KYOTO FUSIONEERING

The paradigm shift in fusion energy: How Kyoto Fusioneering is accelerating the path to commercialisation

University of Oxford | Oxford, UK | 29 October 2024

Richard Pearson – *Co-founder, Chief Innovator & UK Director*

FUSION for the FUTURE.

Outline

- About me
- What is fusion?
- The innovation paradigm shift
- The emergence of a new fusion industry
- Kyoto Fusioneering: Who we are & what we do
- Key technical projects & activities
- Recap & closing remarks

About me

About me

- **Education and background:**
  - **BEng Mechanical Engineering** (Swansea University)
  - **MSc Nuclear Engineering** (Imperial College London)
  - **PhD Fusion Engineering & Innovation** (The Open University)
    - *Innovation models applied to the commercial fusion paradigm*
    - *Commercialisation pathways via Technology Roadmapping (sponsor: Tokamak Energy Ltd.)*
    - *Strategic challenges in fusion fuel cycle (with focus on resource availability, supply and use)*
- **Career and experience:**
  - Co-founded **Kyoto Fusioneering** in 2019 – serve as Chief Innovator & Director (UK)
  - Other Positions:
    - **Field Editor** – Journal of Fusion Energy
    - **Member (elected)** – IEEE Fusion Technology Standing Committee
    - **Member (appointed)** – IAEA Blanket Fusion Technology Committee
    - **Visiting Senior Research Associate** – Bristol University, UK
    - **Board Member** – Fusion Industry Taskforce, UK


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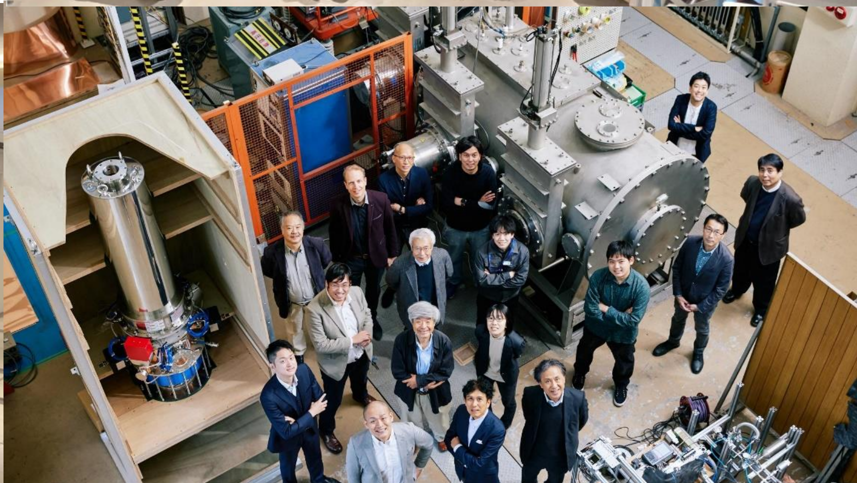

About me: what I do with the rest of my time..!

So, what is fusion?

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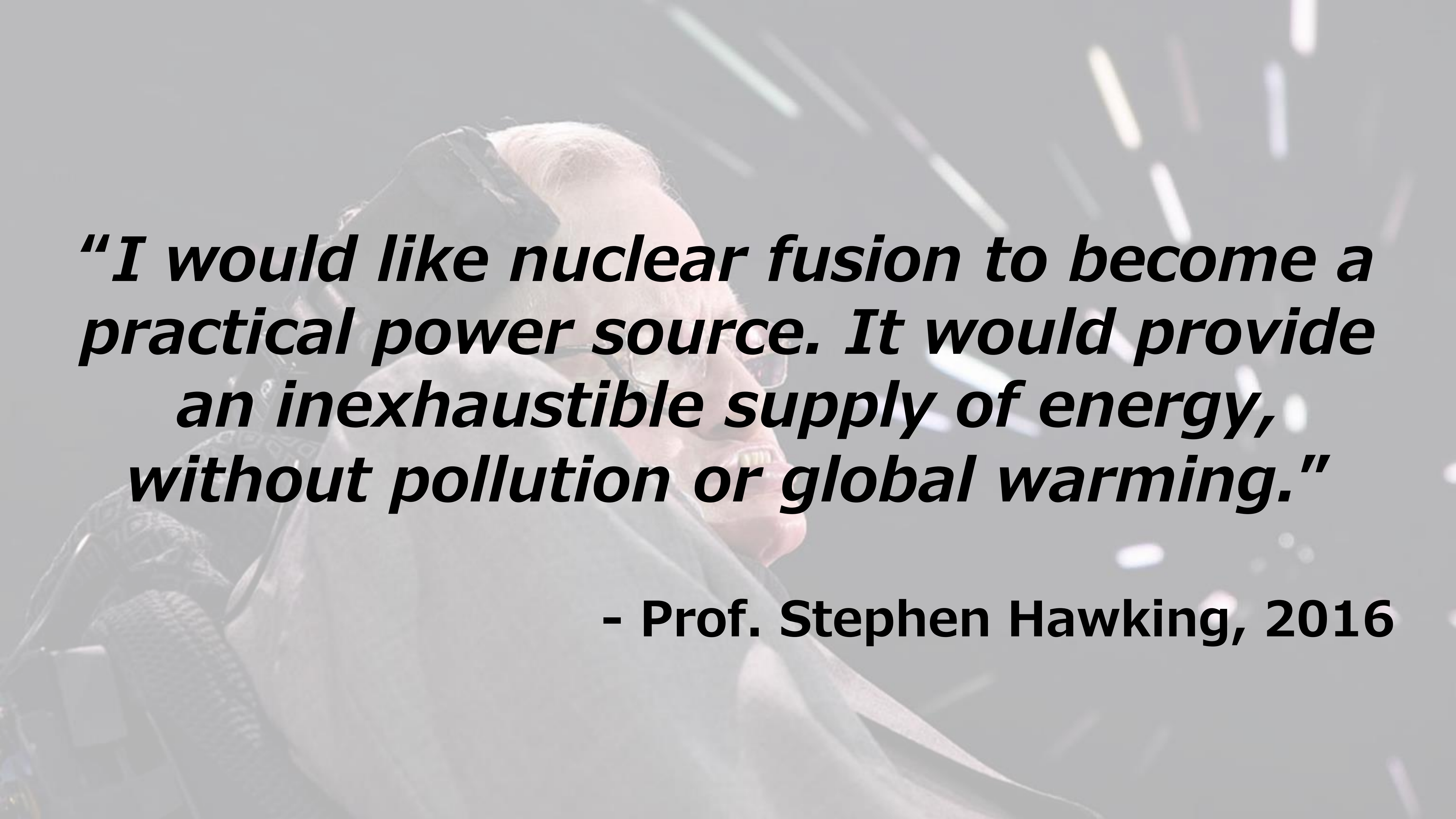
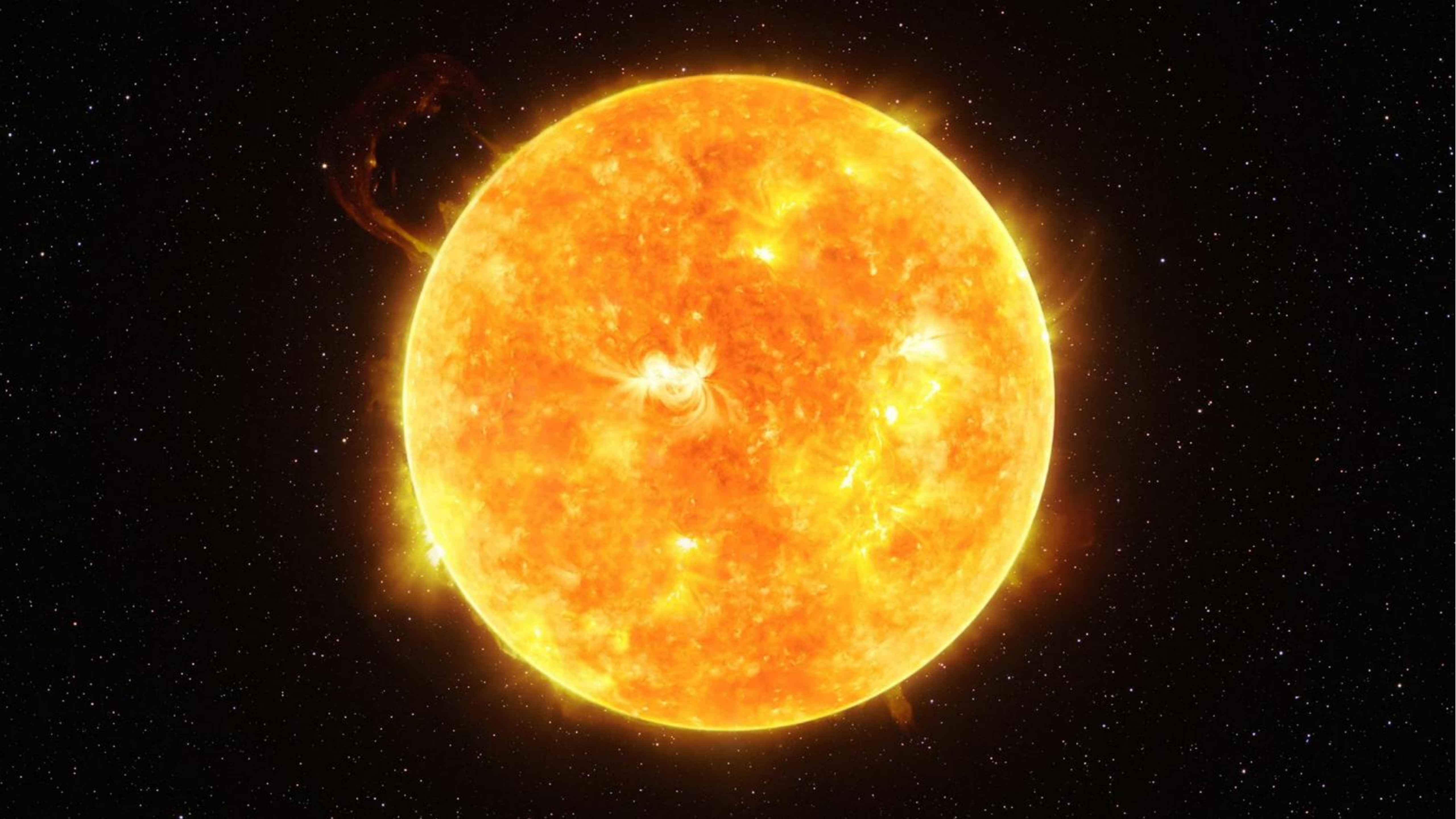
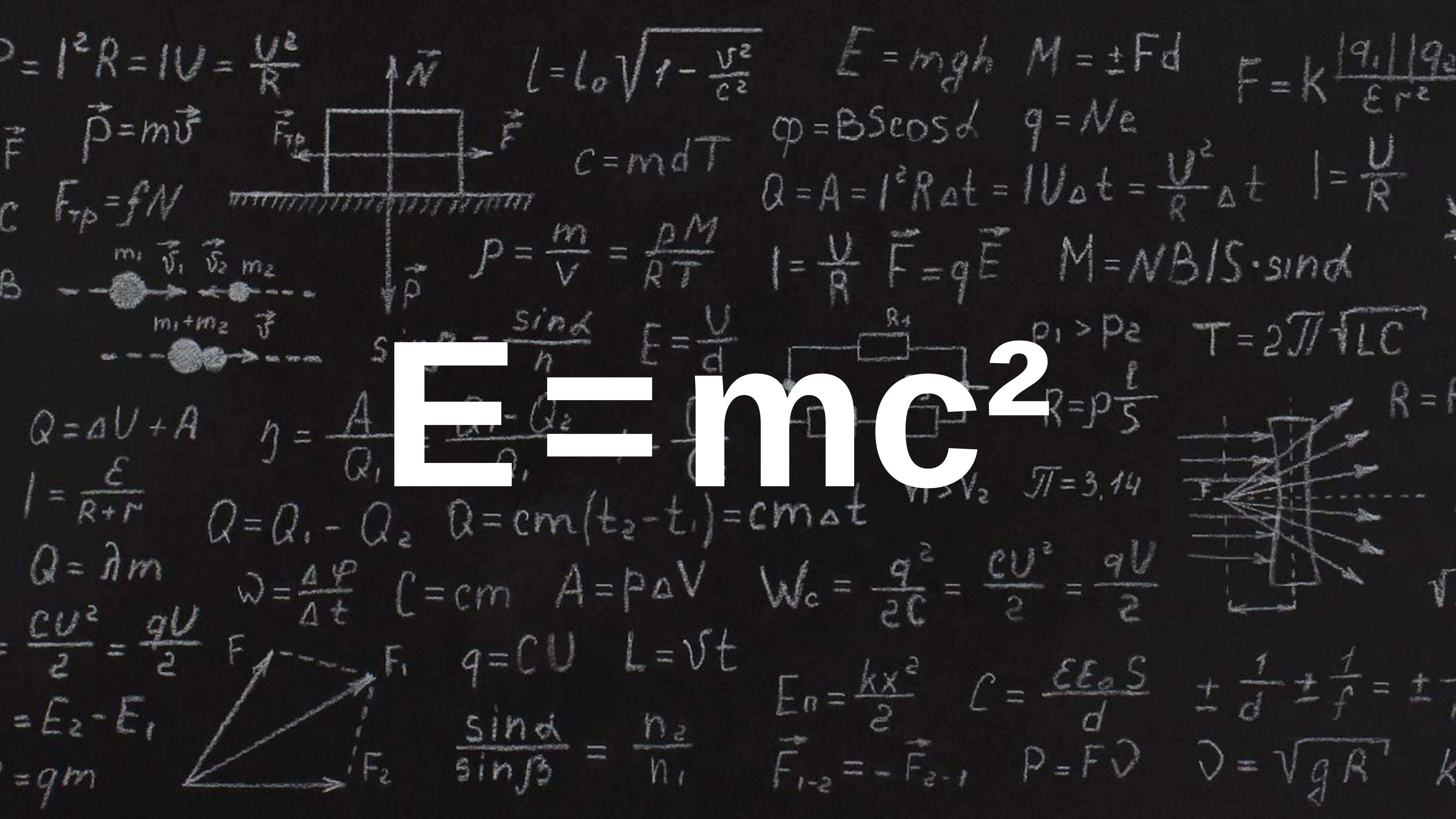
Fusion Energy: Getting Closer? | Richard Pearson | TEDxWoodLane

Richard Pearson | TEDxWoodLane • October 2022


"I would like nuclear fusion to become a practical power source. It would provide an inexhaustible supply of energy, without pollution or global warming."
- Prof. Stephen Hawking, 2016





$E=mc^2$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7
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The Backdrop

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Climate Change

Current warming rates not seen in 10,000 years.

Net-zero by 2050

Energy Poverty

13% without electricity

40% without clean cooking fuels

Energy Insecurity

27% of US households having difficulty meeting energy needs

Energy Dependence

Global energy supply controlled by few nations

[Supply – Key World Energy Statistics 2021 – Analysis - IEA]

Why Fusion

The Opportunities

A *world of* ***energy superabundance.***

More Energy Lifts All Boats

Causal and bidirectional relationship between energy consumption and economic growth.

Return Carbon to Earth

We may pay back our carbon debt.

Unlock Ability to Innovate

We will unleash our potential of manipulating our physical environment.

Energy is a vital determinant of a society's success.

The Promise of Fusion

Dispatchable

Can be turned on and off, independent of environmental factors.

Clean

Fusion doesn't emit harmful substances like carbon dioxide or other greenhouse gases into the atmosphere.

Geographically independent

Primary fuels are found in sea water. Fusion is manufactured, not mined.

Sustainable

Deuterium can be distilled from all forms of water. Terrestrial lithium will last >1,000 years, sea-based reserves fulfil needs for millions of years.

More than electricity

Can be used for synthetic fuels, industrial process heat, and more.

Safe

No meltdown risk due to inherent safety features. Limited proliferation risk; no fissile materials. Possible to avoid high-level waste.

