



Transformational Leap

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ISEC

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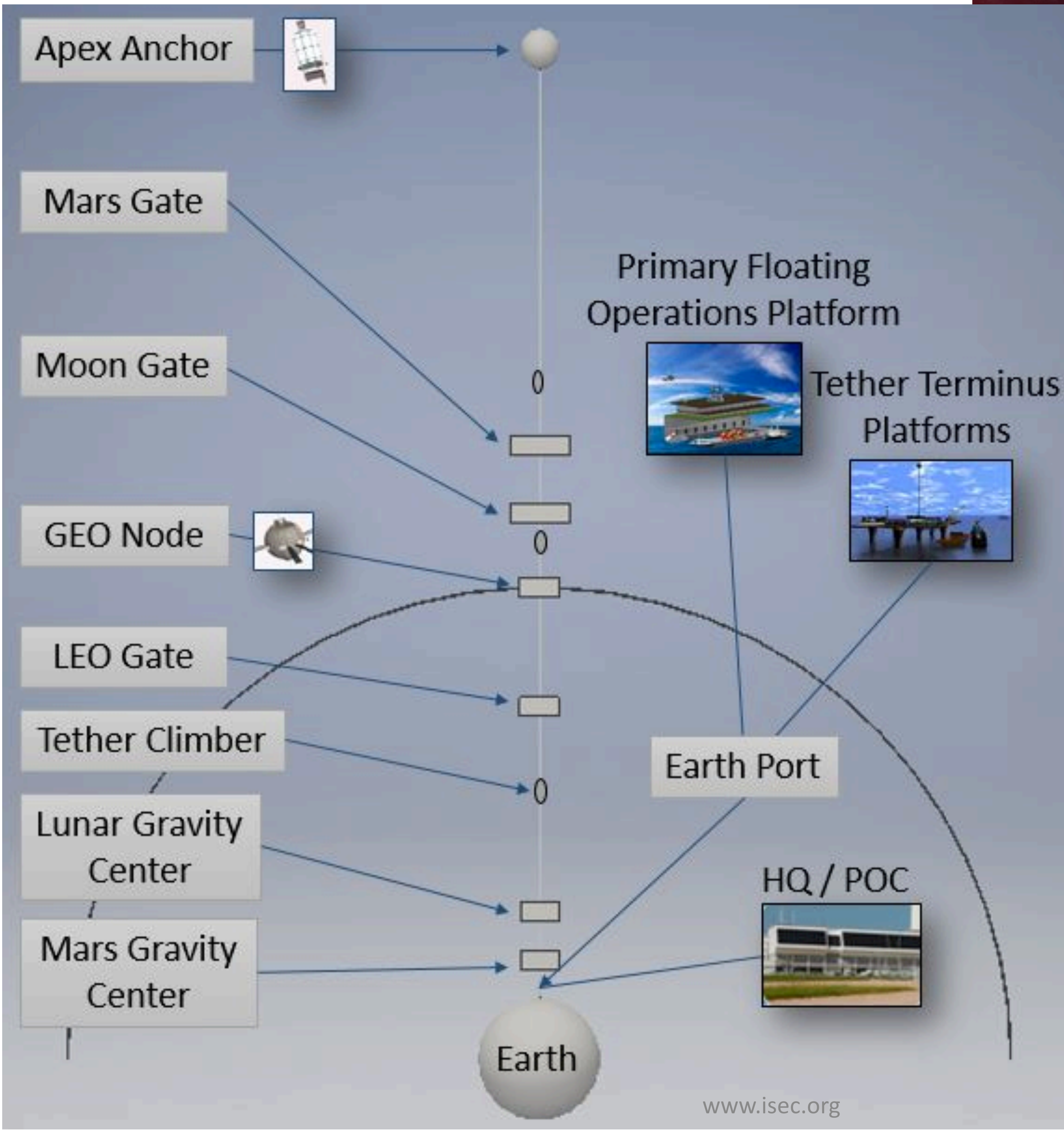
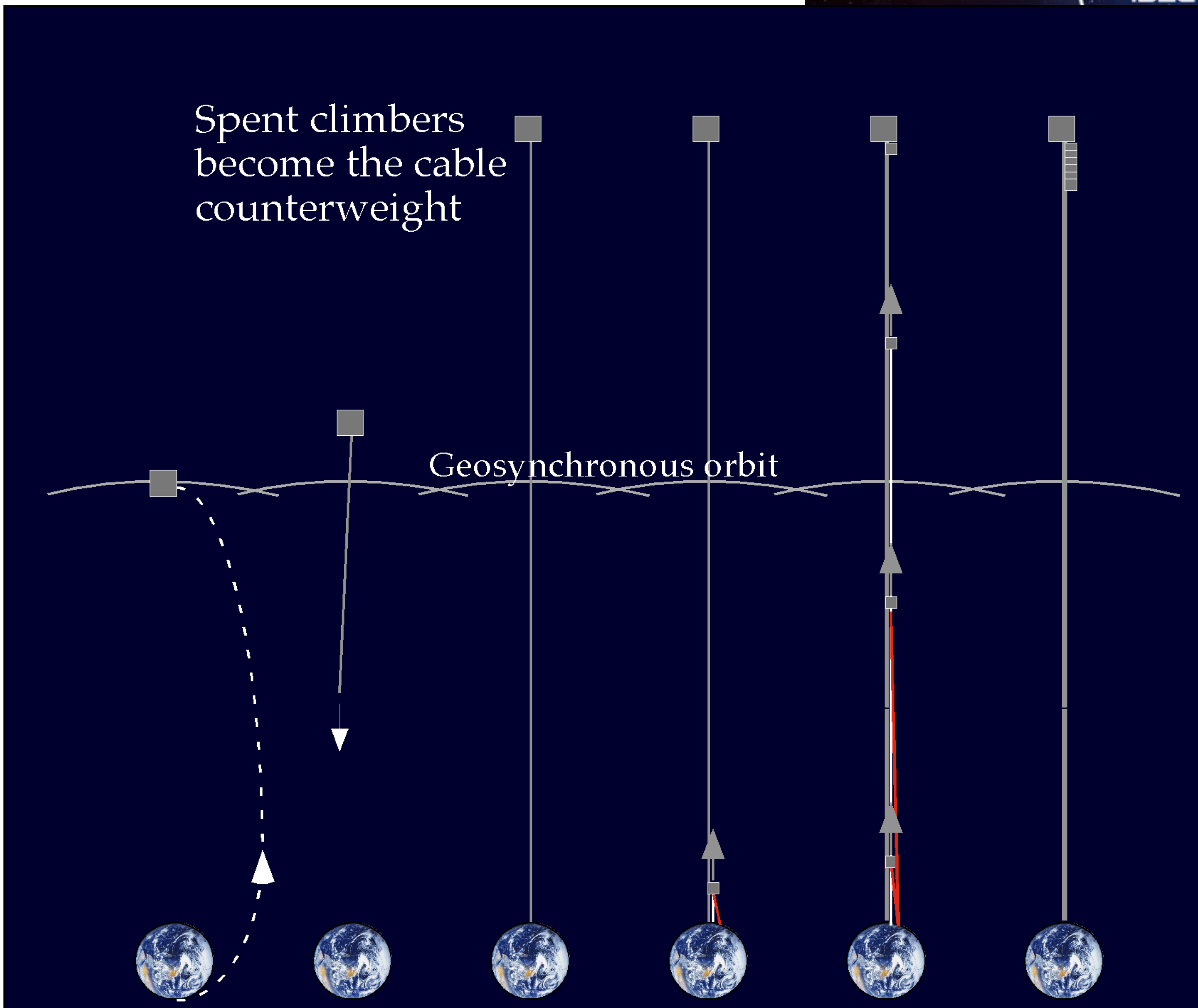
System Overview



