# *Modern-Day Space Elevators, as Permanent Space Transportation Infrastructures, and how they will Open UP Space!*


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Former Chairman, Commission VI - IAA
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Fellow, American Institute of Aeronautics and Astronautics
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Past Industry Professor, Delft Technical University
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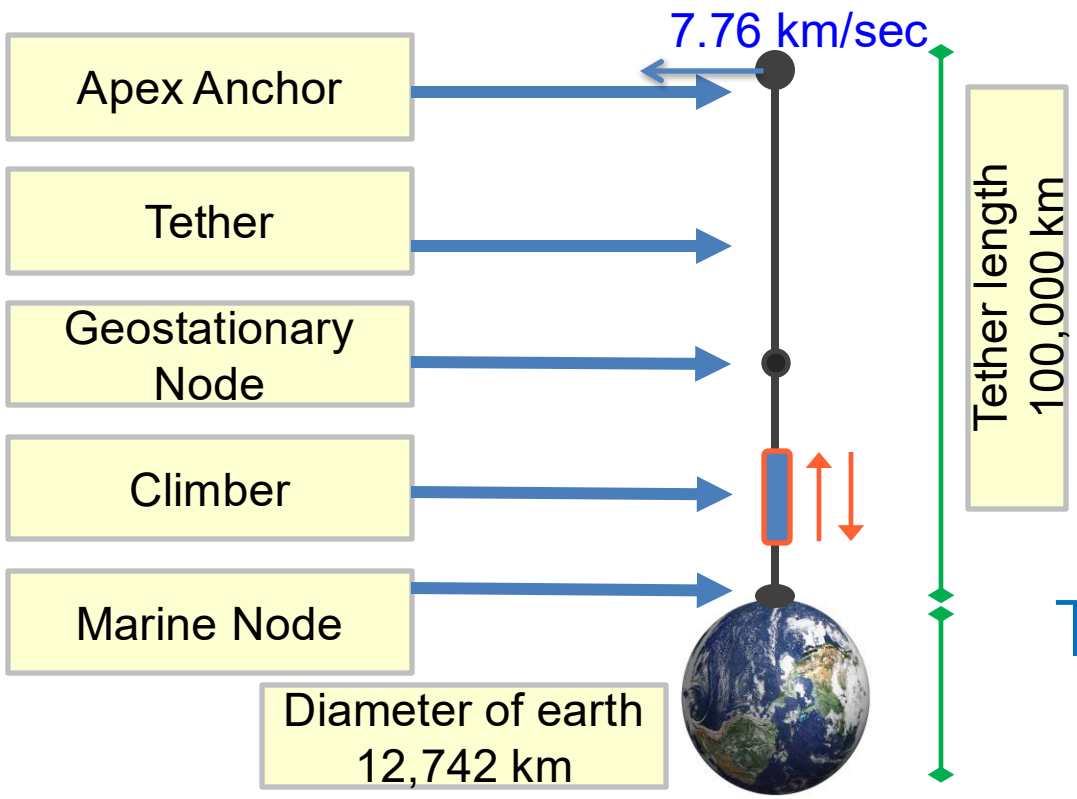
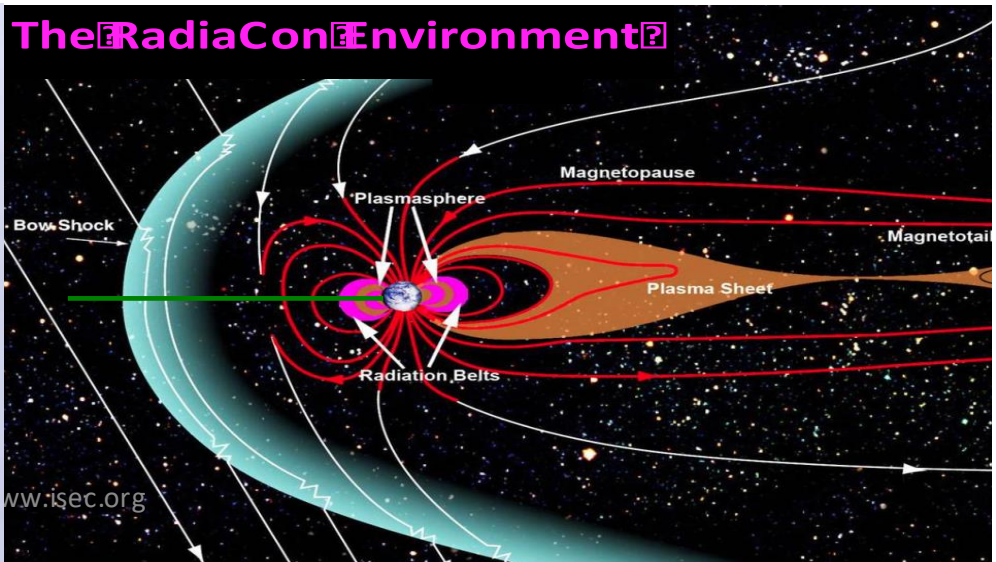
Note: many images from Heinlein Prize Trust
and Excalibur Exploration
Image from IAA Study





# The Space Elevator

Art by Bartoszek



## *Modern Day Space Elevators*
## *Why, Architecture, Where are We?*



## *Vision – Humanity's and Ours*
## *Our Customers, 2037 +*

## *What are Space Elevators' Transformation Strengths?*

## *Current Architecture*

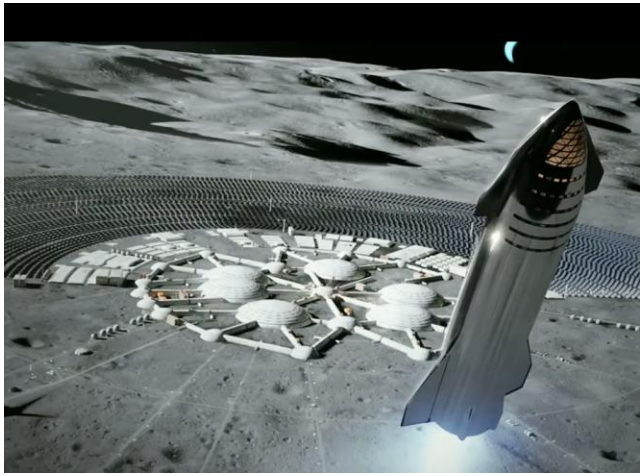
## *Where are we in Development?*

# Living and working in thriving communities beyond Earth – NSS


Dream Big!
But How much mass to Orbit?

