Lecture 1: Overview

ManchesSTAR nuclear fusion lecture series

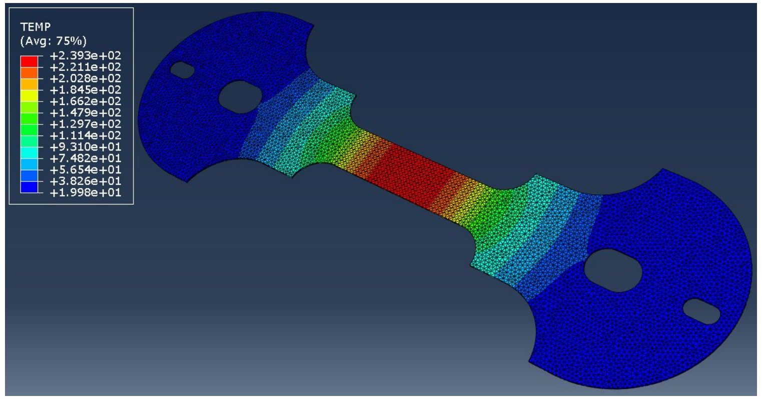
Tom Hughes, Charlotte Brown 2025/6

Sign in form

Before we start…

- Postdoctoral researcher at UoM
- Studying “In-Situ Experimentation of Nuclear Materials”
    - Sponsored by UKAEA
- Completed Undergrad at Lancaster University in Mechanical Engineering
- Knowledge base:
    - General fusion stuff
    - Irradiation damage
    - Simulation of proton beams and thermal loading
    - CAD/FEA
    - Tensile testing small samples and digital image correlation
    - Materials science for metals

Presenting at NUMAT 2024, Singapore



An example model from a paper I’m writing; thermal effects of proton beams in metals for synergistic testing

Feel free to contact me via whatsapp or thomas.hughes@manchester.ac.uk

About Charlotte:

FUSION CDT

3rd Year PhD student at UoM (finishing Sept 2027)

Working on the development of tungsten welds for fusion applications

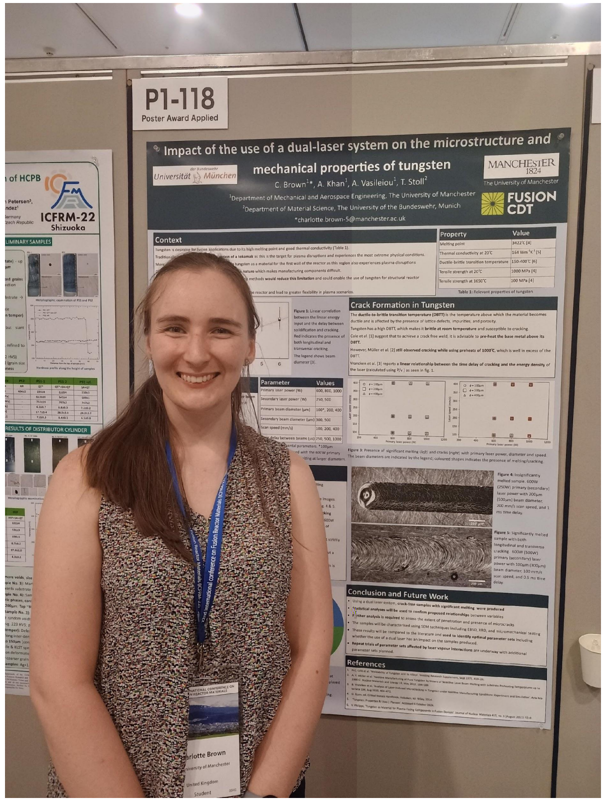
Interested in:

- Welding
- Additive Manufacturing
- Pre- and post-heating techniques
- Laser melting of tungsten
- Fusion education and outreach

MPhys from Durham University in Theoretical Physics (2023)

- Masters project simulating the expected results from MAST-Us neutron cameras

Questions? Get in touch! charlotte.brown-5@manchester.ac.uk



Course learning objectives

- To learn enough about fusion to do your own reading
  - To know what you don’t know
- To prepare students with knowledge of fusion problems to be solved
  - Plasma physics
  - Materials and engineering
  - Diagnostics
  - Proliferation
- To give a generic overview across many aspects of fusion and fusion power plant design
- To create an understanding of current developments in the nuclear fusion industry

Course outline (subject to change!)

1. Overview/Introduction
2. Plasma physics (how does nuclear fusion create energy, basic maths etc)
3. Reactor design (Tokamak)
4. Reactor design (alternatives)
5. Tritium breeding (how it is done, options in ITER, current developments as suggested by the Dalton nuclear institute)
6. Radiation damage 1 (overview into basic materials science and why radiation is bad for materials)
7. Radiation damage 2 (more specific issues, eg. 316L steel, zirc, a case study with tungsten etc.)
8. Superconductors (magnets, alternative magnet options e.g. tape, current issues in manufacture etc)
9. Control and monitoring (starting and sustaining plasma, monitoring devices and how they would fit into a reactor)
10. Designing and testing for fusion (links to own work and current developments)
11. Concerns with fusion (Waste, Proliferation and Will it work?)
12. Summary and quiz

Suggested reading

- *Michael Short's MIT youtube series* is very good
- Gary Was' textbook the *Fundamentals of radiation and materials science* is the bible on fusion materials engineering.
- Fusion society group chat posts good lectures/informational videos
- Or see me for specific bits on various topics.

Fusion?

Let’s see if this works…

What do you think about when asked about nuclear fusion?

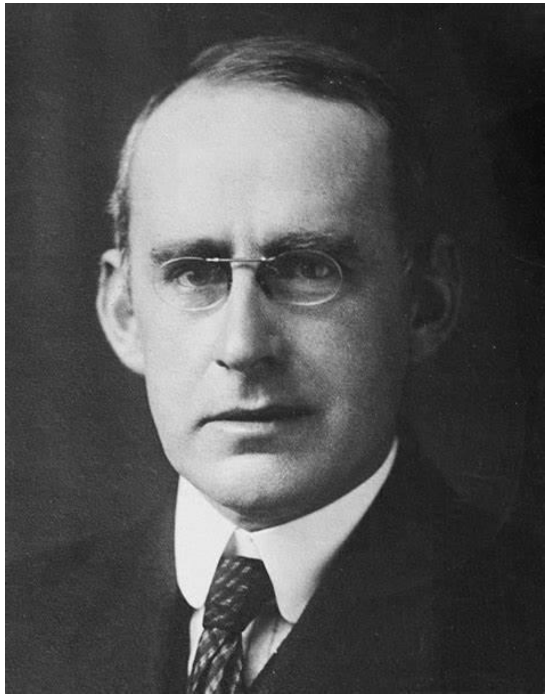
What do you do?

