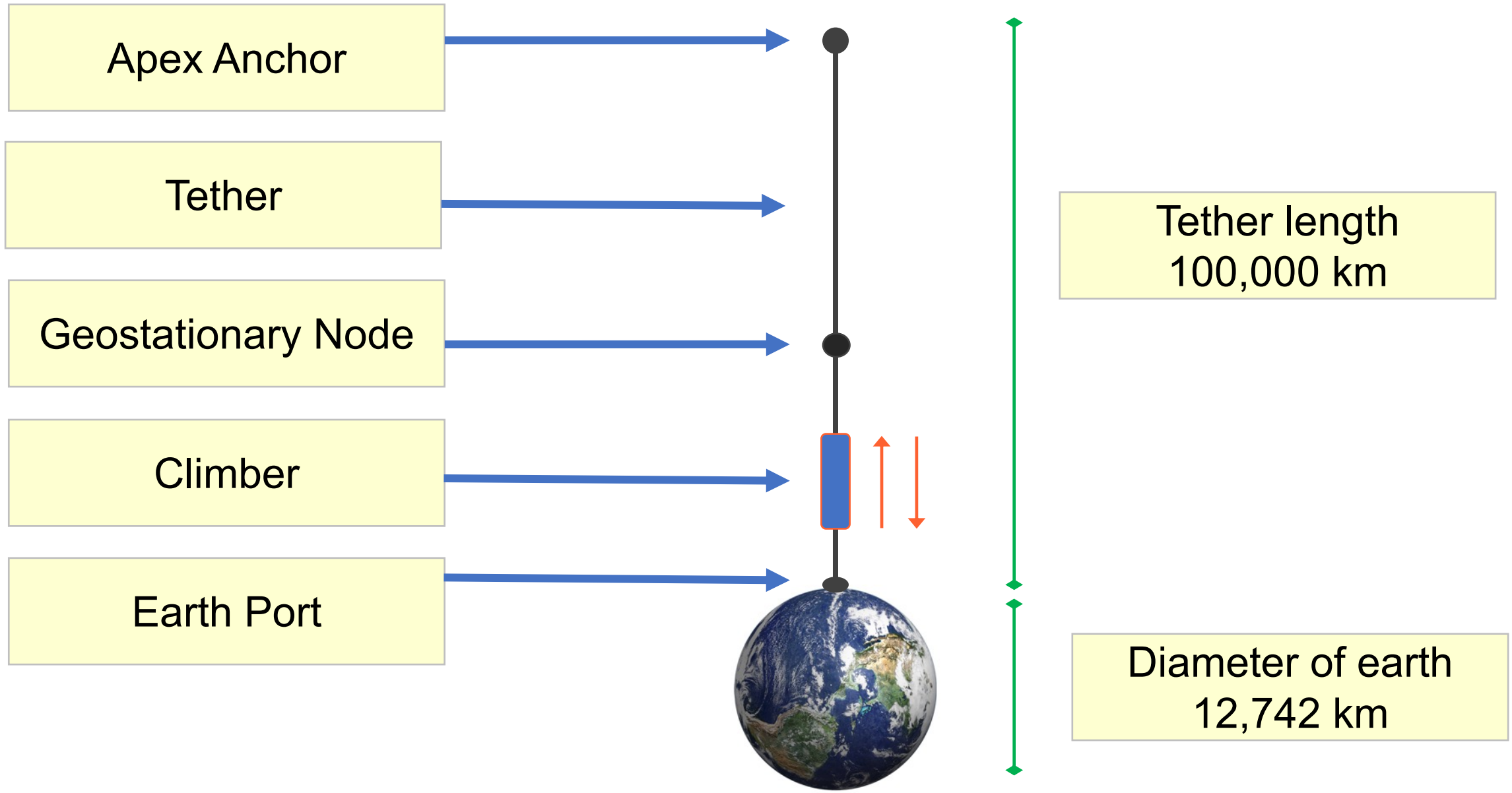
Space Elevator Tether Materials:

An overview of the current candidates

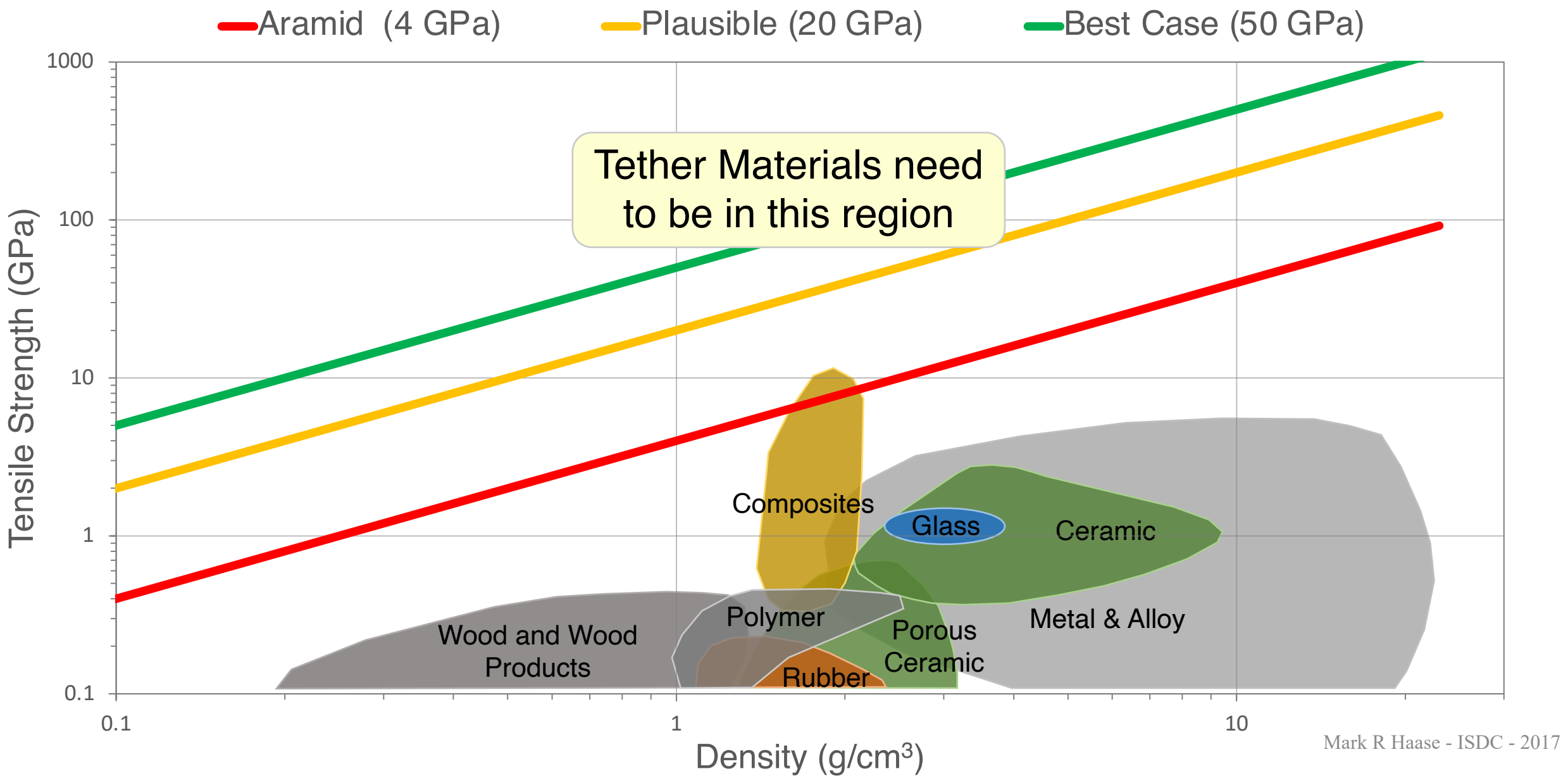
Space Elevator Overview

The Space Elevator components (not to scale)