Images from SpaceX website

Image from Blue Origin website



Images by NASA and Rick Guidice

# *Reference Missions: (customer demands) – How much does it weigh?*



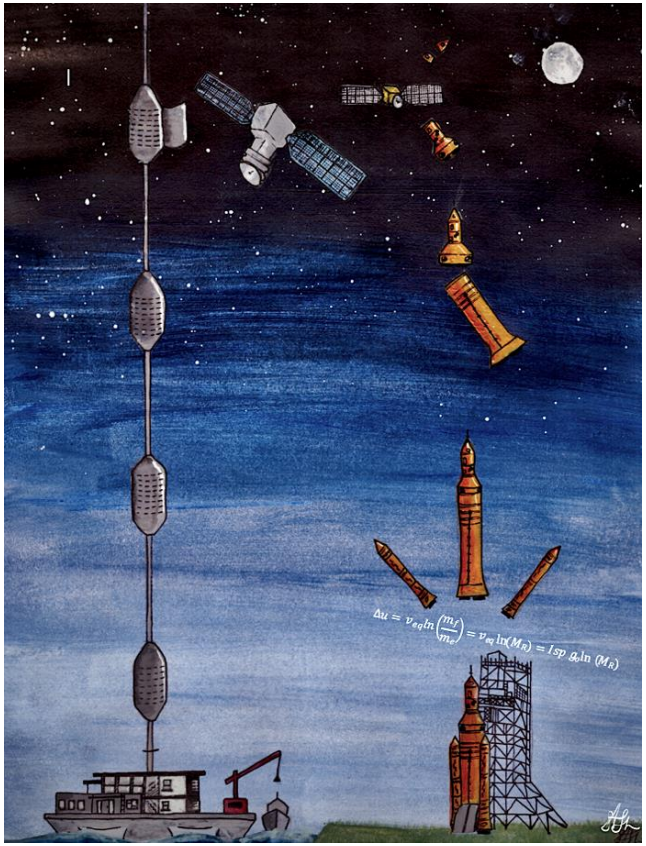
Note: Humanity has only orbited about 20,000 tonnes during our history (thru 2020)

- Space Solar Power – 3,000,000 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 reduction

* 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

1,000,000/100 = 10,000 per mission vehicle
Now x 5 launches per mission vehicle = 50,000 launches

# Space Elevator Vision 2038 Timeline

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

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

# Modern Day Space Elevator Transforming Space Access



Art by
A. Stanton

The Modern Day Space Elevator has evolved from a dream to a scientific engineering reality. The understanding of the new 3-D material characteristics have enabled the transition to a real meg-project. The five 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.
- Space Elevator's Transformational Characteristics Revolutionize the future of Space

# Characteristics of Permanent Transportation Infrastructure


- Revolutionarily inexpensive to GEO [$100/kg to GEO]
- Commercial development similar to bridge building
- Efficient, 70% of pad mass to GEO
- 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

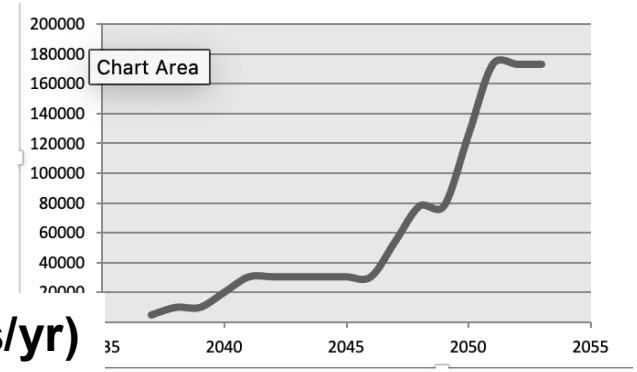
Beats the Gravity Well in an environmentally friendly manner

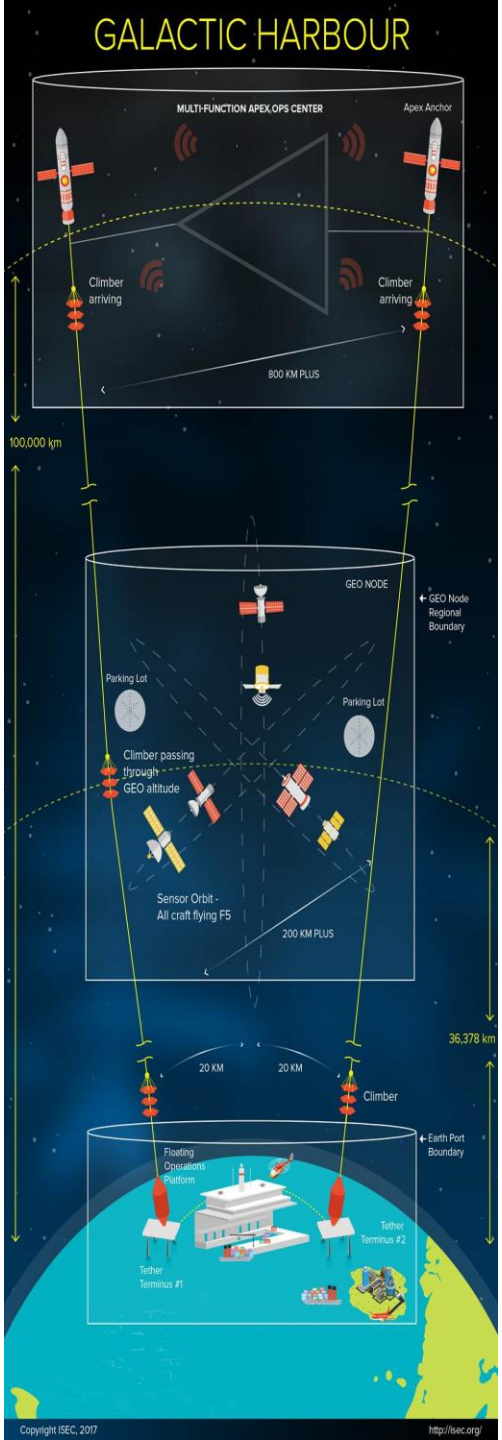
# Transformational Characteristics
# The WHY for Space Elevators


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 of Delivery to Destinations
- Unmatched Massive movement (30,000 tonnes/yr vs. approx.. rockets' 20,000 tonnes over 65 years)
- 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
- Transforming the economics towards an infrastructure with access to more valuable, lucrative, stable and reliable investments

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



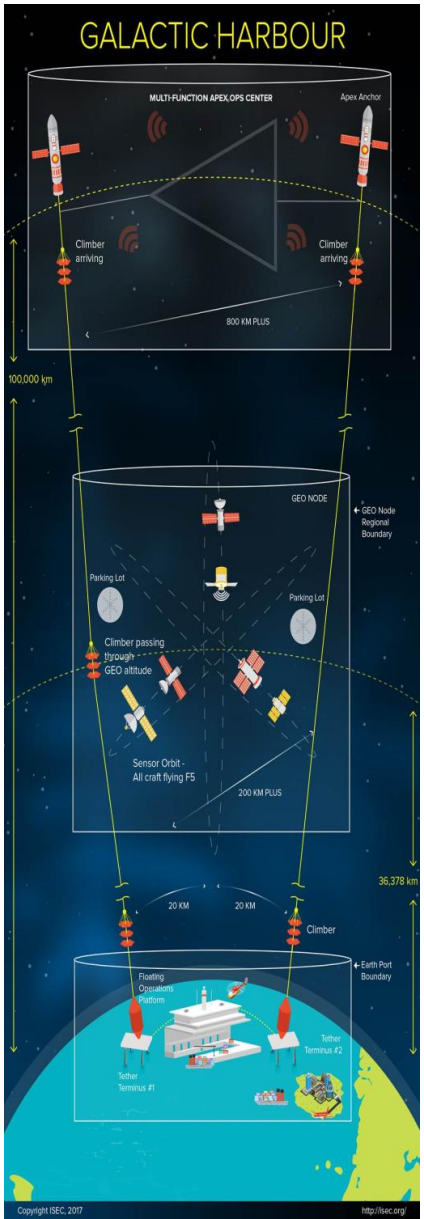




# Strength One: *Daily, routinely, safely, and inexpensively*:

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

# Strength Two: *Unmatched Efficiency of Delivery to Destination*


- Unmatched efficiencies - Comparison of Rocket and Space Elevator efficiencies shows the mass delivered to GEO & Beyond by rockets is minimal while the future of Space Elevators reaches towards 70% of the mass on the ocean is delivered beyond GEO.
  - Rockets (4% to LEO, 2% to GEO, 0.5% to Lunar surface)
  - Space Elevators (70% to GEO and beyond with 30% are reusable climbers)
- Unmatched fast transit to destination (Mars as short as 61 days). Arizona State University (ASU) research illustrated the remarkable transit times periodically during the 26 month repeating orbital relationship between Earth and Mars. Release every day of the year towards Mars
- Unmatched liftoff capability (14 metric tons payload per day, initial capability). Space Elevators start out with huge throughput capacity with daily liftoffs (5,110 tonnes per year- Initial Operations Capability 30,660 tonnes per year).