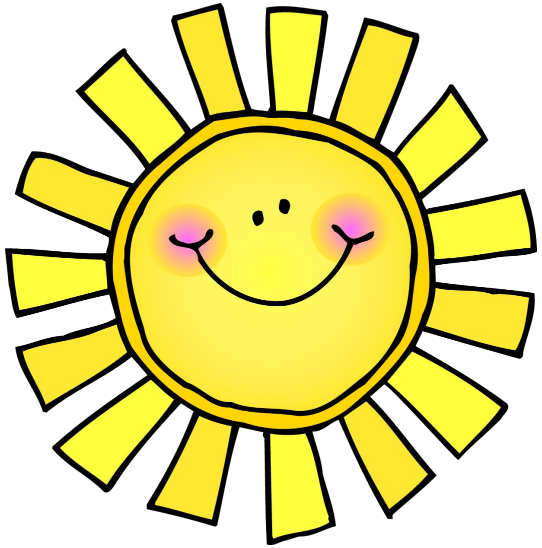
Please put in your degree title, e.g. Physics, Mechanical Engineering, etc.

Word Cloud

The discovery of fusion

- When was the concept of nuclear fusion theorised?
- During the creation of the nuclear bomb? Nope!
- The concept of fusion is now over 100 years old, with Sir Arthur Eddington theorising how stars work in 1920!
- He noticed the mass difference between hydrogen and helium, over 4 times.
- Eddington said: "… we sometimes dream that man will one day learn how to release it [the energy] and use it for his service. The store is well nigh inexhaustible, if only it could be tapped. …" Address to the British Association in Cardiff, 24th Aug. 1920; in Observatory, 43 353 (1920)





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Hydrogen

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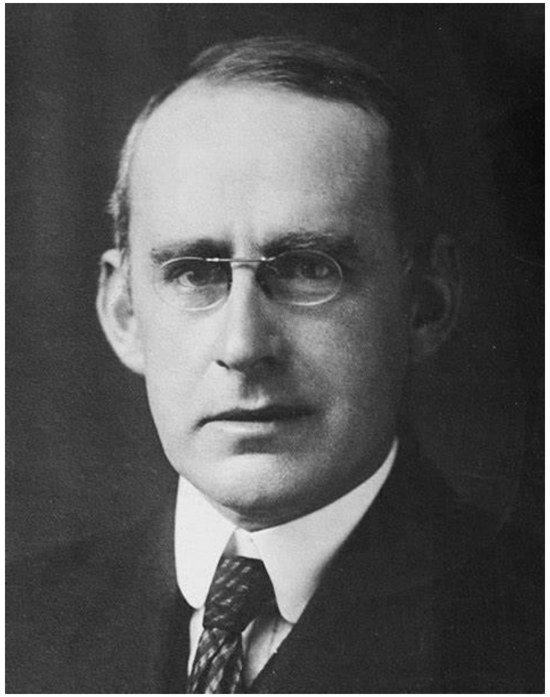
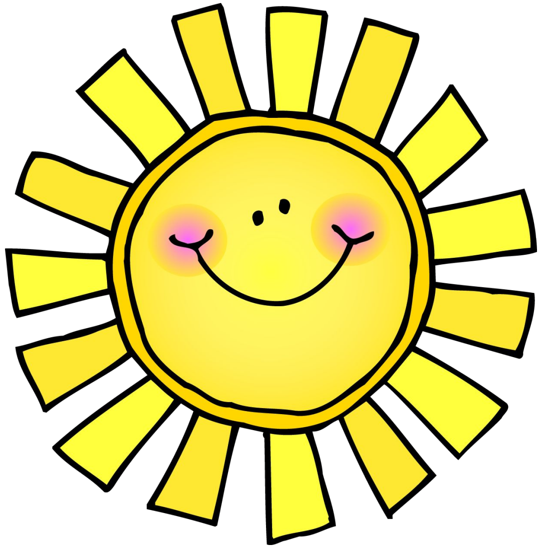
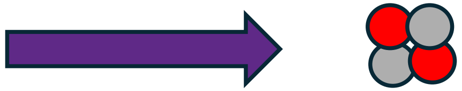