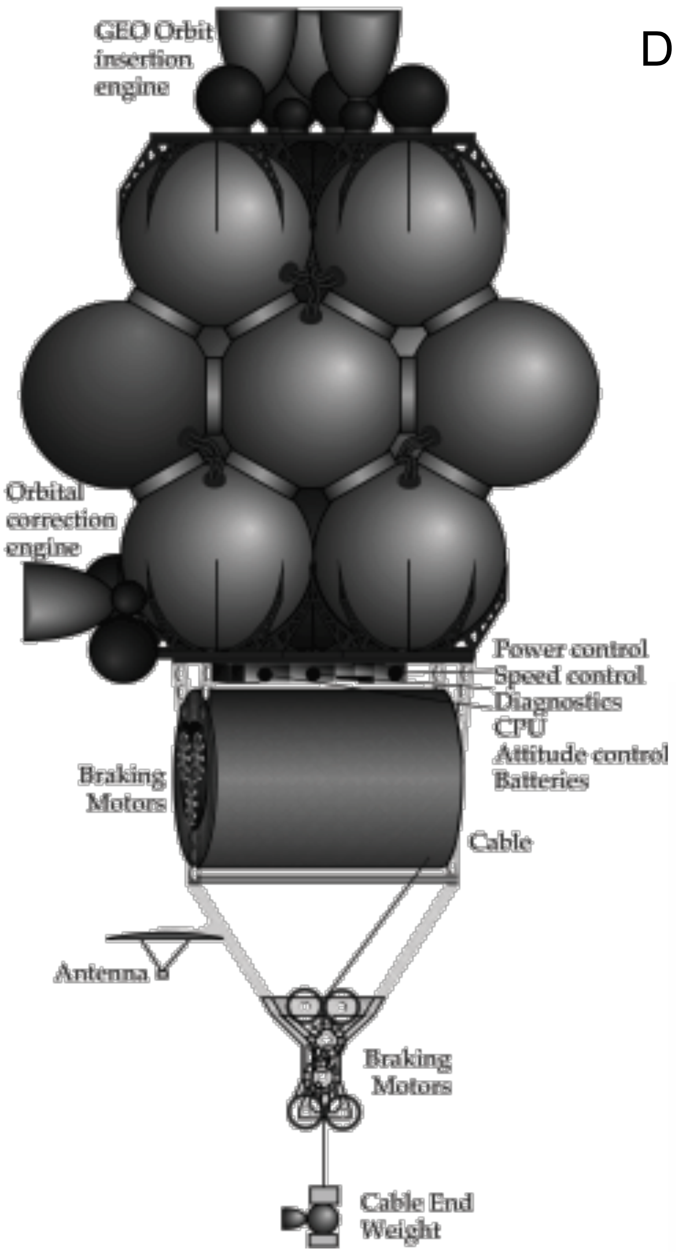
Deployment Overview



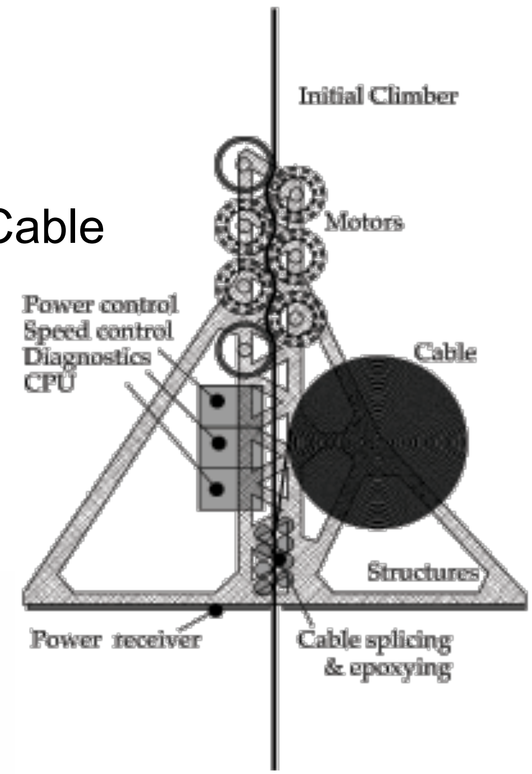
Spacecraft for Space Elevator

INTERNATIONAL SPACE ELEVATOR CONSORTIUM
ISEC

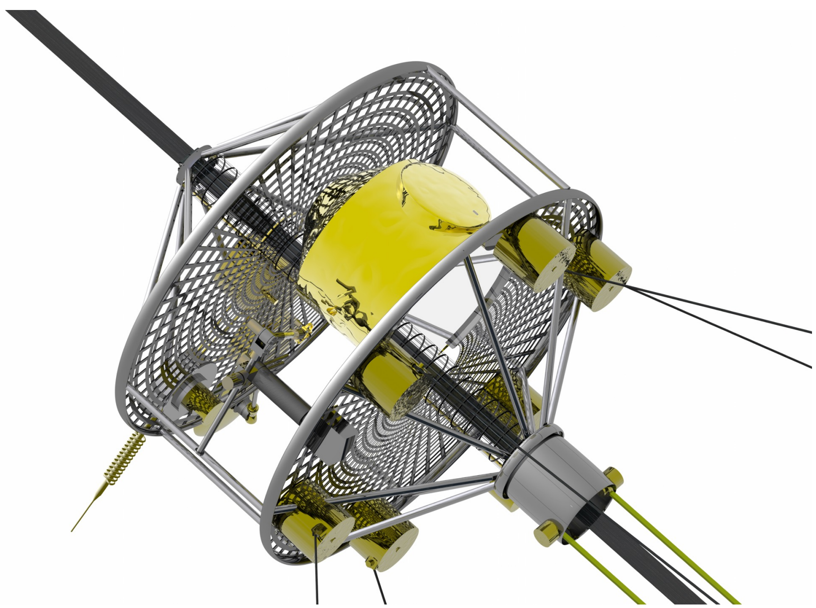
Deployment Spacecraft
& Future Apex Anchor