# 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 |

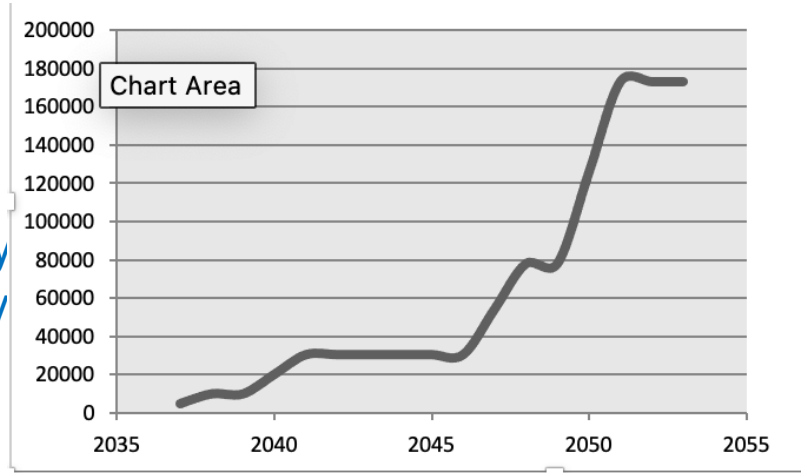
Note: Leo is 4% of launch pad mass
GEO, Interplanetary, Lunar 2% of pad
*Shuttle launch vehicle reached orbit as an operational satellite

22,216 tonnes between 1957 and 2020.

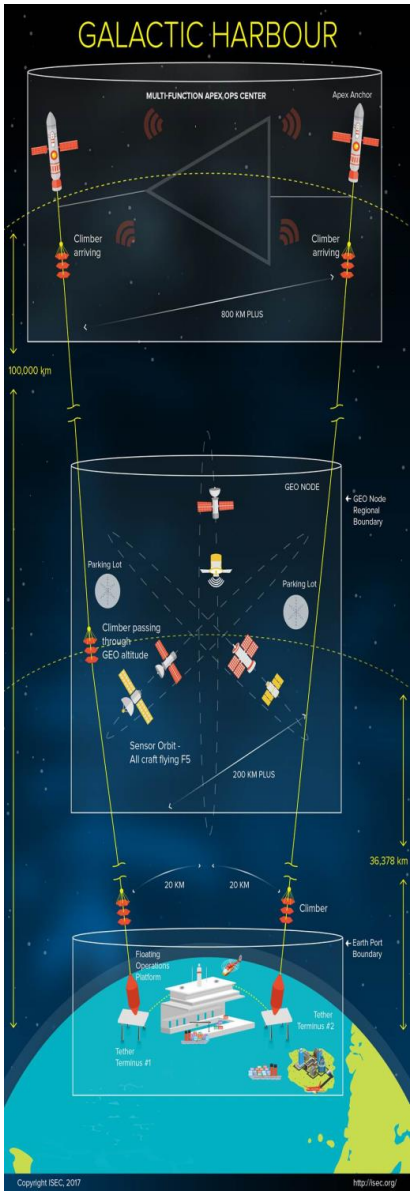
Historic Movement
(1957 – 2020)

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

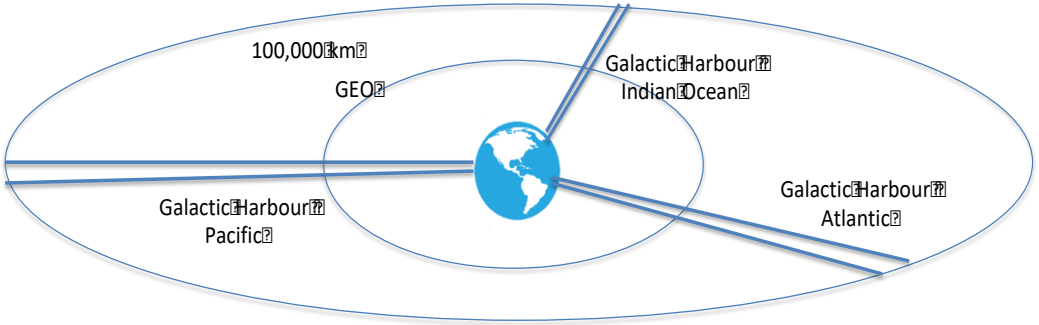
**Annual payload (tonnes/yr)**



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


# A Green Road to Space

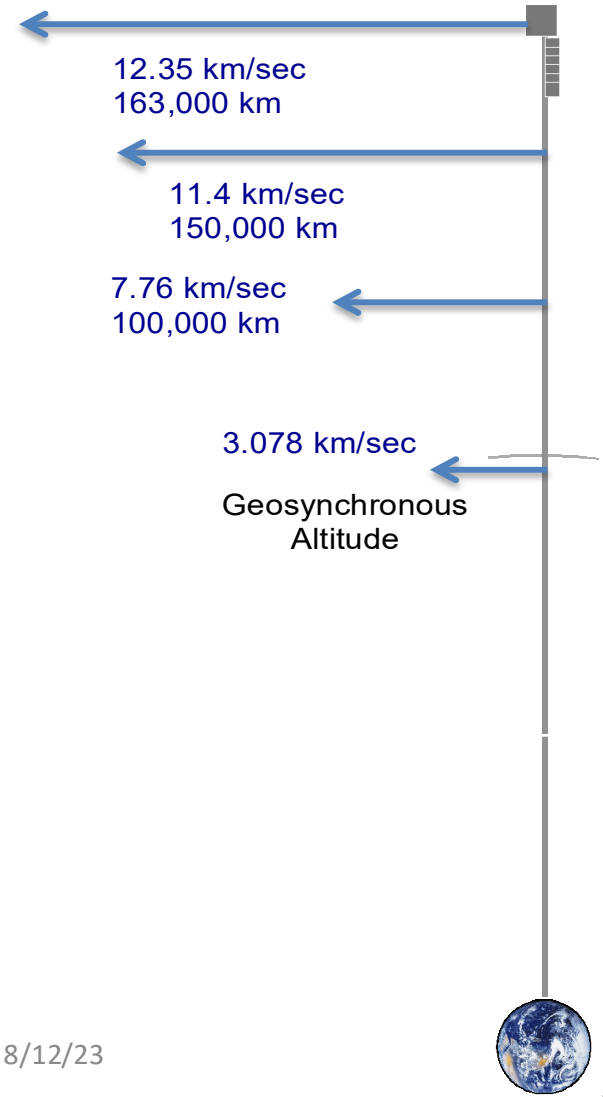



Massive tonnage* raised by electricity to GEO and beyond, daily, routinely, inexpensively, safely, and in an Earth Friendly manner.