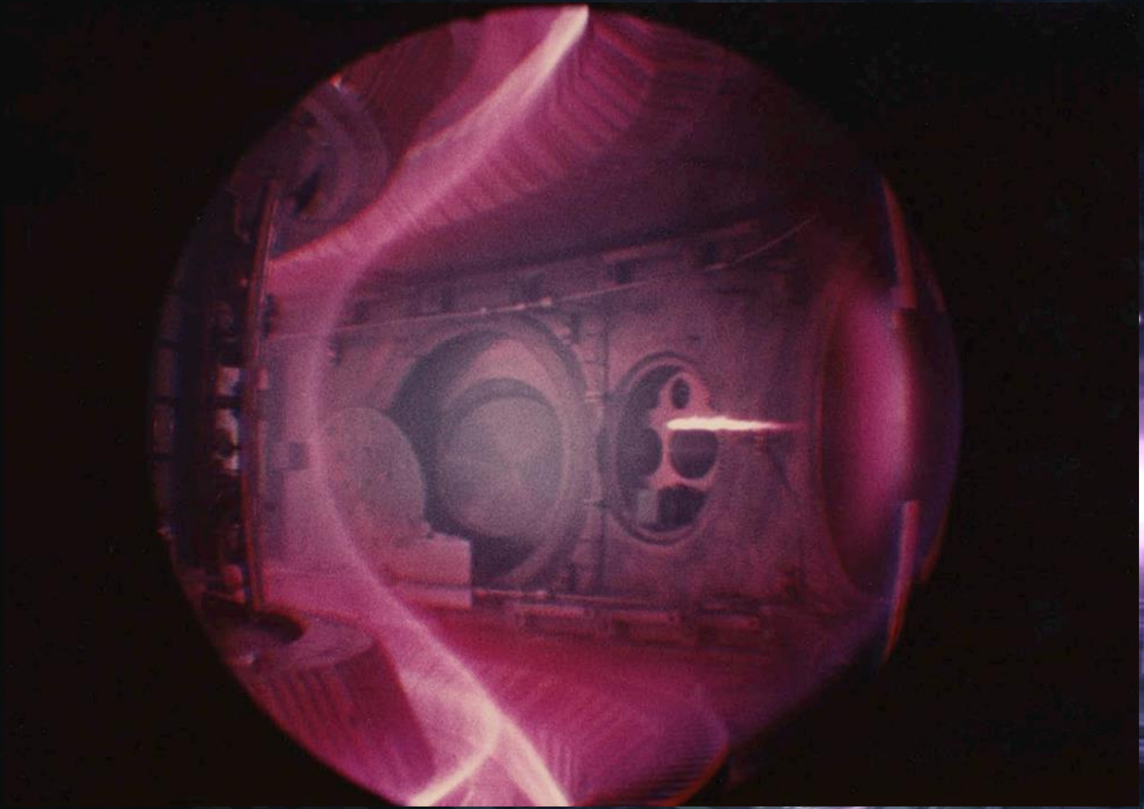
Energy dense

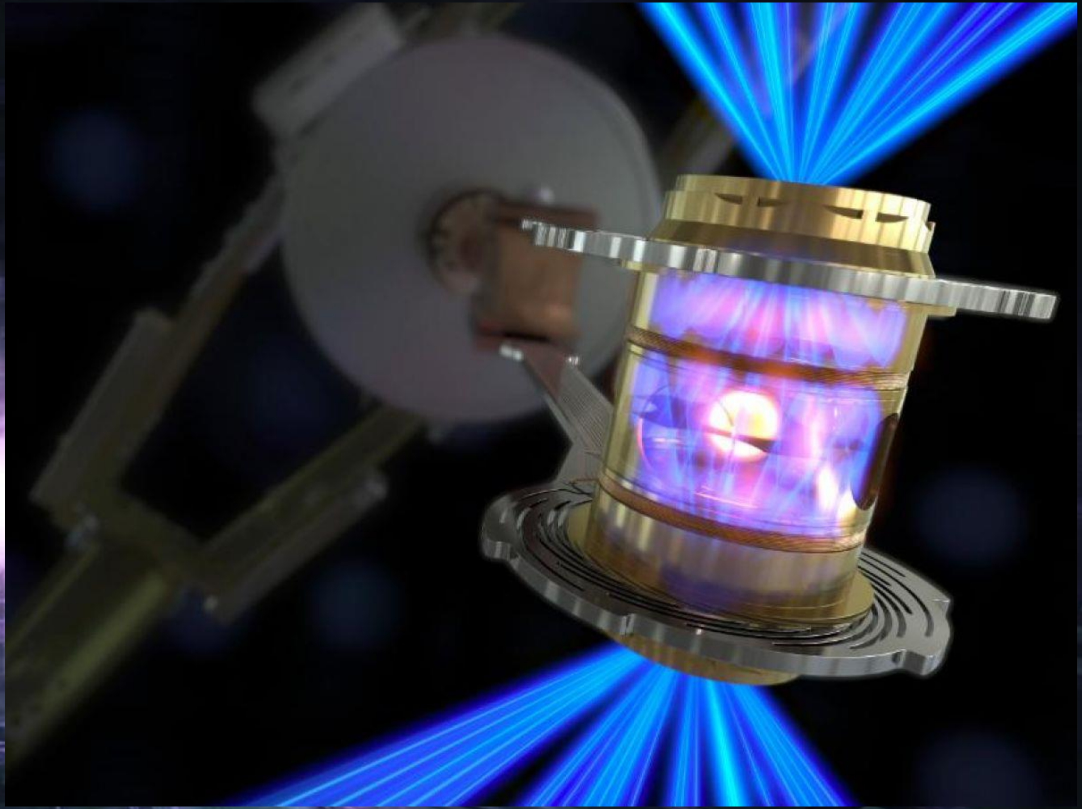
Four million times more energy than burning of coal, oil or gas and four times as much as nuclear fission reactions.

Economical

Cost is hard to extrapolate now but is expected to be competitive once economies of scale are reached.

How does it work?





Images: Combs & Baylor, 2018; Lawrence Livermore National Laboratory

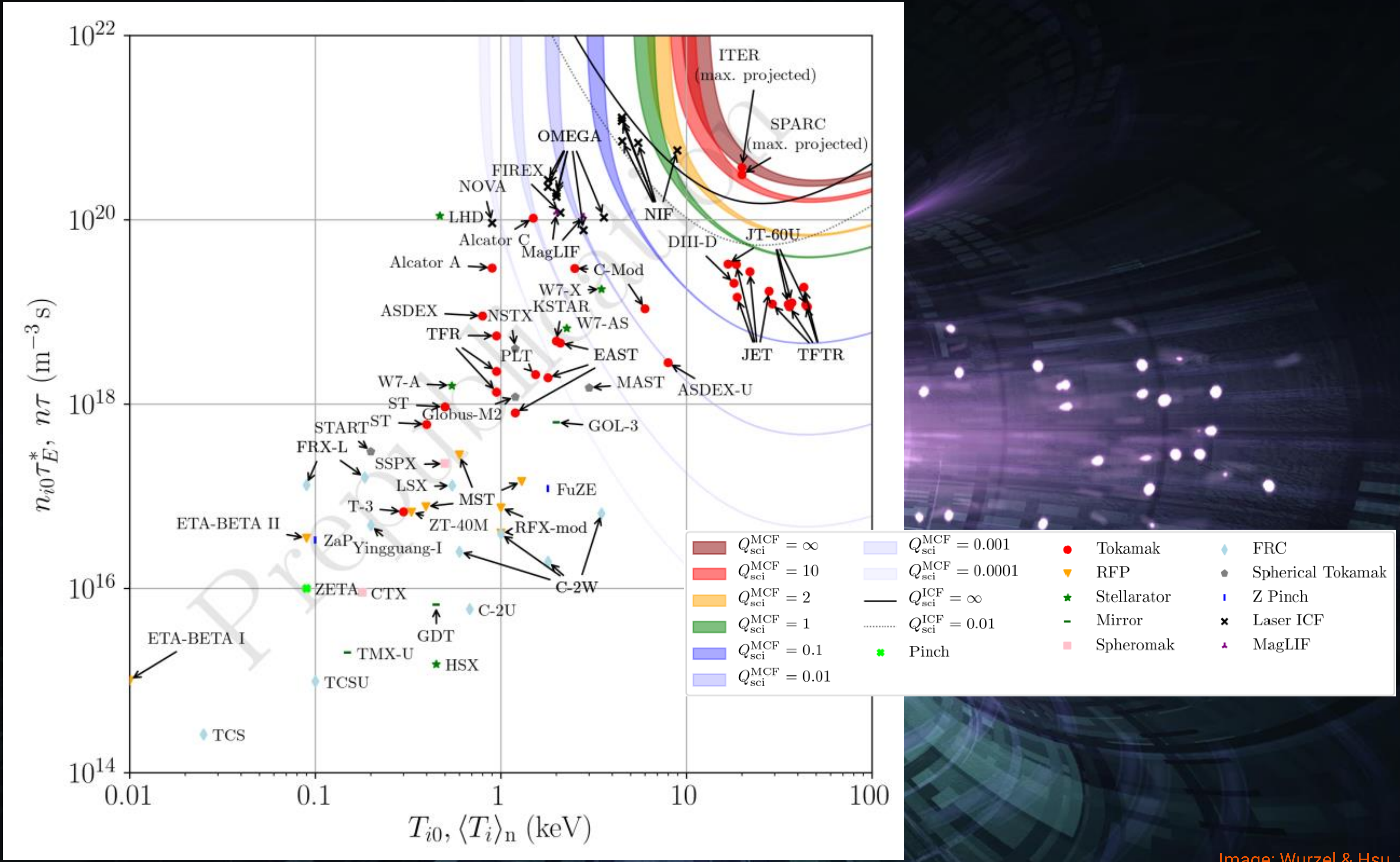
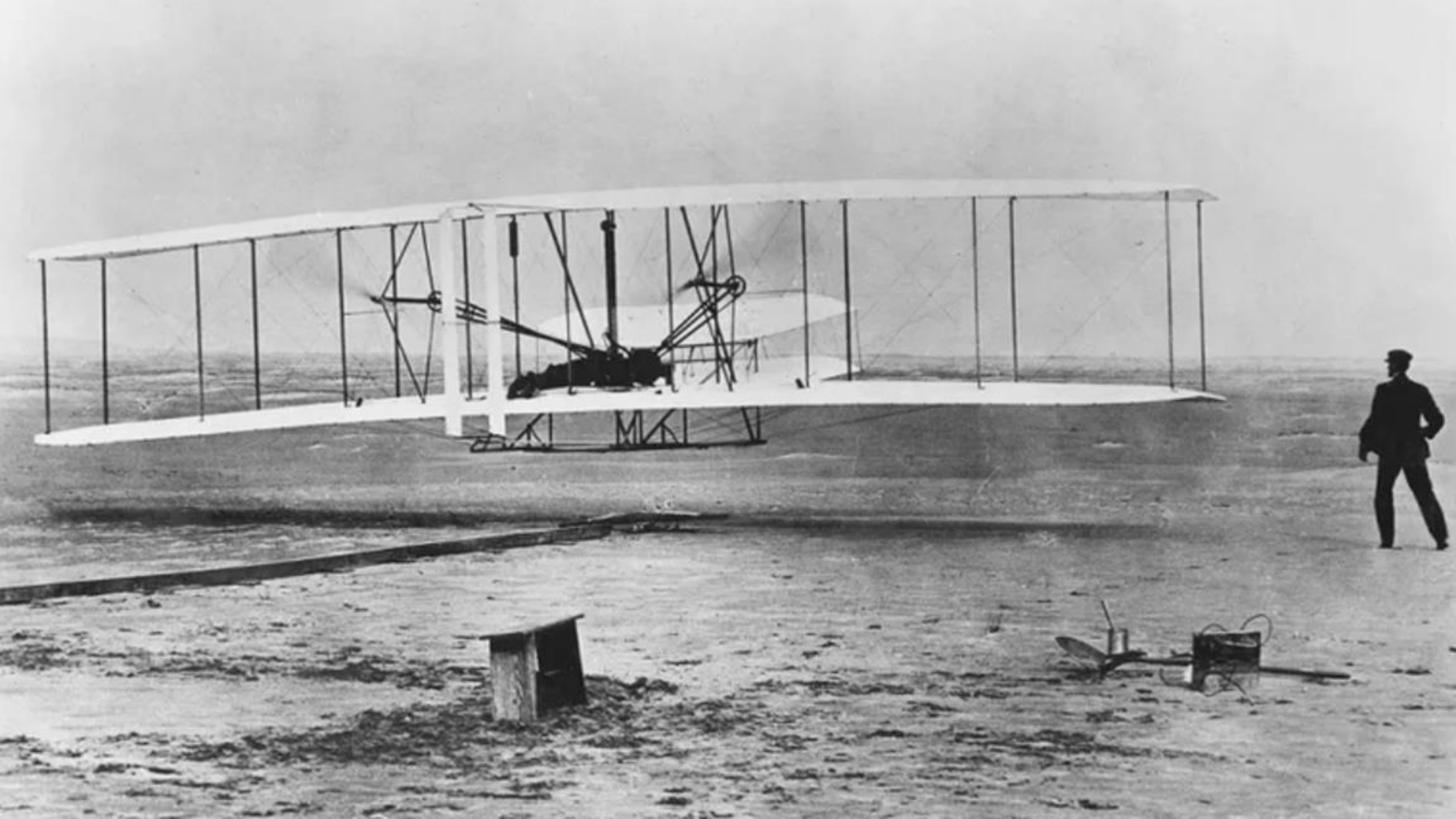
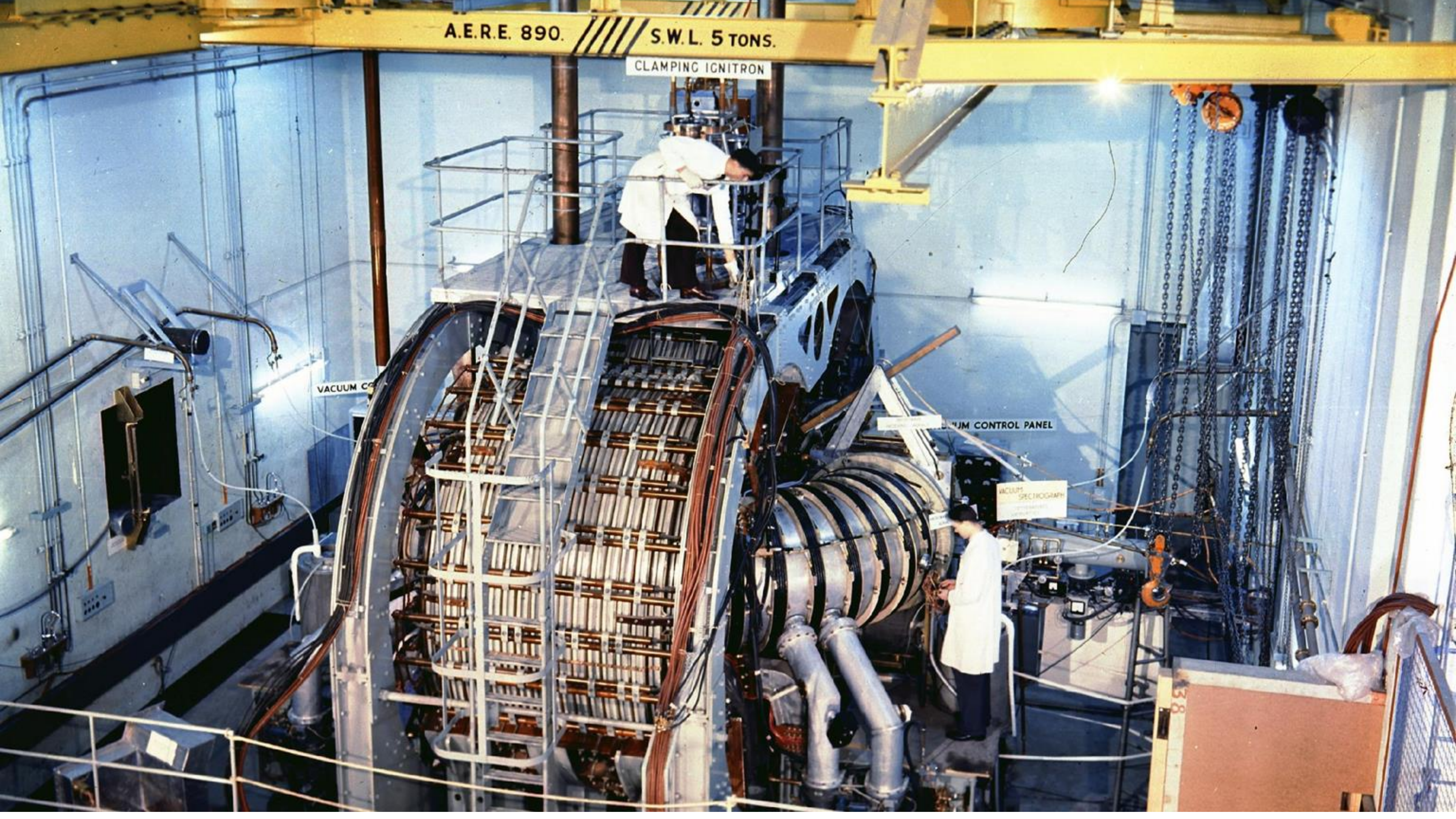
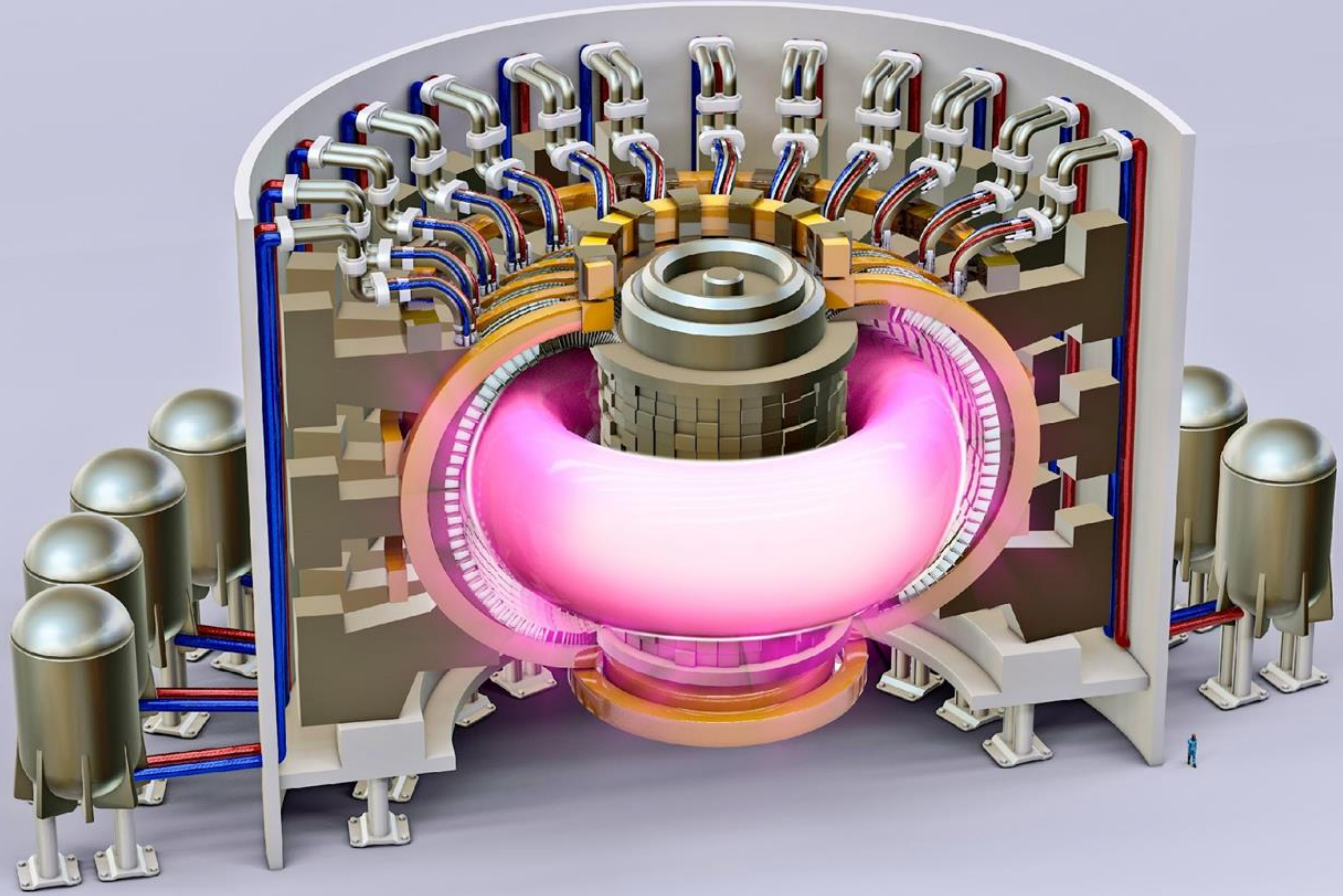