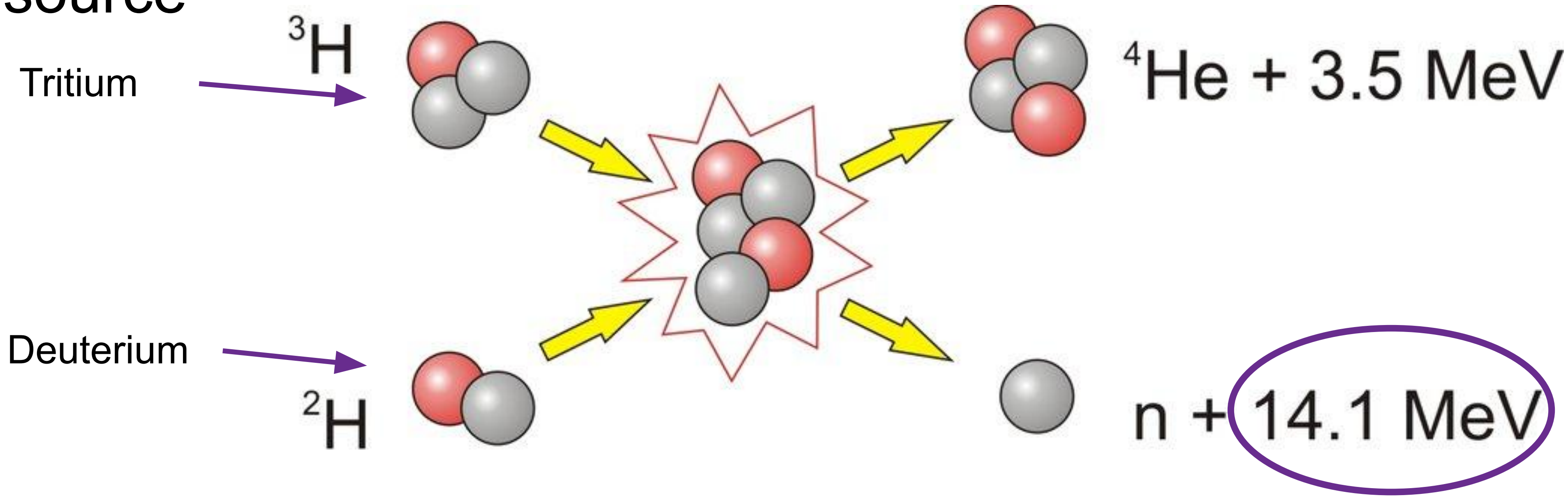




1 Helium

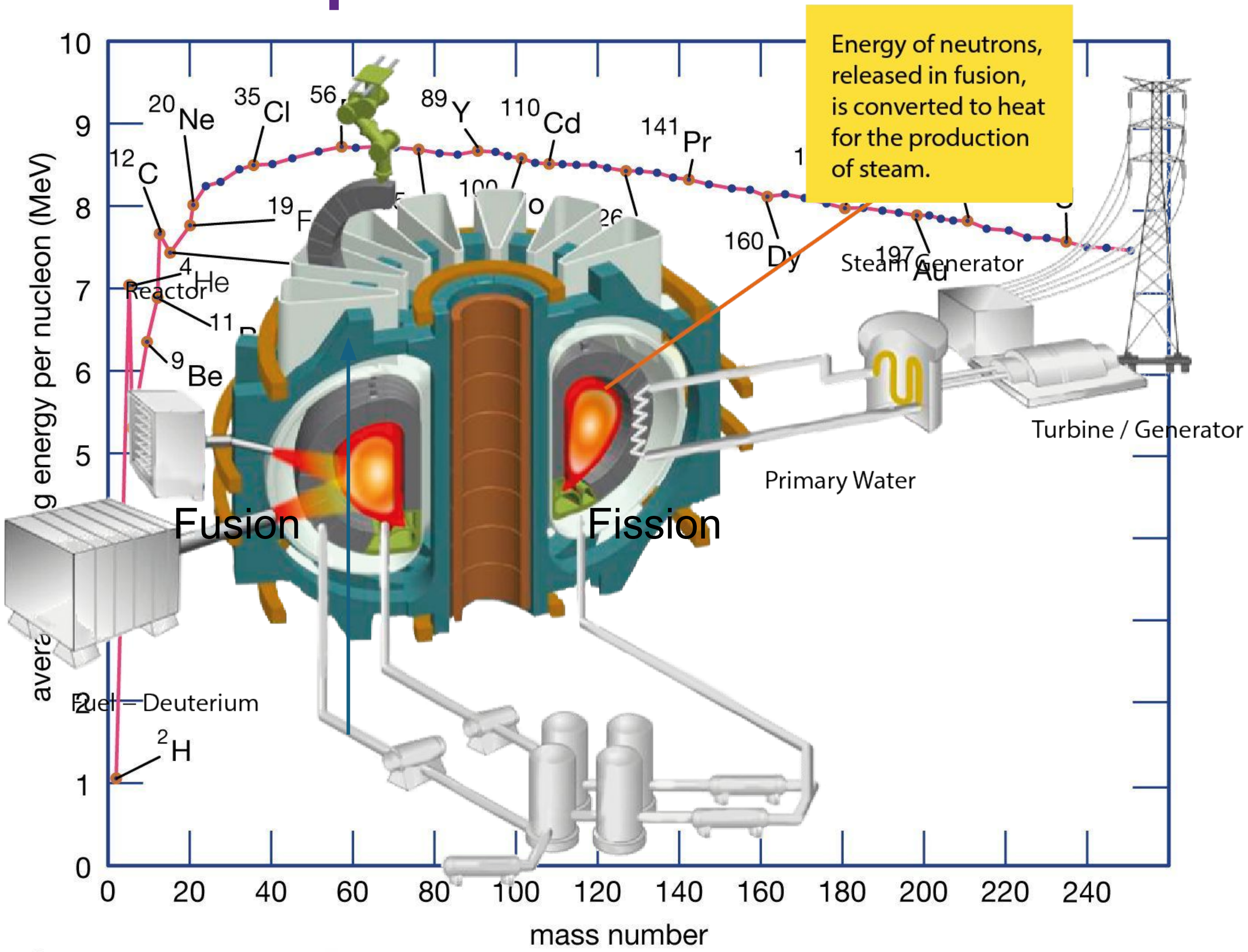
So, what is it?

- Combination of small nuclei to release energy
- In the sun, the force from this outward push keeps it from collapsing in on itself
- In the nuclear industry it is a potential, nearly unlimited power source



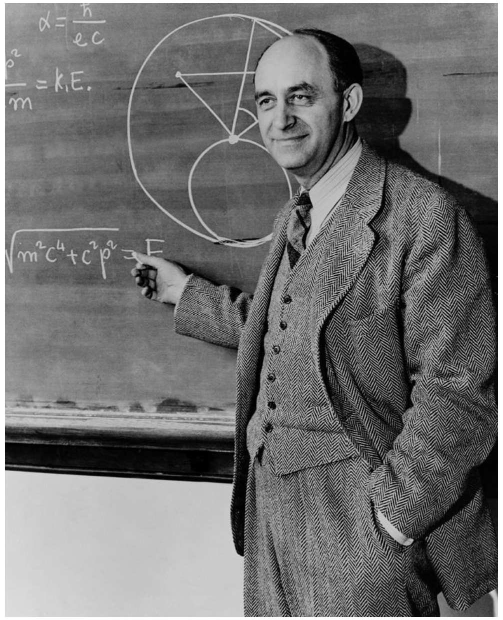
Where is the power output?

- Most of the released energy is in the form of the 14.1MeV neutron
- These will collide with the reactor and deposit energy
- The reactor heats up, heat is extracted via cooling channels, and this turns a turbine after heating water or other gases (e.g. helium)
- For something so sci-fi, we're still using power generation methods from the Victorian times!
- Alternative fuels work if we look at the energy released per nucleon. This graph also displays why nuclear fission works.
- Iron is the most stable and the endpoint for fusion. Hence why stars need to go supernova to create heavier elements