Space Elevators Beat the Rocket Equation
We Enable Dreams

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

# 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).

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 | |

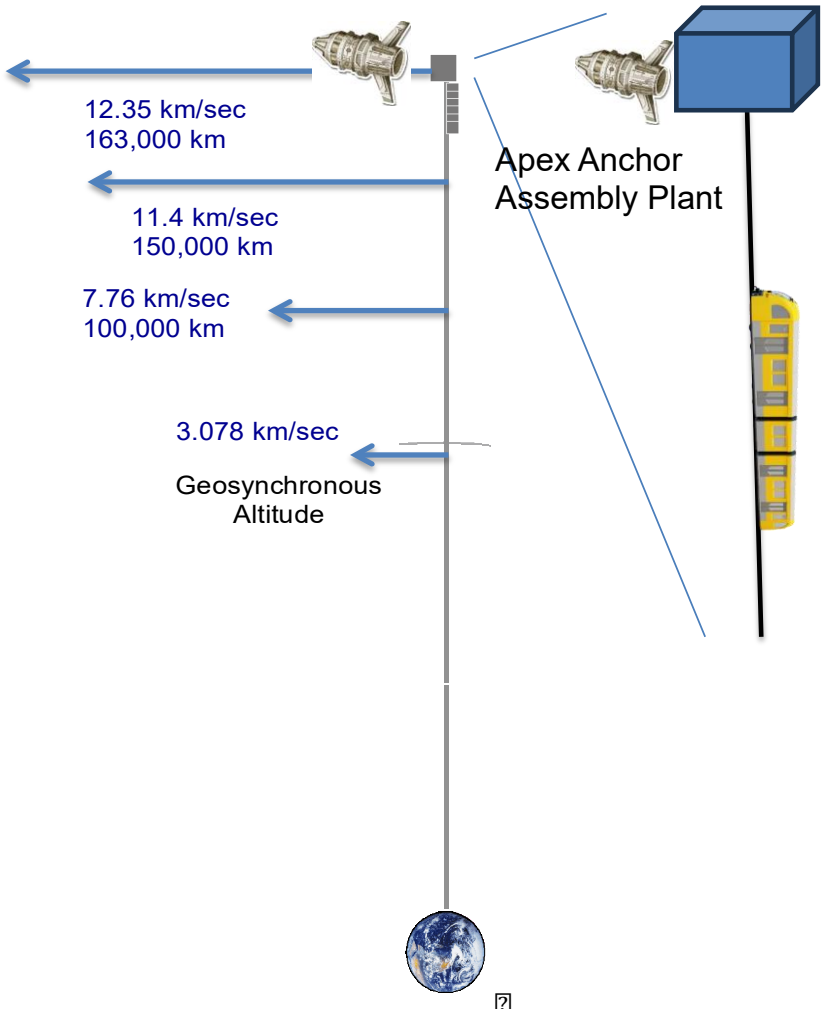

# Bus Schedule to Mars*

Note: Departure for Mars every day with varying trip times.

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

# 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.
- Can you image robotic assembly in a garage 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/refuel/build Facility?
- Assembly at the Apex Anchor results in beating Gravity! 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. This statement combines th 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.



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## *Why, Architecture, Where are We?*