Image: Wurzel & Hsu, 2022




A.E.R.E. 890.
S.W.L. 5 TONS.
CLAMPING IGNITRON
VACUUM SPECTROGRAPH



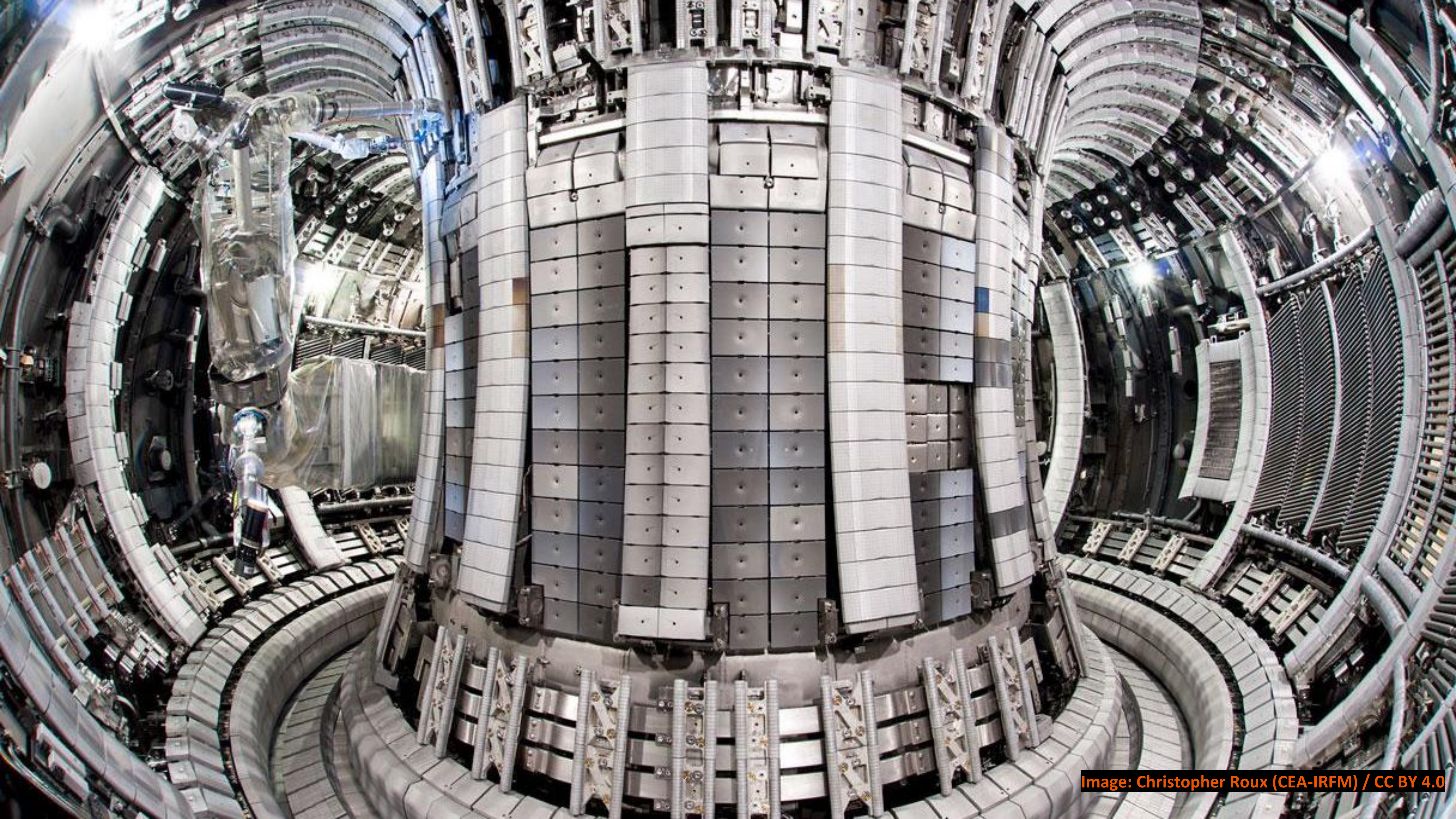
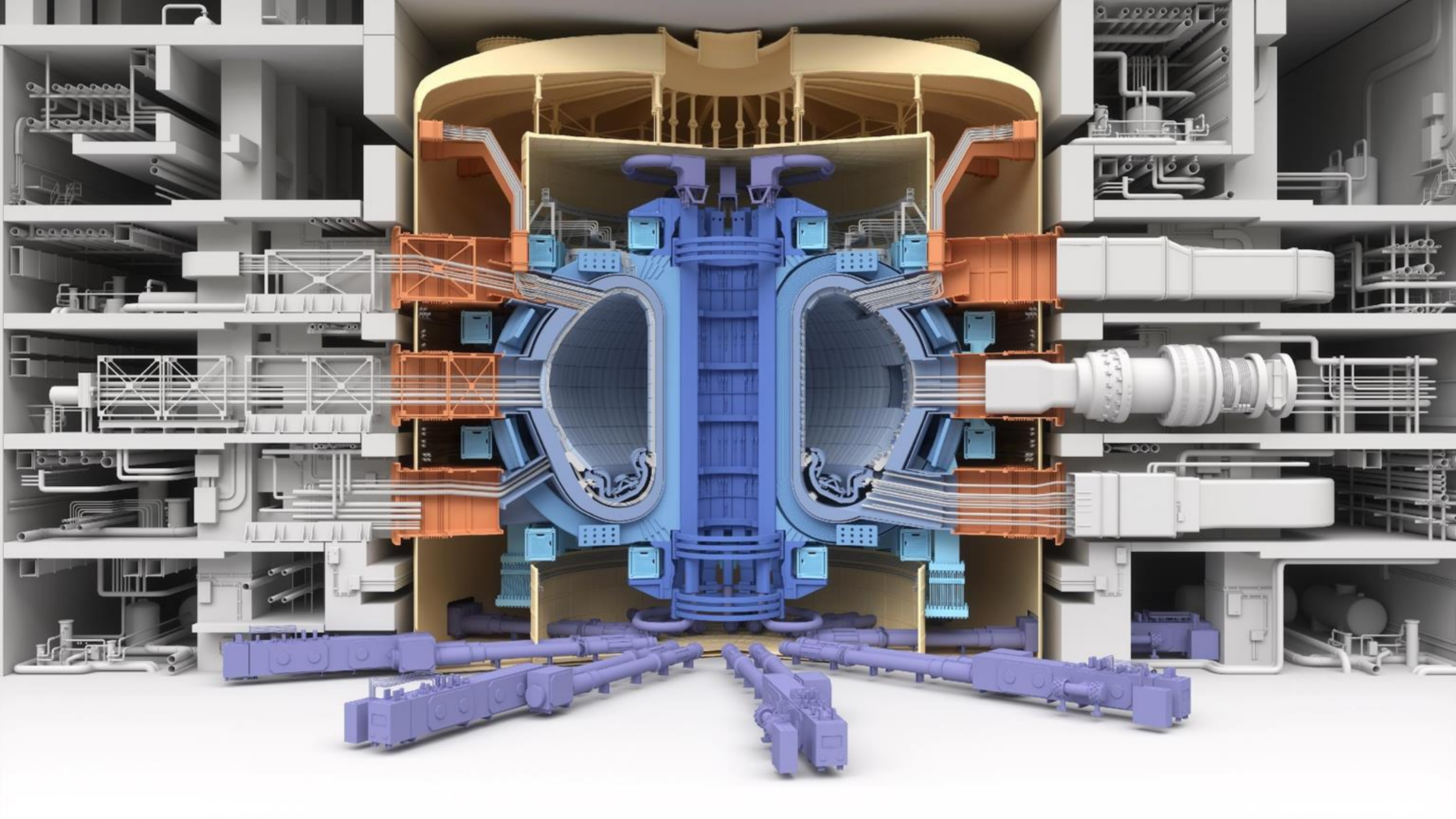


Image: Christopher Roux (CEA-IRFM) / CC BY 4.0



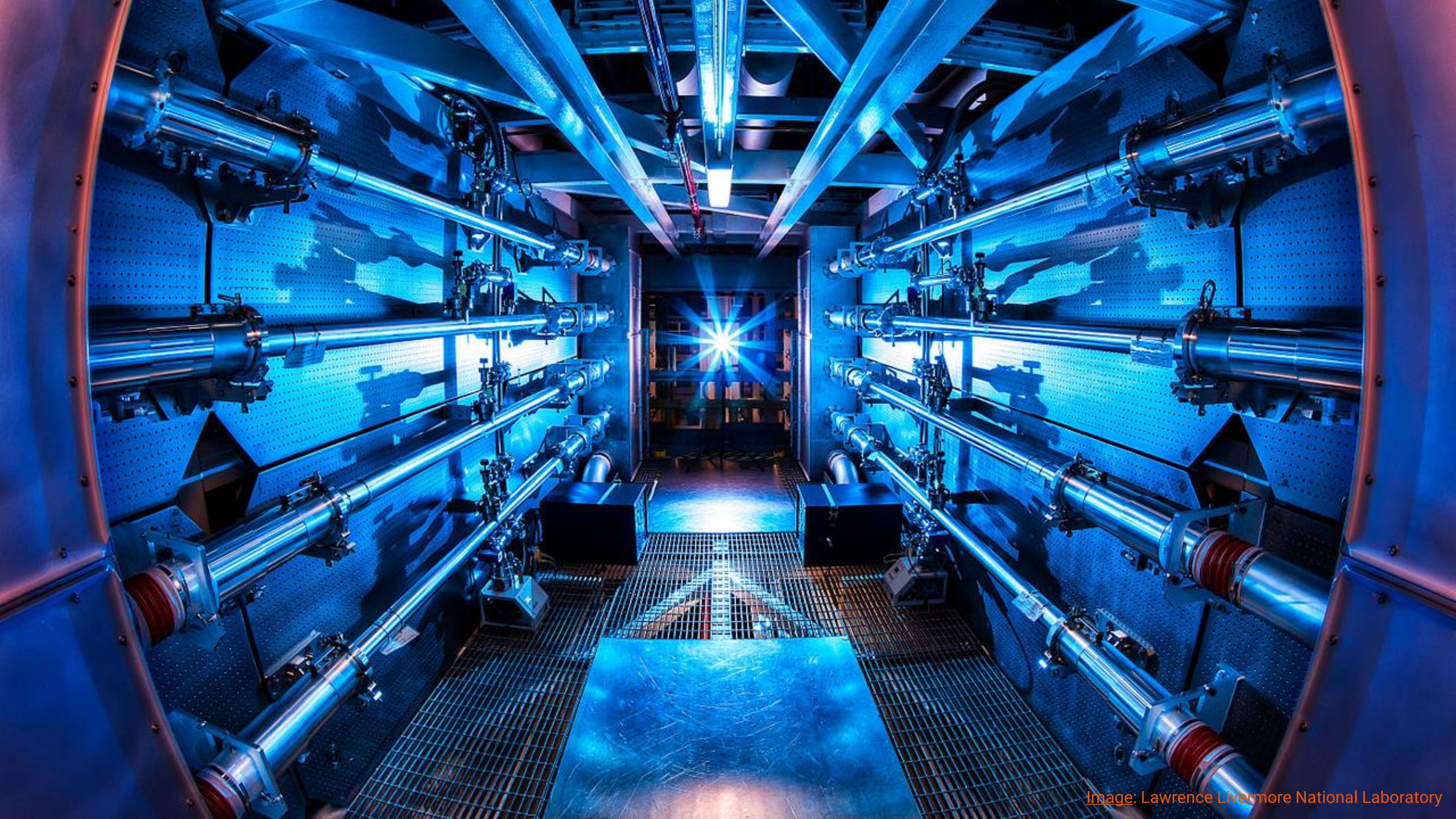
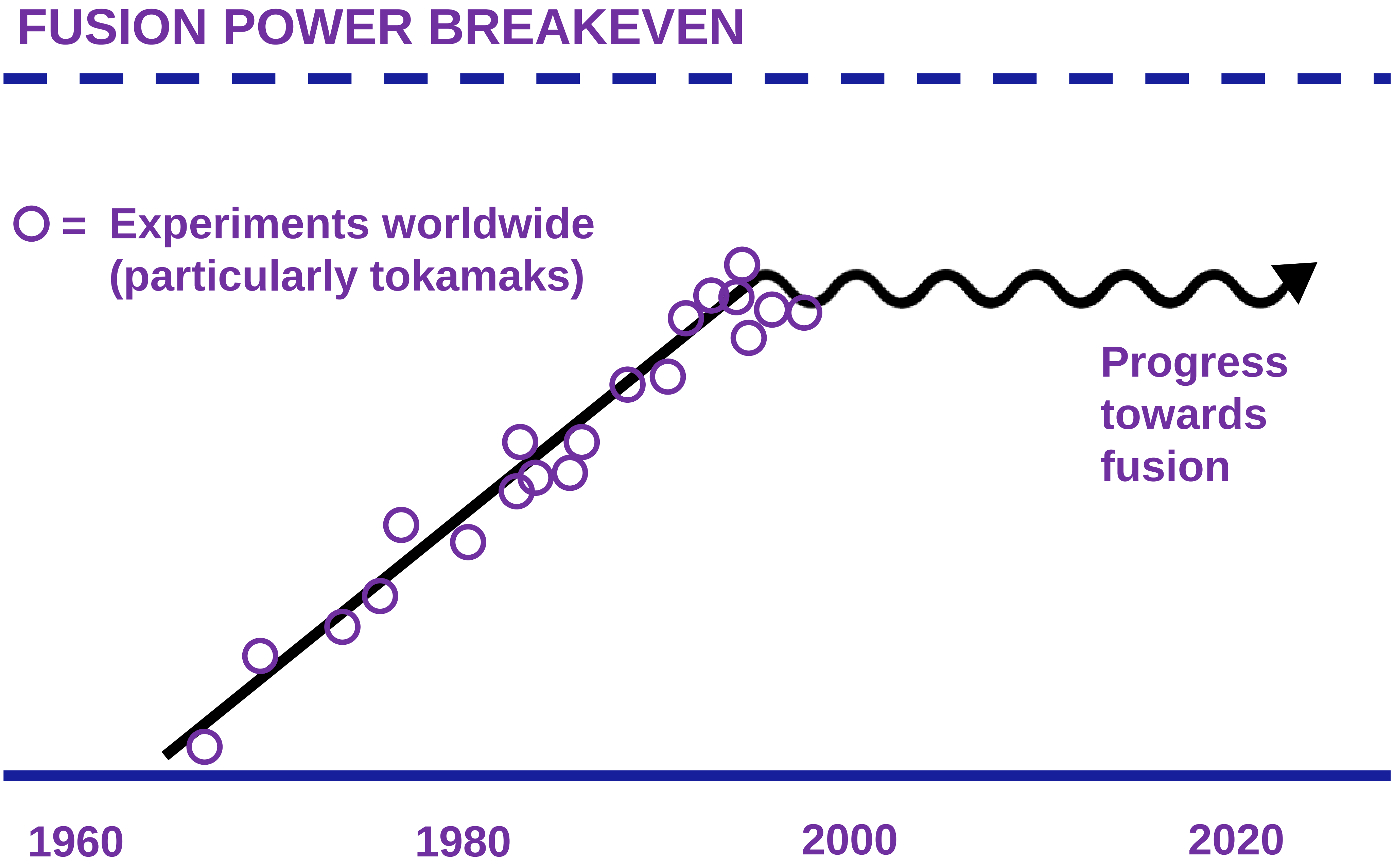


Image: Lawrence Livermore National Laboratory


FUSION POWER BREAKEVEN
= Experiments worldwide
(particularly tokamaks)
Progress
towards
fusion
1960
1980
2000
2020

Lawrence Livermore National Laboratory achieves fusion ignition

Charting the First Year of Ignition

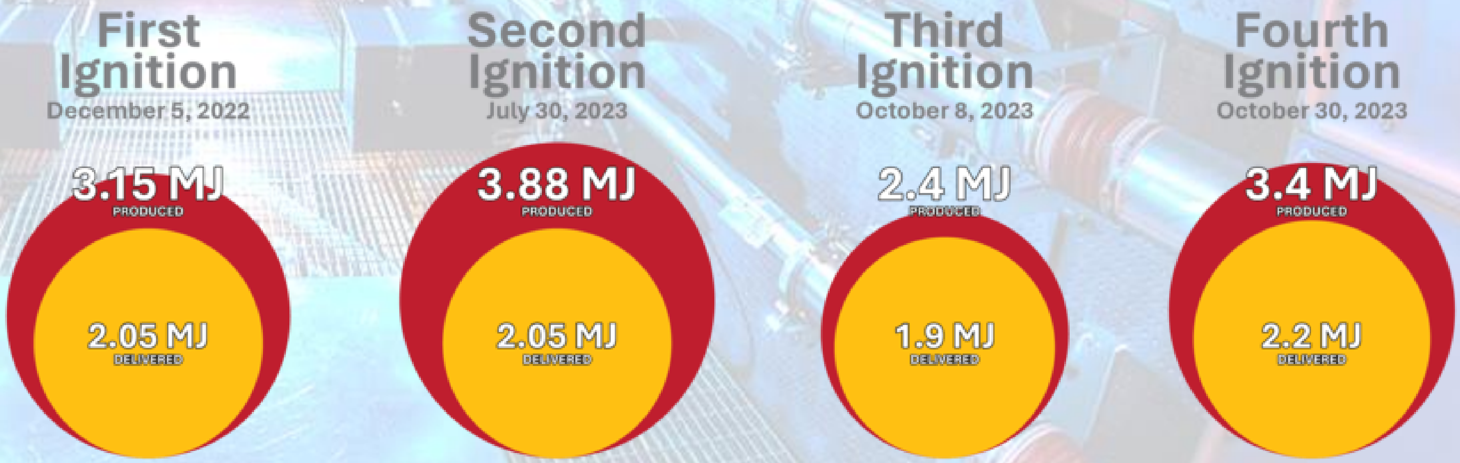


Image: Lawrence Livermore National Laboratory

So, next stop: commercial fusion… right?