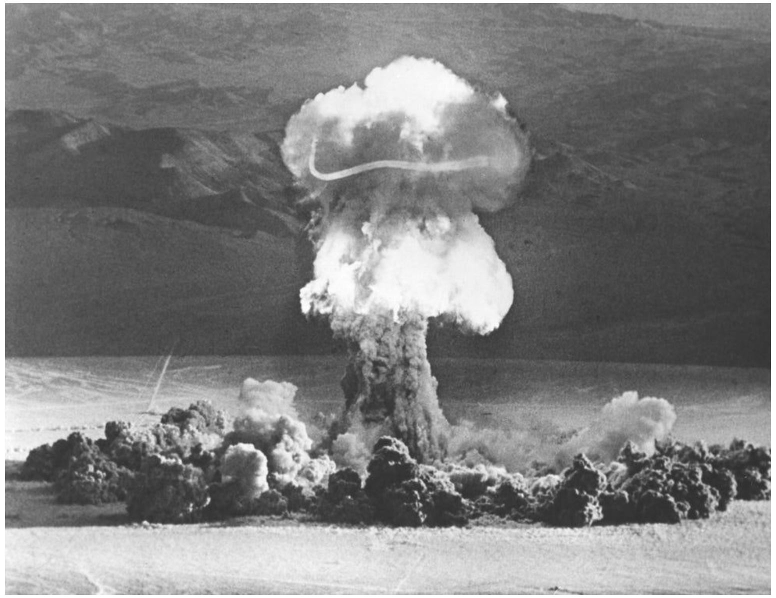


History of fusion

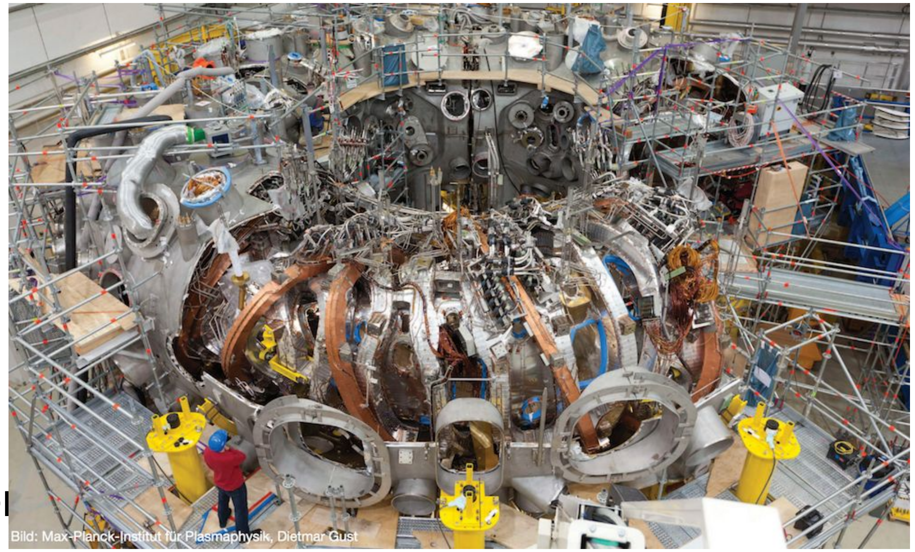
- 1920: Sir Arthur Eddington theorises the force behind the sun
- 1941: Enrico Fermi proposes the idea for a nuclear fusion bomb
- 1950s: The USA and USSR both have successful demonstrations of the ‘super’
- 1950: Enter the fusion machines. Andrei Sakharov and Igor Tamm proposed the magnetic confinement ‘Tokamak’
- 1951: Lyman Spitzer introduces the concept of the Stellarator, which dominates the 50s, but due to the Tokamak being proved more efficient, it falls out of fashion. Wendelstein 7-X remains as the main stellarator design today.



Enrico Fermi



Las Vegas nuclear demonstration



Tokamak design

Wendelstein 7-X

1970s: Designs for JET begin in 1973, the Joint European Torus

1985: Due to the fall of the iron curtain, ITER is set in motion as proposed by General Secretary Gorbachev

1997s: First experiments conducted at JET, making it the first reactor to run on 50/50 Deuterium and Tritium. JET sets the world record for nuclear fusion output at 16MW from 24MW heating

2022: ITER passes the 77.7% milestone of work completion, with a proposed Q factor of 10

2025: China's EAST reactor shatters the previous record 403 seconds for sustained plasma by breaking the 1000 second barrier.
This was broken by WEST only weeks later, current recor[d] stands at 1337 seconds (22 minutes)

ITER: Under construction…

Reagan and Gorbachev "for the benefit of all mankind"

China's EAST reactor

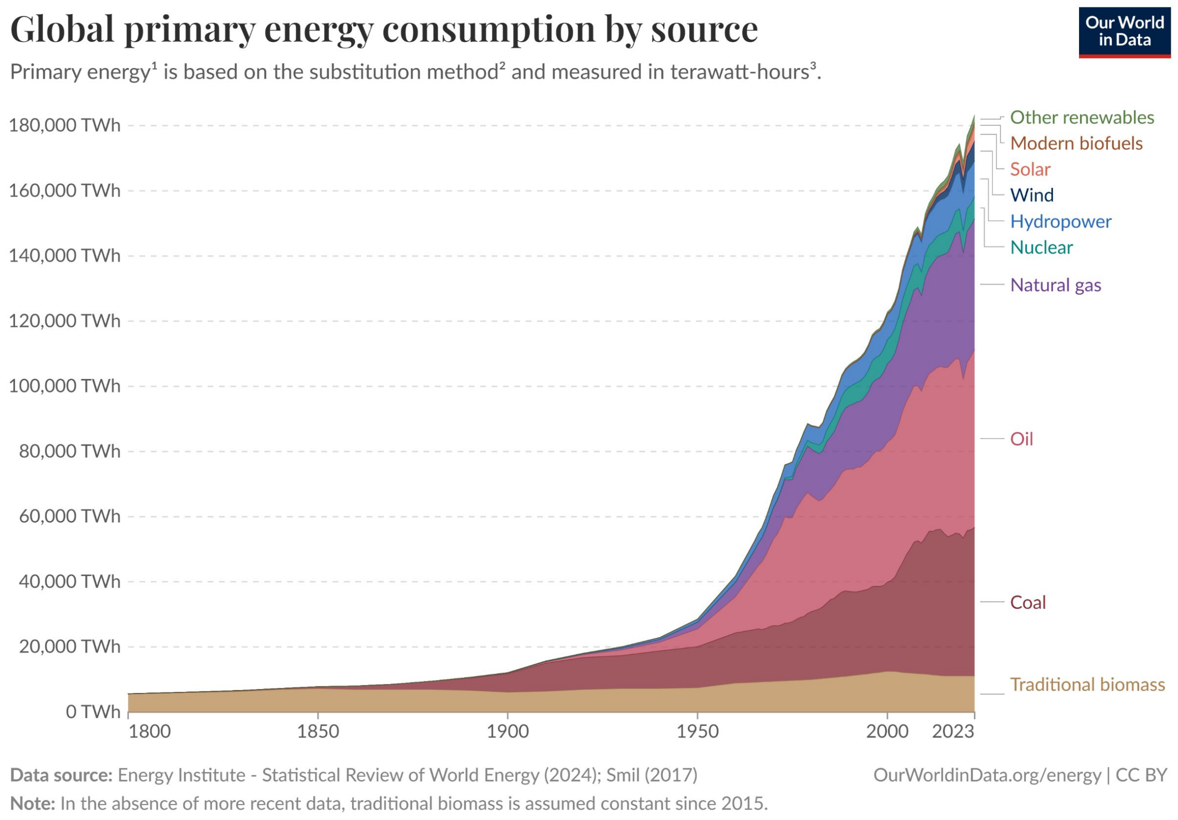
JET based in, Culham, Oxford with plasma shown on the right of the image

Why fusion, why now?

