Graphene: the last piece of the space elevator puzzle?

Adrian Nixon, Board Member, ISEC

Webinar 29th May 2020

13:00 Coordinated Universal Time (UTC)

Adrian Nixon: Who is he?

https://www.linkedin.com/in/adriannixon/

ISEC Board member

A qualified industrial chemist,
member of the Royal Society of Chemistry

Over 20 years experience in industry;
Technical Service and R&D, Author of several patents

Editor of the Nixene Journal
Focused on graphene and 2D

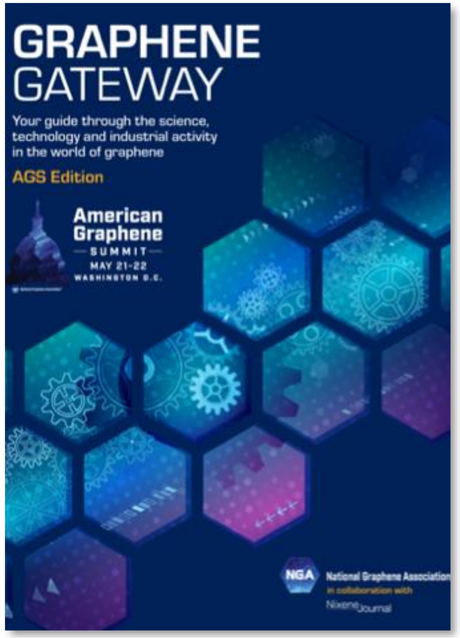
Advisory Board member of the
National Graphene Association in the USA

Invited to brief industry leaders and policy makers about graphene and 2D materials last year

The Nixene Journal is dedicated to graphene and 2D materials

ISEC

We operate a subscription model and do not take advertising
This means we have a completely independent view of this rapidly emerging field
Each issue explains the technology and commercial activity taking place



Since 2017, each month we report developments in the world of graphene and 2D materials with the Nixene Journal™
We also create special editions

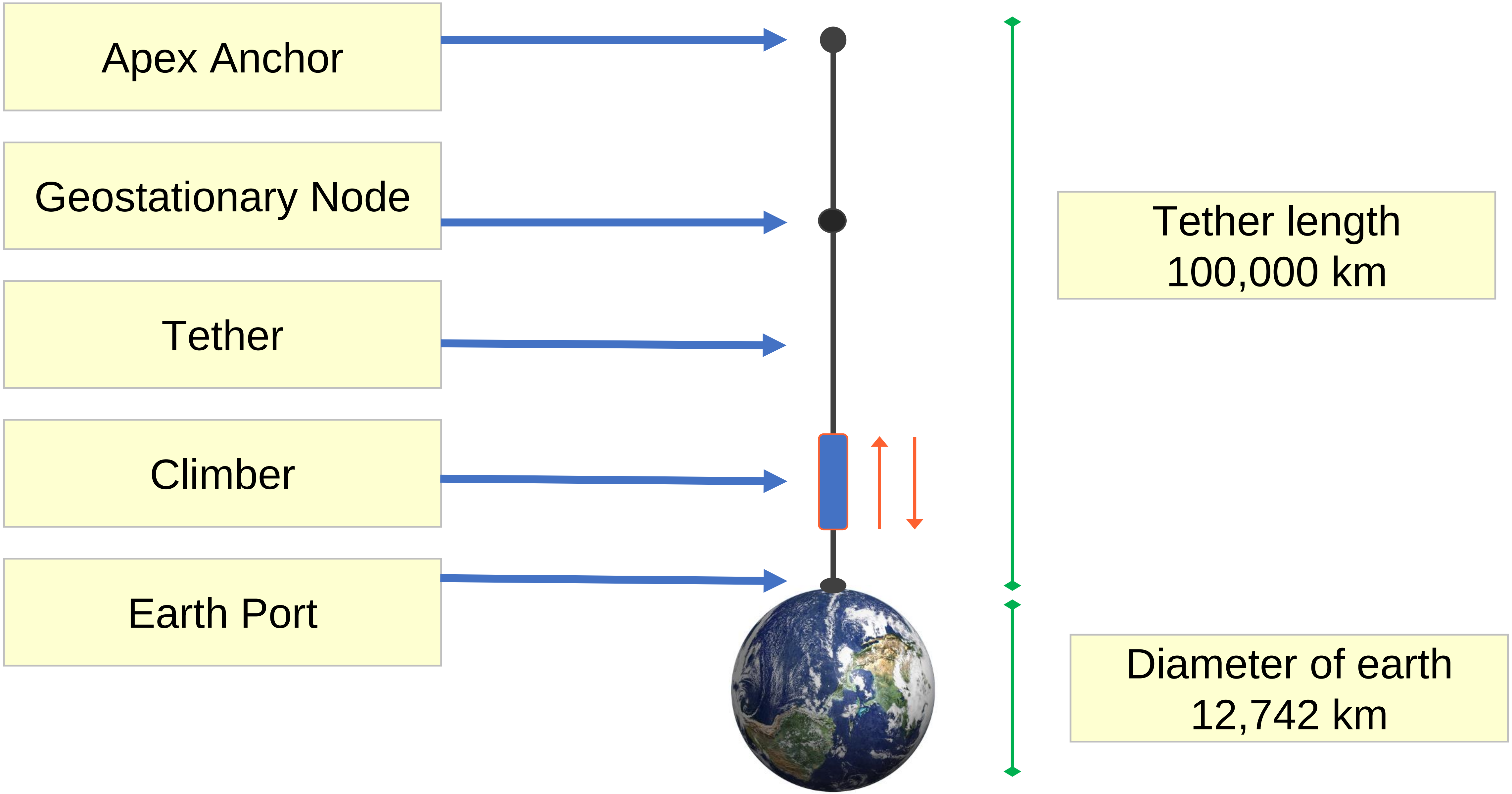
NixeneJournal

Poll 1: Now you know about me, I would like to know about you…

What we will cover…

- Space Elevator components
- Review of the properties for tether materials
- Review of the candidate materials
- Update on candidate materials and graphene
- I'll assume a mixed audience and start from the basics…

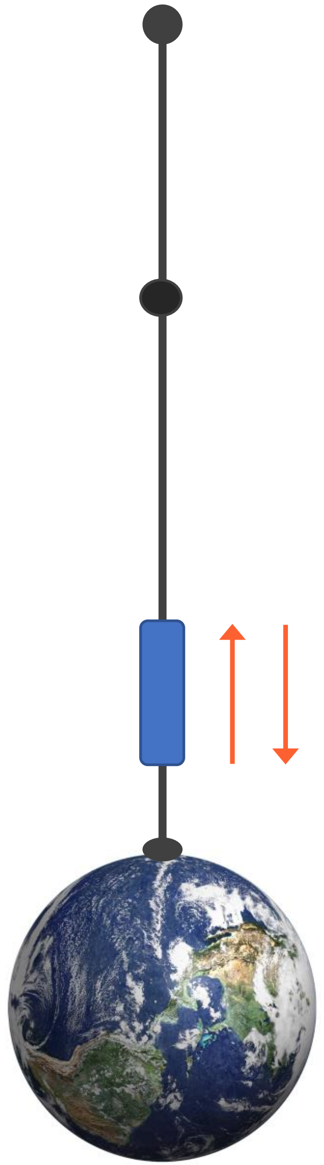
The Space Elevator components (not to scale)