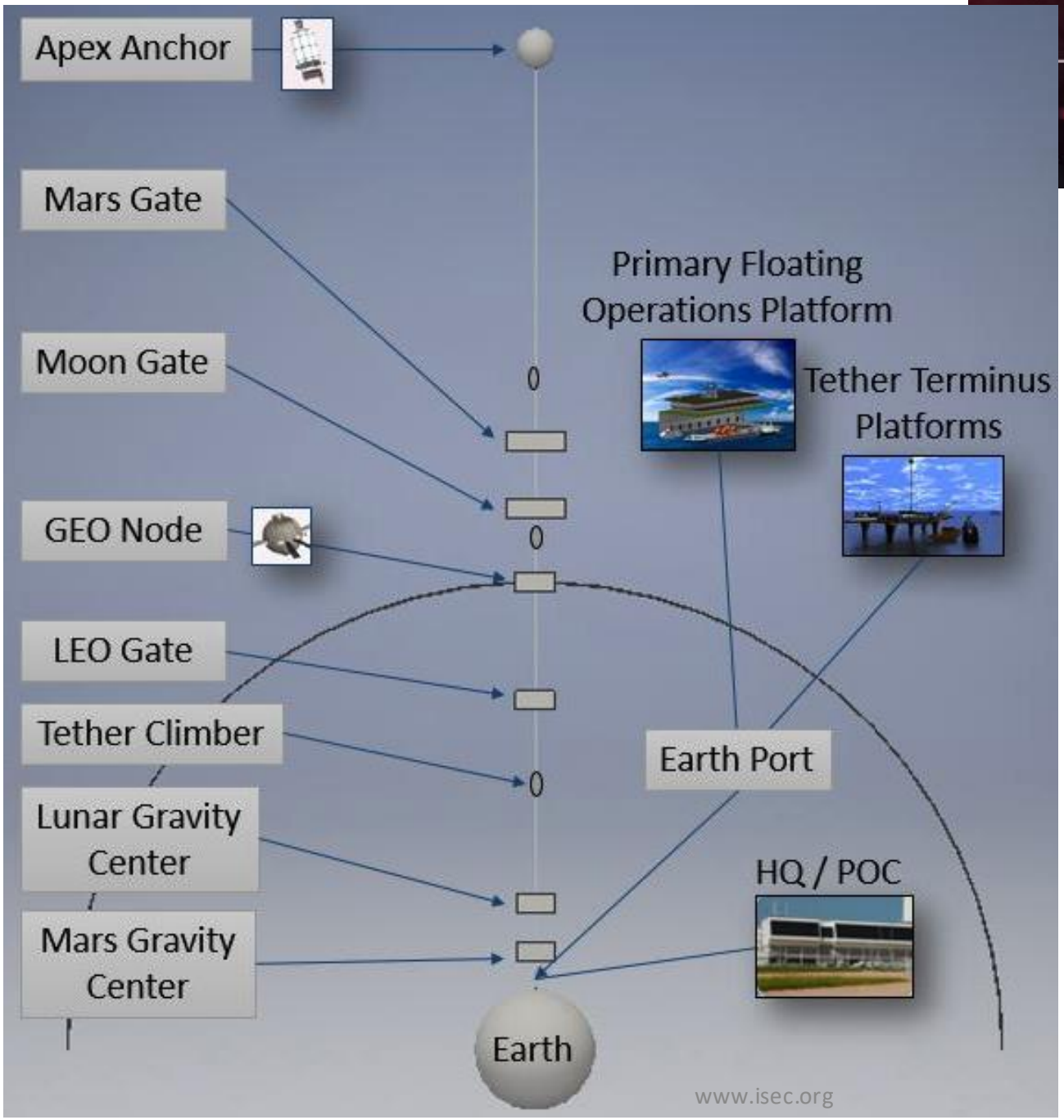


***Vision – Humanity's and Ours***
***Our Customers, 2037 +***

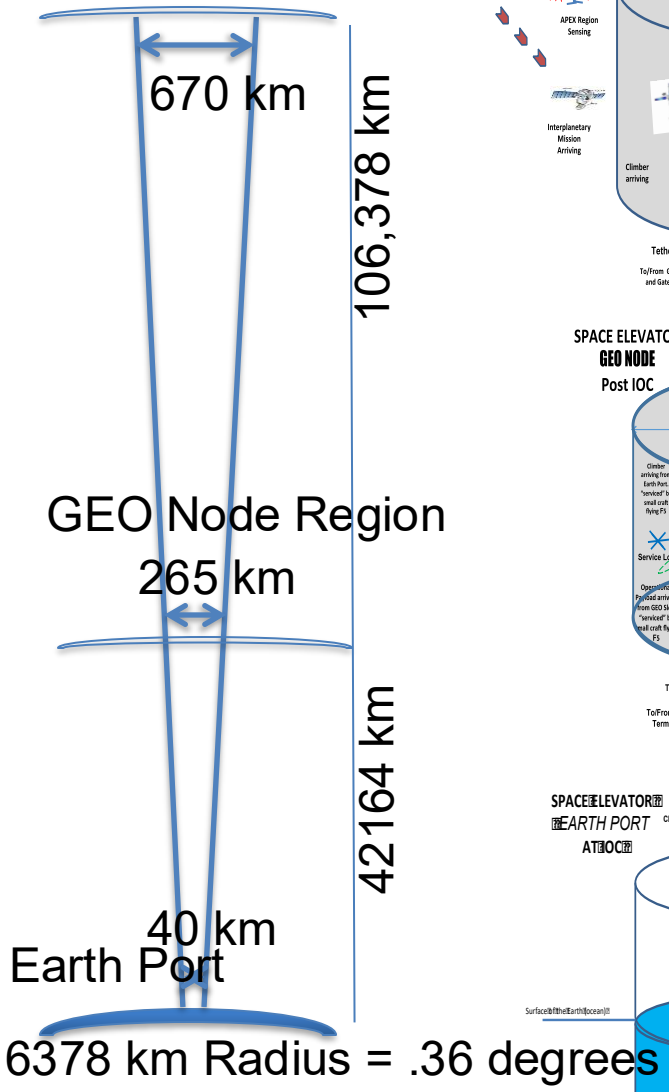
***What are Space Elevators' Transformation Strengths?***

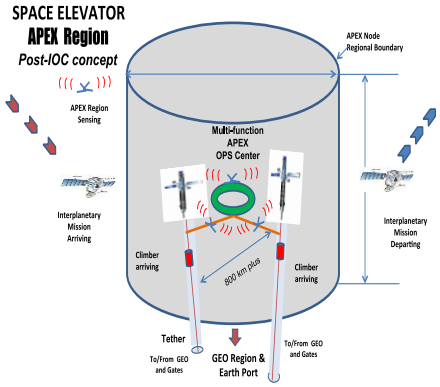
***Current Architecture***

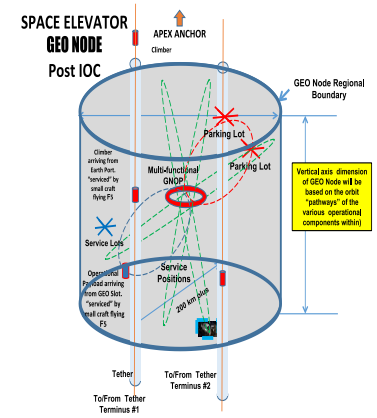
***Where are we in Development?***

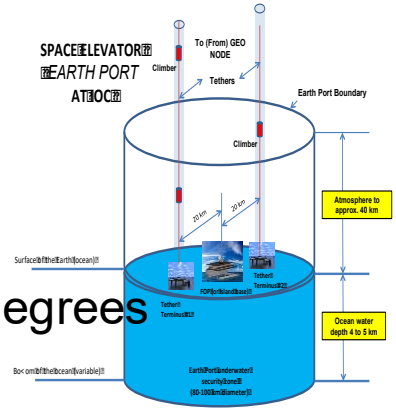



# System Overview

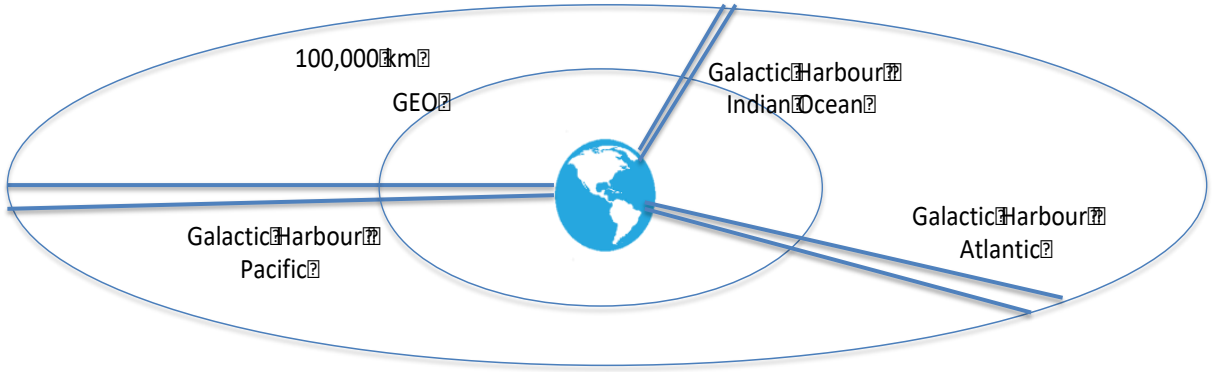




- Galactic Harbour includes two Space Elevators radially extending from Ocean surface to Apex Anchor for a permanent space access infrastructure.
- One reusable tether climber lift-off per day
- Three Regions, Earth Port – GEO – Apex Anchor, where commercial ventures will grow

# *Vision of Galactic Harbours – A Green Road to Space*


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

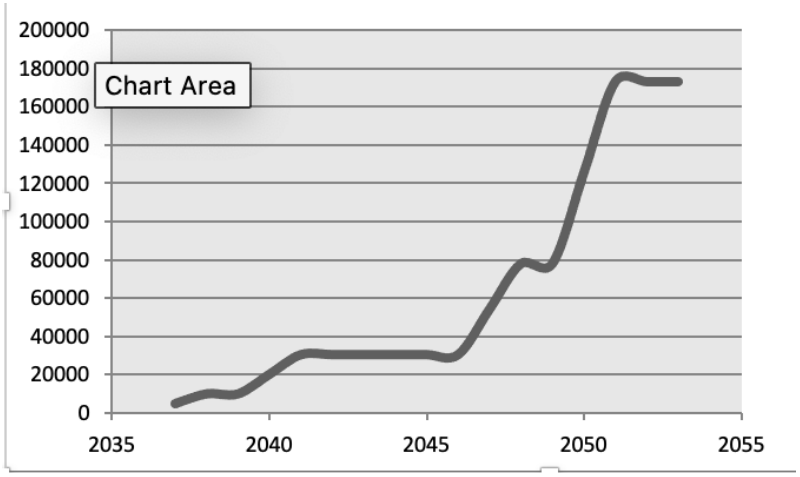
Three Galactic Harbours

– 7 climbers a week/elevator

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

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

**Annual payload (tonnes/yr)**



# Space Elevator *Body of Knowledge*


Table 1, Study Summaries, ISEC

| *Year* | *Title of ISEC Yearly Study Reports (www.isec.org/studies)* |
|---|---|
| 2024 | Apex Anchor Missions & Characteristics (just started) |
| 2023 | Leverage Dual Space Access Architecture (Sept 2023) |
| 20221 | Design Considerations for the Space Elevator Climber-Tether Interface - just starting in progressCllimbe-Tether Interface for the Space Elevator |
| 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 |