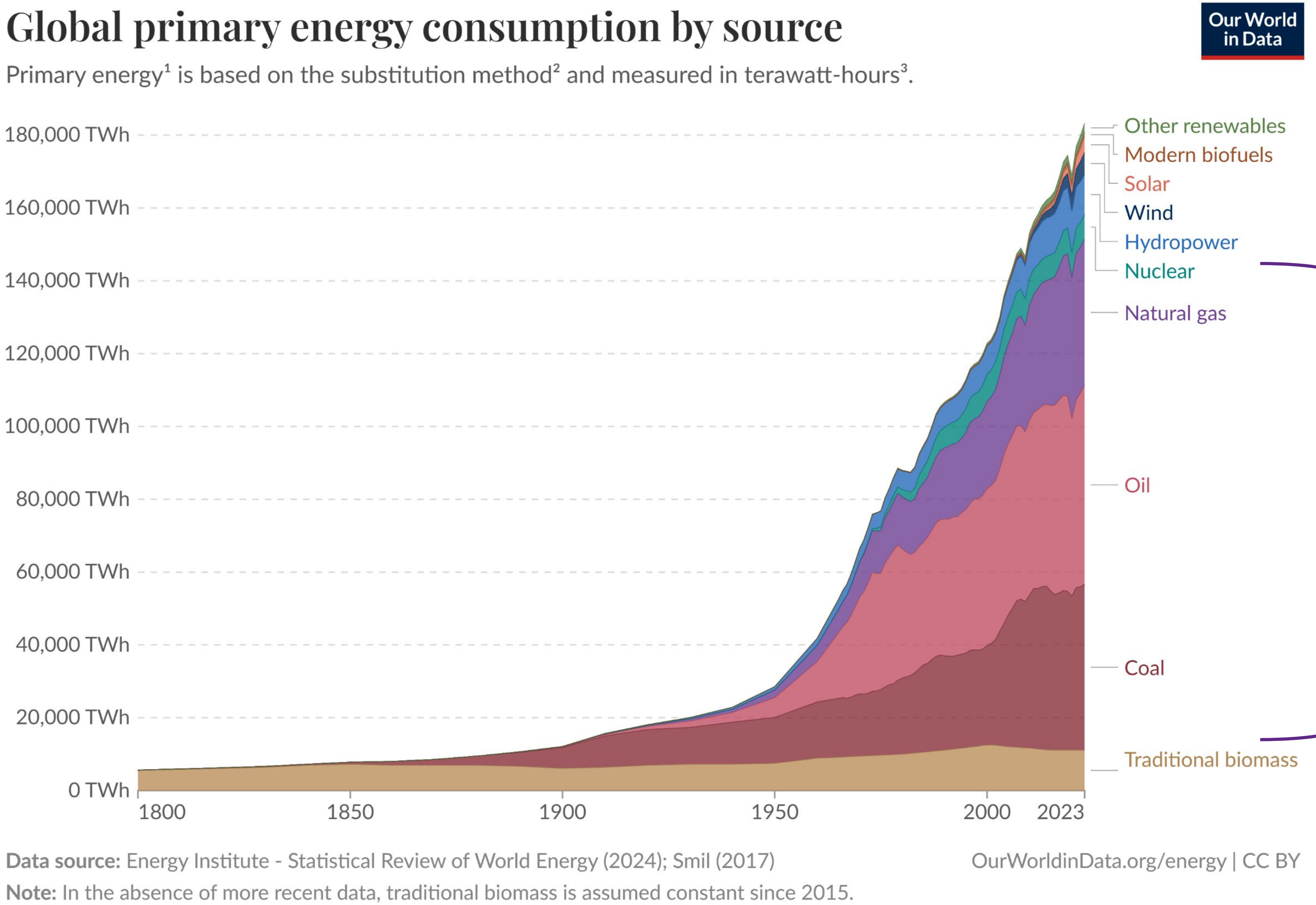
- So where does that leave us?

Why fusion, why now?

- So where does that leave us?
- Global energy needs are expanding
  - Population growth
  - Developing world
  - Electrification
  - Fossil fuels becoming extinct
- Fusion provides an opportunity for the densest energy production
- Exponential growth of energy demand needs every solution available to humanity