Buildup Climber with Cable

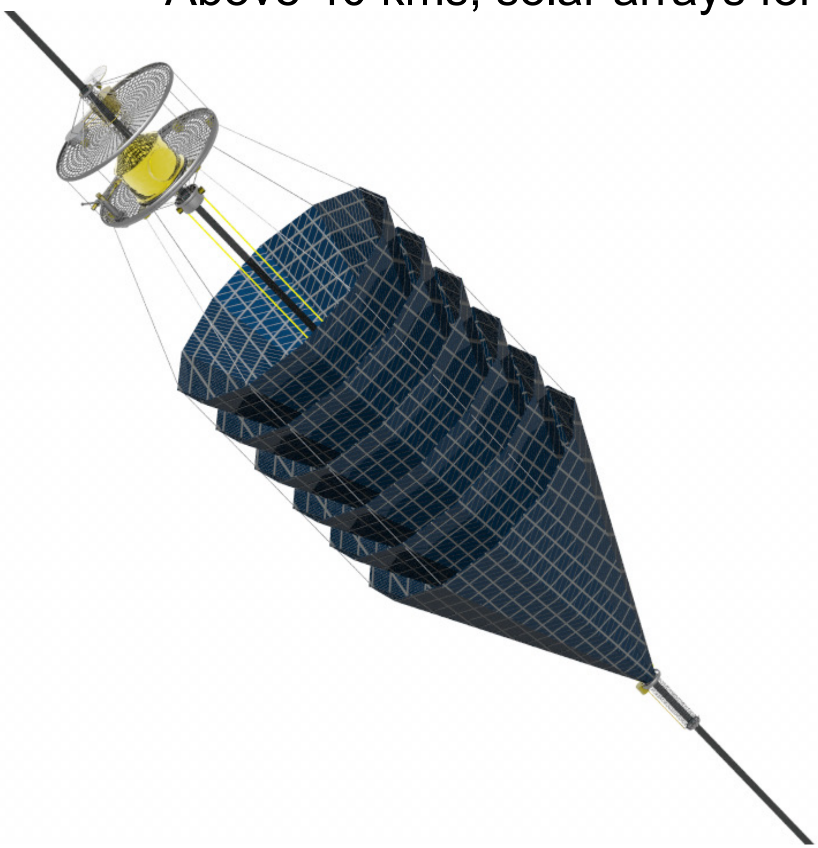


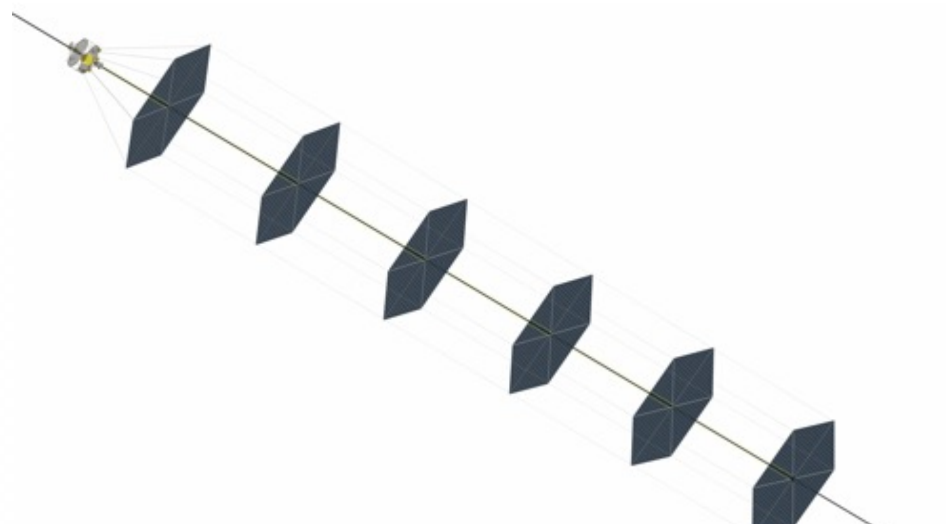
Baseline Tether Climber

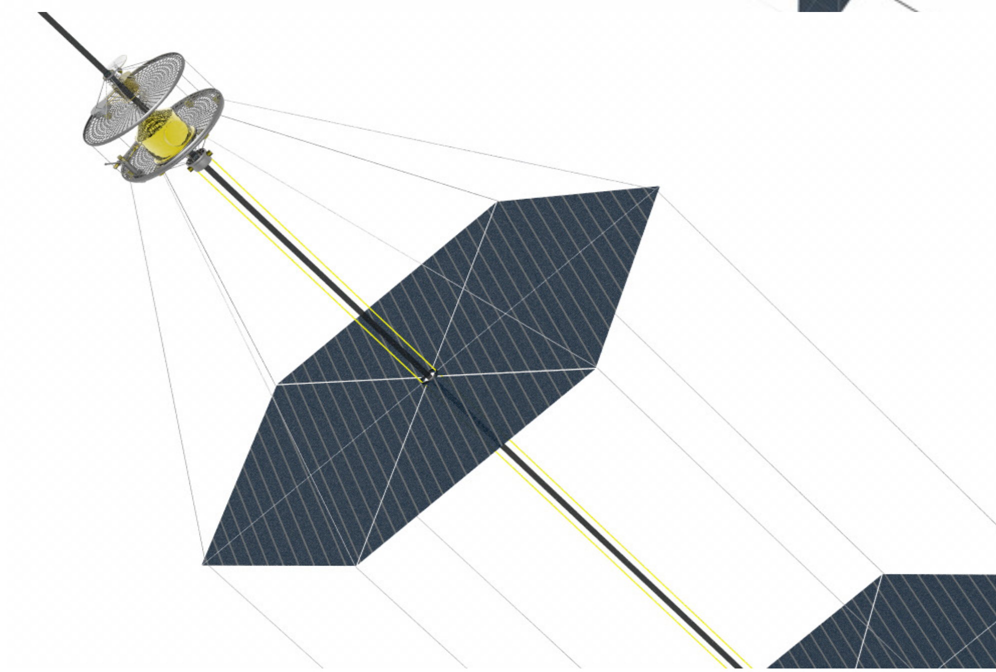


Tether Climber

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



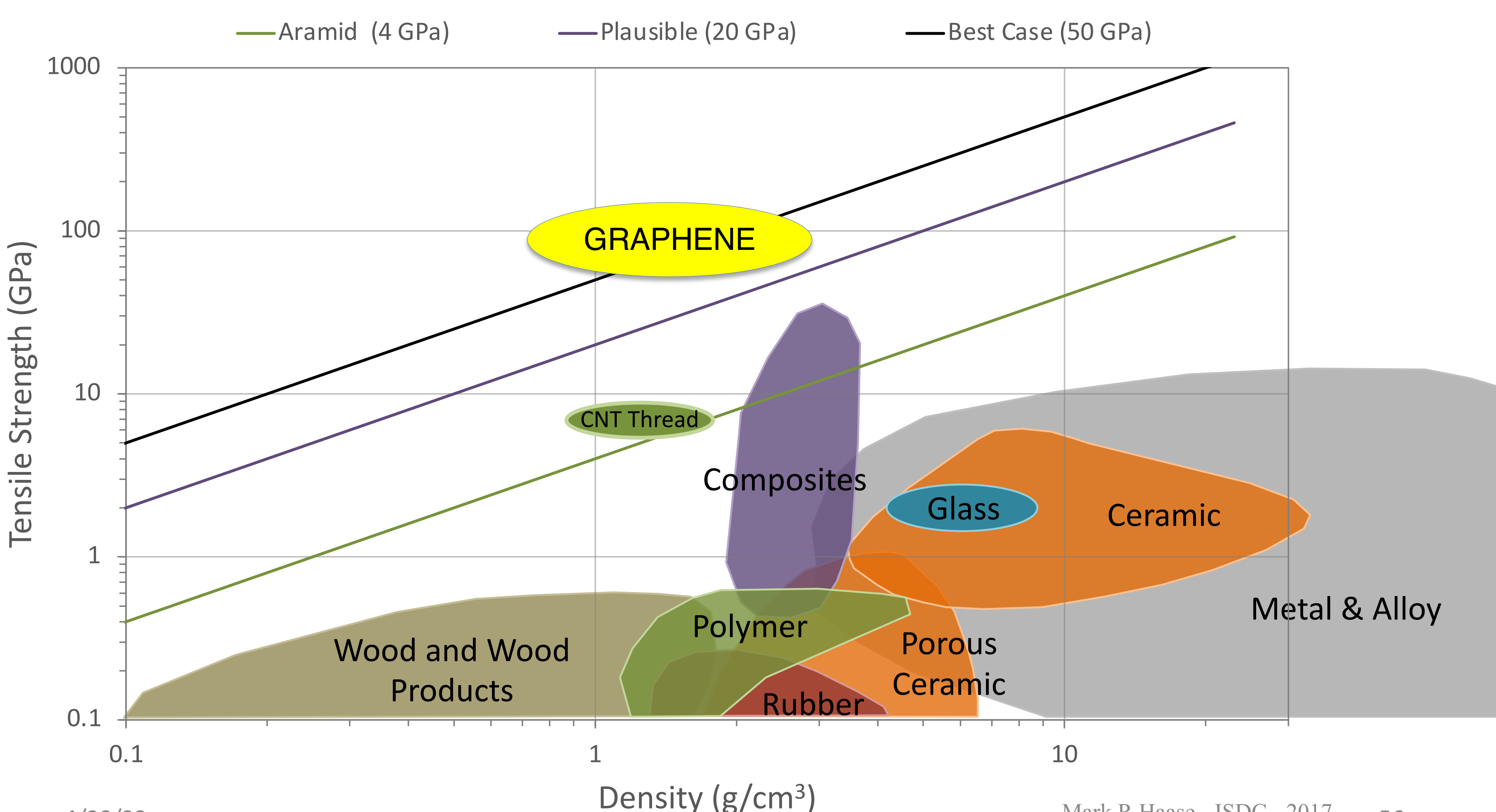




Images by chasedesignstudios.com

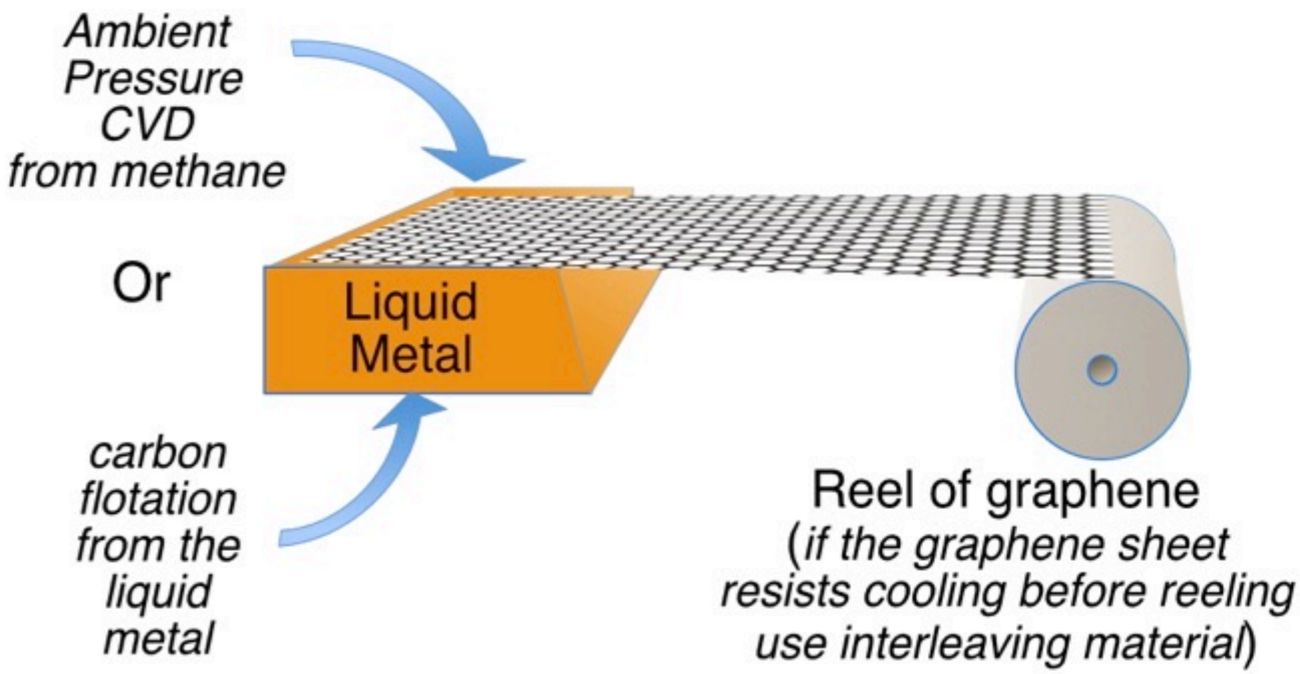
Tether candidate materials

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



Graphene: A new continuous process

Principles for making continuous single crystal sheet graphene



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-

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].

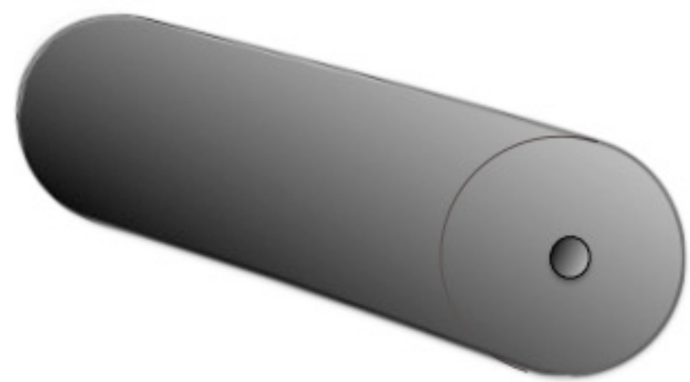
Tether manufactured on earth, assembly in orbit

INTERNATIONAL SPACE ELEVATOR CONSORTIUM