Poll 2: The tether has to be strong

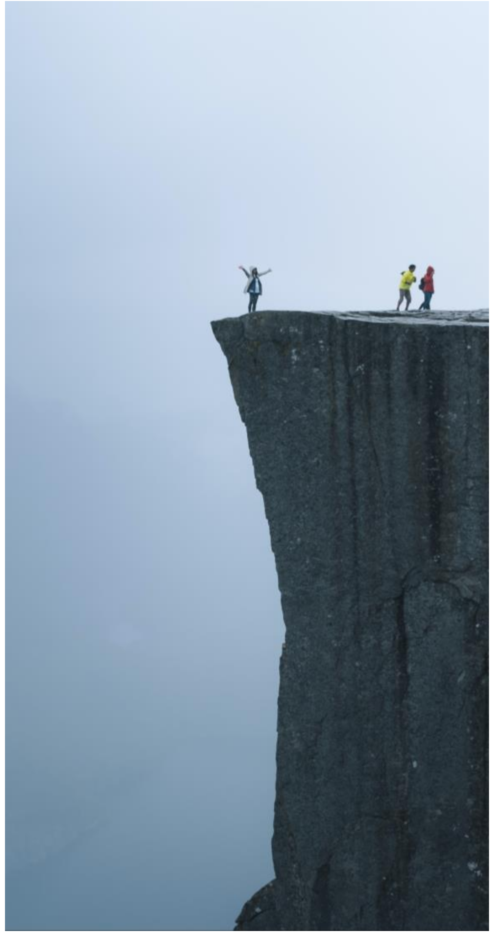
The space elevator can be made with today’s technology, except for the tether

- The tether is a continuous piece of material
- One Hundred Thousand Kilometres long
- Stretching from the surface of the earth into space
- It has to support the mass of Climber and payload
- It also has to be strong enough to support itself

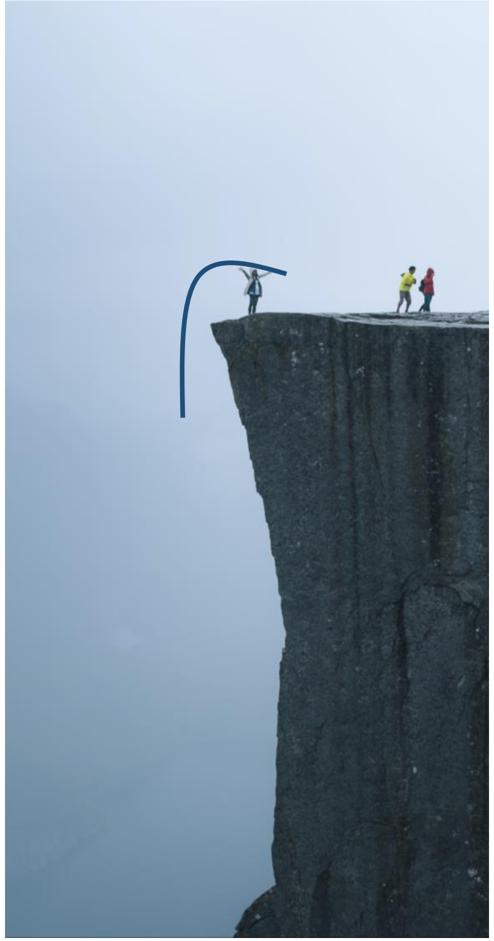


None of today’s available materials
is strong enough to make the tether
So a key part of the Space Elevator project is stalled

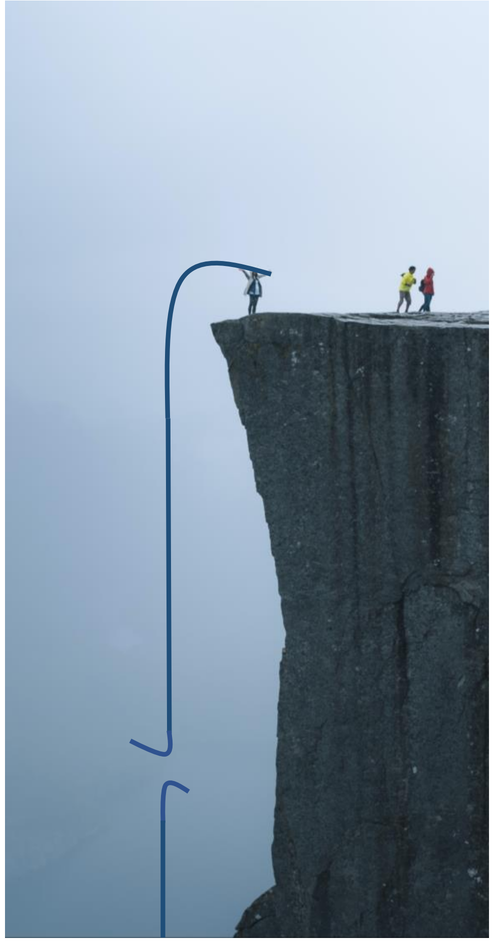
Illustrating the tether material problem



Imagine you are standing at the edge of an infinitely high cliff



You lower a super strong cable over the edge



The cable eventually breaks under its own weight

Image credit: D. Valdermaras, Unsplash

Tether material needs

The tether material needs to be both lightweight and super strong

Strength is measured in Pascals (Pa)

Today's super strong materials such as Kevlar have strengths around 3.7 GPa

The space elevator tether requires material with a strength of over 60 GPa, preferably 100 GPa

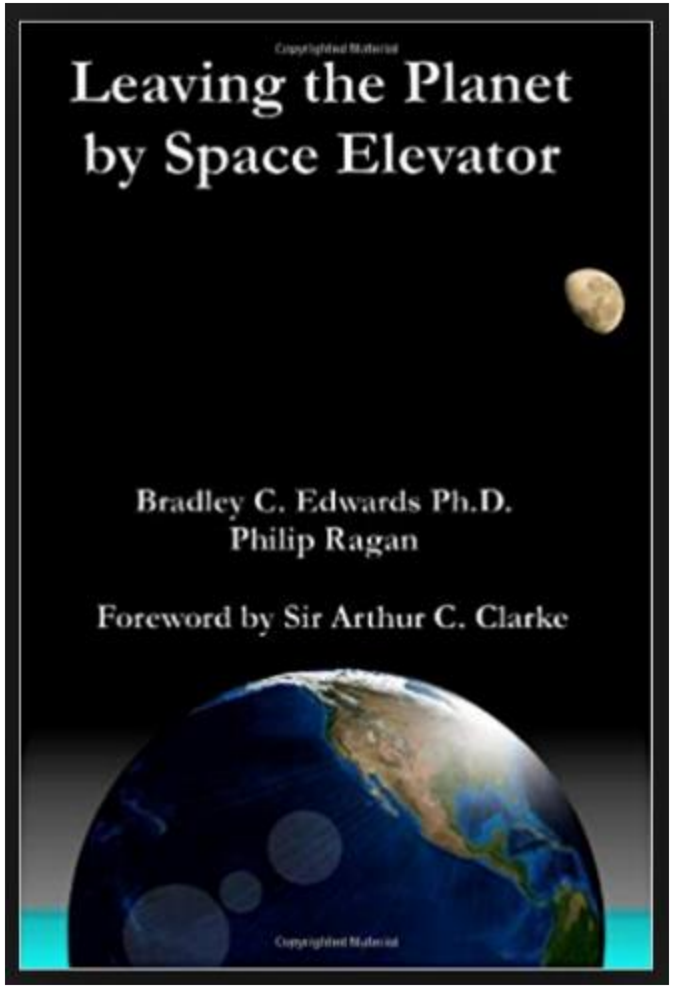
Edwards. B, (2003) The Space Elevator NASA Institute for Advanced Concepts (NIAC) Phase II Final Report
http://images.spaceref.com/docs/spaceelevator/521Edwards.pdf