Let’s take a step back.

Let’s look at innovation, what it means, and why its relevant to explain what is happening in fusion today

What is innovation?

“The exploitation (useful application) of invention”

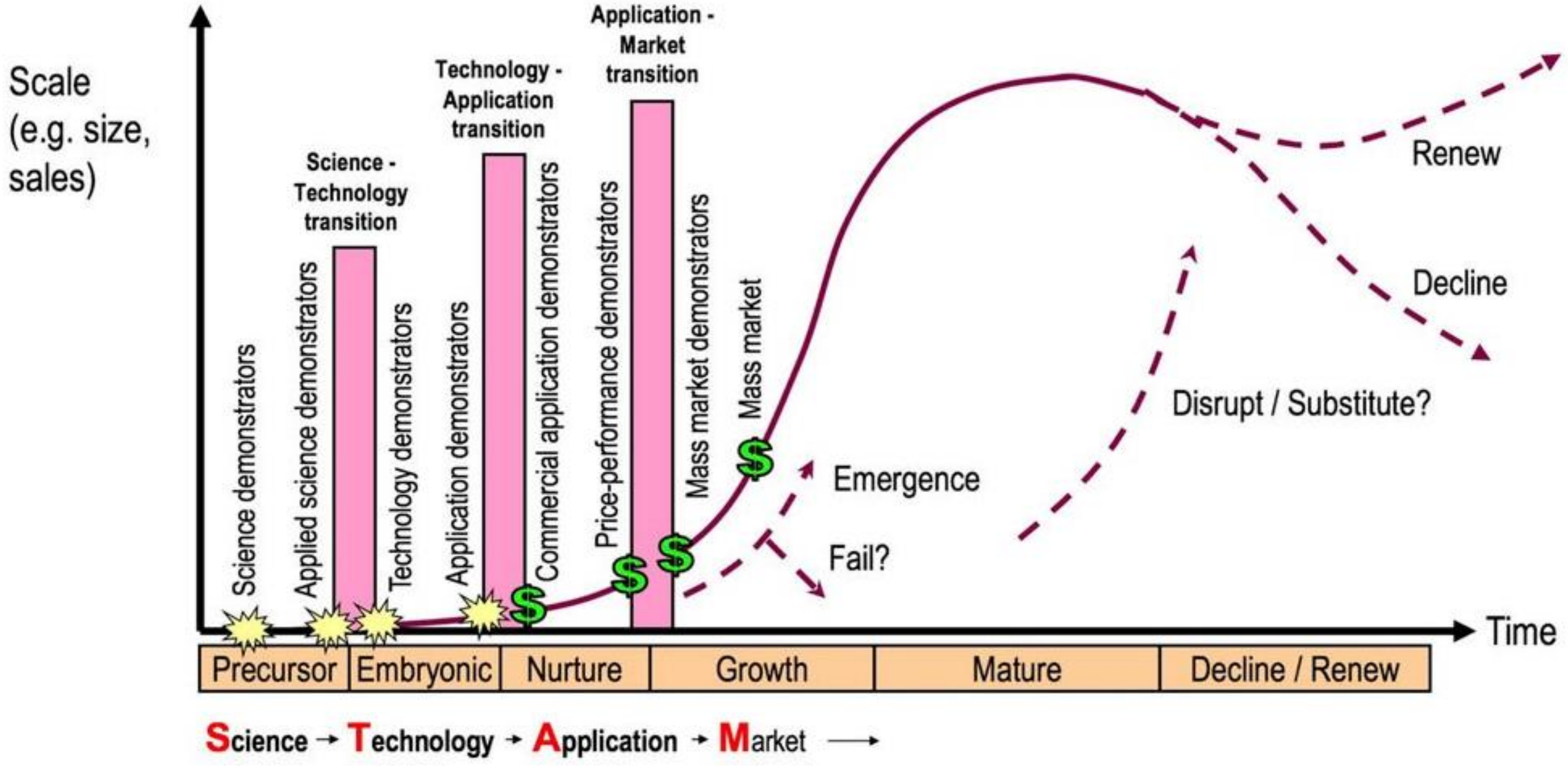
Reference: adapted from Pearson et al., 2020

What is innovation?

- Innovation is often used to describe ***an “advanced” or a “promising” invention***.
- For an invention to constitute innovation, it must have a **useful application**, i.e. the invention must provide some kind of useful application.
- *Technological innovation* refers to **inventions that provide a new or improved technical use**; scientific discoveries or inventions—*even remarkable ones*—are not innovations in and of themselves.
- Innovation is the ***translation of invention*** into something that can tangibly ***improve the quality of human life*** (society) and/or ***generate economic impact***.

References: Kline & Rosenberg, 1986; Park, 2005; Bonvillian & Weiss, 2015

Innovation: Charting the Path of Technology to Market (Use)



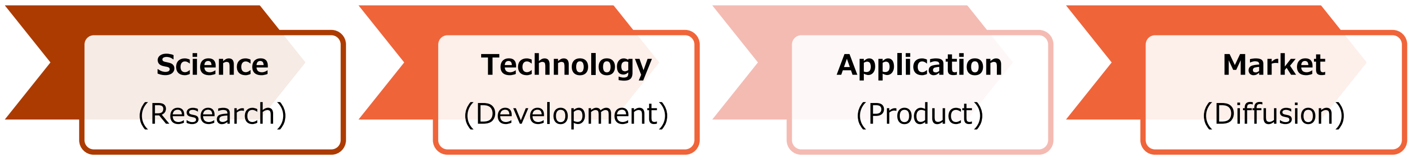
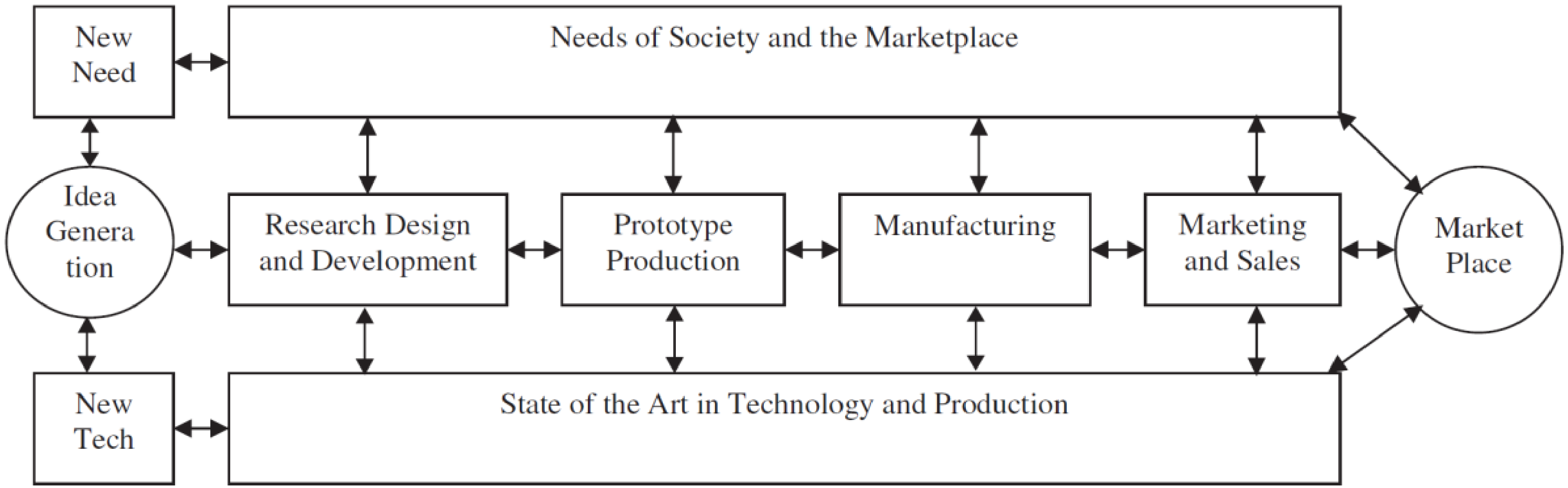


Image: Phaal et al., *Technological forecasting and social change* 78.2 (2011)

Innovation Looks Like a Linear Process—In Reality, it is Dynamic

*Innovation should NOT be viewed as a **linear** process, but instead as a **dynamic system**, with feedback loops that link all stages.*



Innovation as a system, showing the feedback between all stages (Galanakis, 2006)

In a successful innovation ecosystem, we must understand and account for the **requirements**, **actors** and **processes** in both the **front-end** (*technical: R&D*) and **back-end** (*commercial: product for market*) of the system.

The Linear Model of Innovation

Historically, advanced technology missions – endeavors with a **high degree of technical risk, but with potentially high (often societal) reward** – have been developed on a linear model.

Such missions require **significant investment** (money and time) and are thus, typically, shouldered by **governments**. Key examples are the development of ***nuclear fission***, the ***Apollo moon landings***, and ***the internet***...

The linear model places scientific understanding (**technological innovation**) as the first goal:

Science → **T**echnology → **A**pplication (product) → **M**arket

The linear model thus perpetuates a "***technology push***" approach in which technology is developed in an ***R&D vacuum***. The mechanisms to **deploy technology in the market (diffusion)** are not explored until later – i.e. until ***after*** a promising invention is realised/discovered.

References: Fitzgerald et al., 2011; Bonvillian & Weiss, 2015; Pearson et al., 2020; Godin, 2006

The Former Fusion Status Quo: Public Sector Innovation on a Linear Model

Fusion has been the subject of major R&D efforts for well over half a century.

- Historically, **national laboratories ran (almost) all the world's fusion programmes**.
- These were **geared towards the "front-end" of the innovation lifecycle**, i.e. on technological innovation (***not*** commercialisation), with focus being on:
    1. **Fundamental research** to **advance scientific understanding of fusion.**
    2. **Mission-led experiments** to **demonstrate fusion technology.**
- This was the primary mission of the **ITER project**.
- After ITER, the idea was that we would know enough about the science, and we'd have demonstrated technologies that could be **scaled to products** that eventually go to market. *Ipso facto*: we can enter the **commercialisation** phase.

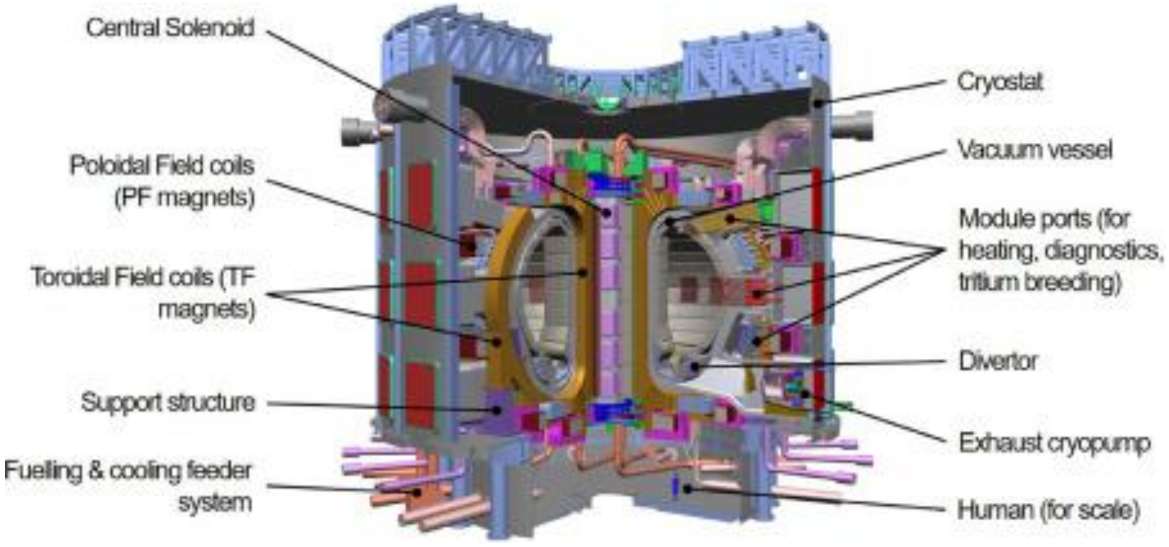


Image: ITER Organisation.

The fusion innovation paradigm shift

The Paradigm Shift: from Science-led Linear Innovation

- Over the past decade, the fusion sector has shifted from a purely **science-driven model** to one focused on **commercialization**.
- Over **40 privately funded fusion companies have emerged**, having collectively raised billions of dollars in investment, and they are prioritising rapid commercialisation through technologies that prove scientific viability and accelerate market entry for faster fusion and substantial returns.
- This emergence has ushered a **new era**; I contend **fusion has undergone a paradigm shift**.
  - **Paradigm shift – Kuhn, 1962:** "*The world view underlying the theories and methodology of a particular scientific subject*".

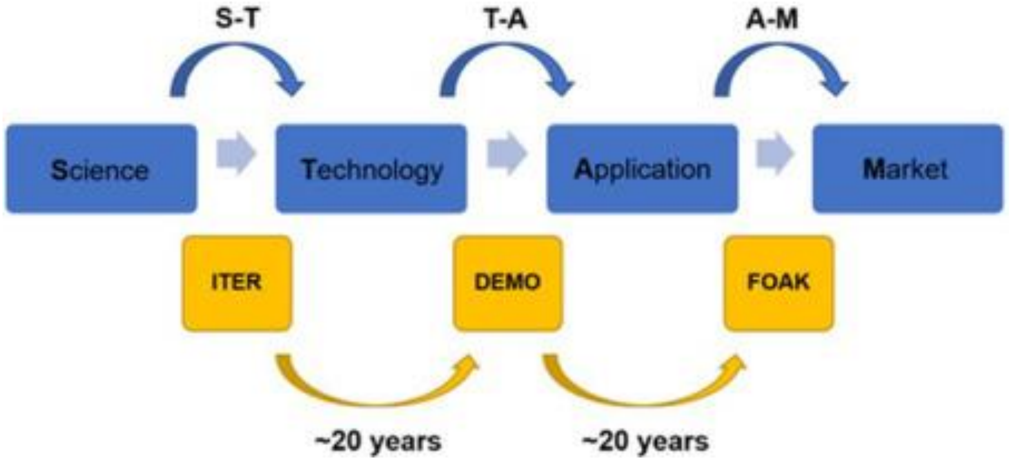


Image: Pearson et al., *Technological Forecasting and Social Change*, 158, 120064 (2020)