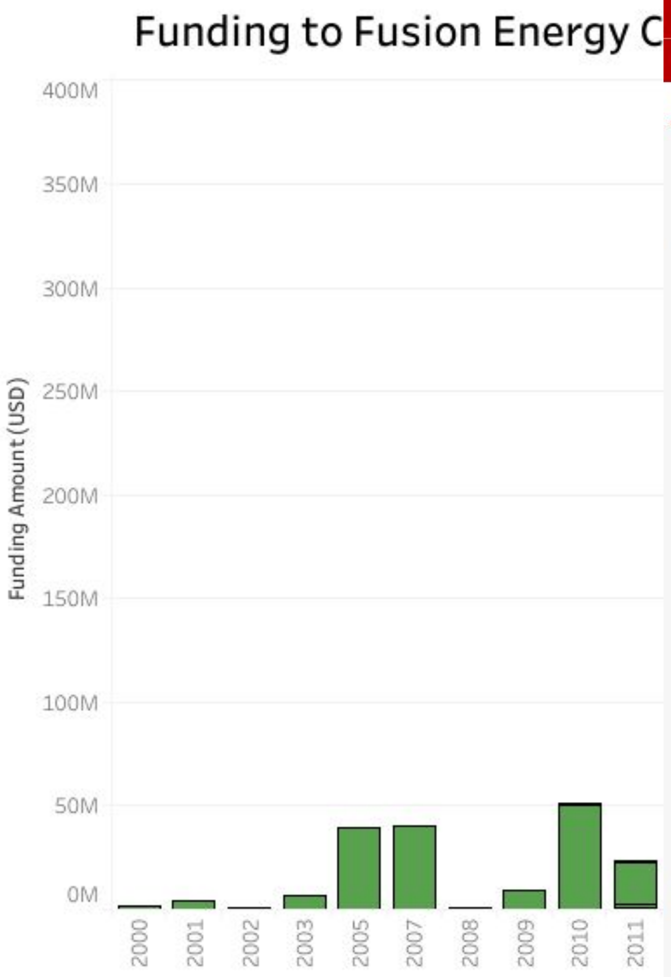


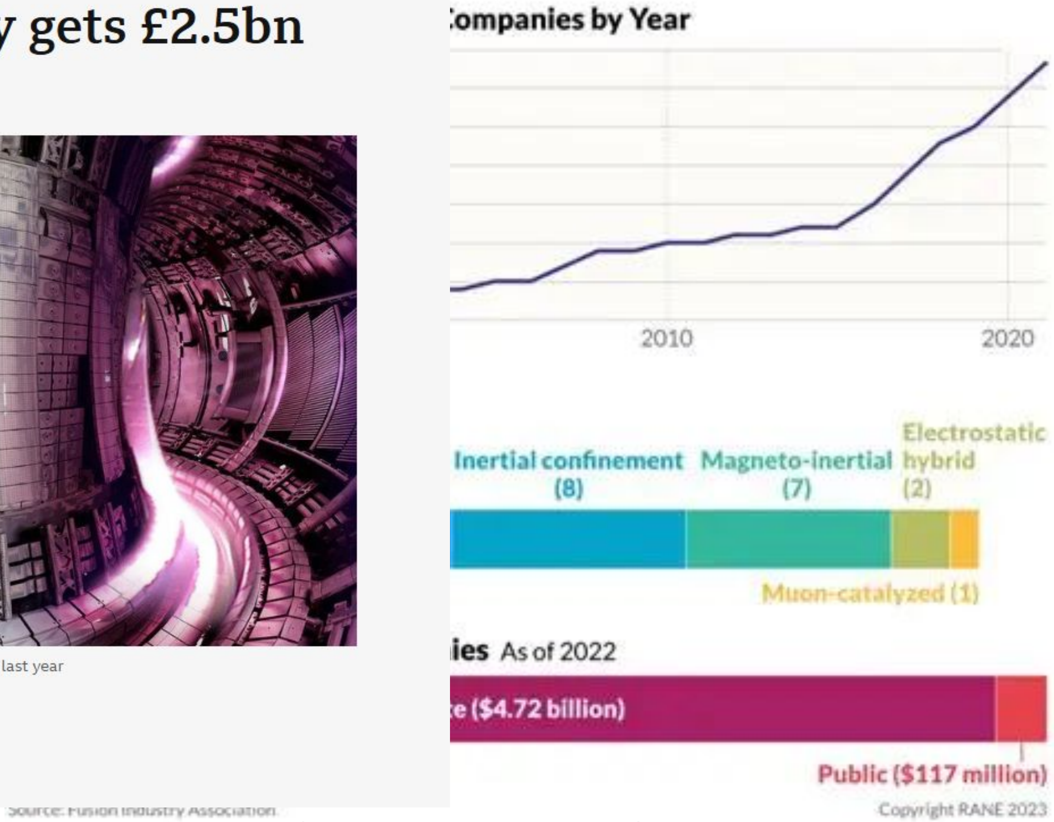
Why fusion, why now?



Fossil fuels making up a significant majority. Clean energy is playing catch up!

Nuclear Fusion Investment – up and away!





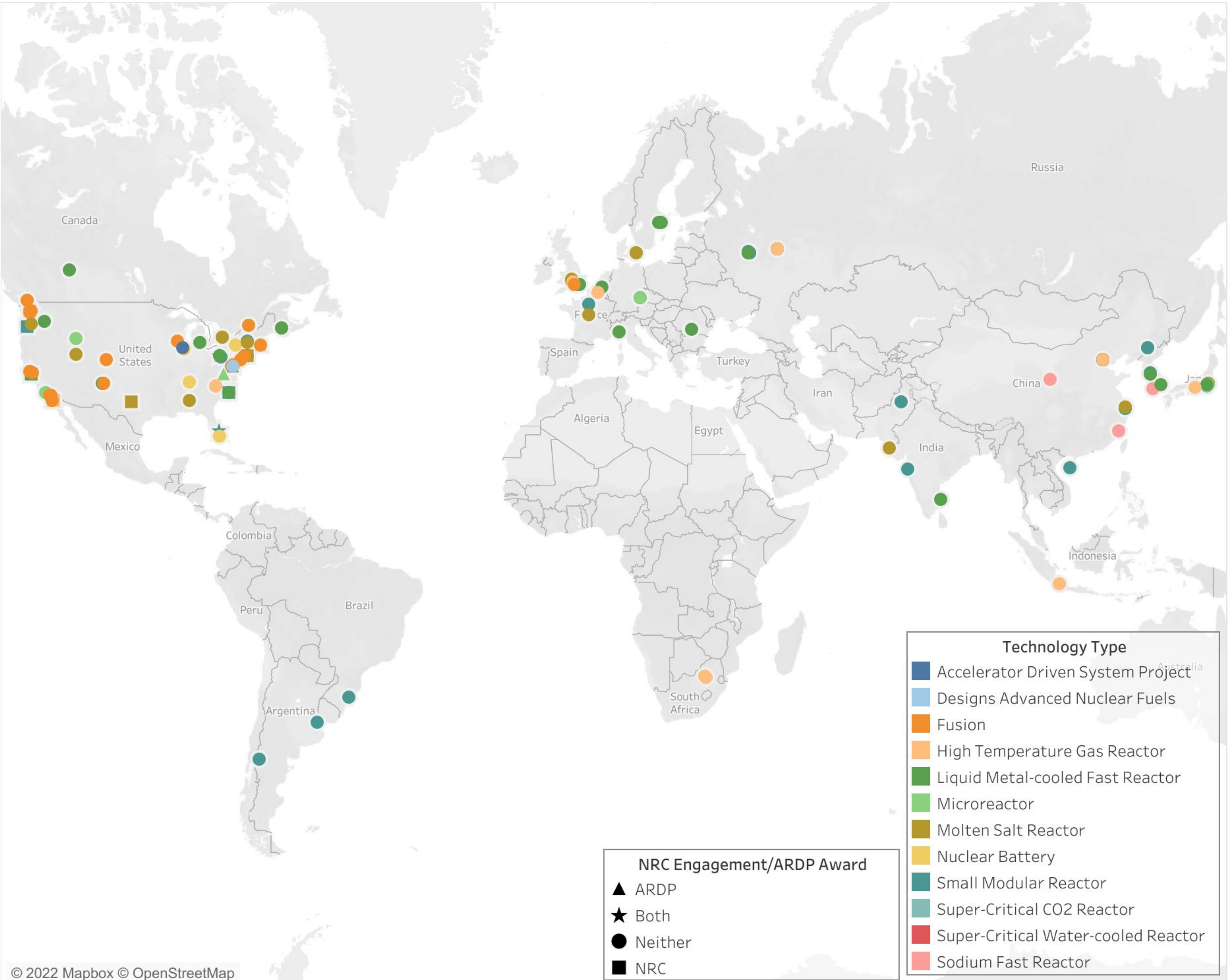
Funding to Fusion Energy Companies Since 2000 | Fusion Energy B