ISEC

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

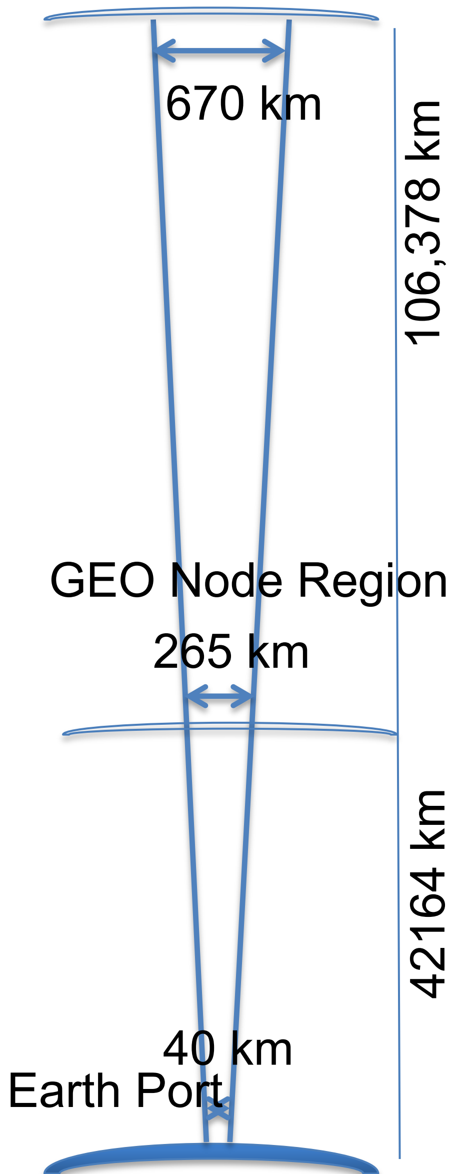
Dr Peter Clark helped with the calculations
https://www.linkedin.com/in/peter-clark-30ab9221/

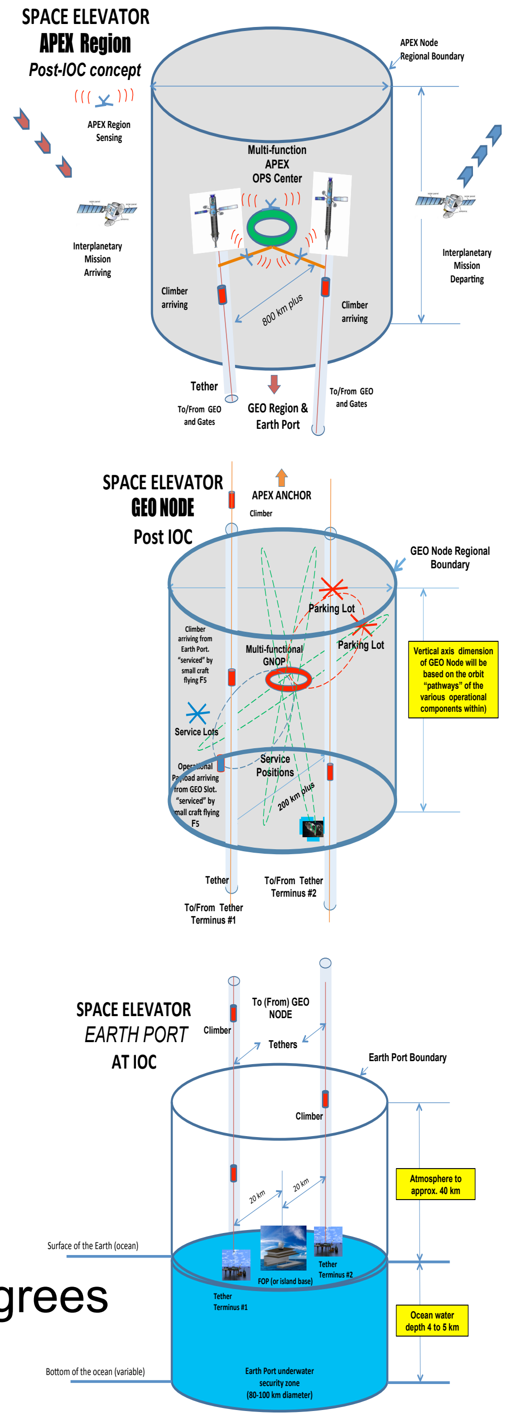
The Earth Port's Floating Operations Platform
(As Presently Envisioned)

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

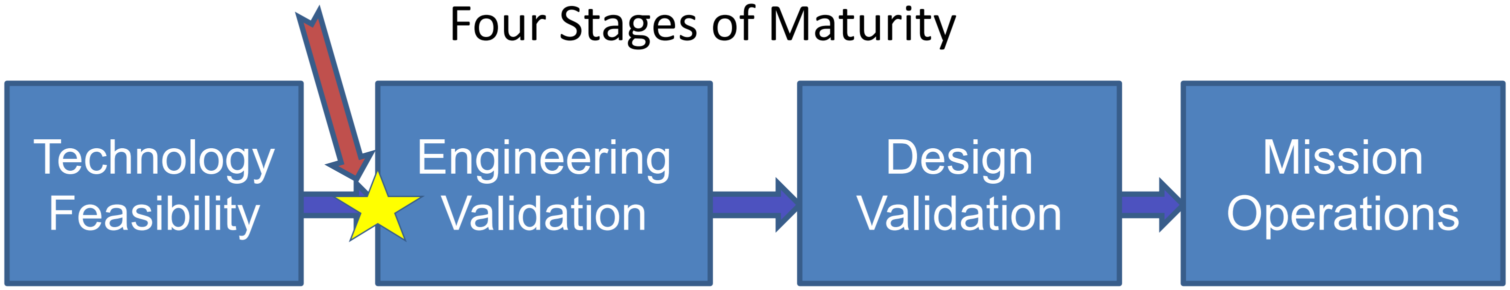




- Galactic Harbour includes two Space Elevators radially extending from Ocean surface to Apex Anchor for a permanent space access infrastructure.
- One reusable tether climber lift-off per day, powered with solar power with 1-meter wide tether
- Three Regions,
  Earth Port – GEO – Apex Anchor
  Where commercial ventures will grow

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.