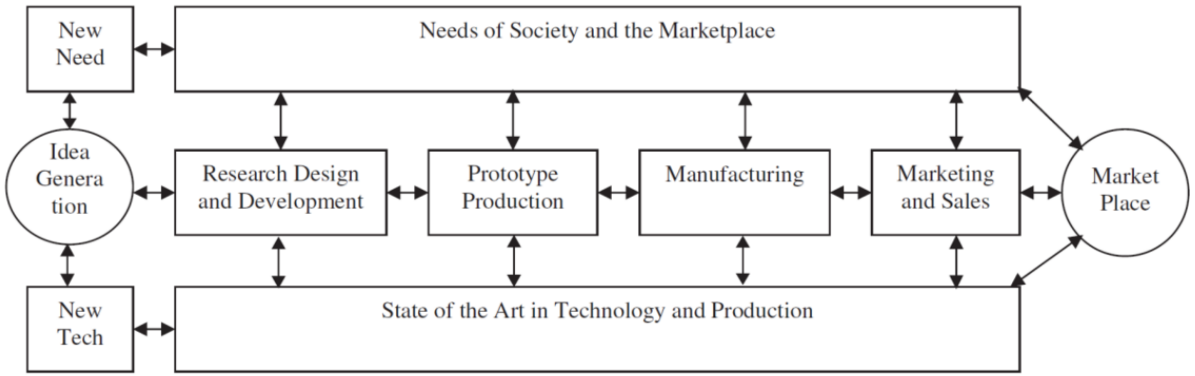
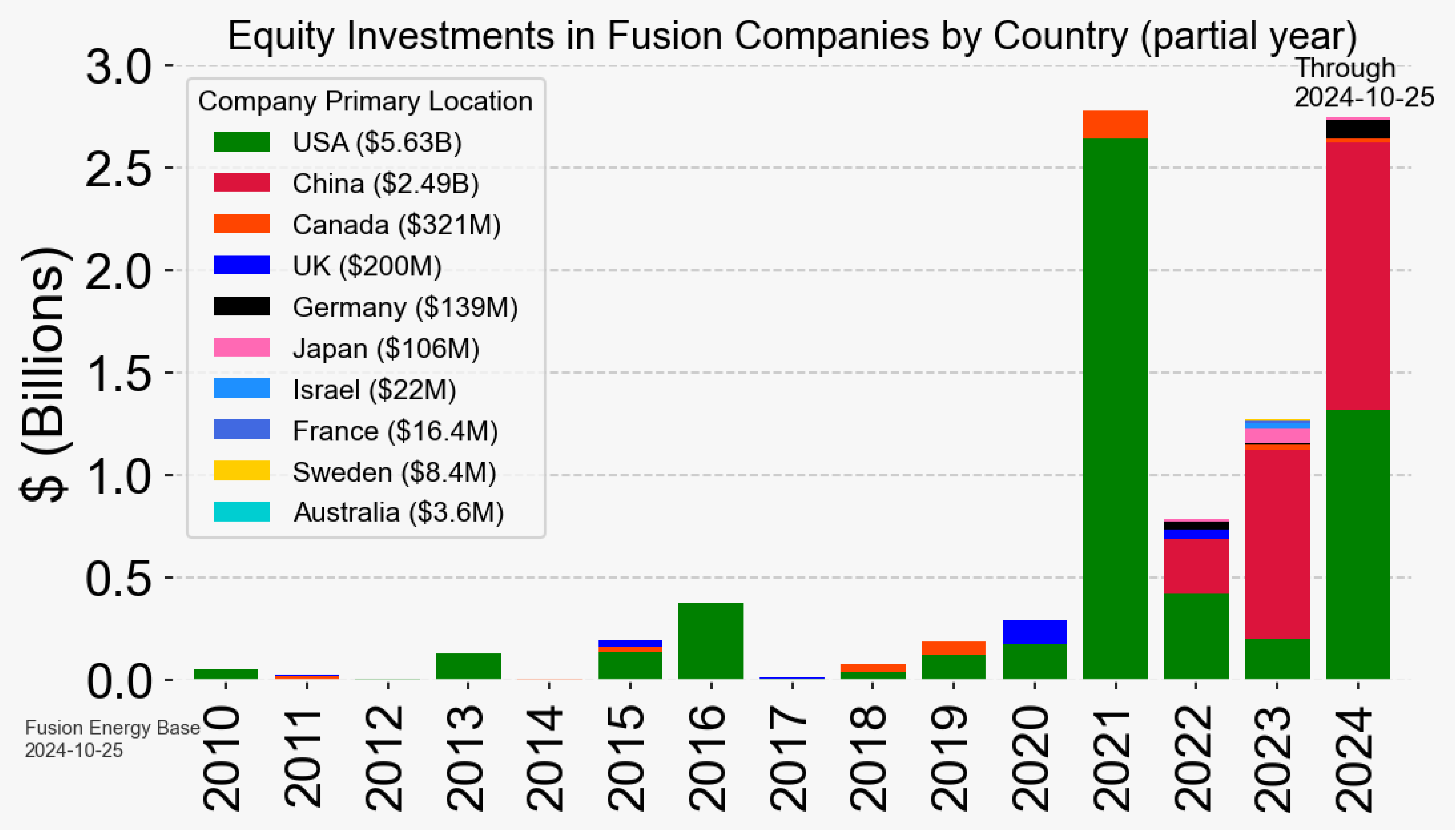


Image: Galanakis, Technovation 26.11 (2006) *“it’s not science becomes technology becomes products. It’s technology that gets science to come along behind it”*

– Gordon Moore, Co-founder Intel



Reference: fusionenergybase.com (with thanks to Sam Wurzel)

GLOBAL FUSION PRIVATE COMPANIES MAP

PRESENTED BY KYOTO FUSIONEERING

United States

- AVALANCHE
- BLUE LASER FUSION
- CFS
- ELECTRIC FUSION SYSTEMS
- EXO FUSION
- HELICITY SPACE
- HELION
- HORNE TECHNOLOGIES
- HYPERJET FUSION CORPORATION
- LaserFusionX
- LONGVIEW FUSION ENERGY SYSTEMS
- LPPFUSION .com
- MIFTI
- nearstar FUSION
- NK
- Princeton FUSION SYSTEMS
- REALTA FUSION
- SHINE
- STELLAREX
- tae
- THEA ENERGY
- TYPE ONE ENERGY
- XCIMER
- ZAP ENERGY

Canada

- generalfusion
- fuse

Great Britain

- CROSSFIELD
- Tokamak Energy
- first light

Germany

- FOCUSED ENERGY
- GAUSS FUSION
- Proxima Fusion
- Marvel Fusion

Japan

- EX-Fusion
- Helical Fusion
- KYOTO FUSIONEERING

Italy

- DEUTELIO

France

- RENAISSANCE FUSION

Sweden

- NOVATRON

Israel

- nT-tao

Australia

- HB11 ENERGY LASER BORON FUSION

New Zealand

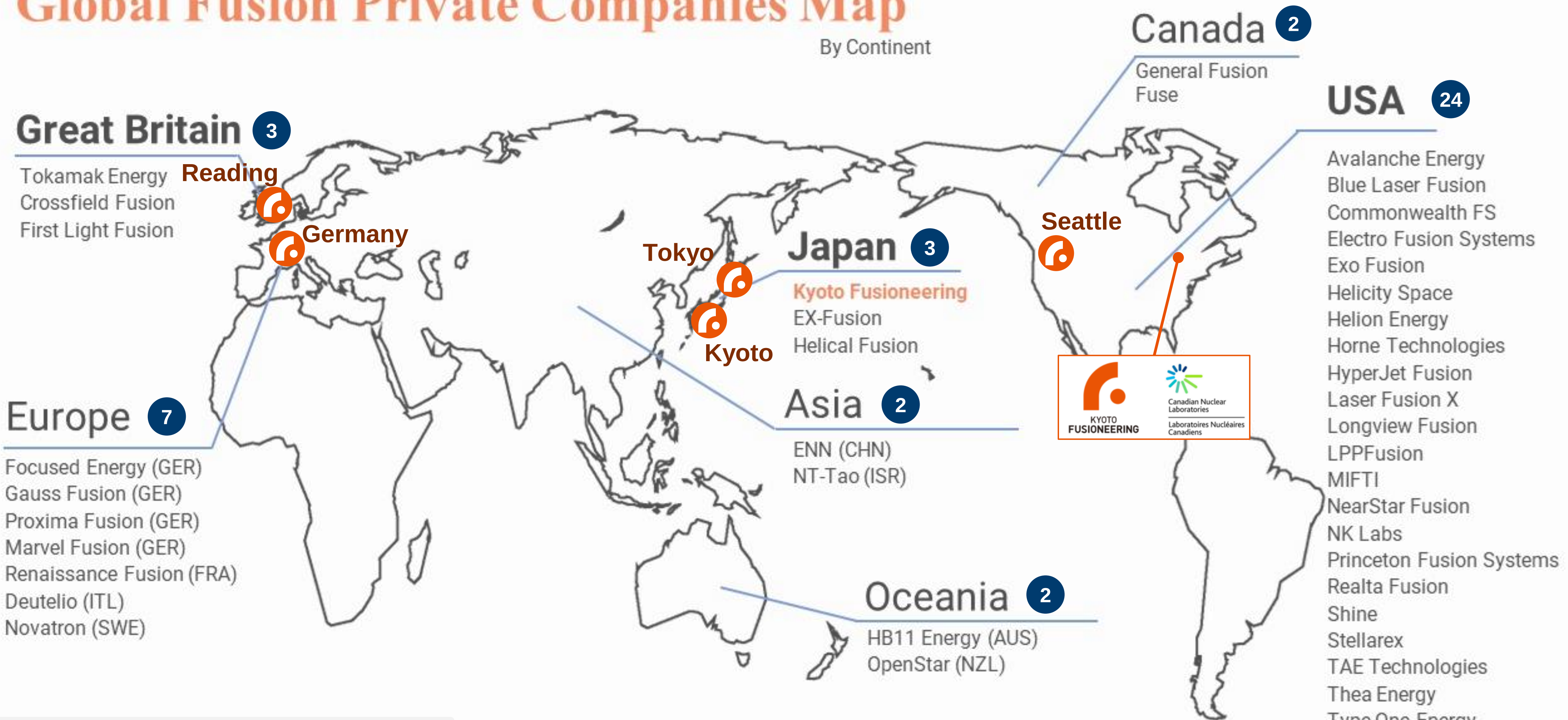
- OPENSTAR TECHNOLOGIES LTD

China

- ENN 新奥

Global Fusion Private Companies Map

By Continent



Current KF office

**Location and count of fusion startups**

Source: FIA "Global Fusion Industry in 2023"

Technology

Nuclear Startup Pacific Fusion Nabs $900 Million in Funding

- Tranched deal would pay out if startup hits certain milestones
- Nuclear energy has become VC hotspot as AI guzzles power

By Sarah McBride

25 October 2024 at 17:00 BST

Updated on 25 October 2024 at 18:04 BST

This was just last week!

Private Fusion Developers: Focused Sharply on Commercialisation

- Private fusion developers are:
  - (Mostly) pursuing **technical concepts** that originate from **publicly-funded institutions**
  - Trying to **transform the technologies into products** suitable for the market
  - Compelled to find a way to make a **return on investment** to shareholders
  - Often proceeding without full technical maturity (whether in reactor concepts, or in enabling technologies like HTS magnets or low-cost lasers)—and are thus **proceeding with risk**.
- This new paradigm has reshaped the fusion landscape, and now the sector is starting to try to **align technical breakthroughs with the commercial demands of a global energy market**
  - *And also spin-offs…*

Public vs. Private: Linear vs. Dynamic (“Agile”)

*The emergence of private developers means the sector is not just considering what may be scientifically possible or technically feasible, but what may work commercially. The same technical challenges remain—fusion still has a **long way to go**.*

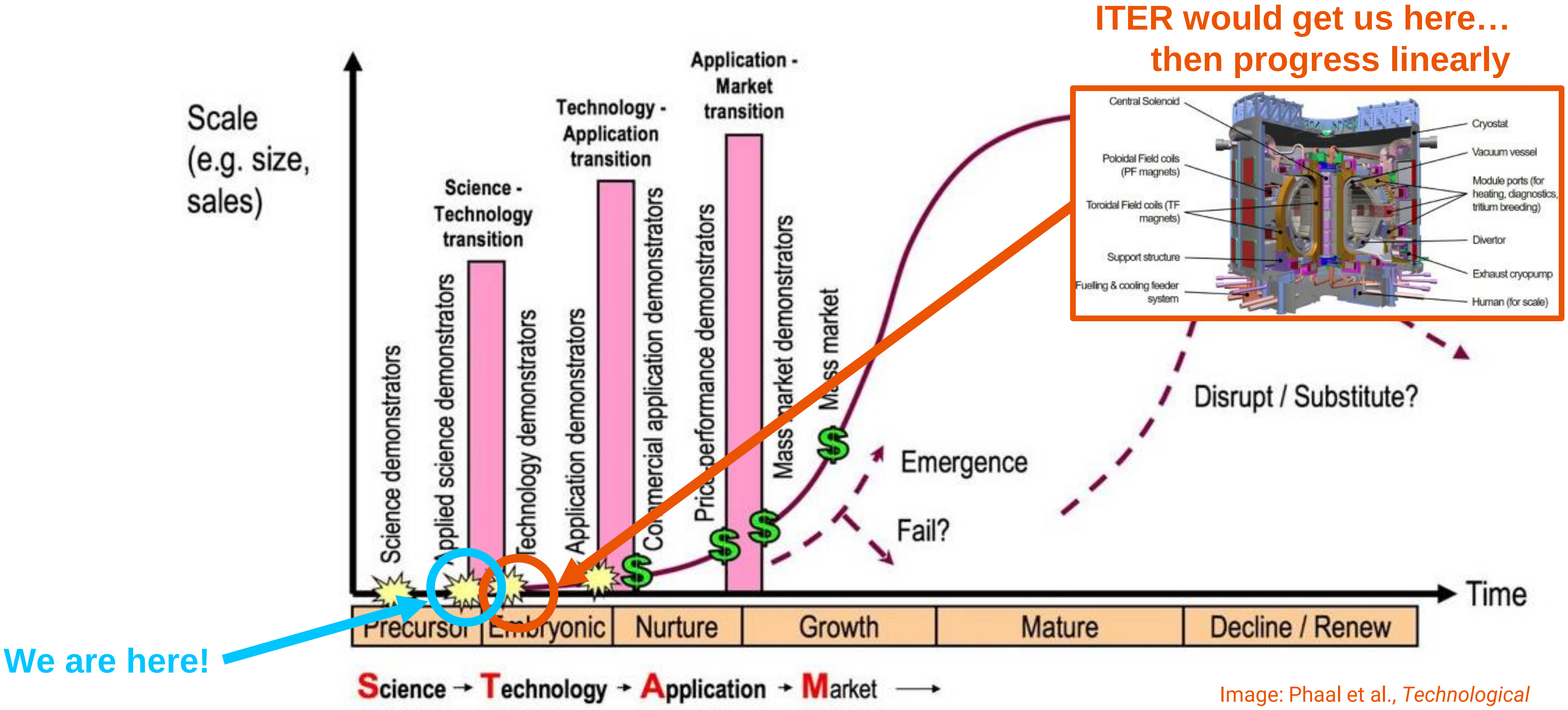


Image: Phaal et al., *Technological forecasting and social change* 78.2 (2011)

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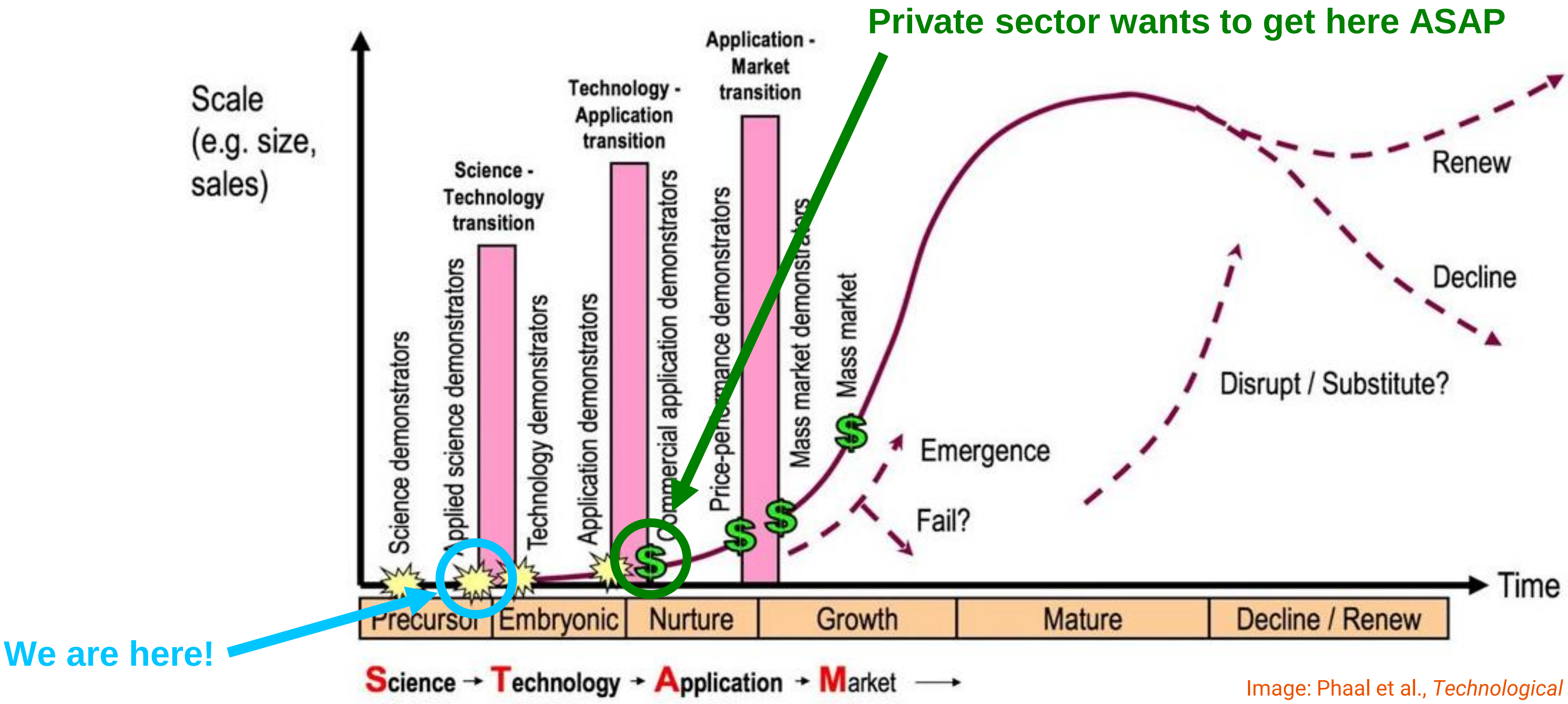


Image: Phaal et al., *Technological forecasting and social change* 78.2 (2011)

The Current Fusion Paradigm: A Move to Public-Private Partnerships

- **Private sector impact:** Fusion's long-standing goal of getting to net fusion power gain has been **slow**. The private sector's emergence has sharpened **focus on commercialization** and **increased risk-taking** to demonstrate the technology.

- **Looking forward at shared challenges:** Several major fusion machines are expected within the next decade but **face the same technical challenges as faced by the public sector**.

- **Private sector cannot solve everything alone**. Technical hurdles, budget constraints, and skills shortages persist.