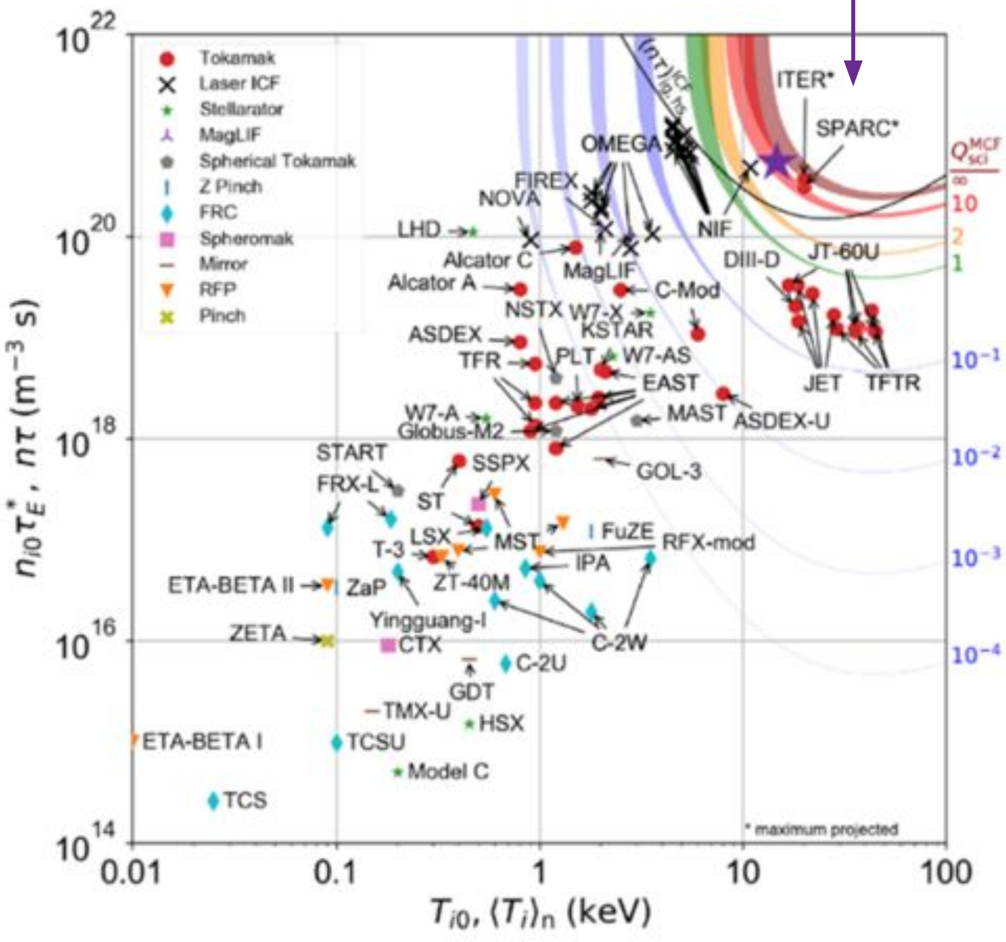
The Prospects of Nuclear Fusion as Scientists Reach Ignition

Power plants around the world

SPARC – smallest possible ARC (affordable, robust, compact. Burst type tokamak (10 seconds)