Tether material has to be very strong and lightweight

Tether materials: Ashby Plot - Tensile Strength vs Density



Mark R Haase - ISDC - 2017

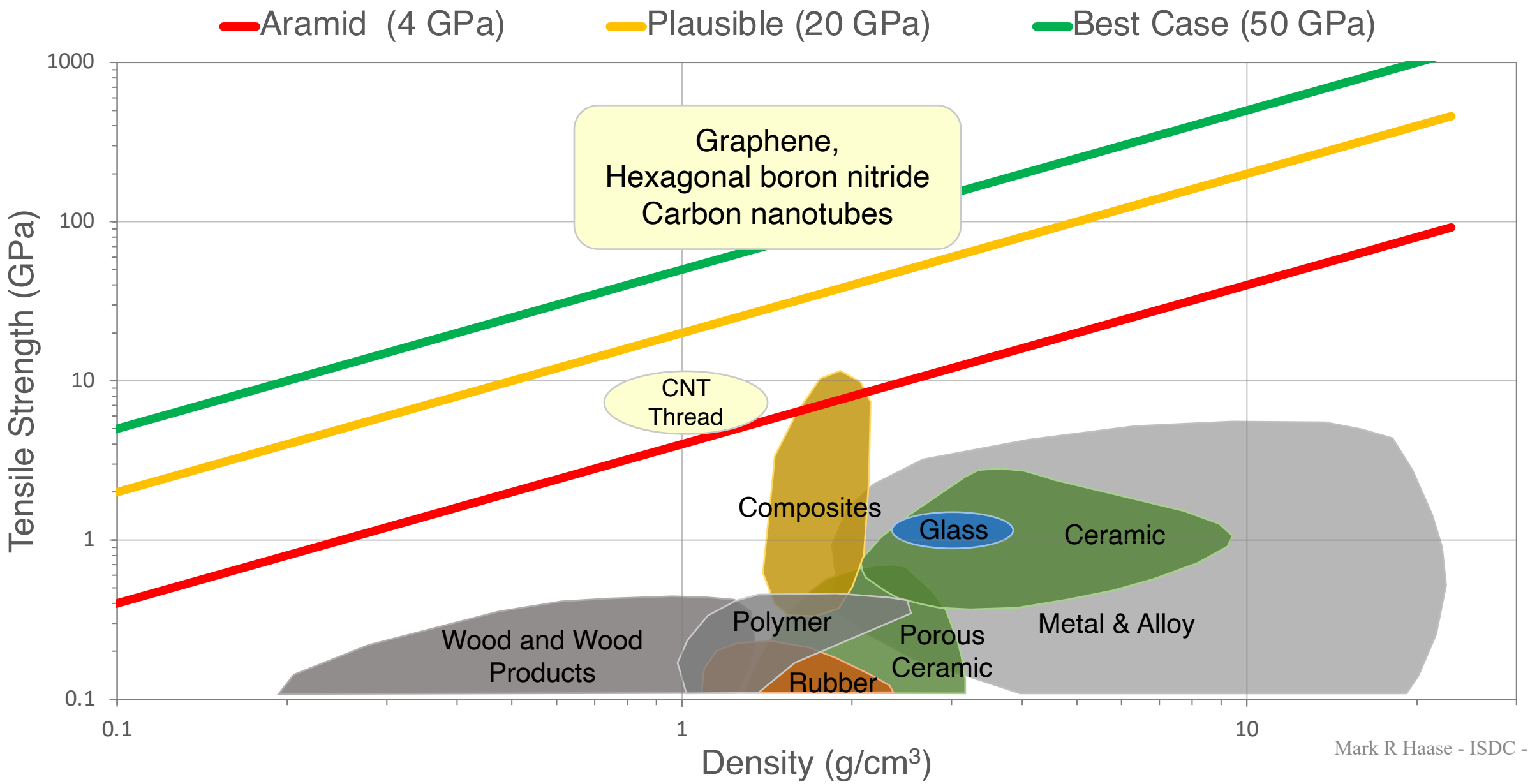
All the components for the space elevator can be created with today's technology

The exception is the material for the tether *

There are advanced materials
that have the strength needed

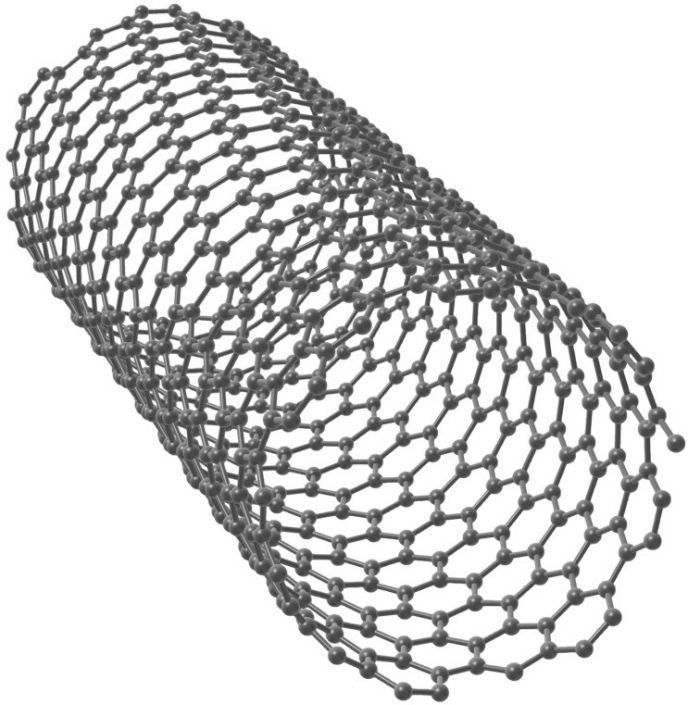
*Swan, P., Raitt, Swan, Penny, Knapman., Space Elevators: An Assessment of the Technological Feasibility and the Way Forward, International Academy of Astronautics Study Report, Virginia Edition Publishing Company, Science Deck (2013) ISBN-13: 978-2917761311