NASA Institute for Advanced Concepts (NIAC) study

Dr. Edward’s excellent feasibility study and book concluded that only one material was strong enough to be a candidate for the tether

Carbon nanotubes

Since the feasibility study was published materials science has been developing. There are other candidate materials now…



Edwards. B, (2003) The Space Elevator NASA Institute for Advanced Concepts (NIAC) Phase II Final Report
http://images.spaceref.com/docs/spaceelevator/521Edwards.pdf

Tether candidate materials

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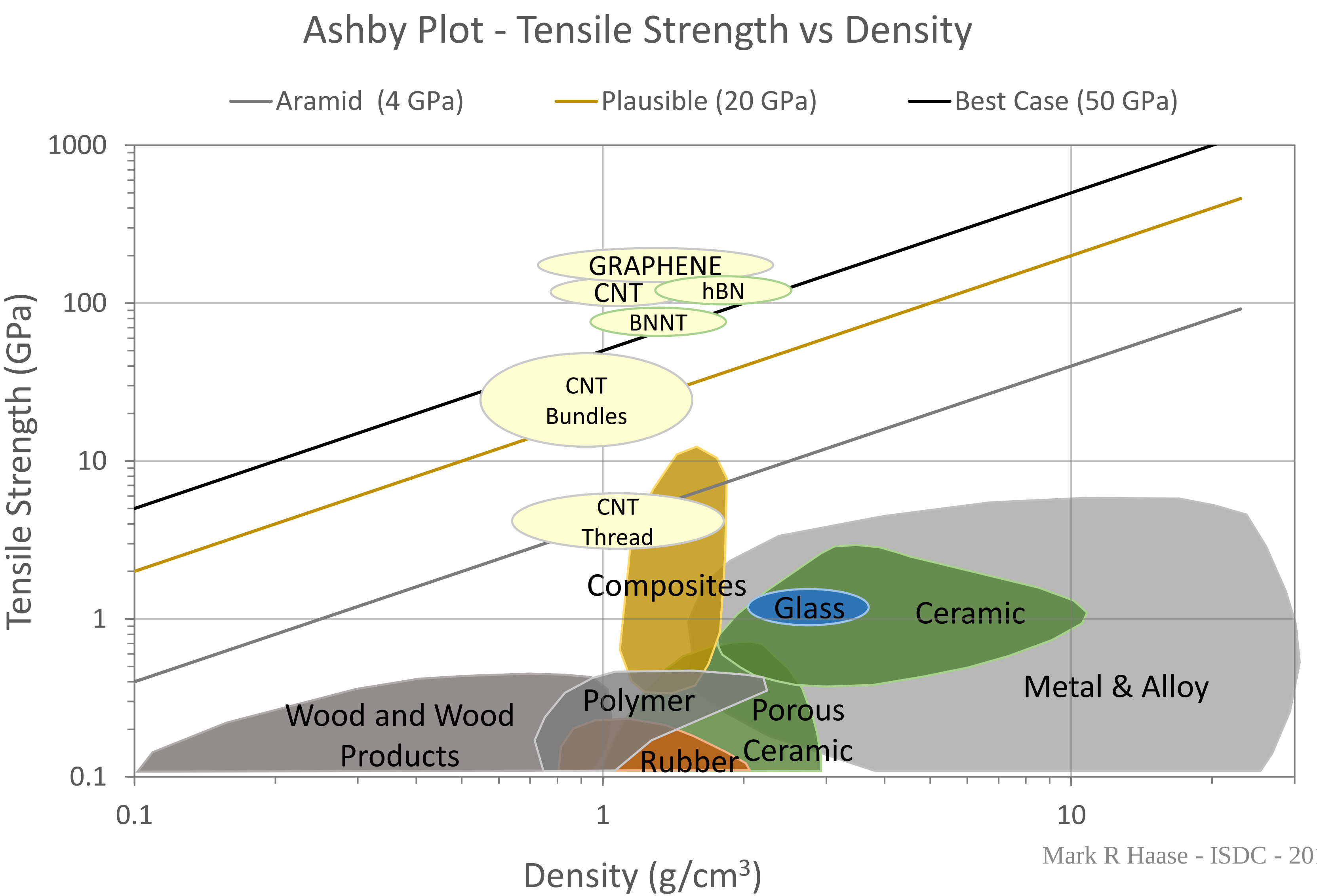


Mark R Haase - ISDC - 2017

These materials are strong enough

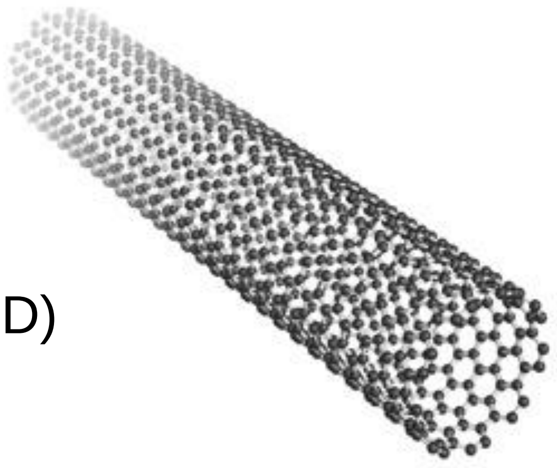
Carbon nanotubes
1D material

Graphene
2D material

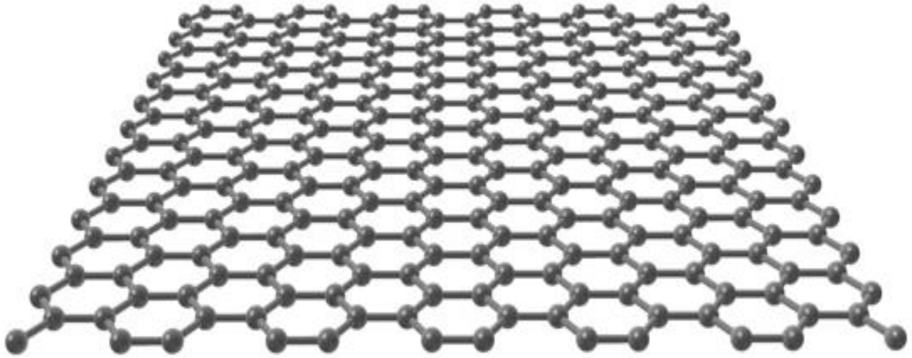
Hexagonal Boron Nitride (hBN)
2D material