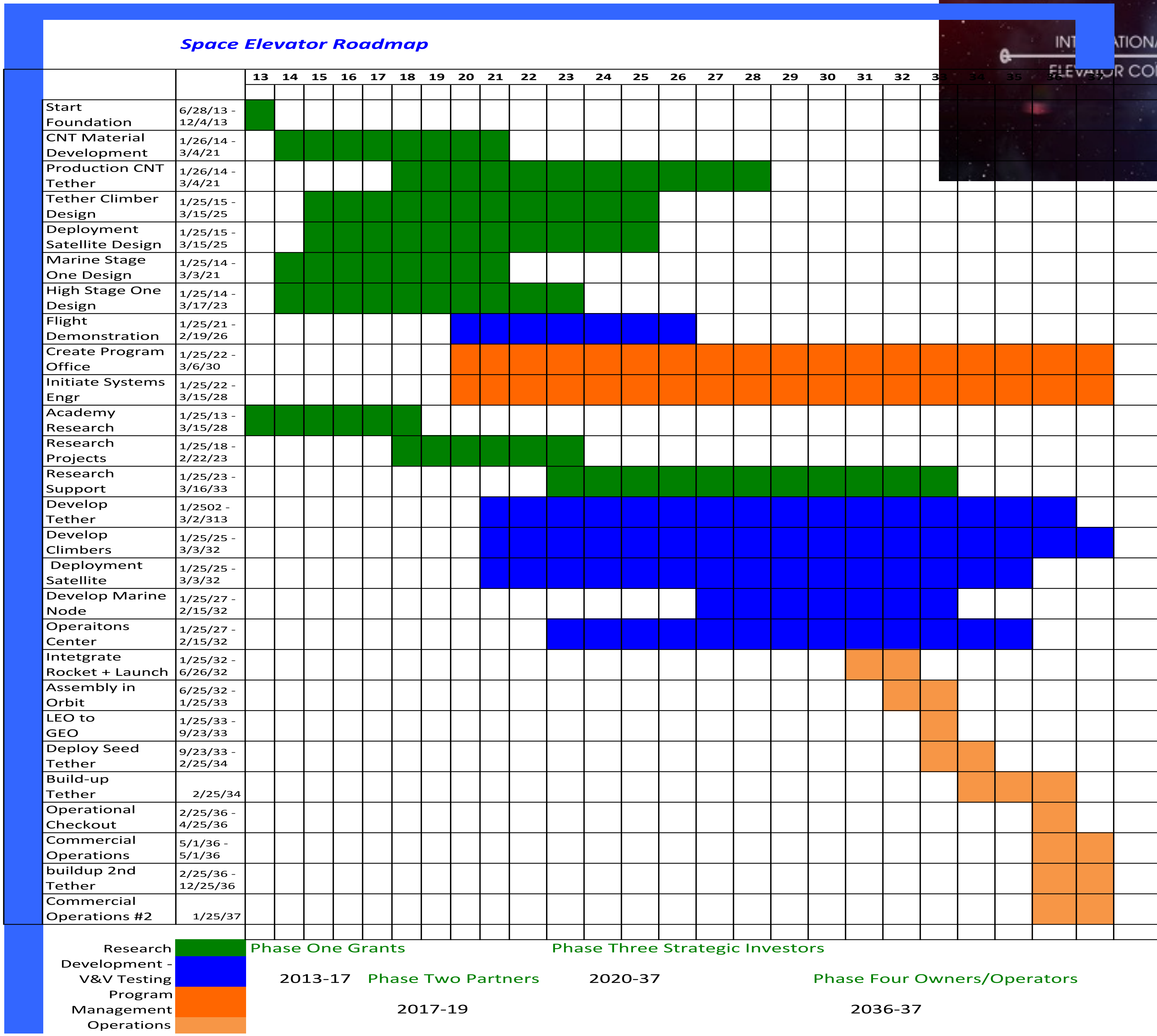
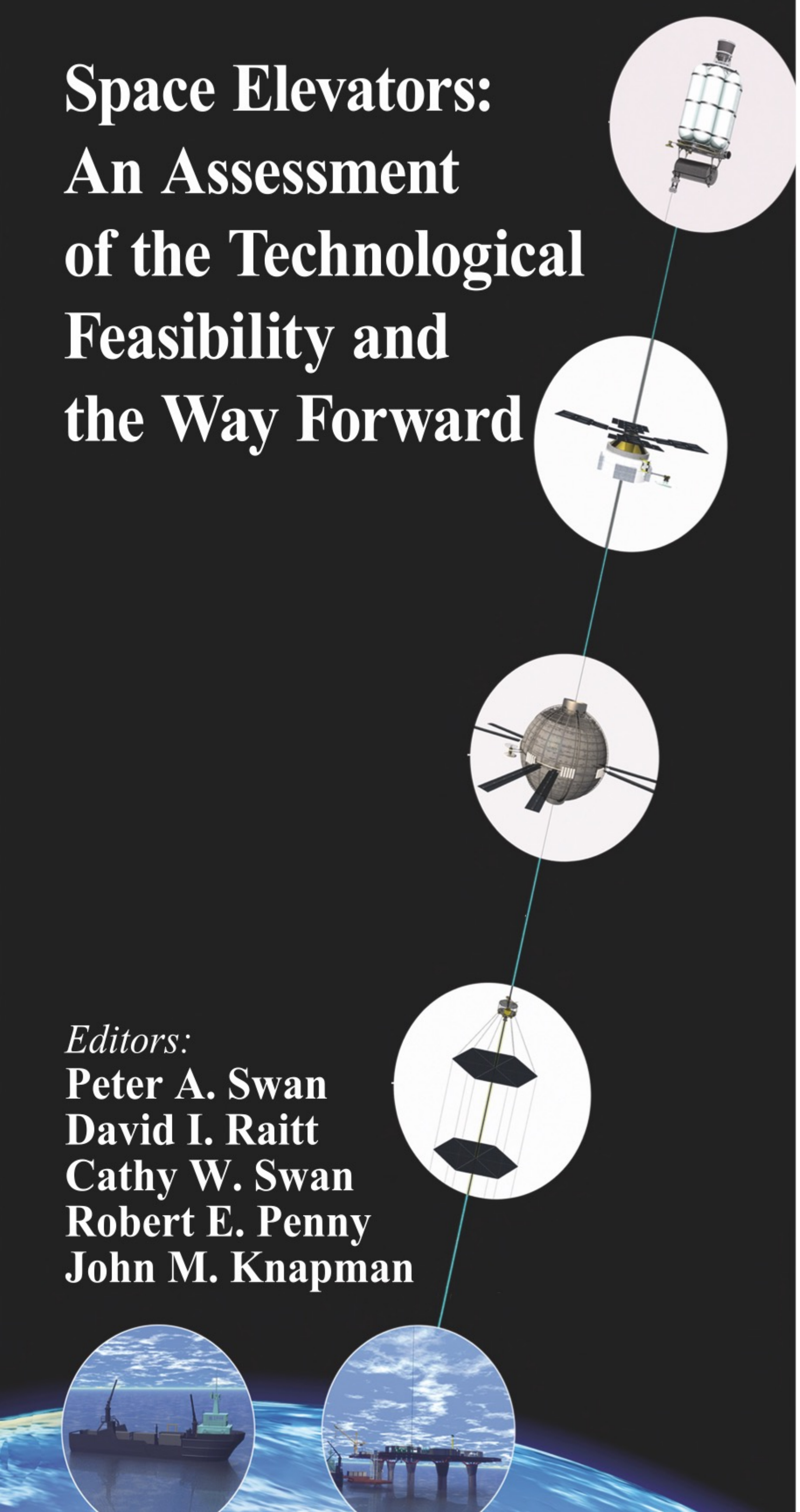
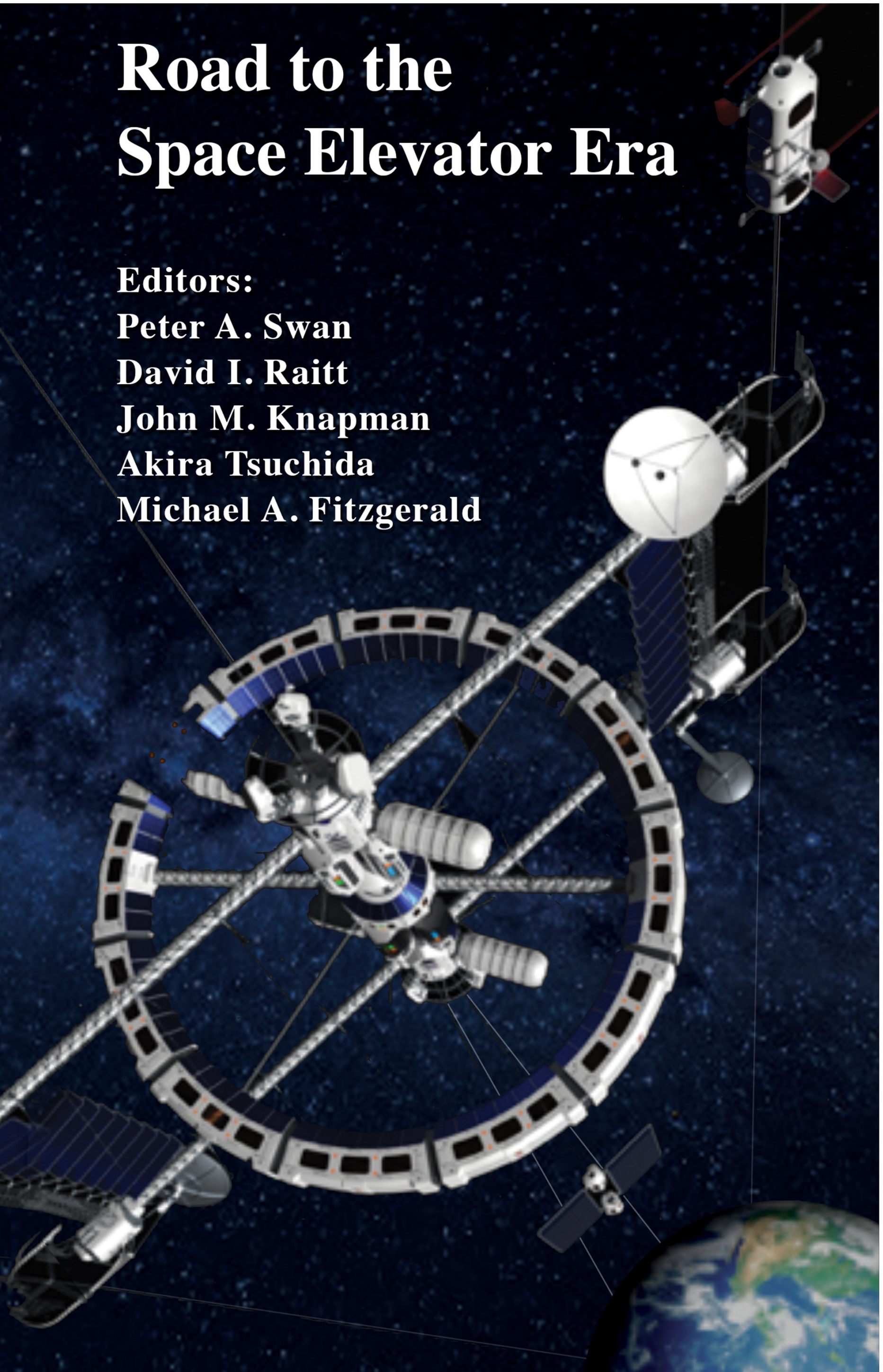