Tether materials: Ashby Plot - Tensile Strength vs Density

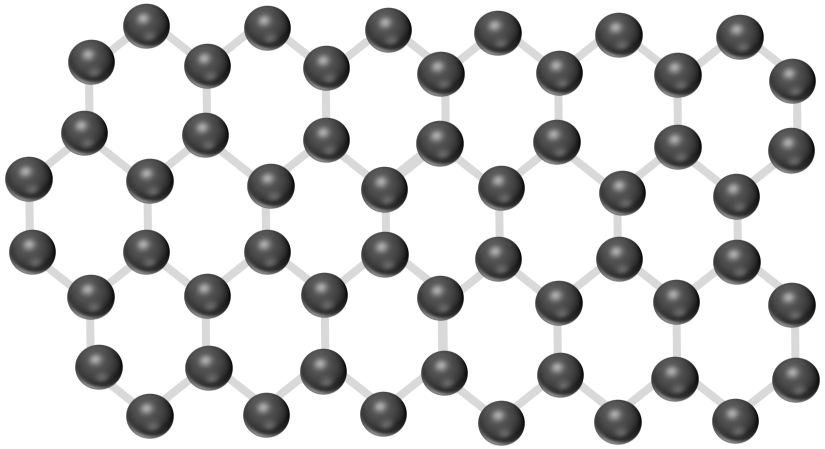


Mark R Haase - ISDC - 2017

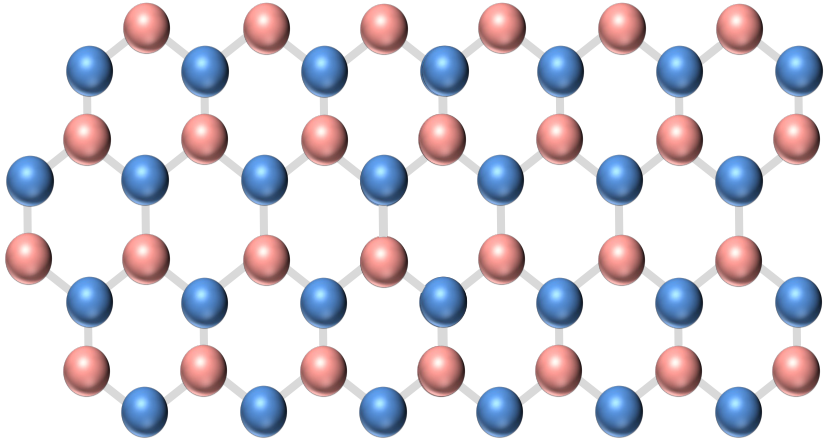
Candidate tether materials for the space elevator



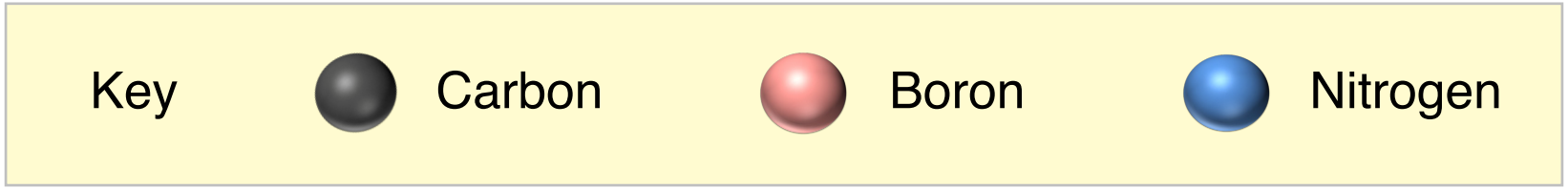
Single crystal
carbon nanotubes (CNT)
1D material
(77 to 200 GPa)



Single crystal graphene
2D material
(130 GPa)



Single crystal
hexagonal boron nitride (hBN)
2D material
(100 GPa)



Material manufacturing

To take full advantage of the immense strength, a tether material needs to be made from a continuous molecule.

The term ‘single-crystal’ is used to refer to this for both 1D and 2D materials.

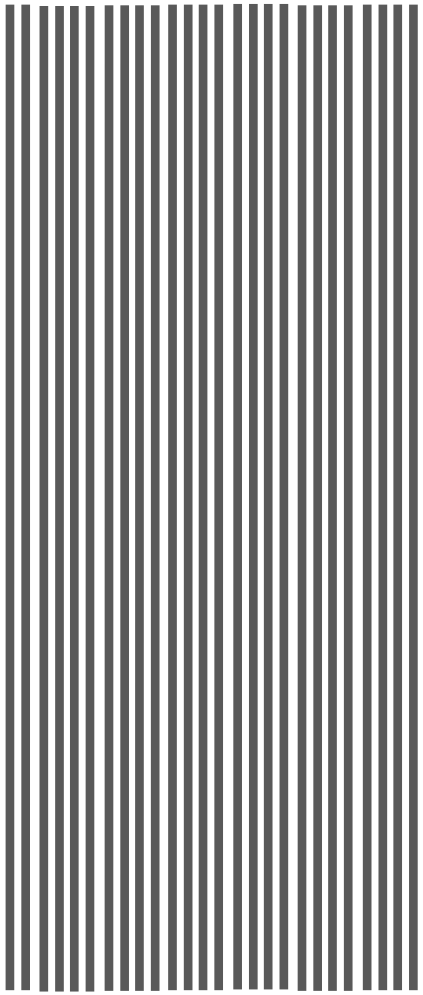
A polycrystalline layer or tube consists of a patchwork of individual grains separated from each other via grain boundaries that create domains of different crystalline orientations