Poll 3: Review of tether materials

Candidate materials update
Overview

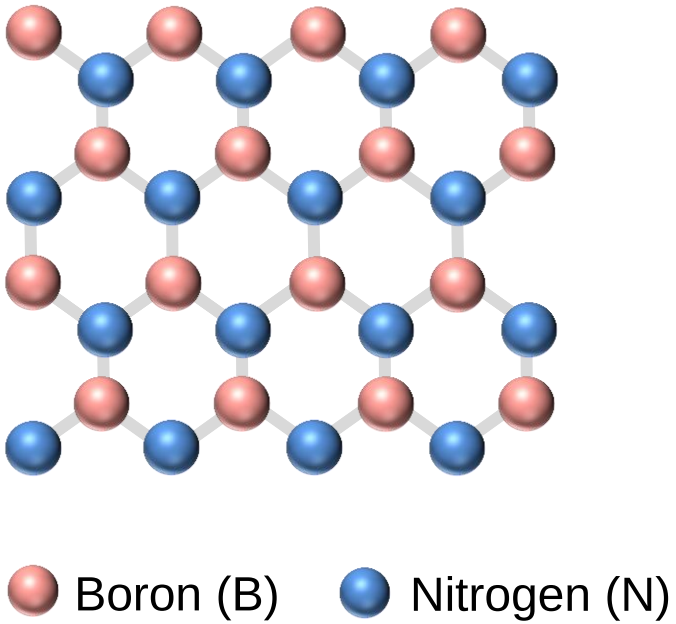


Carbon nanotube
One Dimensional material (1D)



Graphene
Two Dimensional material (2D)

Hexagonal Boron Nitride (hBN)
(white graphene)



Two Dimensional material (2D)

Candidate materials update
Carbon nanotube thread: work in 2019

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Carbon nanotube synthesis and spinning as macroscopic fibres

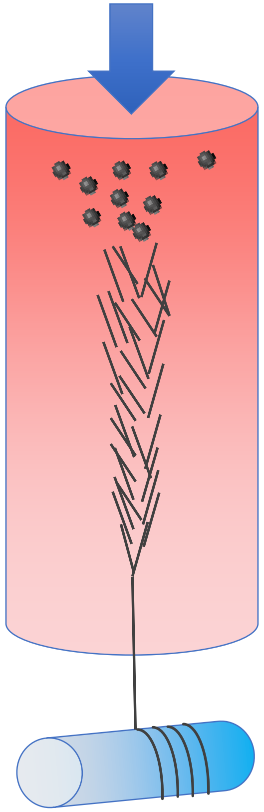
Feed stock Butanol (carbon source) with catalysts ferrocene and thiophene in hydrogen carrier gas

Butanol decomposes to C precursors

Carbon nanotubes (CNT) form 1mm long

Gas flow spins the CNT fibres into an aerogel fibre

CNT aerogel fibre wound onto a drum



Ceramic tube furnace
Heated to 1250°C

This work did not measure the strength of the CNT fibre

Expect it to be in MPa rather than GPa range

Source:
https://www.nature.com/articles/s41598-019-45638-6.pdf

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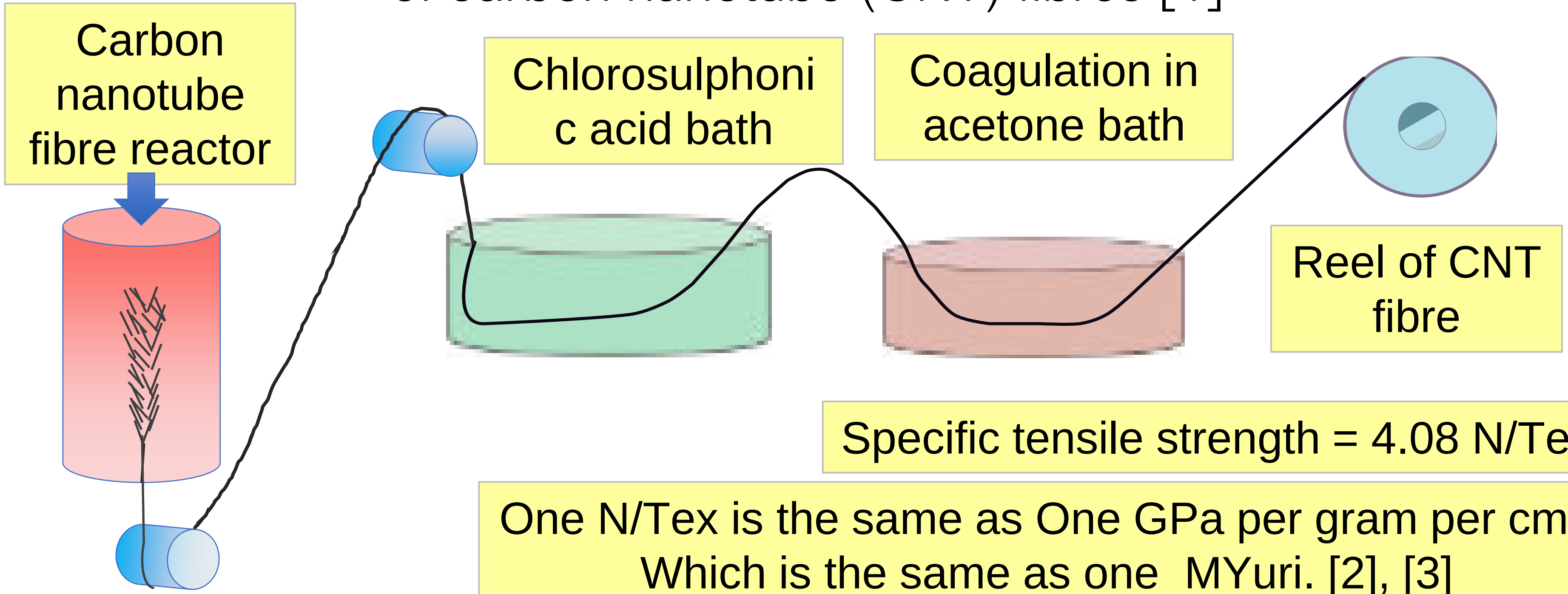
June 2019

Candidate materials update
Carbon nanotube thread: work in 2019

Direct spinning and densification
of carbon nanotube (CNT) fibres [1]



Specific tensile strength = 4.08 N/Tex

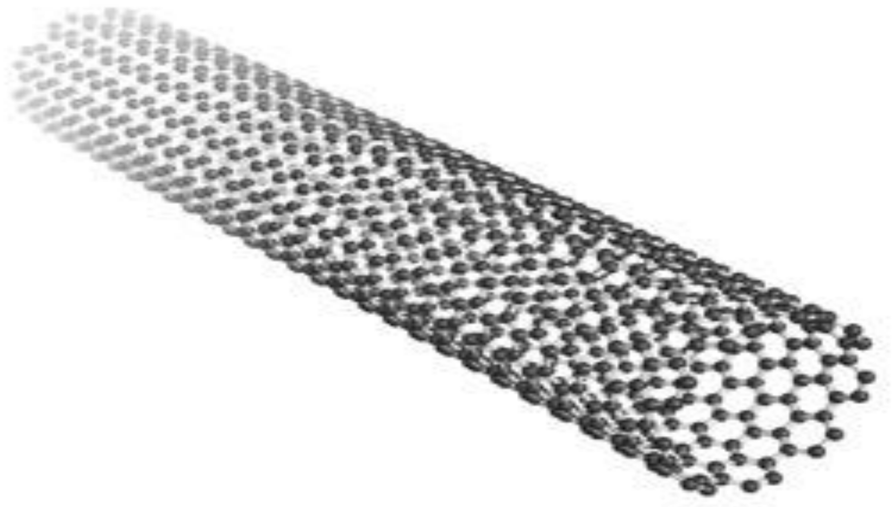
One N/Tex is the same as One GPa per gram per cm3
Which is the same as one MYuri. [2], [3]