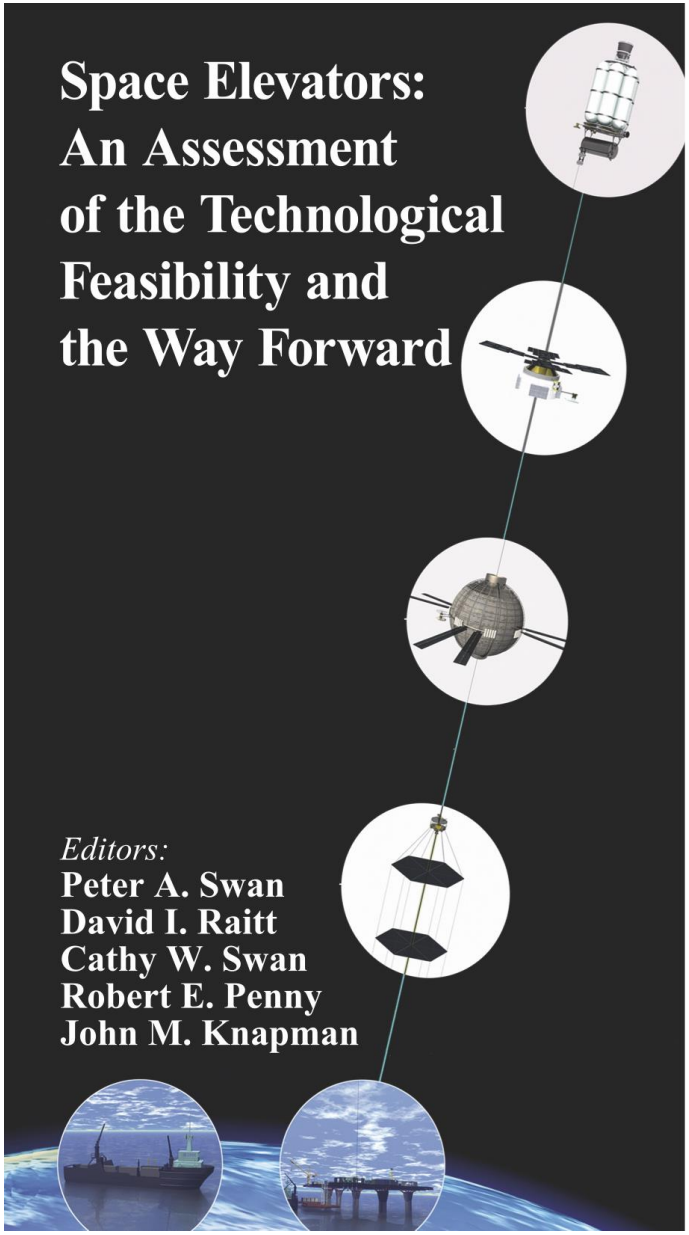
| *Modern Space Elevator Explanations* | *Speaker* |
|---|---|
| Dreaming of Space? Take a Space Elevator | Pete Swan |
| Why Space Elevators and Customer Demands/Visions? | Pete Swan |
| Architectural Features of Galactic Harbours | Michael Fitzgerald |
| Green Road to Space Leads to Environmentally 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 |

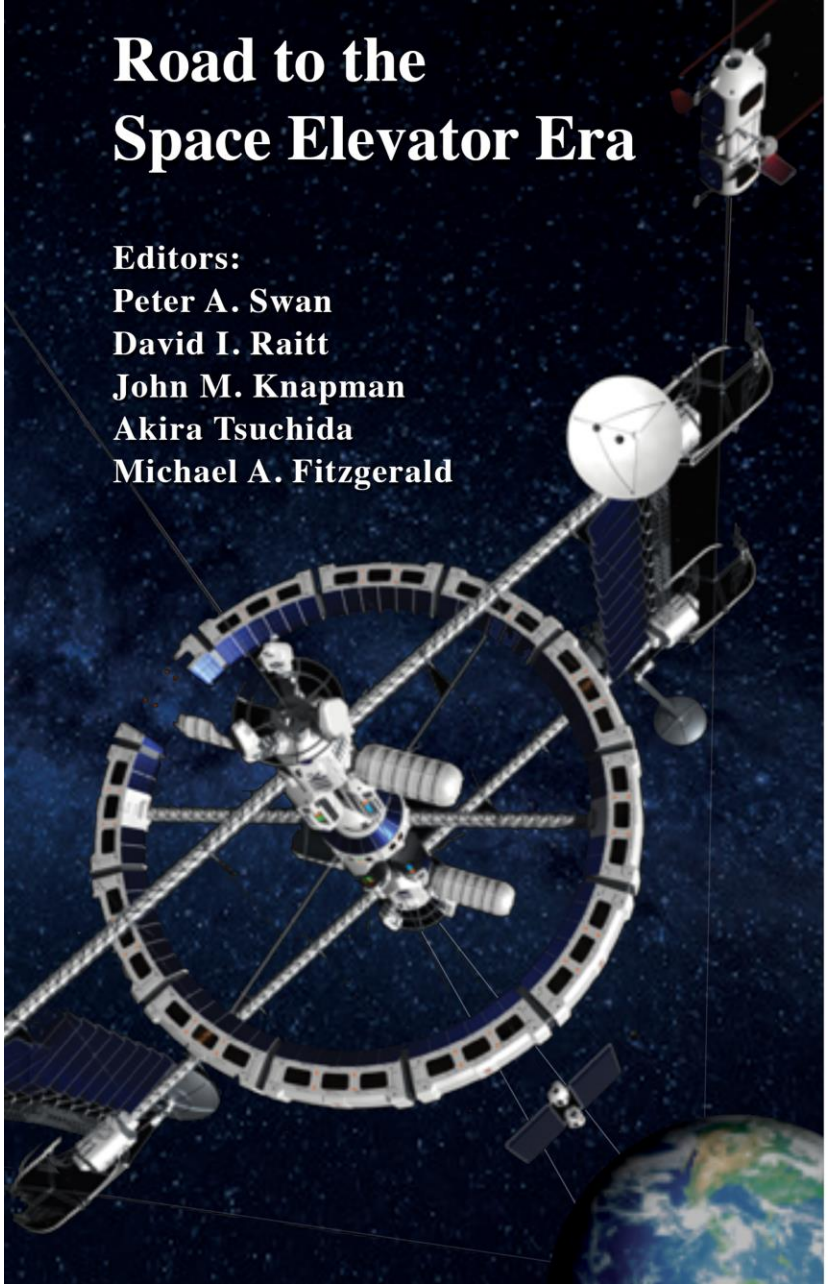
Completed studies on www.isec.org in pdf format are free

| | *Other Study Reports* |
|---|---|
| 2019 | The Road to the Space Elevator Era - IAA<br>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<br>(https://www.obayashi.co.jp/en/news/detail/the_space_elevator_construction_concept.html) |

## ISEC Studies and Videos

www.isec.org


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


Road to the
Space Elevator Era
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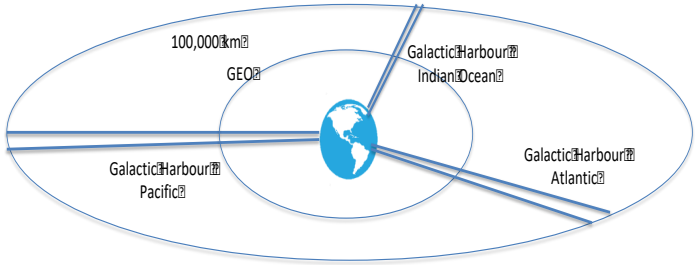
# Developmental Plan