- **Public-private synergy:** By combining scientific understanding and technology advancements in fusion with market-oriented product development, **public-private partnerships can accelerate progress**.
  - **Caveat:** *Fusion development cycles will remain long—fusion is hardware intensive, complex and costly. Progress will come, but only so fast!*

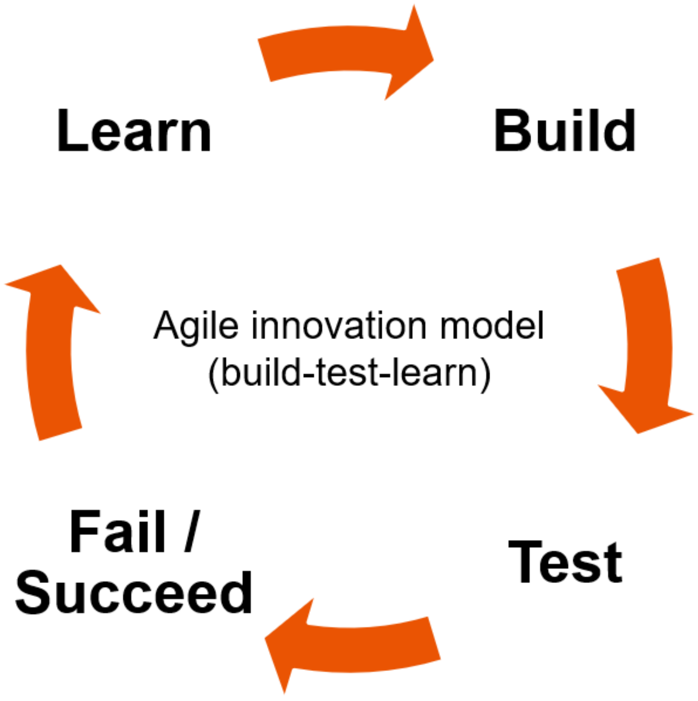


Image: Pearson, 2022

Deep Tech Innovation Through Public-Private-Partnership

A space sector style program (NASA + SpaceX) is one model being adapted for fusion

Public Program
Strategic projects based on long-term vision

Public Private Partnership
Innovation that combines a long-term vision with an agile, iterative approach

Private (Startups)
Agile, iterative approach with risk-tolerant private capital

The Players in the New Paradigm: Governments Have Adapted

Governments developing national strategies to promote private fusion through public-private-partnerships.

Nov 2020 – The UK government: **"Ten Point Plan for a Green Industrial Revolution"**

"Aims to build the commercially viable fusion energy plant in the UK by 2040"
15 sites are shortlisted for the UK fusion energy plant (June 2021)

Mar 2022 – US government: **"Bold Decadal Vision for Commercial Fusion Energy"**

"Accelerate the viability of commercial fusion energy in coordination with the private sector"
NASEM "Have a viable design by 2028 and initial pilot plant operation in 2035~2040"

Apr 2023 – Japanese government: **"Fusion Energy Innovation Strategy"**

"Our strategy for the next 10 years is to 'industrialize fusion energy,' … the world's next-generation energy source. It is necessary to promote further participation of Japan's private sector and cooperation between industry, academia, and government, and to develop a national strategy that includes specific actions that will attract private investment."

Stimulating International Collaboration…

DECEMBER 02, 2023

International Partnerships in a New Era of Fusion Energy Development

Department of Energy

Joint Statement Between DOE and the UK Department for Energy Security and Net Zero Concerning a Strategic Partnership to Accelerate Fusion

NOVEMBER 8, 2023

Department of Energy

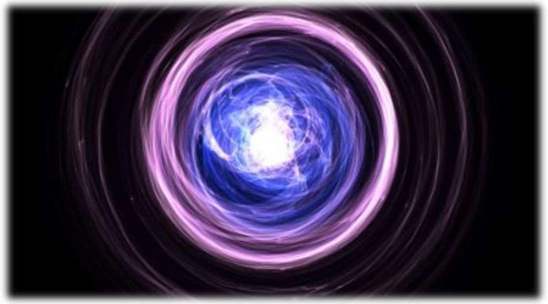
Joint Statement between DOE and the Japan Ministry of Education, Sports, Science and Technology Concerning a Strategic Partnership to Accelerate Fusion Energy Demonstration and Commercialization

APRIL 10, 2024

Department for Energy Security & Net Zero

Towards Fusion Energy 2023

The next stage of the UK's fusion energy strategy



October 2023

JUNE 14, 2024

FACT SHEET: The 2024 G7 Summit in Apulia, Italy

- **Promoting International Collaboration on Nuclear and Fusion Energy:** The G7 recognized nuclear energy as a clean/zero emissions energy source that can reduce dependence on fossil fuels to address the climate crisis and improve global energy security, and pledged to support multilateral efforts to strengthen the resilience of nuclear supply chains. Recognizing the potential for fusion energy to serve as a breakthrough energy solution, the G7 is establishing a Working Group on Fusion Energy to share best practices and promote cooperation on research and development.

… and International Competition …

CNN Climate Solutions Weather

Climate / Solutions

The US led on nuclear fusion for decades. Now China is in position to win the race

By Angela Dewan and Ella Nilsen, CNN
7 minute read · Published 4:00 AM EDT, Thu September 19, 2024

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NEWS FEATURE | 28 August 2024 | Correction 11 September 2024

Inside China's race to lead the world in nuclear fusion

The country has ambitious plans for fusion power plants to provide clean, limitless energy. Can they be realized?

US Vs China: Race for Nuclear Fusion Energy | World News | WION
9.4K views · 1 month ago
YouTube › WION

Nuclear Fusion: Inside the breakthrough that could change our world | 60 Minutes
3.7M views · 16 Jan 2023
YouTube › 60 Minutes

Major breakthrough on nuclear fusion energy - BBC News
4M views · 10 Feb 2022
YouTube › BBC News

We Went Inside the Largest Nuclear Fusion Reactor
4.1M views · 13 Apr 2022
YouTube › The B1M

Financial Times
https://www.ft.com/content/bf012cd9-1624-49c1-8352-5a91fb4d9a21

Chinese start-up aims for nuclear fusion at half the cost of US rivals
8 Sep 2024 · A Shanghai start-up is seeking to raise $500mn to develop cheaper next-generation nuclear fusion technology, as China races with the west to crack the problem of …


UNITED
STATES

Kyoto Fusioneering

What we do & where we fit in

KYOTO FUSIONEERING

Founded in

2019

~140

Team members

$100m+

Raised

4

Countries

JP

US

UK

EU

CA FFC Inc.

Kyoto Fusioneering: Company Overview

Founded: Oct 2019

Funding: 14.8B JPY (~US $102 M)

Shareholders:

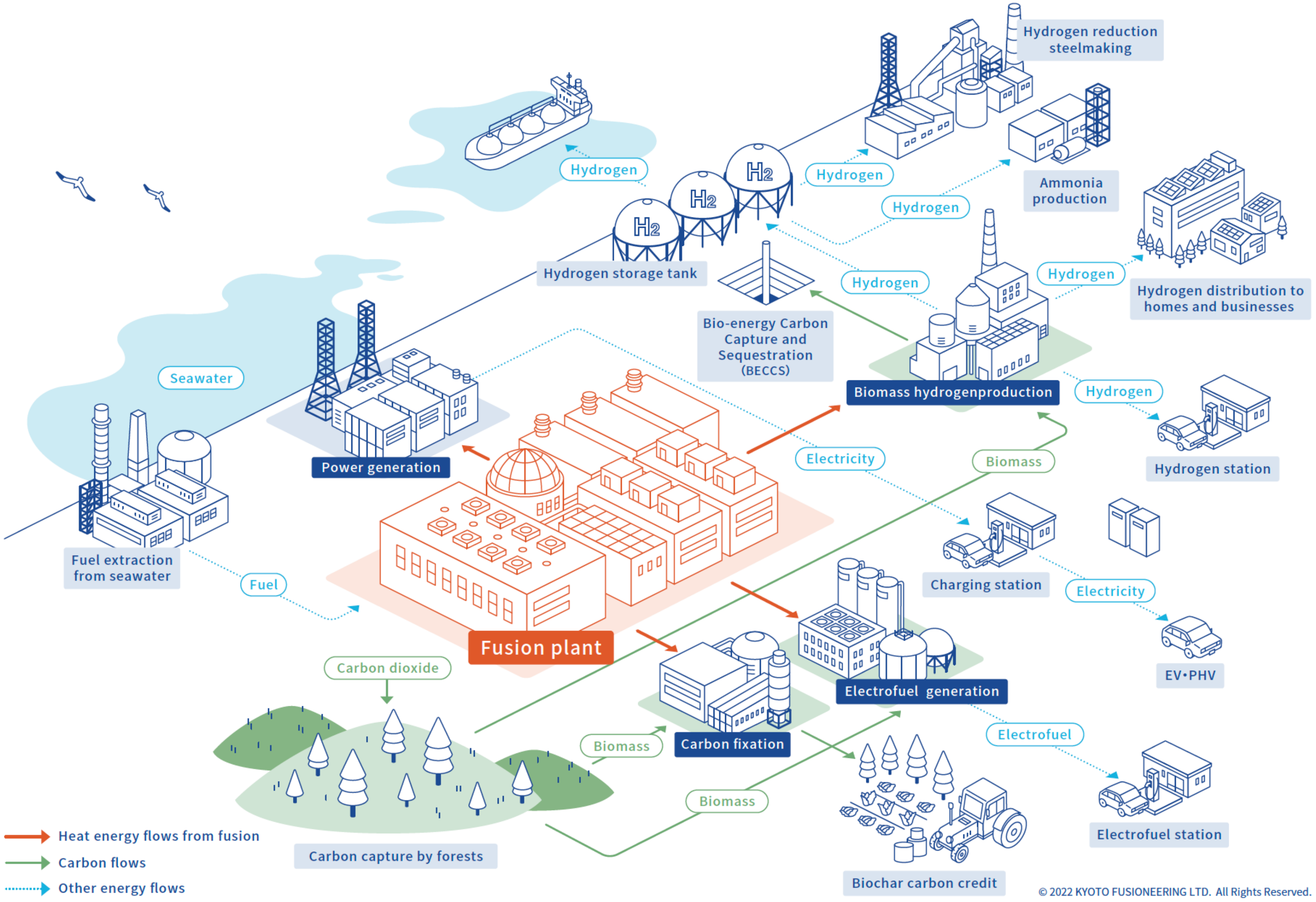
31VENTURES, CORAL CAPITAL, Daiwa Corporate Investment, DBJ, J-POWER
Fujikura, INPEX, iqt, JAFCO, JGC
global brain, JIC VENTURE GROWTH INVESTMENTS, Kansai Electric Power Group, KCAP, KYOTO-iCAP
Marubeni, Mitsubishi Corporation, MUFG Mitsubishi UFJ Capital, MITSUI&CO., MITSUI FUDOSAN
mol plus, MUFG MUFG Bank, nichicon, SMBC SMBC VENTURE CAPITAL

*logos that we have obtained permission to use, in alphabetical order

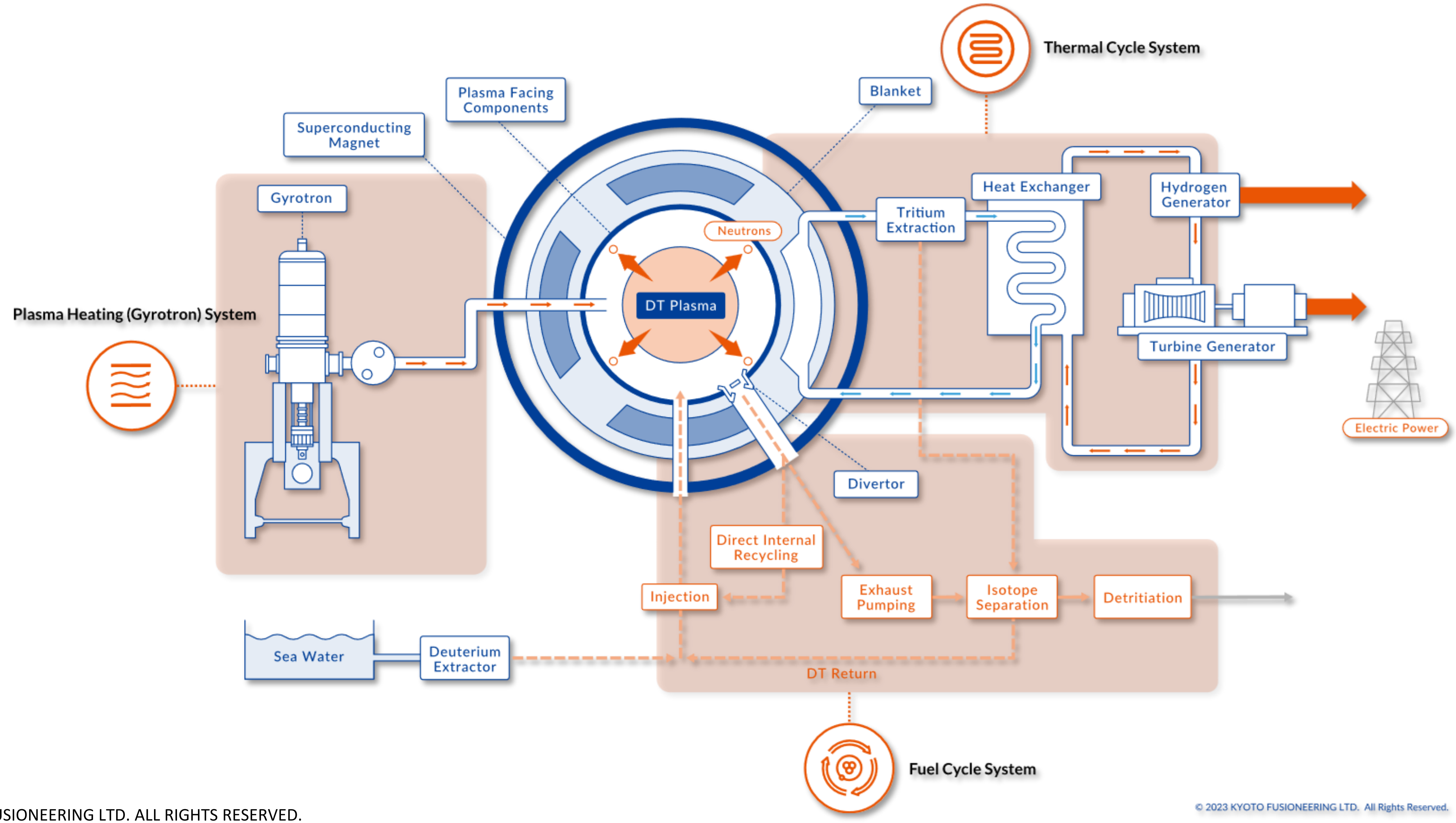
Location: Kyoto, Japan
Tokyo, Japan
Seattle, WA, USA
Reading, UK
Karlsruhe, Germany
Chalk River Canada (FFC Inc.)

Employees: Total ~140

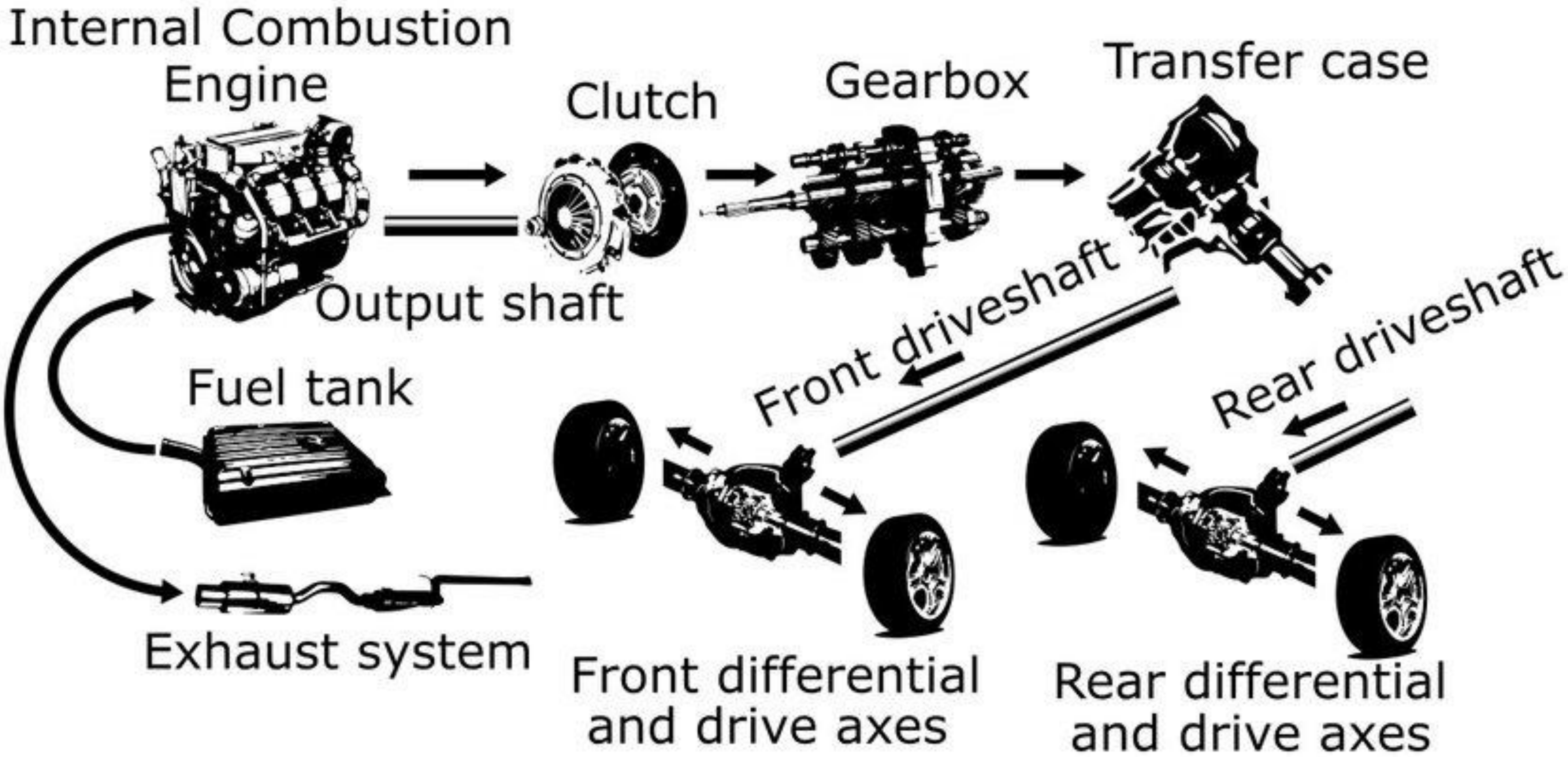
Vision: a Future Society Realised by Fusion Energy