Sources:
[1] https://www.nature.com/articles/s41467-019-10998-0.pdf
[2] https://www.nextbigfuture.com/2009/01/understanding-strength-of-materials-and.html
[3] “Space Elevators : An Assessment of the Technological Feasibility and the way forward”, IAA 2013

Candidate materials update
Carbon nanotubes

The longest carbon nanotubes that have been made were 500mm

This was done by a team at Tsinghua University, Beijing, China
In 2013



This work seems to have stalled
No reported improvements in length have been made in the past six years

Growth of Half-Meter Long Carbon Nanotubes Based on Schulz-Flory Distribution https://pubs.acs.org/doi/10.1021/nn401995z

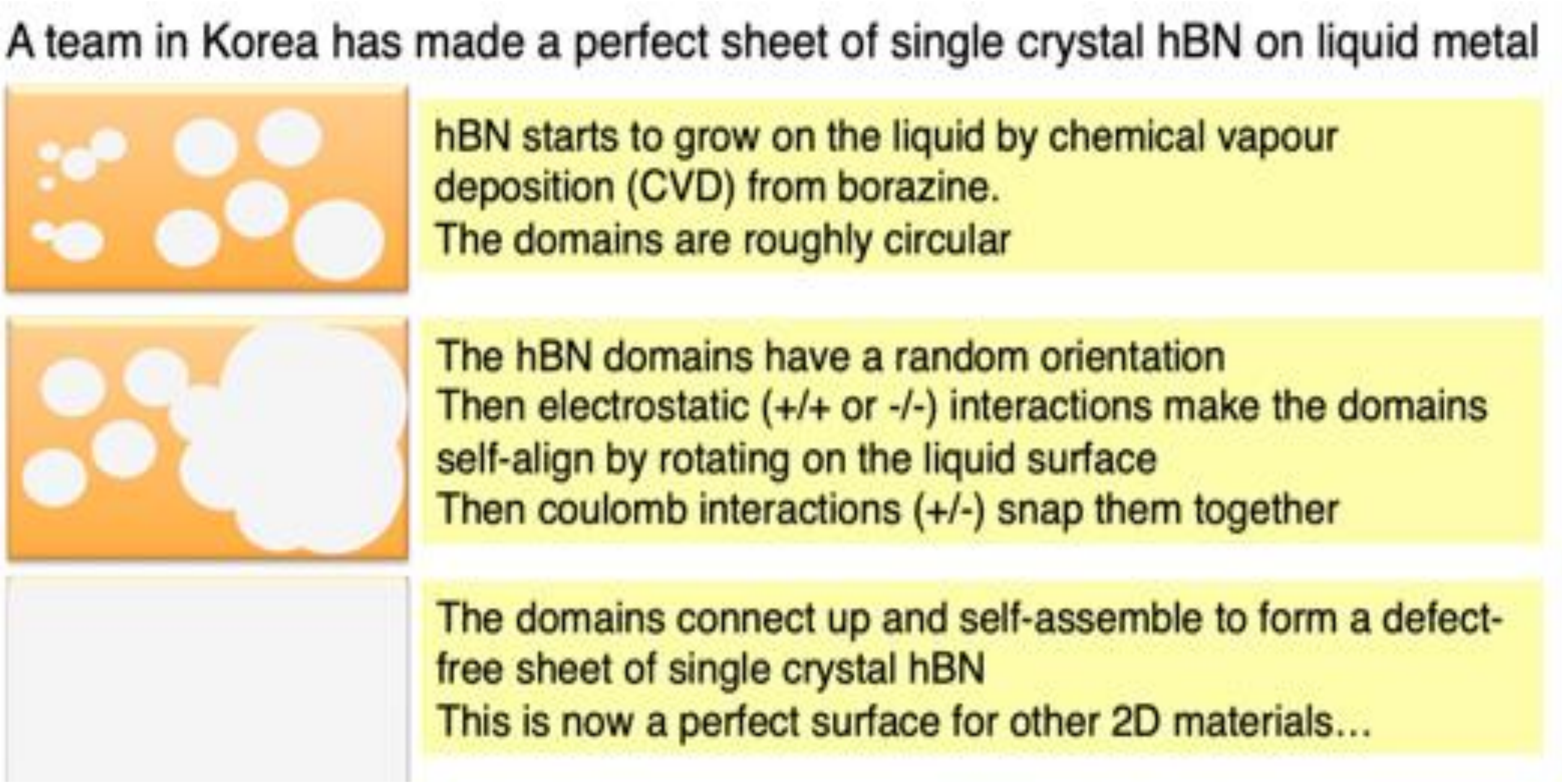
Candidate materials update
hexagonal Boron Nitride Summary

- Very little work seems to be published on boron nitride nanotubes

- However interesting work is taking place making small scale hexagonal boron nitride as a single crystal

We will keep a watch on developments with single crystal hBN

Candidate materials update
hexagonal Boron Nitride



Source:
https://science.sciencemag.org/content/362/6416/817

Nixene Journal
July 2019

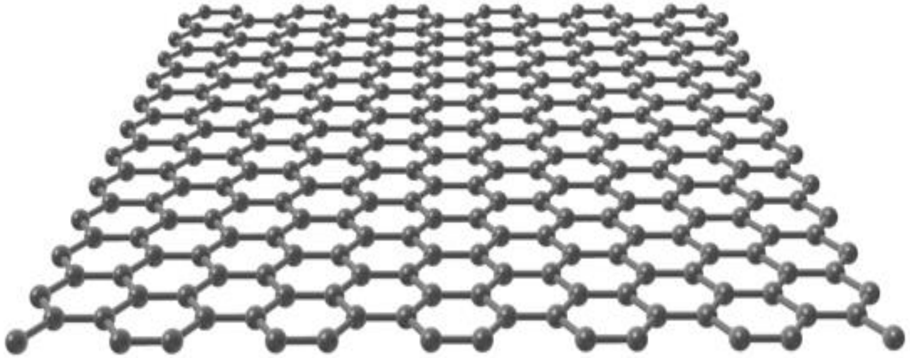
Candidate materials update
Graphene

There are two types of graphene:

Most of the commercial activity is being done with powdered graphene and this is less relevant to us from Space elevator tether perspective

Graphene Powder

CVD Graphene

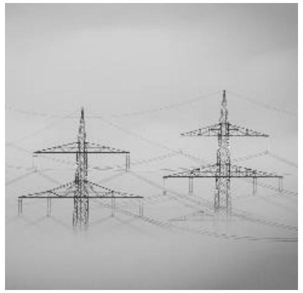


We are interested in a type of Chemical Vapour Deposition (CVD) graphene called single crystal graphene