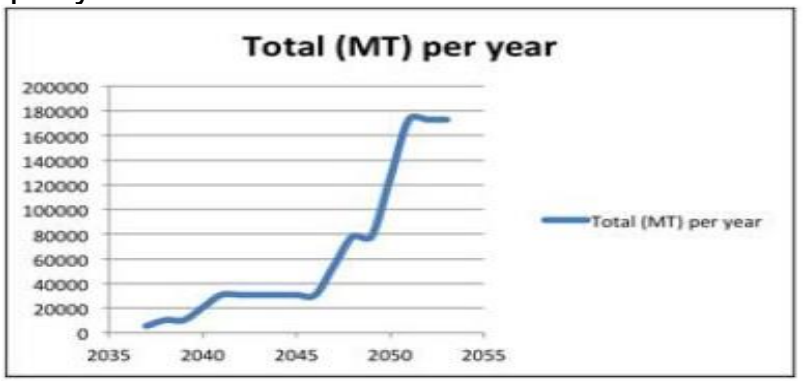

- Growth of Galactic Harbours
  - First Space Elevator then two
- Competition of Galactic Harbours
  - Three around the equator
- Mass movement:
  - Initial Operational Capability 14 tonnes per day per elevator
  - Full Operational Capability – 79 tonnes per day per elevator