Figure 11- 1. Space Elevator Roadmap A



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

  The Space Elevator Seems Feasible



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

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)

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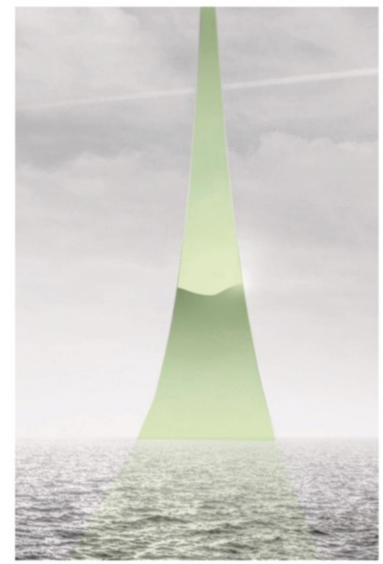


ISEC

A Primer for Progress in Space Elevator Development

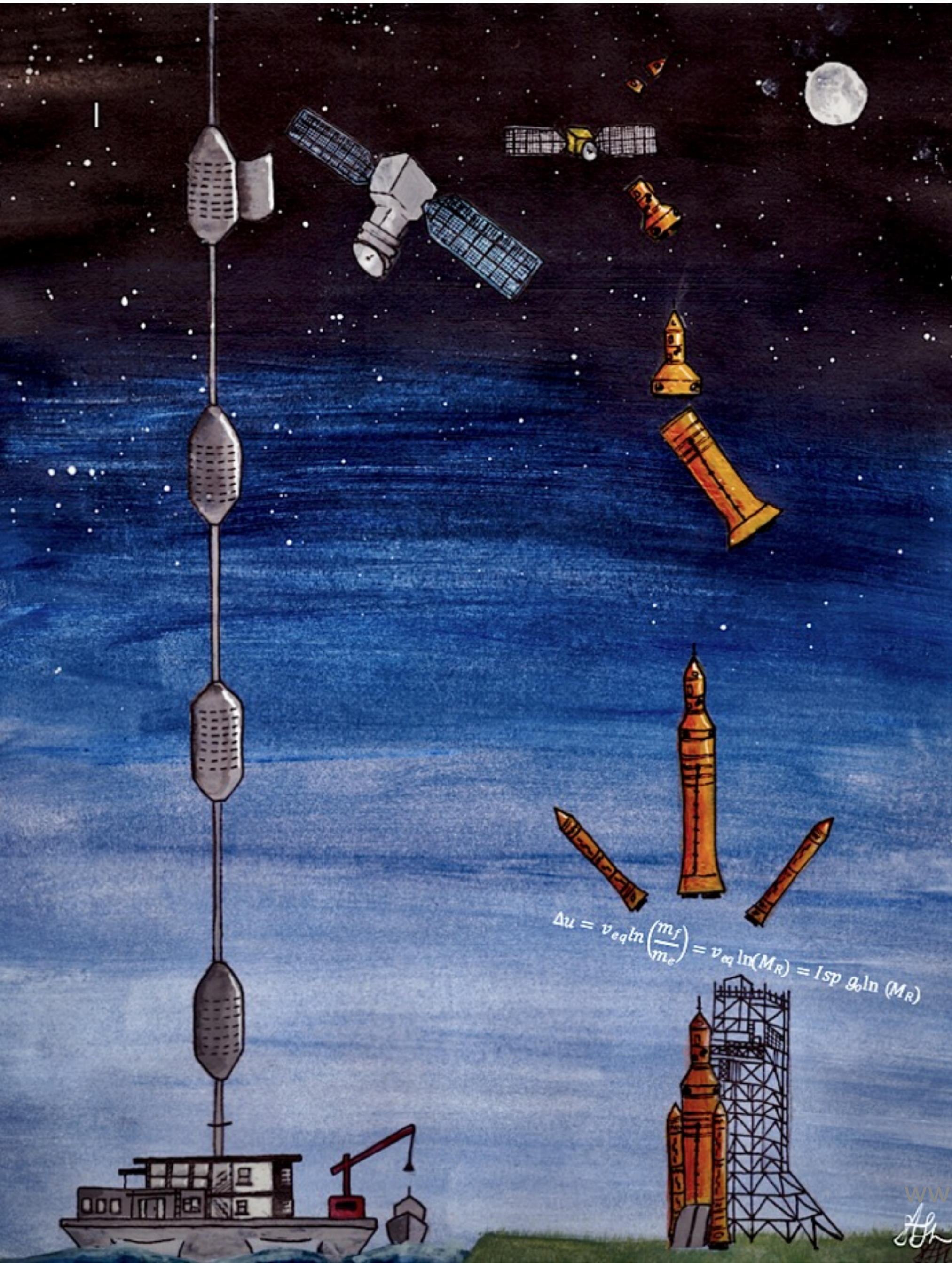
Transformational Leap

- Dreamers
- Space Elevator Vision
- Transformational Characteristics
- Dual Space Access Future
- Engineering Status
- Summary

Why Space Elevators?
Because we Must!