Graphene: The new material revolution

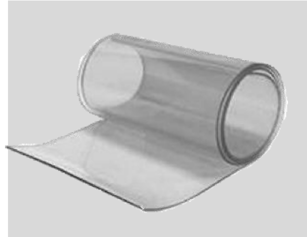
200 times
stronger than steel

World's best
conductor of electricity

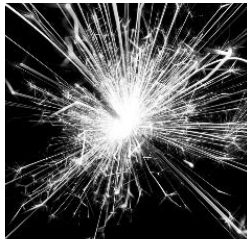


Very stable material

Flexible and
transparent



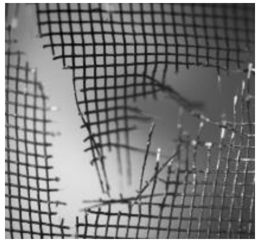
Highest melting point of
any material
in a vacuum



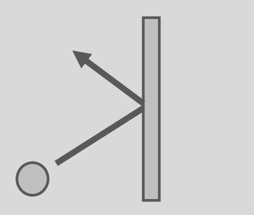
100 times more
tear resistant than steel

World's best
conductor of heat

World's most fatigue
resistant material



World's most impermeable
material



Source: https://www.nobelprize.org/uploads/2018/06/advanced-physicsprize2010.pdf

Candidate materials update
Single Crystal Graphene

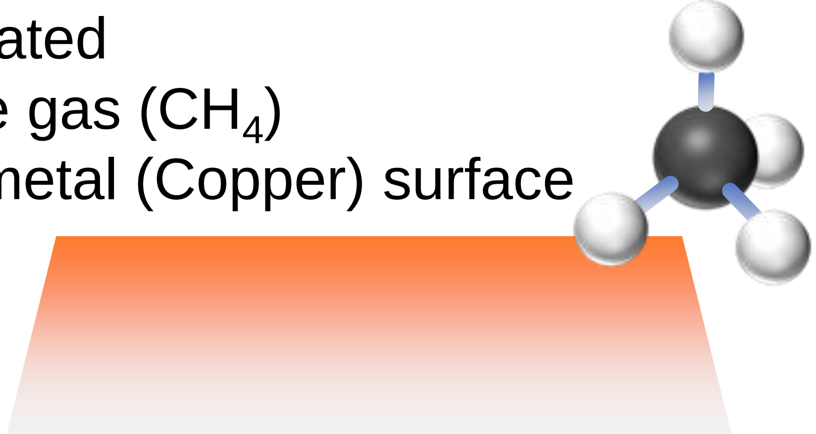
This image is of plastic film
Not graphene

Crystal in this context means a repeating pattern forming something like cling film (one atom thick) rather than the everyday perception of a brittle solid

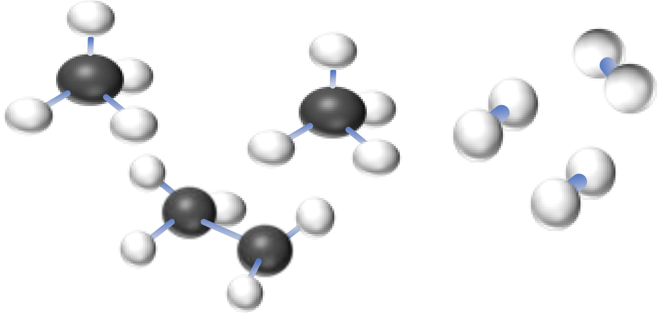
Single crystal graphene is the term for large scale sheets of defect free graphene. (a single molecule)

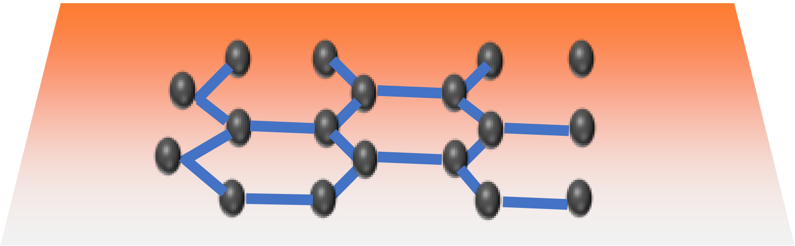
Making graphene from the 'bottom up'
By Chemical Vapour Deposition

Pass heated
methane gas (CH_4)
Over a metal (Copper) surface

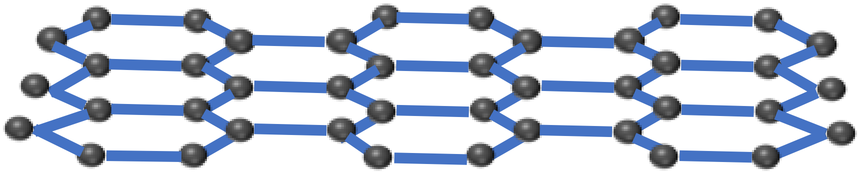


The copper helps
carbon and hydrogen
separate from the methane





Carbon builds up on the copper
as a hexagonal graphene layer



Remove the copper to leave
the one atom thick graphene sheet

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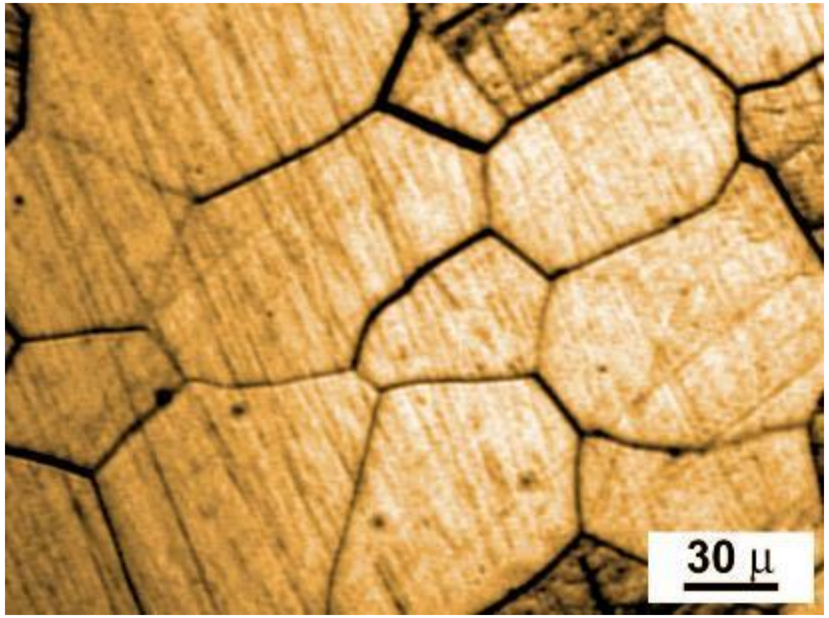
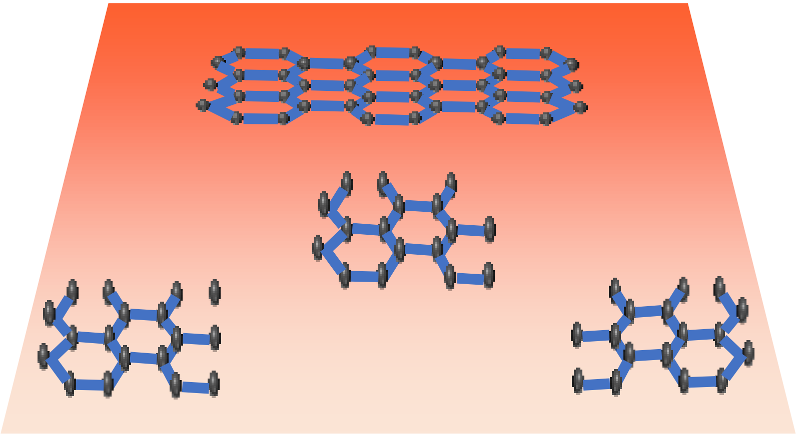
CVD production problems