Note: history
25,000 tonnes
Mostly to LEO

AT IOC 30,000 tonnes to GEO per year
At FOC 170,000 tonnes to GEO per year

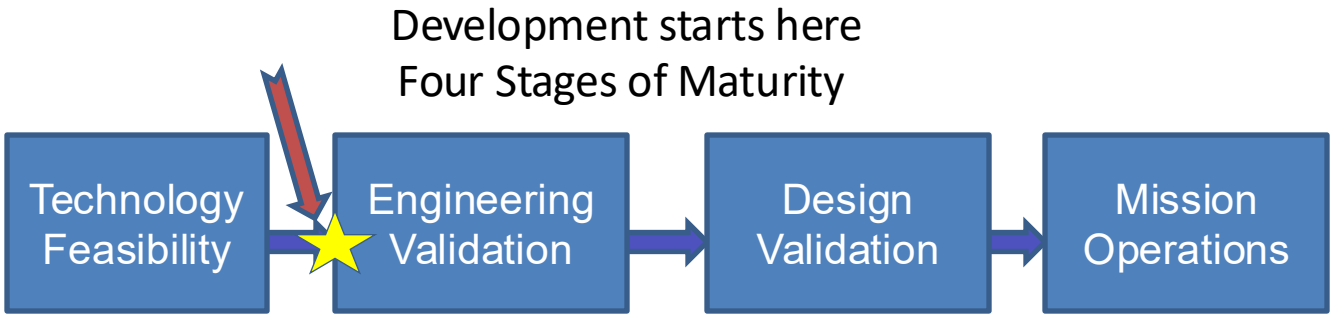



Three Galactic Harbours



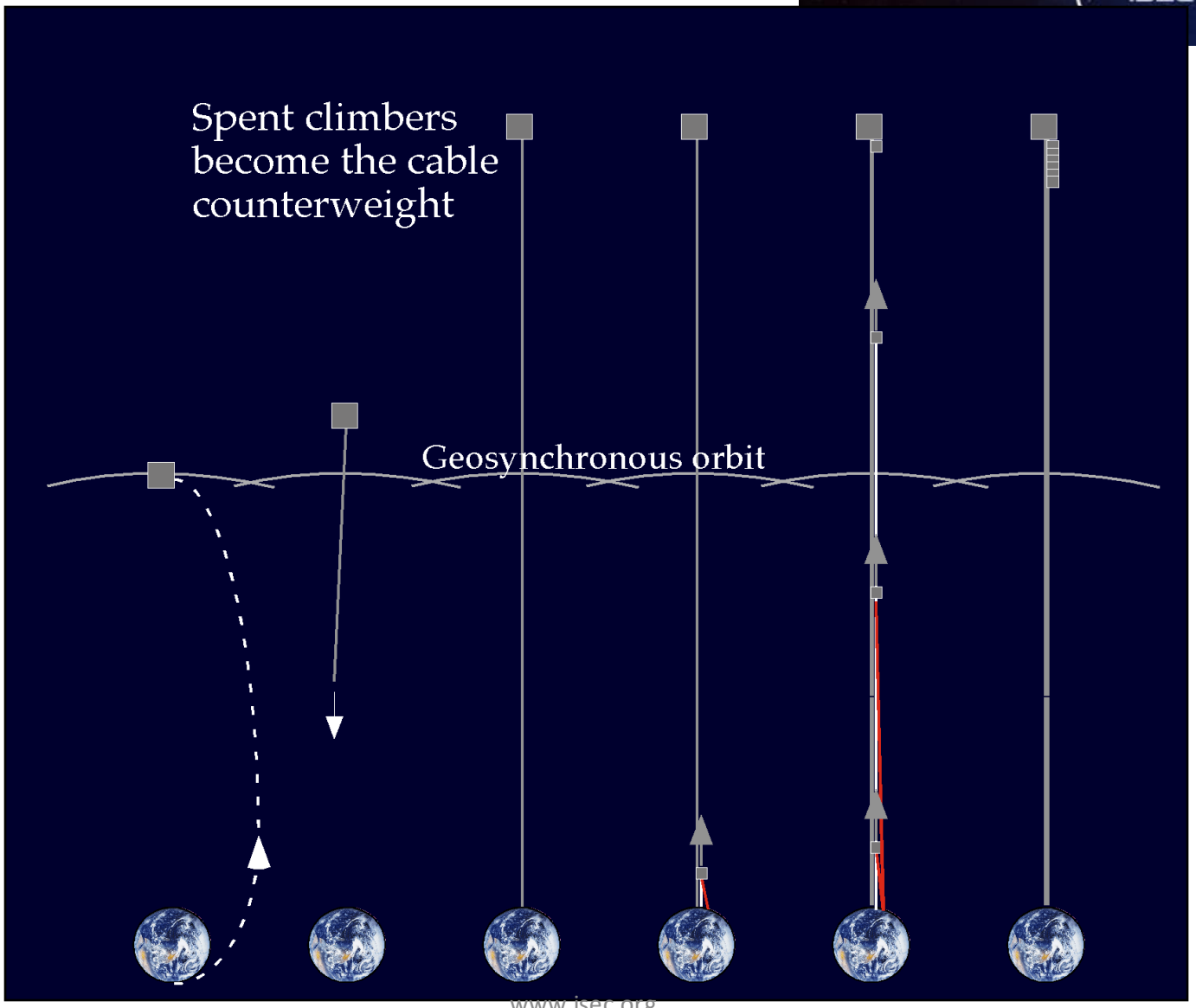

Yearly lifts with 6 Space Elevators
With daily lifts Developing from IOC To FOC

# The Space Elevator has Entered Engineering Validation!

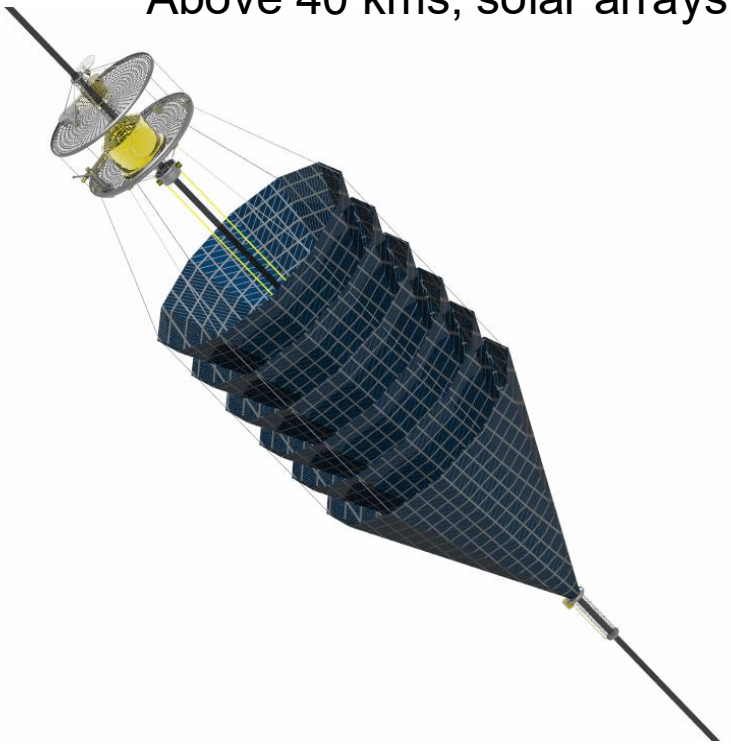

1. The ISEC team has been assessing the technology feasibility situation since 2008.
2. Recently the team has begun an open dialog with members of industry, academia, and others who could be the deliverers of developmental solutions.
3. Industry (especially) will show how the needed technologies are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

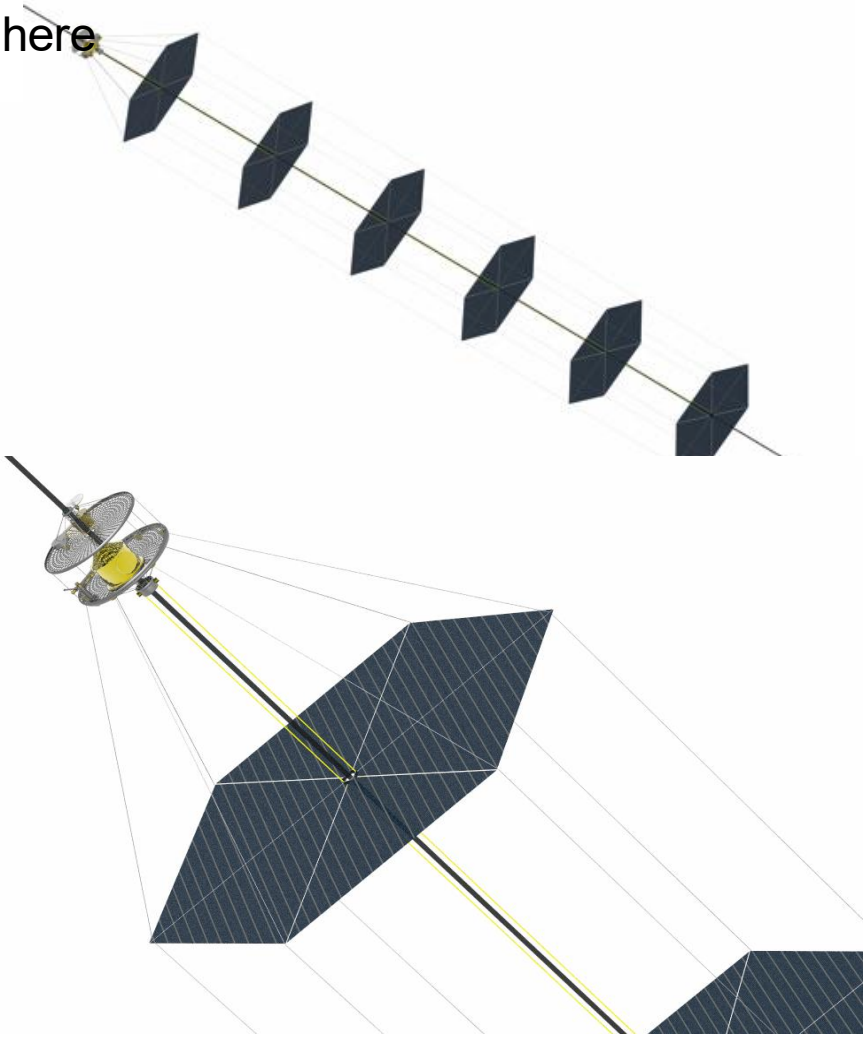
# Deployment Overview

# Tether Climber


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





Images by chasedesignstudios.com

# Is a tether made from single crystal graphene feasible?


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

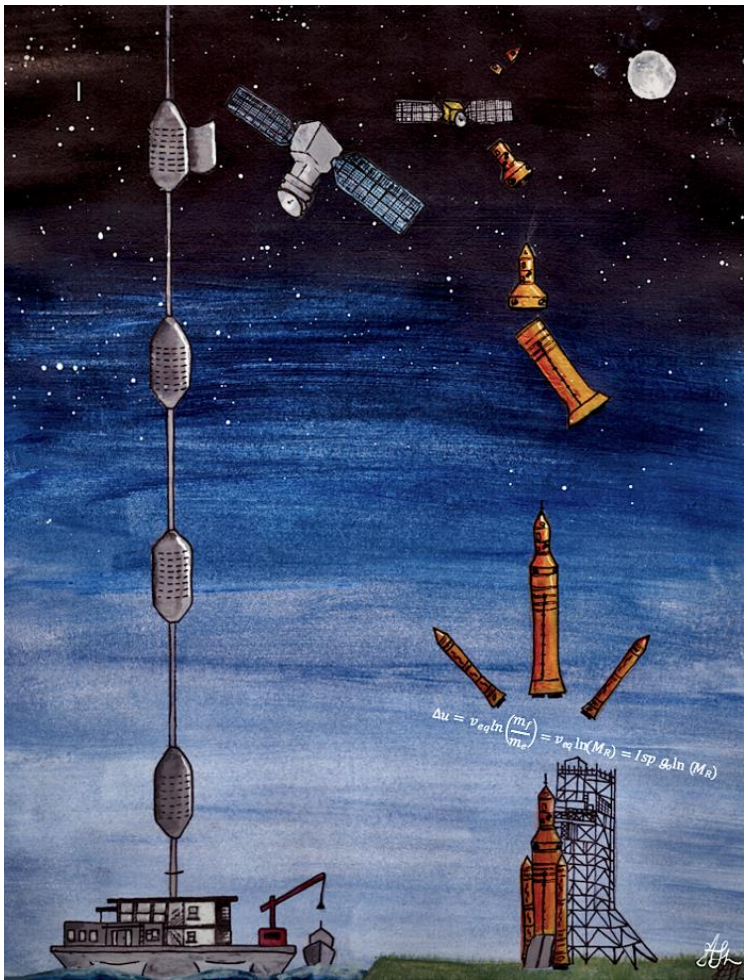
However, 500mm of single crystal graphene has been made 13 years after graphene first isolated.

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.

# 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!

# Modern Day Space Elevator 101


Time for Questions

# Backup Charts

Earth Radius
6,378 Km

Space
Elevator
100,000 km
In green