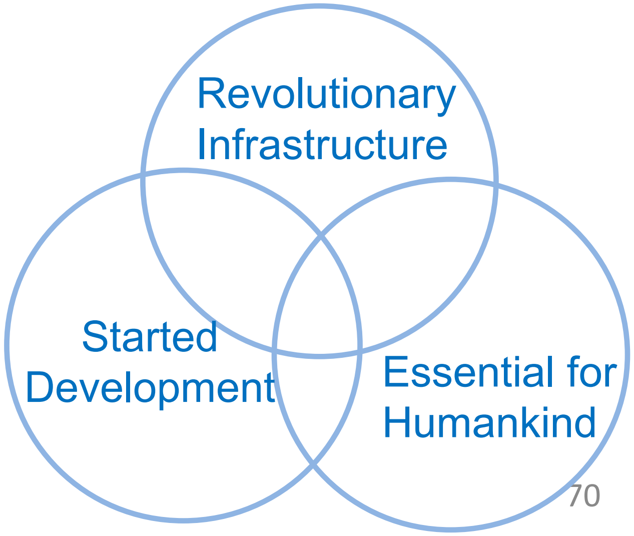
- Fulfills the Dreams of Many
- Raises Massive Cargo using Solar Energy
  - Green Road to Space
  - Permanent Infrastructure for GEO & Beyond
  - Daily, Routine, Safe, and Inexpensive
  - Early Operations: 30,000 tonnes per year
- Space Elevators are a Simple Elegant Solution to the Rocket Equation.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

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



International Space Elevator Consortium www.isec.org

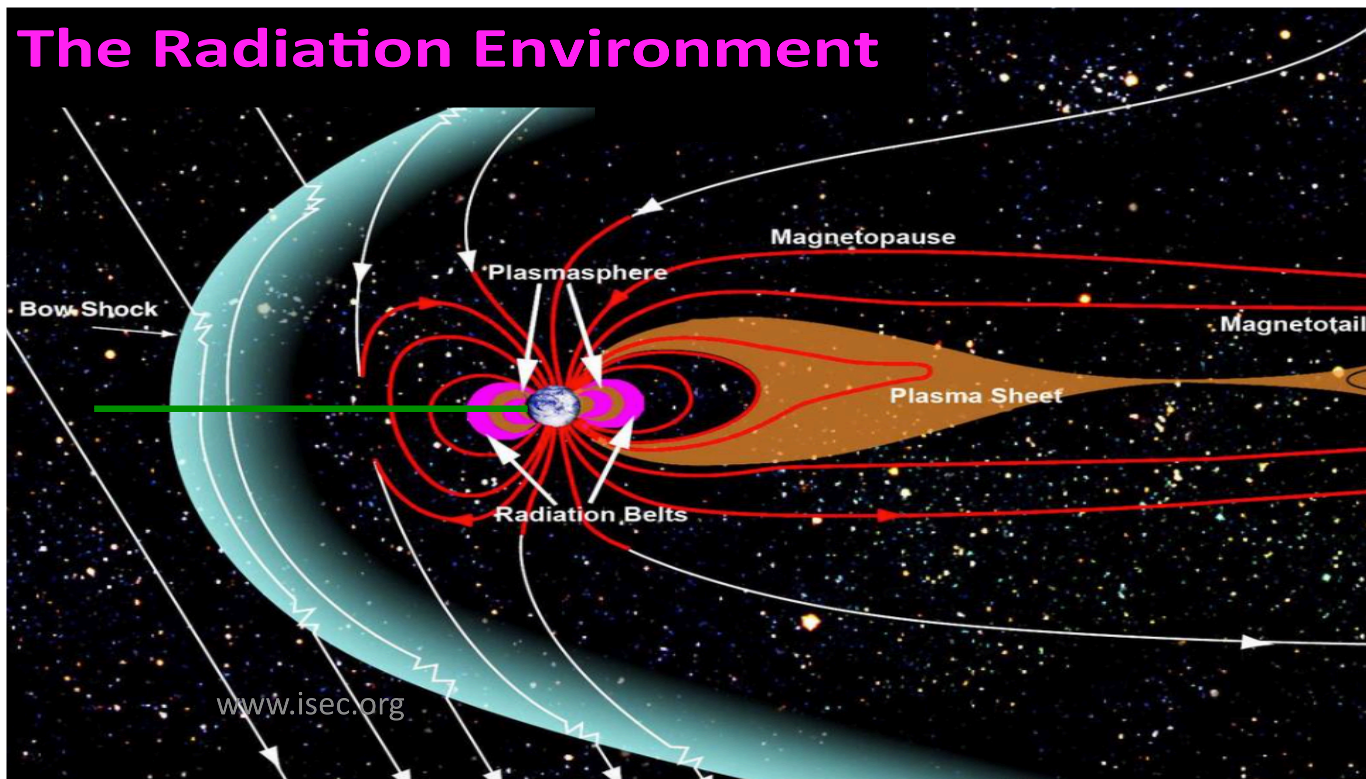
Who are we?

- ***Vision***: Space Elevators are the Green Road to Space while enabling humanity's most important missions by moving massive tonnage to GEO and beyond. They accomplish this safely, routinely, inexpensively, and daily - all while being environmentally neutral.
- **Mission Statement:** "... ISEC promotes the development, construction and operation of a space elevator as a revolutionary and efficient way to space for all humanity ..." – and builds the body of knowledge to share on our website
- **International**:Works with International Academy of Astronautics, European Space Elevator organization [Eurospaceforward], and the Japanese Space Elevator Association.
- **Yearly Thrusts and Research Concentrations**. During the year, a topic is provided to focus ISEC research, activities during the yearly conference, Journal papers, and a study report.
- **Yearly Conference:** International Space Elevator Conference each August in Seattle Washington – with webinars and you tube videos available
- Join for $25 US for student members

Backup Charts

Earth Radius
6,378 Km

Space Elevator
100,000 km
In green



Is a tether made from single crystal graphene feasible?

INTERNATIONAL SPACE ELEVATOR CONSORTIUM ISEC

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

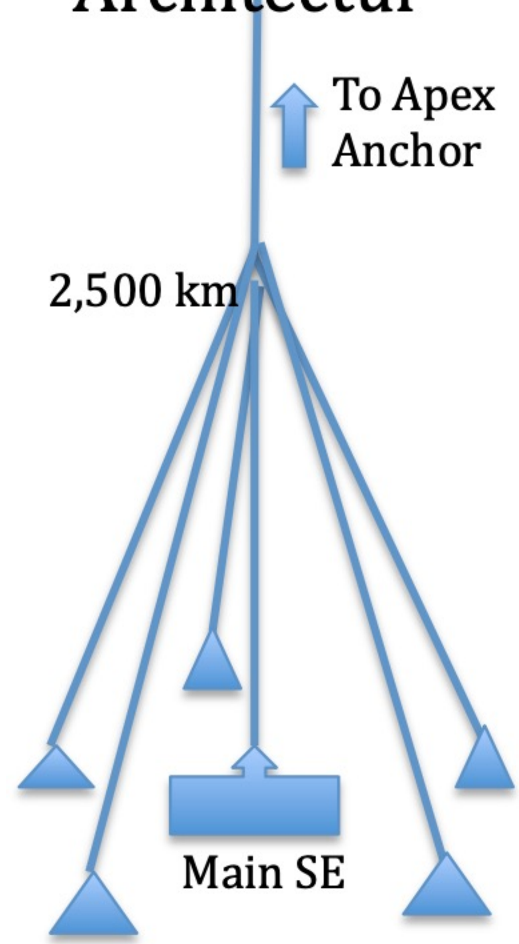
Graphene tether material really is possible within our lifetimes.