Metals like copper contain
crystal grain boundaries
That cannot be removed



Graphene picks up
these discontinuities

Snowflake deposition



Graphene starts to grow at many places
Where these domains collide
discontinuities are created

Current CVD graphene production manufactures polycrystalline graphene – we need single crystal graphene

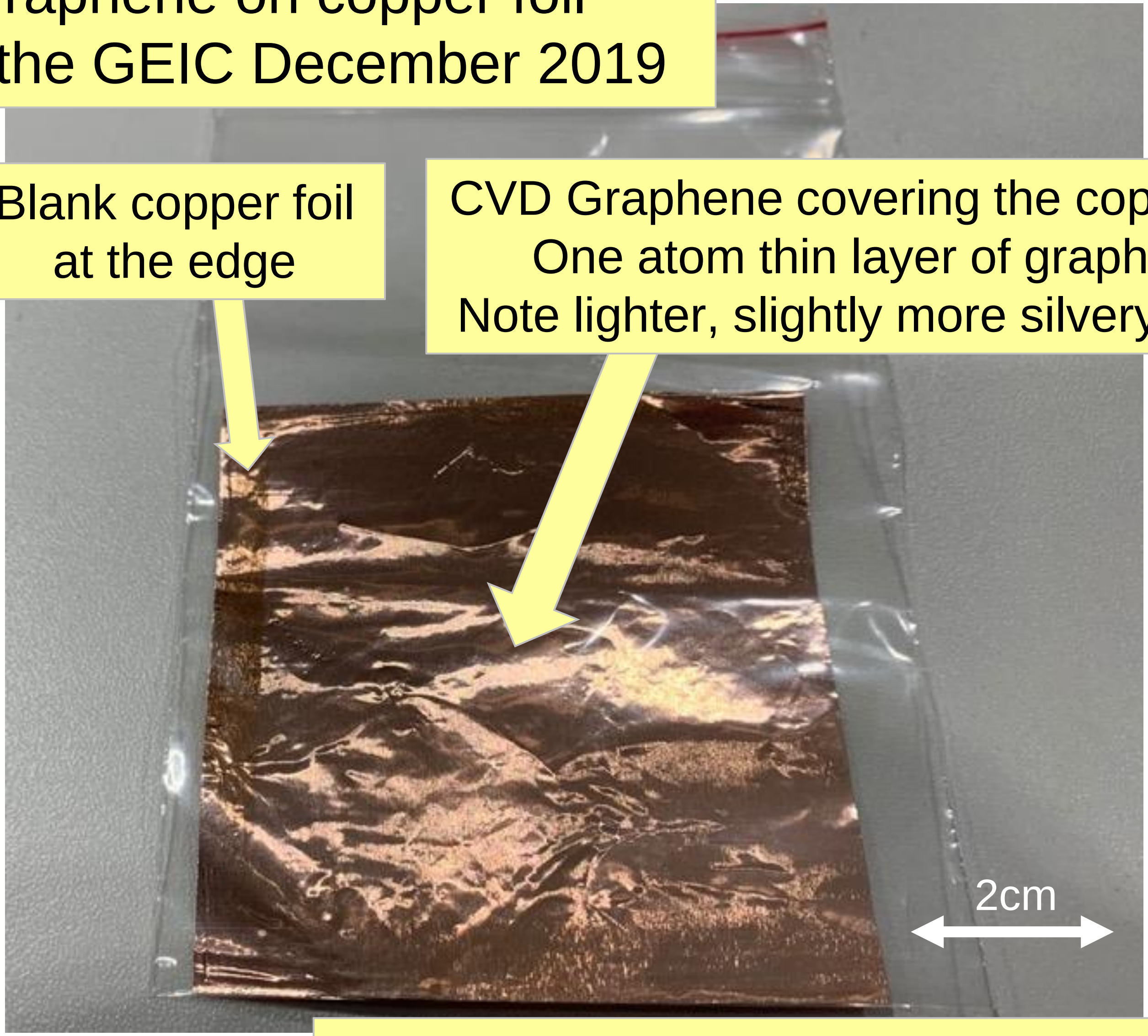
https://en.wikipedia.org/wiki/Grain_boundary

One atom thin graphene on copper

Fresh CVD Graphene on copper foil
Picture taken at the GEIC December 2019

Graphene Engineering Innovation Centre (GEIC) Manchester, UK

Nixene Publishing is one of the affiliate partners at the GEIC



Blank copper foil at the edge

CVD Graphene covering the copper foil.
One atom thin layer of graphene
Note lighter, slightly more silvery colour

This is polycrystalline graphene

Nixene Journal

May 2020

Images by Adrian Nixon

Single Crystal Graphene has already been made in the lab in 2017

A team at Peking University started by annealing a copper shape from the point to create a single crystal of metal with no grain boundaries

Then they arranged the growing conditions to form hexagon domains
These domains aligned and joined up rather than form discontinuities

This produced a sheet of continuous graphene that contained
99% ultra highly orientated grains forming a single crystal 50mm x 500mm

Source: X. Xu et al. (2017) Ultrafast epitaxial growth of metre-sized single-crystal graphene on industrial Cu foil, Science Bulletin 62. 1074-1080

Poll 4:
Ultimately, we will have to make the tether at very high speeds, we start with baby steps right now

A few weeks ago…

3. LG's Technology

LG Life's Good

Large Area & High Speed 400 mm R2R System for Mass Production

Specifications

- Configuration : 3300(H) x 2000(D) x 2000(W)
- Pressure : ~ 10^{-3} Torr
- Temperature : Max. 1,100 ℃ (± 1 %Deviations)
- Roll Speed : ~ 60m/hr
- Roll Width : 400 mm width (double roll)

Image credit: LG Electronics

LG in Korea announced they have developed a continuous graphene production line

This is a roll to roll (R2R) process

Vertical tube furnace making polycrystalline graphene for electronics

This is a high speed process 1m / minute

LG are making graphene like this for electronics rather than the space elevator
This announcement shows that graphene can be made at high speed by a continuous process

Feasibility of building the tether…

How big is a reel of single crystal graphene 100,000km long?