Carbon nanotubes were the leading candidate tether material

However, industrial manufacture has stalled

Graphene manufacturing is making rapid progress

Graphene has the strength to make the space elevator tether



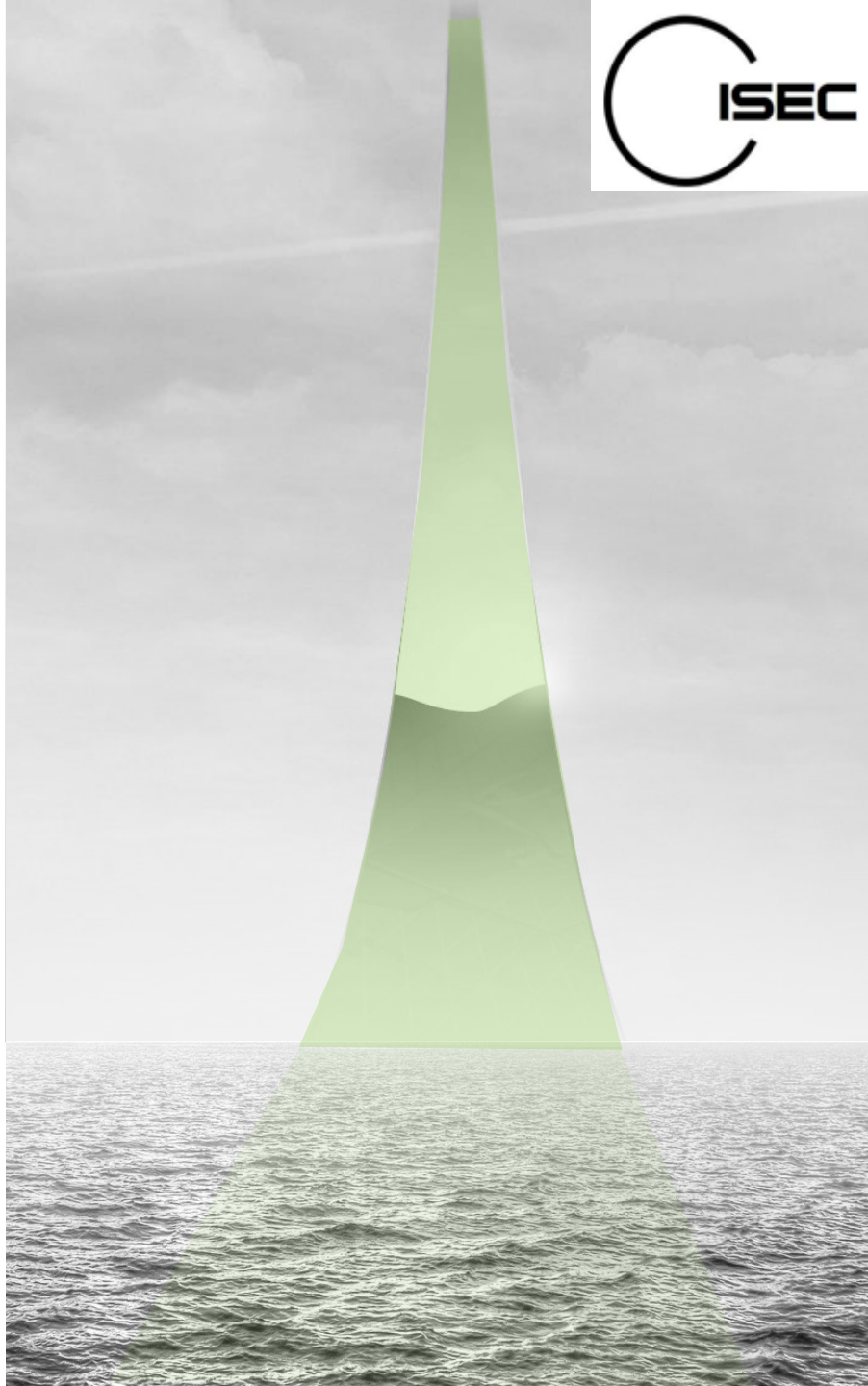
100 million metres long

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

The design can support seven
20-tonne climbers spaced along it,
because of the weaker gravity
at the higher altitudes