Manageable Operations

Item	*2010*	*2019*	*2030 Est.*	*Comment*
Total Tracked Debris by NASA (2010 & 2019 measured, 2030 estimated)	15378	19137	38,000	Assume Internet constellations will add many space objects by 2030
Threats in GEO region (possible conjunction)	0.0026 per year	0.005 per year	0.01 per year	Good operational procedures a must.
Threat in MEO region (possible conjunction)	0.0003 per year	0.0006 per year	0.0012 per year	Good operational procedures 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 and movement planned to account for this - with continuous repair[12]
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 tracked objects or movement 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 peak regions	Note, this assumes there is no active movement of tracked objects or movement of the tether

Table 2.6 Summary by Year and Altitude Region

Multi-Leg Architectur



Operating Safely in Debris Environment

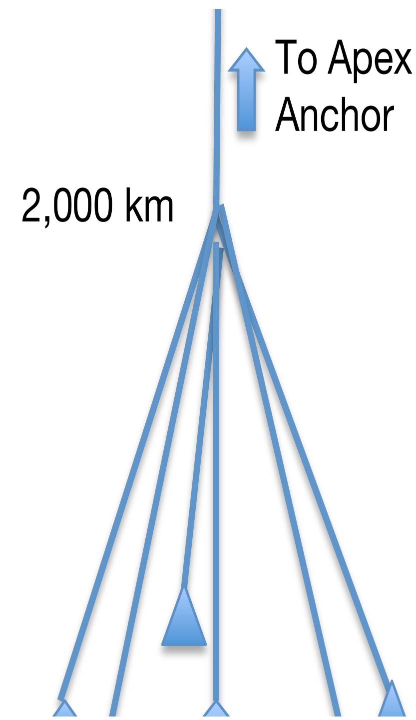
Two Reports and seven pg summary in “Start Now” work book.

- 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

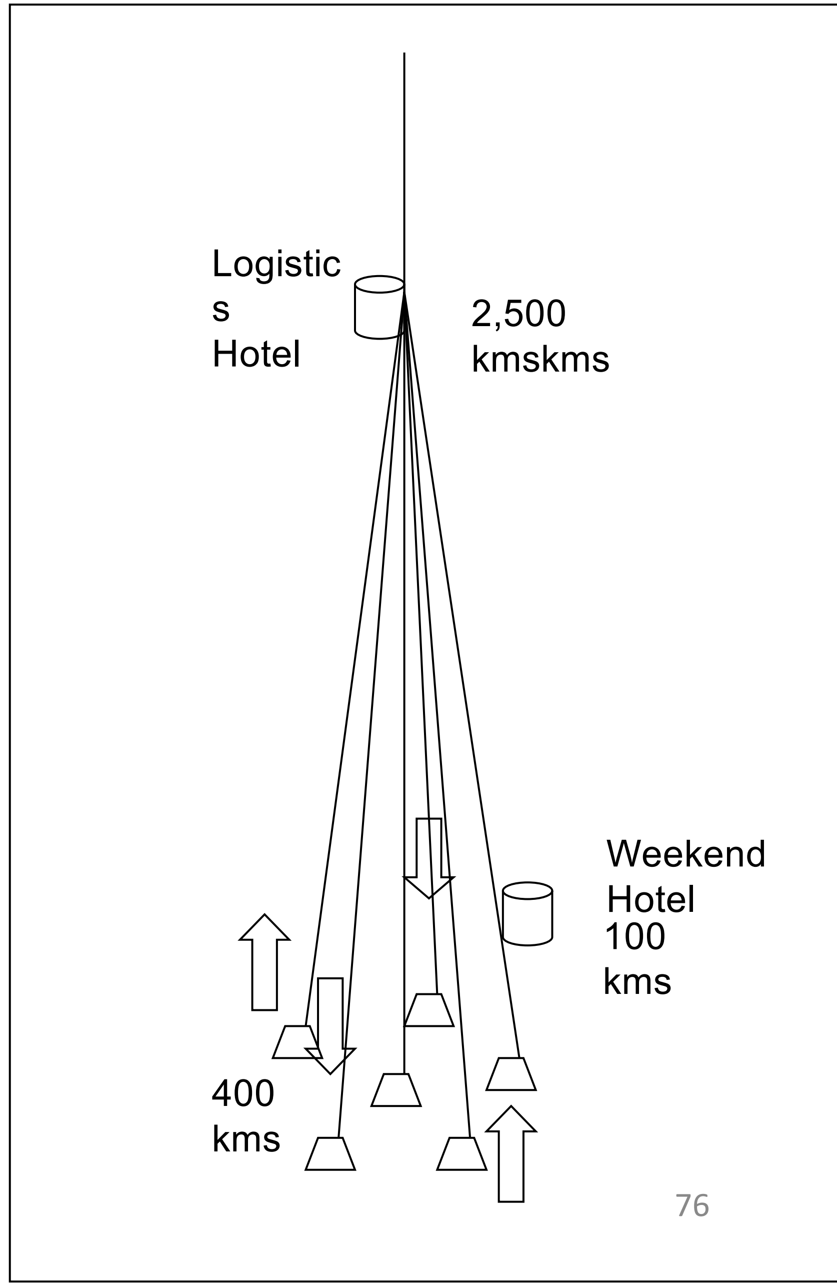
Debris sizing → as a threat variant

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.



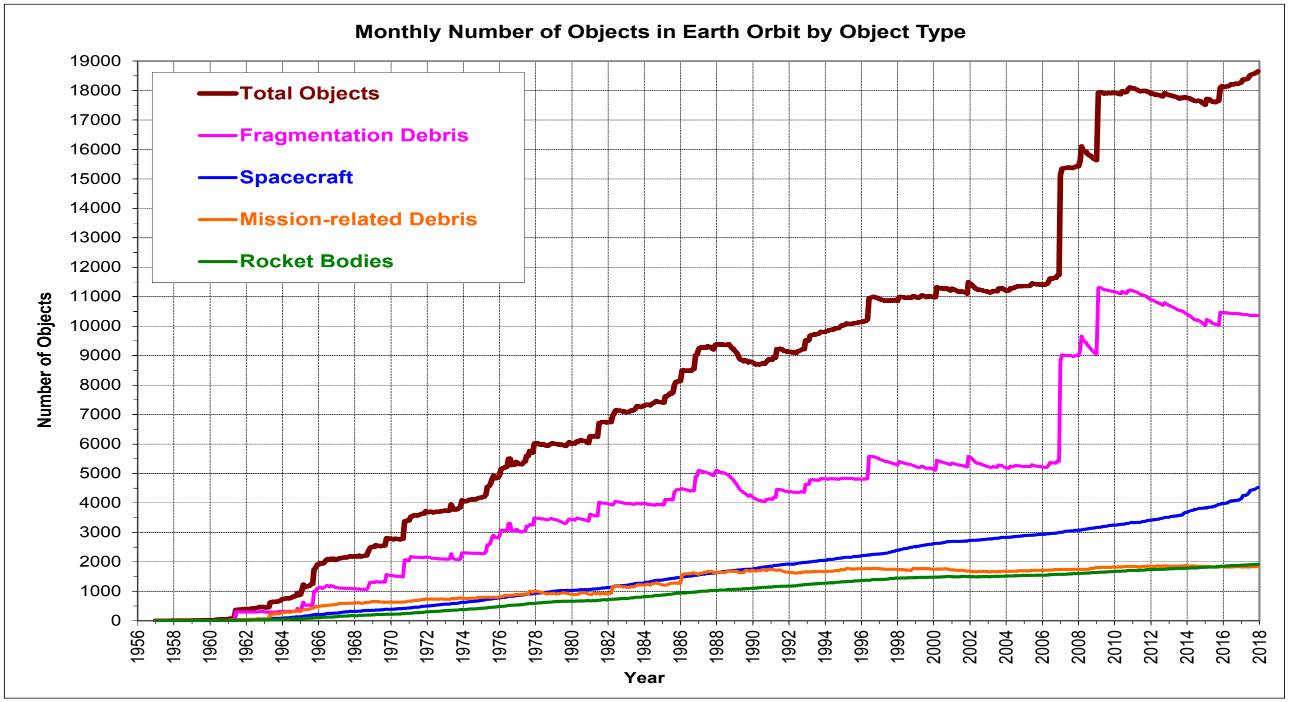
Summary for Future

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.

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

Orbital Debris Quarterly News

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*