20mm core
1000mm wide

300mm Diameter

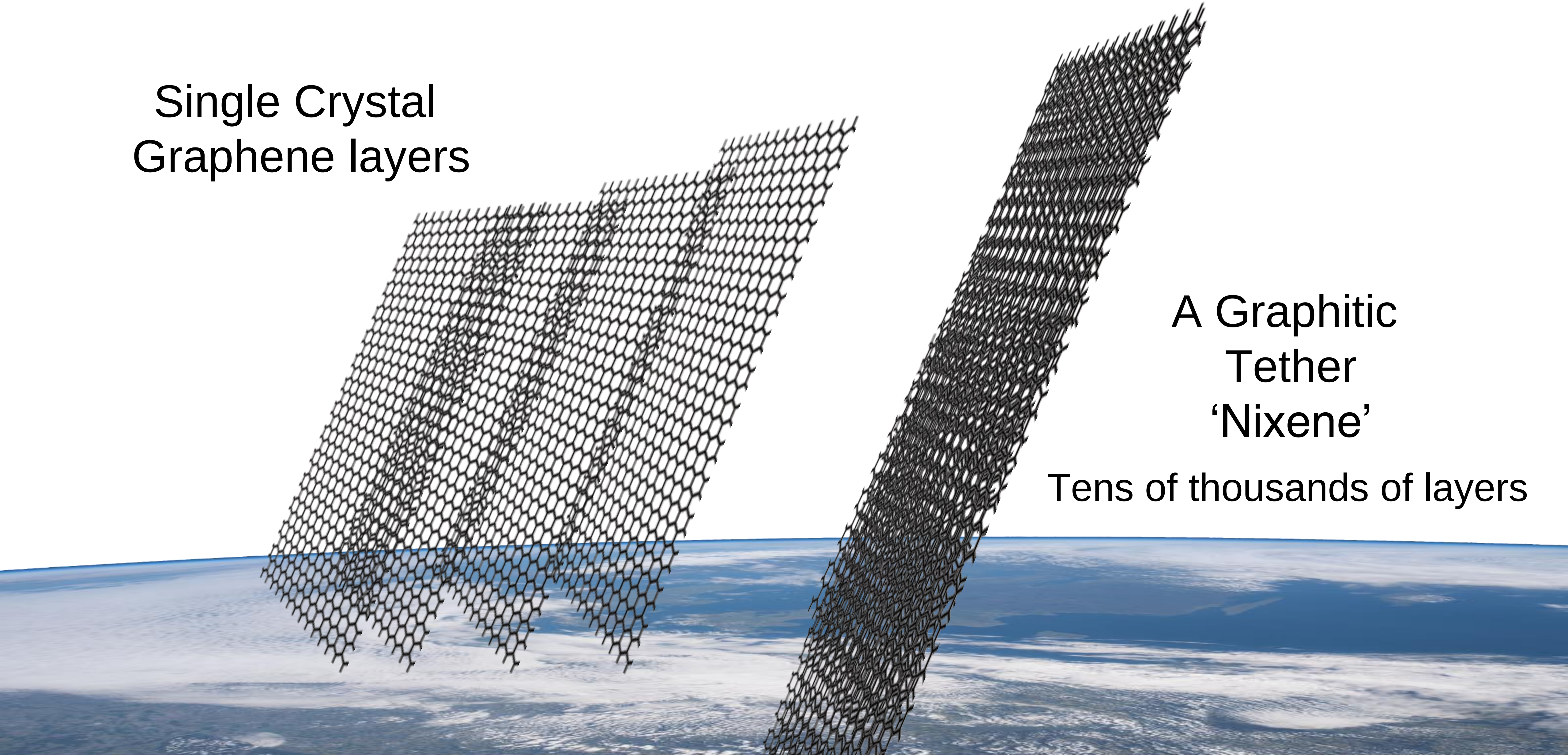
How much would it weigh?

77kg

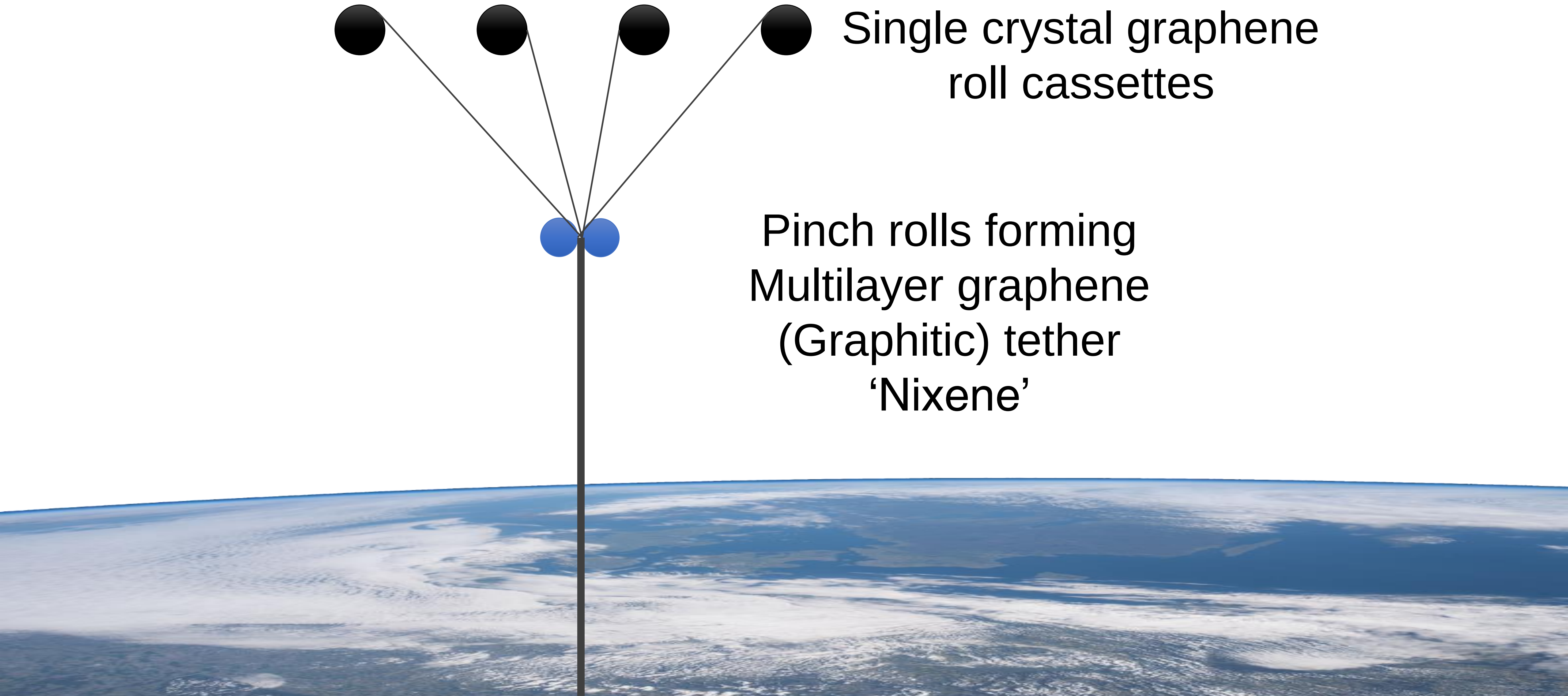
Dr. Peter Clark helped with the calculations…

https://www.linkedin.com/in/peter-clark-30ab9221/

Combine the tether layers in orbit…



Combine the tether layers in orbit…



Obayashi Corporation

One of the big five construction companies in Japan

ISEC

Obayashi corporation is a well respected large and capable construction company in Japan

Obayashi are committed to making the Space Elevator a reality by 2050

They kindly gave us permission to show you this short video

https://www.obayashi.co.jp/en/news/detail/the_space_elevator_construction_concept.html

Summary

- Space Elevator components
- Review of the properties for tether materials
- Review of the candidate materials
- Update on candidate materials and graphene
- And extra insider-information from the past few weeks

Thank you for your time

We will maintain a close watch on materials developments and keep you informed at the ISEC conferences and events

Adrian Nixon

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