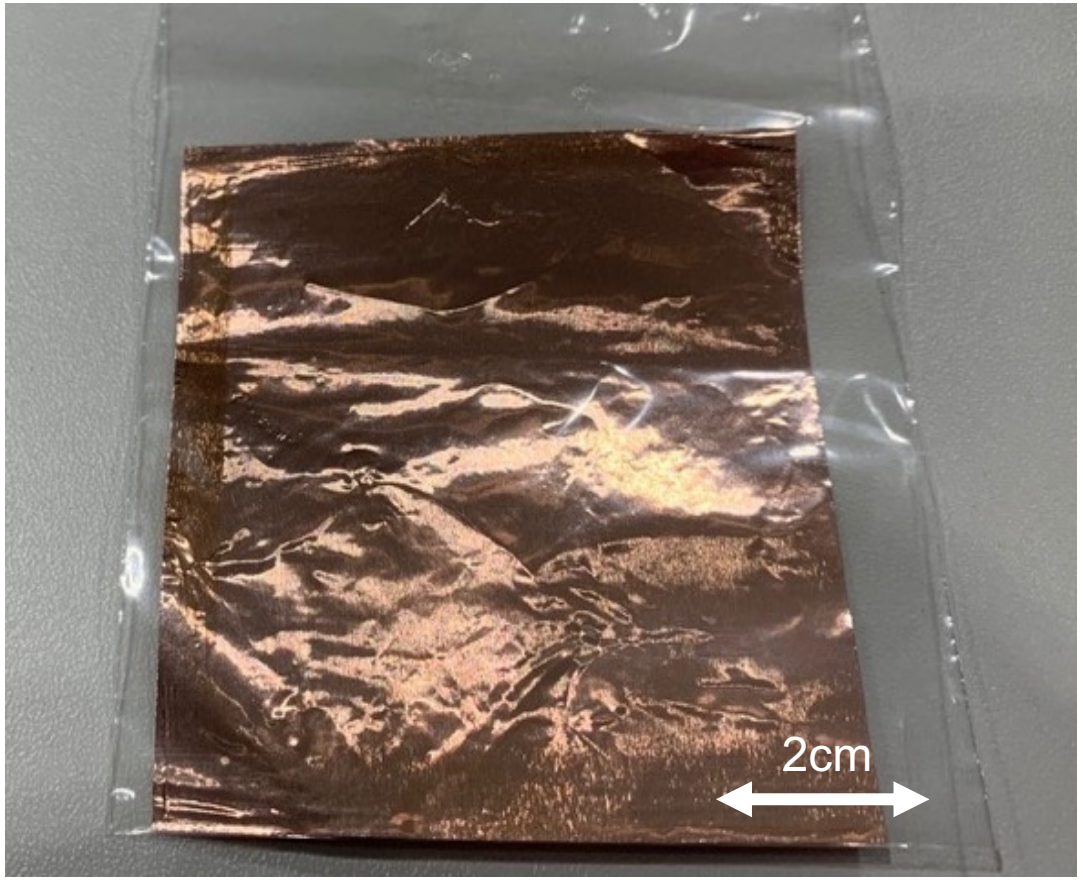


Graphene Powder and Sheet/ Film

Two types of graphene manufacturing

Graphene currently manufactured as powders

Commercial applications starting to evolve



Single layer film graphene on metal foil

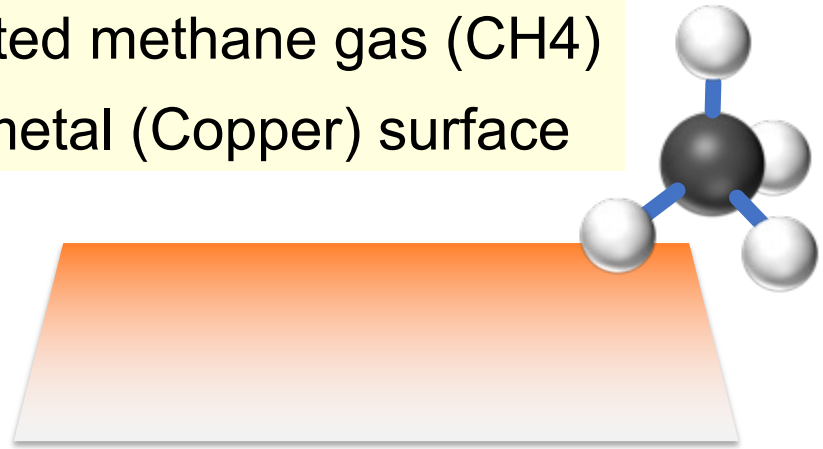
Sheet or Film graphene is a far higher value market

Defect free sheet graphene is the ideal graphene film and is called Single Crystal Graphene