Mission: To Enable the Fusion Energy Era



The KF Mission: An Instructive Analogy



The KF Mission: An Instructive Analogy

Image(s): pexel.com (Open Access)

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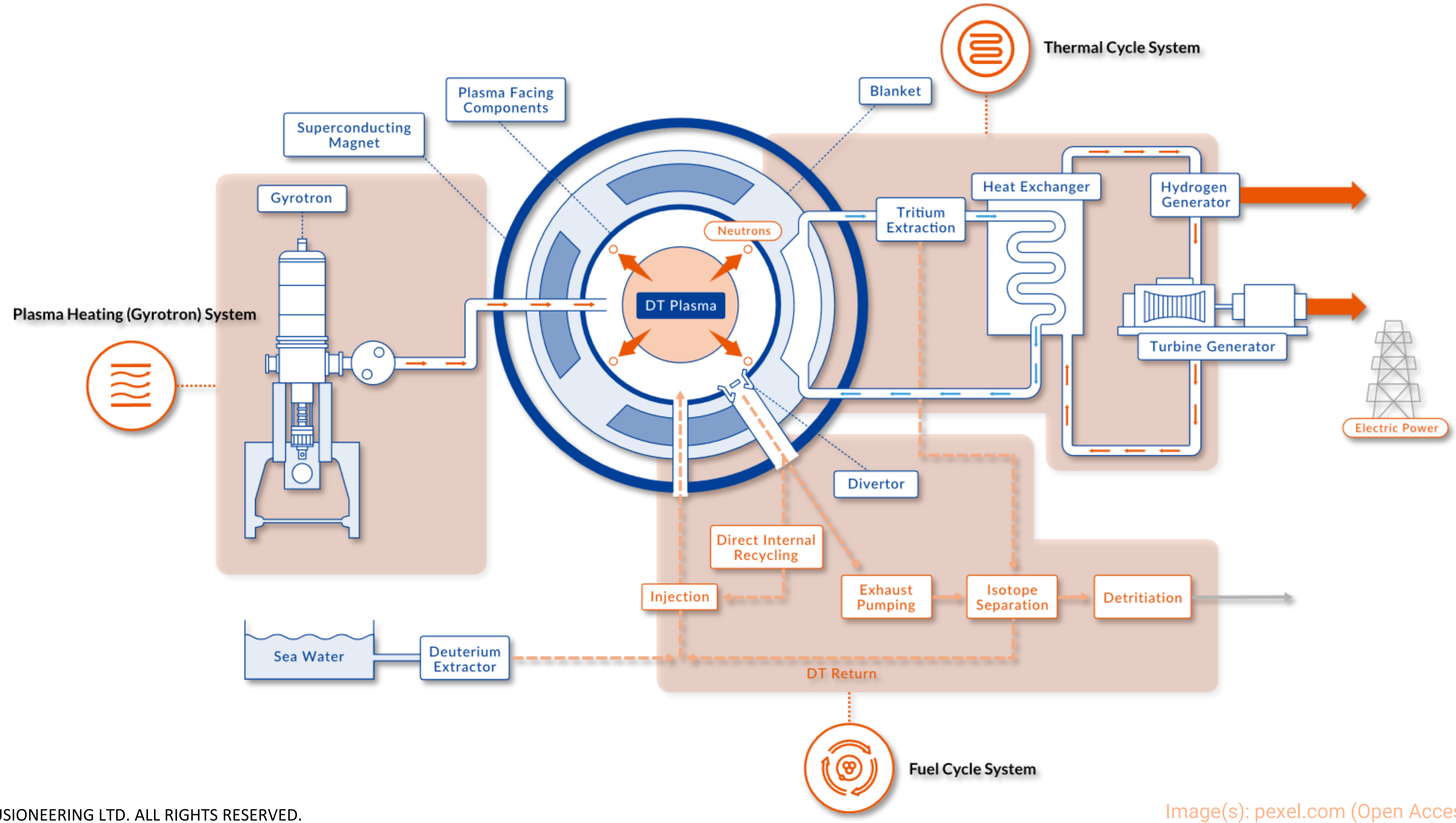

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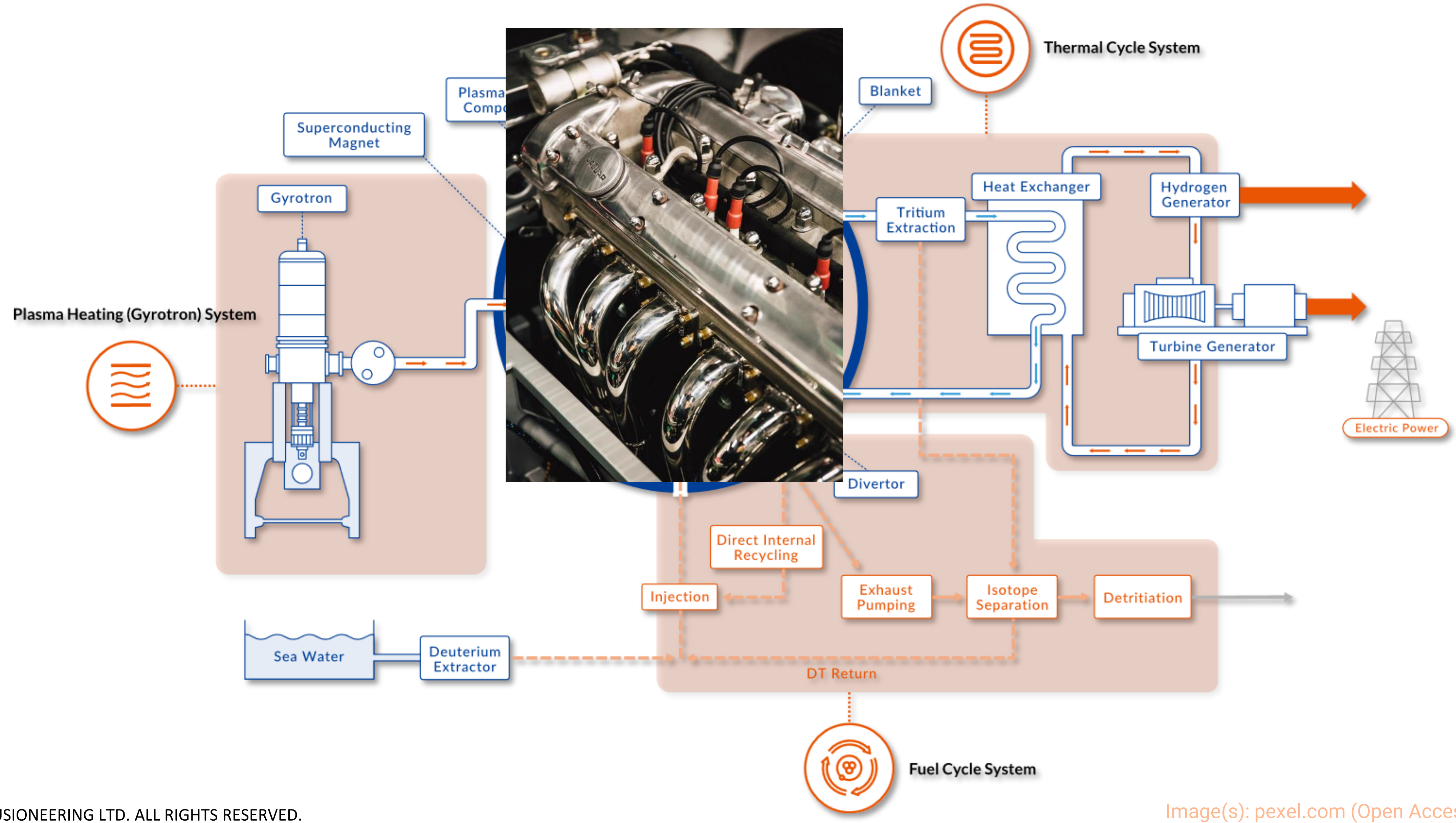
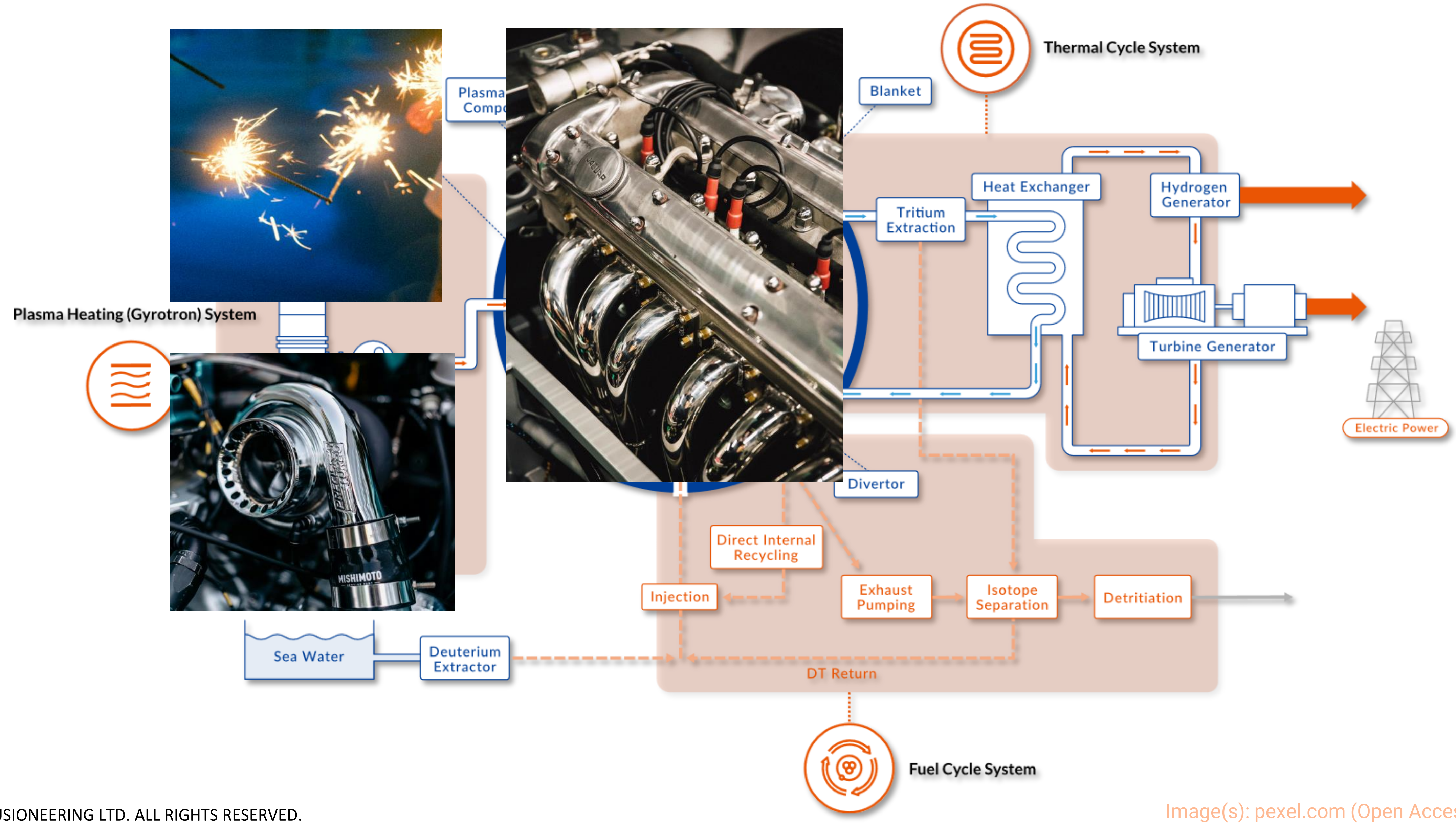


Image(s): pexel.com (Open Access)

The KF Mission: An Instructive Analogy



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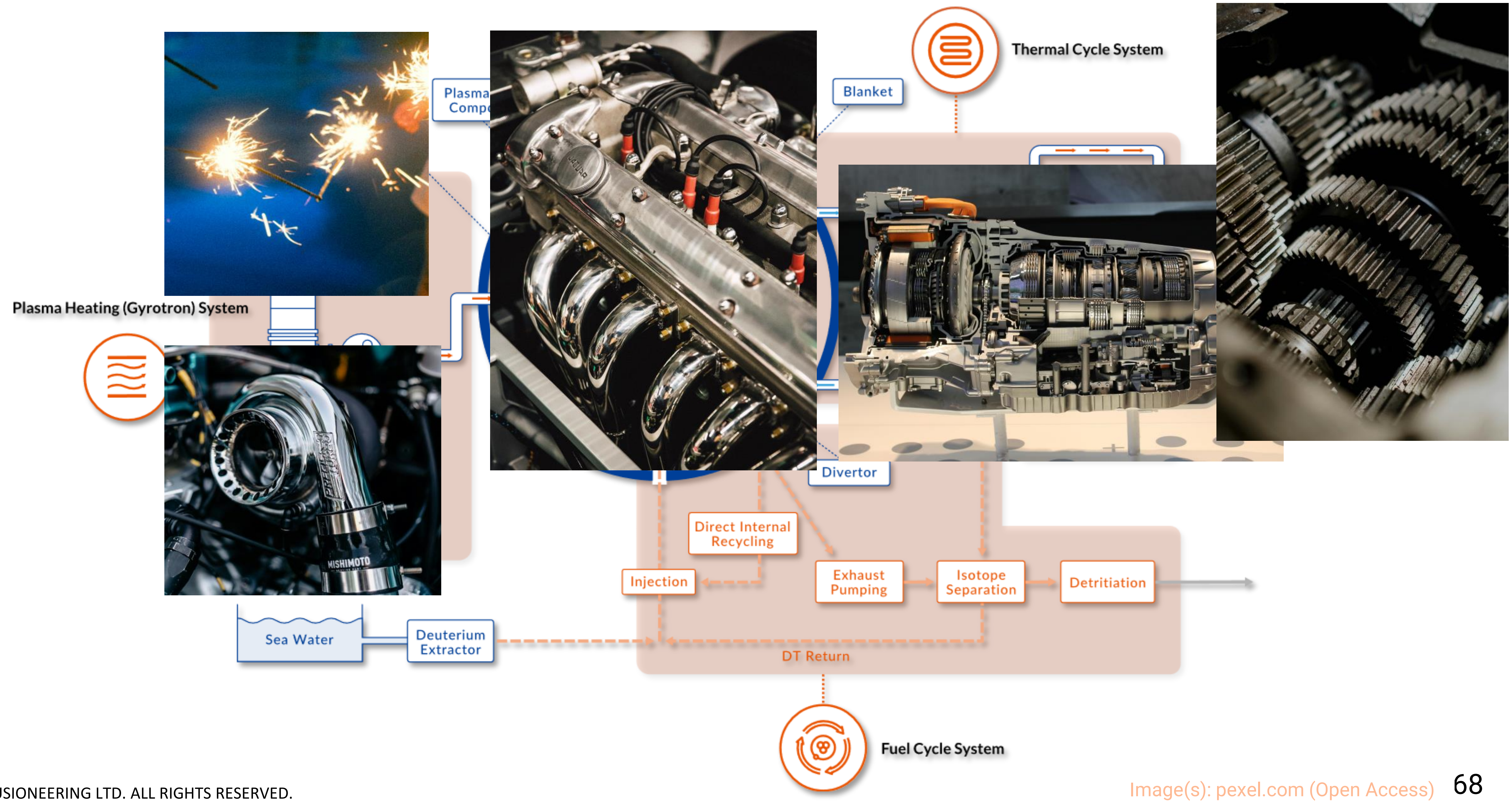

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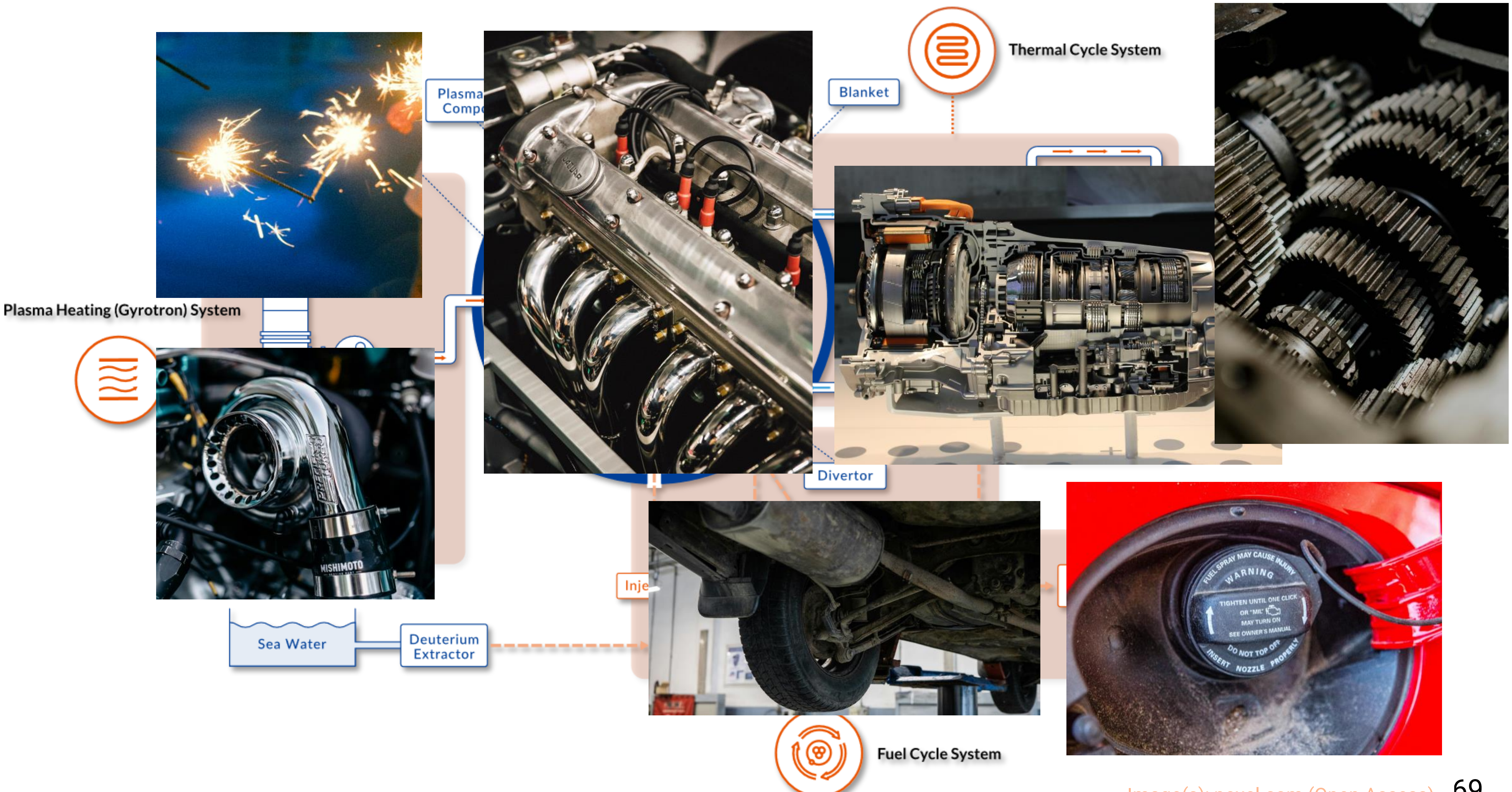
The KF Mission: An Instructive Analogy



Image(s): pexel.com (Open Access)

What is a business model?