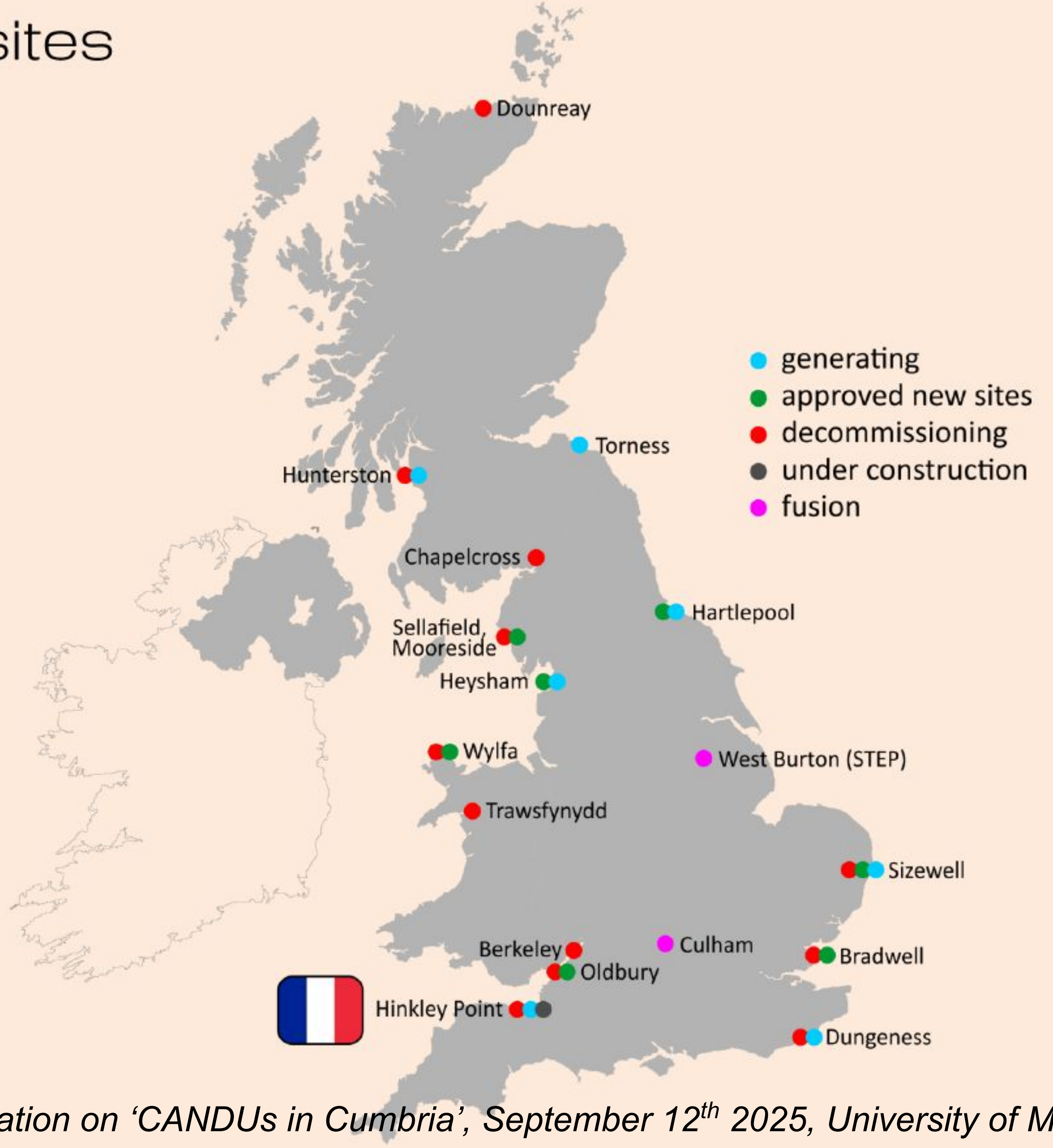
2021 Advanced Nuclear Map





Q factor of plants around the world

Nuclear sites



Slide taken from S.Lisgo's presentation on 'CANDUs in Cumbria', September 12th 2025, University of Manchester

Power plants to come online this century

- ITER – The largest and most expensive.
  - Test reactor for 4 different breeder blanket designs
  - South of France
  - Cost: £10s of billions
- STEP – Spherical tokamak for energy production
  - Smaller reactor sponsored by UKAEA
  - Central UK
  - Cost: Estimated at several billion £s
- Tokamak Energy (UK), China Fusion Engineering Test Reactor, ARC (USA), DEMO (International), Proxima Fusion Plant (Germany), GA FPP (USA)… etc.
- Too many to name, huge investments worldwide.
- Fusion is happening this century.

Full list at IAEA World Fusion Outlook 2024 | IAEA, page 20 onwards.

Key challenges

What ideas can we come up with? Why has fusion taken so long?

Key challenges

- What ideas can we come up with? Why has fusion taken so long?
- H

- M
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- N
- I
- Manufacturing capacity doesn't exist
- Public perception – worried about atomic weapons

Feedback

This is your opportunity to change the course as you see fit.

Reminder of the lecture topics:

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What would you change? What would you add? How do we want the lectures to run?

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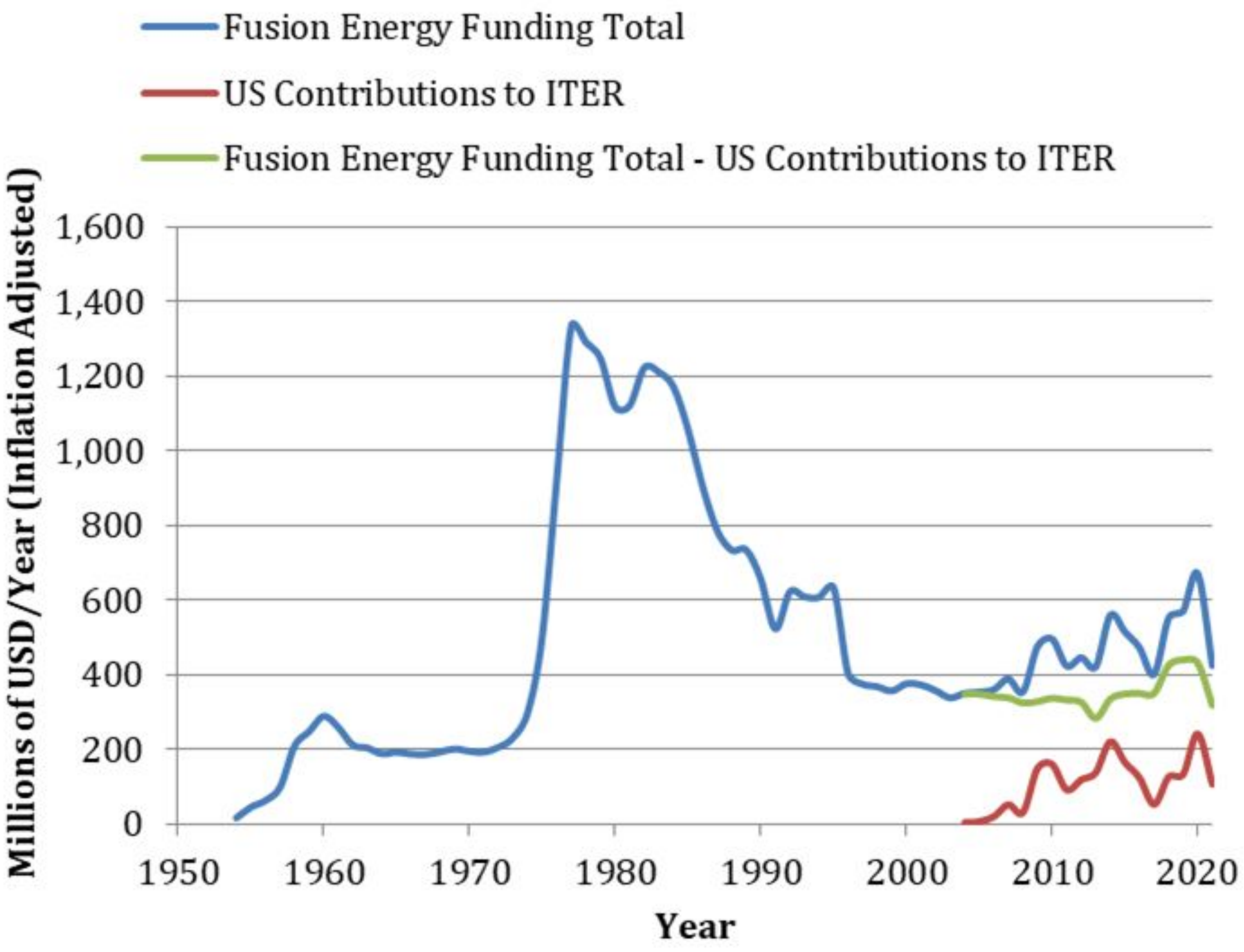
Thank you for listening, any questions?

Next lecture: Plasma Physics

- A Brief His



Fusion Energy Funding Total
US Contributions to ITER
Fusion Energy Funding Total - US Contributions to ITER
Millions of USD/Year (Inflation Adjusted)
1,600
1,400
1,200
1,000
800
600
400
200
0
1950
1960
1970
1980
1990
2000
2010
2020
Year