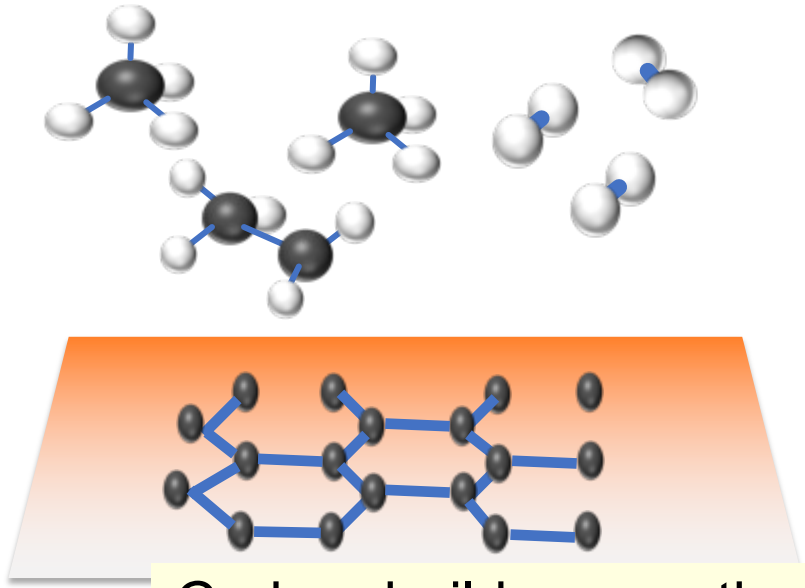
Nixene Journal
November 2020

Making sheet graphene from the ‘bottom up’ by Chemical Vapour Deposition (CVD)

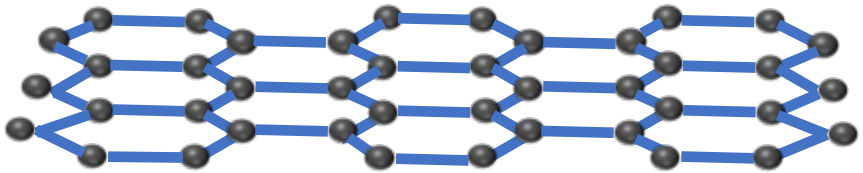
Pass heated methane gas (CH4)
Over a metal (Copper) surface



The copper helps carbon and hydrogen separate from the methane



Carbon builds up on the copper as a hexagonal graphene layer

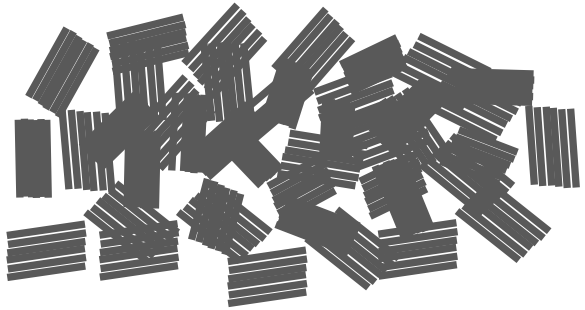


Remove the copper to leave the one atom thick graphene sheet

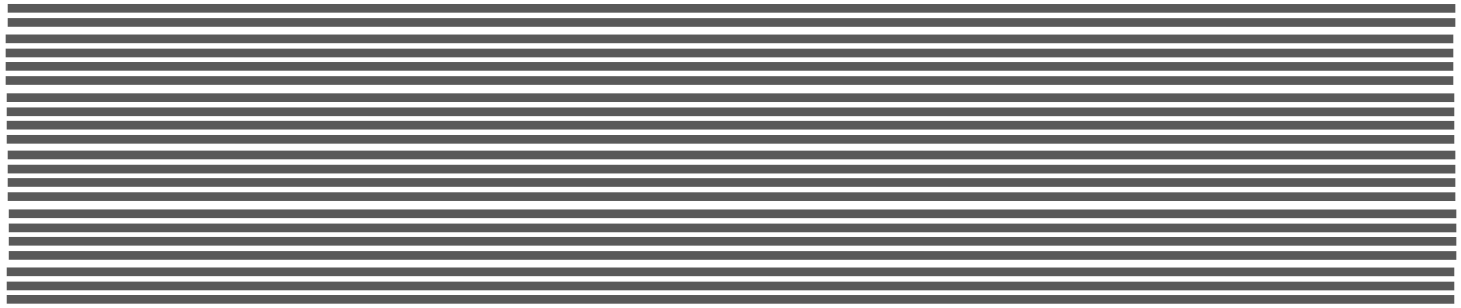
Nixene Journal

Multi-layer large-area graphene is not just an advanced material, it is a frontier material. This is disruptive technology

Graphite
Multi-layered graphene nanoplates



Nixene
Multi-layered sheet graphene



Multilayer graphene exists in nature as graphite
The bulk material is made of jumbled stacks of nanoplates

Multilayer sheet single crystal graphene is an entirely new material that is not found in nature
The bulk material is made of highly coherent layered sheets of single molecules of graphene
on the scale of centimetres, metres, kilometres

Example materials properties of single crystal graphene

Bulk material property	Single crystal graphene performance
Stiffness	5.8 times stiffer than the same thickness of steel
Electrical conductivity	6 times more conductive than copper
Thermal performance	Melting point 5000°C
Gas barrier	Impermeable to hydrogen and helium

Source:
ISEC Climber-Tether interface study group

Can graphene be made industrially?

at speed

in very long lengths

CVD graphene now mass produced at a speed of two metres per minute and in lengths of one kilometre

LG can make CVD sheet graphene at:

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

Graphene roll to manufacture Image credit: LG

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

Charmgraphene can make CVD sheet graphene at:

- Speed of 2metres per minute
- Lengths up to 1kilometre
- 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]

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].

There is at least one other graphene manufacturing company that is focussed on the continuous manufacture of single crystal graphene

Tether manufacture on earth, assembly in orbit

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/

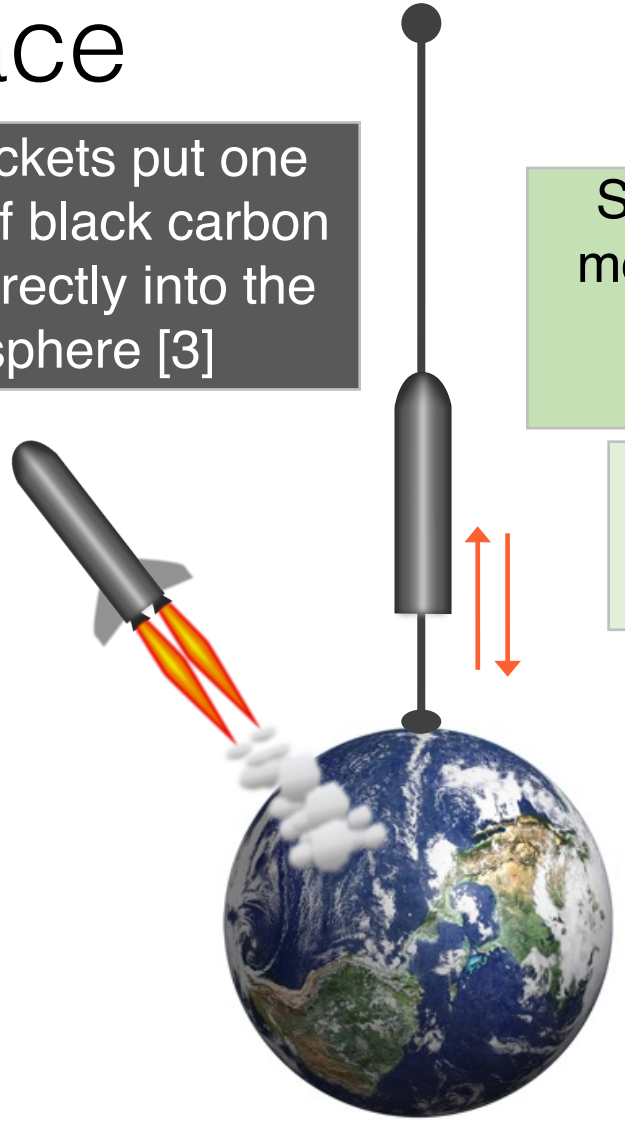
The Green Road to Space

In 2019 Elon Musk estimated that to create a viable colony on Mars one million tons of cargo would be needed [1]

In 2021 rockets put one million kg of black carbon pollution directly into the stratosphere [3]

Solar powered space elevators move lots of mass. 1 million tons could be moved in 5.7 years with no pollution [2]

Rockets get things to orbit fast, however only 2% of the mass on the launchpad reaches GEO while only 0.5% reaches the surface of Mars [2]



Solar powered space elevators move lots of mass but are slow

To get 1million tons to the destination will need 200 million tons of rockets and propellant and take 45.7 years with starships [2]

Rockets need Space Elevators to deliver mass

Space Elevators need Rockets to deliver people

This is the dual space access architecture

Sources:
[1] Brown, M., 2022. *SPACEX Mars city: why, when, and how Elon Musk wants to build his ambitious plan*. [online] Inverse.com. Available at: <https://www.inverse.com/innovation/spacex-mars-city-codex> [Accessed 23 June 2022].
[2] Swan, P., Swan, C., Phister, P., Dotson, D., Bernard-Cooper, J. and Molloy, B., 2022. *The Green Road to Space*. ISEC Position Paper # 2021-1. [online] Santa Ana: International Space Elevator Consortium. Available at: <https://static1.squarespace.com/static/5e35af40fb280744e1b16f7b/t/6082e7524757a75a66311dad/1619191657175/GreenRoad.pdf> [Accessed 23 June 2022].
[3] Maloney, C., Portmann, R., Ross, M. and Rosenlof, K., 2022. The Climate and Ozone Impacts of Black Carbon Emissions From Global Rocket Launches. *Journal of Geophysical Research: Atmospheres*, 127(12). https://doi.org/10.1029/2021JD036373

Space Elevators are the Green Road to Space inside a Dual Space Access Architecture