*“A plan for the **successful operation** of a **business**, identifying **sources of revenue**, the intended **customer base**, **products**, and details of **financing**.”*

- Oxford English Dictionary definition

Why is having a business model important?

*"getting the **business model** and the **technology strategy** right is necessary to achieve **commercial viability** if sustainable competitive advantage is to be built and **innovators are to profit from their innovations**."*

- Teece, "*Business Models, Business Strategy and Innovation*", (2010)

Business Model

Developing the thermal cycle system, to simulate the integration of the fusion power and fuel cycles

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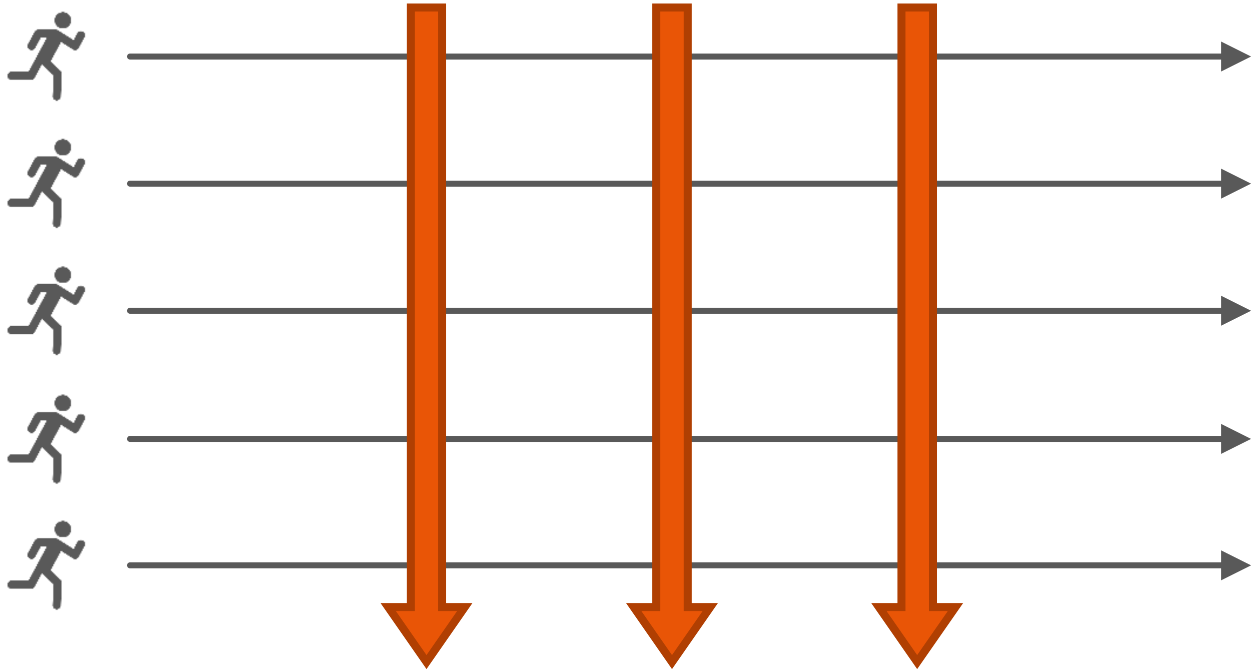
Fusion developers
(public & private)

Net-power producing fusion plasma



Realisation of a power-producing fusion reaction

Integrated plant systems for fusion power plants

Commercialization of Fusion Energy

Our business model, in simple terms

Fusion developers (public & private)

Net-power producing fusion plasma

Kyoto Fusioneering

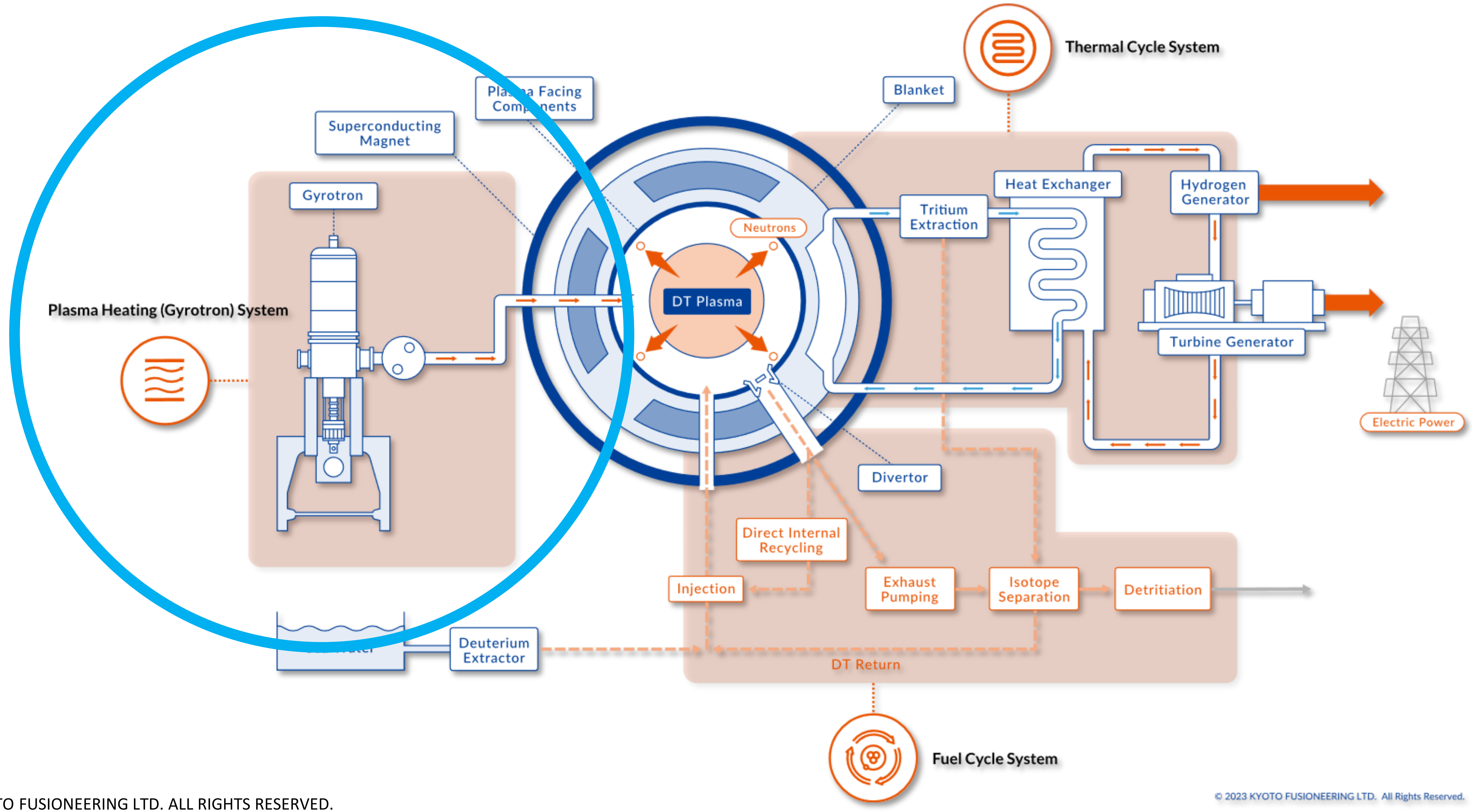
Integrated plant systems for fusion power plants

Image(s): pexel.com (Open Access)

Activities & Key Projects Pt.1: Plasma Heating Technologies

Supporting experiments today and tomorrow with KF's gyrotrons

Refresher



Thermal Cycle System
Plasma Facing Components
Blanket
Superconducting Magnet
Gyrotron
Heat Exchanger
Hydrogen Generator
Tritium Extraction
Neutrons
Plasma Heating (Gyrotron) System
DT Plasma
Turbine Generator
Electric Power
Divertor
Direct Internal Recycling
Injection
Exhaust Pumping
Isotope Separation
Detritiation
Deuterium Extractor
DT Return
Fuel Cycle System
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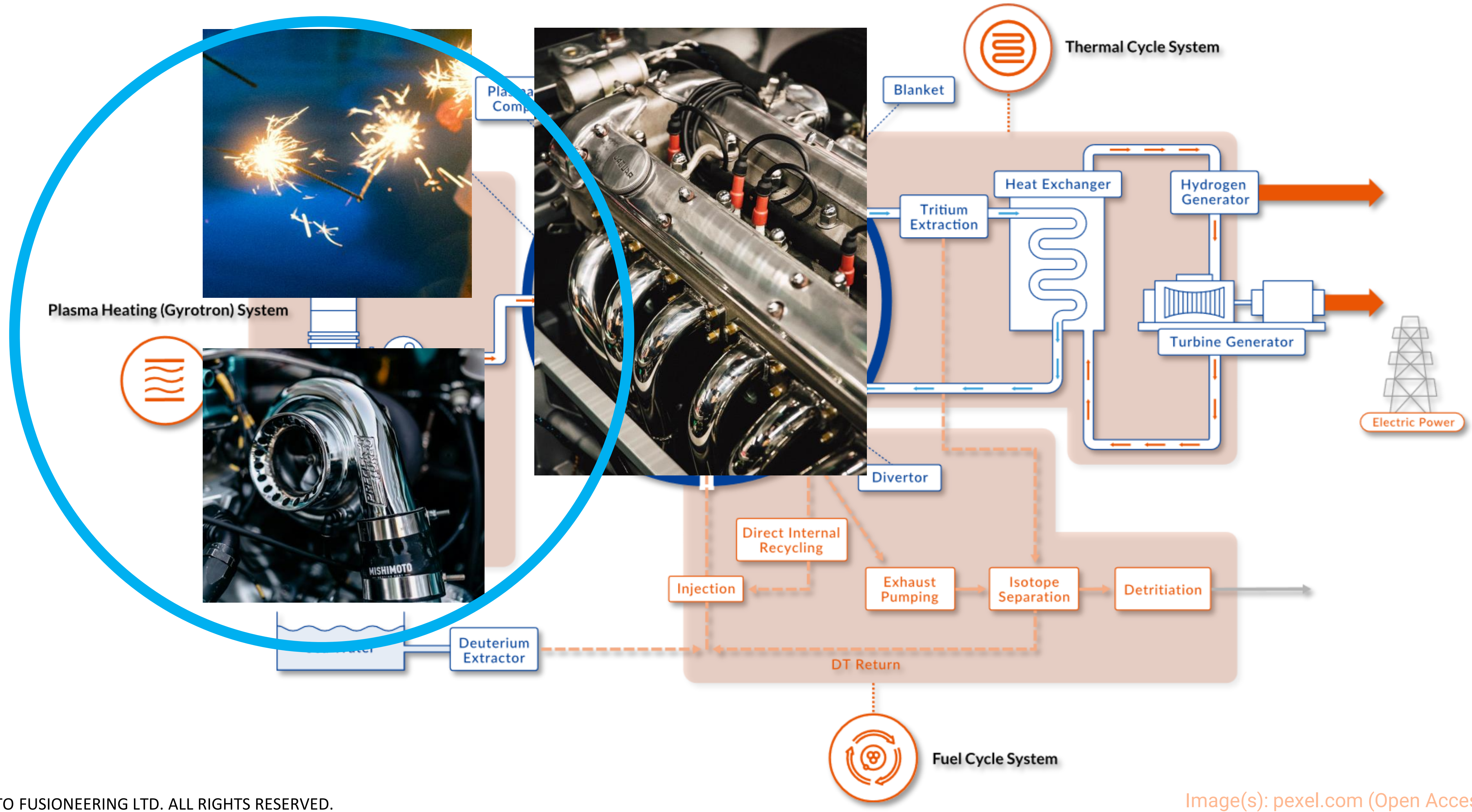
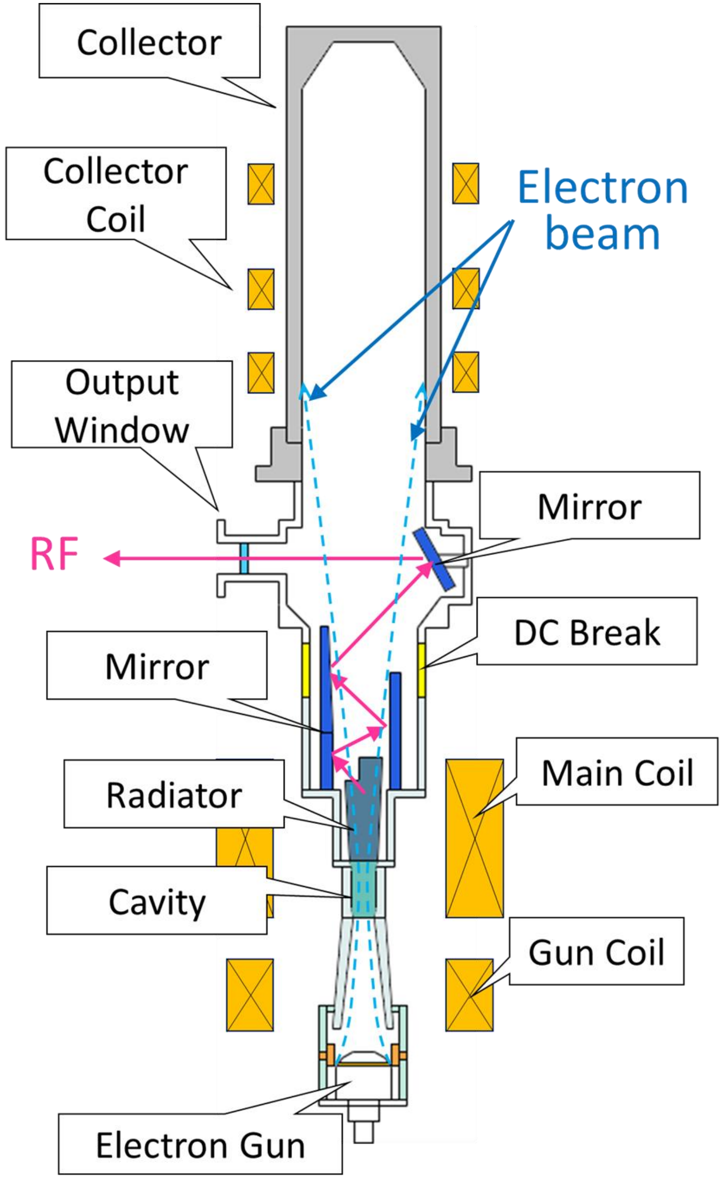
The KF Mission: An Instructive Analogy



Image(s): pexel.com (Open Access)

Gyrotrons for Electron Cyclotron Heating (ECH): How do they work?



- A gyrotron is a high-power (MW-class), high-frequency microwave emitter used for heating fusion plasmas.
- In a gyrotron, an electron beam is accelerated by an E-field, then converts its momentum into RF waves under a strong B-field.
- These RF waves can be directed at a plasma, and at a resonant frequency, they excite electrons in a magnetically confined plasma (typically 170-300 GHz, depending on the magnetic field strength of the fusion device).
- As electrons gain energy, they transfer it to ions, heating the plasma to fusion-relevant temperatures.
- The gyrotron is thus a key enabling technology for fusion energy.
- KF develops and sells gyrotrons globally, including two for the UK national fusion program.

KF's Gyrotron Specifications

Frequency	Output Power	HE_{11} Mode Purity	Pulse Width	Efficiency
28 - 250 GHz	1 MW	> 90%	- CW Operation	≒ 50%

Key Features of Gyrotron Tube

PURPOSES

- Plasma Diagnostic
- Plasma Heating

MULTI-FREQUENCY OSCILLATION

- 28, 35 GHz
- 104, 137, 170, 203 GHz* (Selectable)

*Single frequency can be designed

SIZE ~ 3 m
WEIGHT < 1,000 kg

	236 GHz	203 GHz*	170 GHz*	137 GHz*	104 GHz*	35 GHz**	28 GHz**
Oscillation Mode	$TE_{43,15}$	$TE_{37,13}$	$TE_{31,11}$	$TE_{25,9}$	$TE_{19,6}$	$TE_{10,6}$	$TE_{8,5}$
Output Mode	Gaussian Beam						
Typical Output Power	1 MW (To be tested)	1 MW	1 MW	1 MW	1 MW	1 MW	1 MW

*R. Ikeda, *et al.*, Journal of Infrared, Millimeter, and Terahertz Waves **38** (2017) 531–537.
T. Kariya, *et al.*, Nuclear Fusion **59 (2019) 066009.

ECH/Gyrotron: Key Achievements and Updates

Ongoing Projects

UKAEA – Delivered gyrotron tube and main components.

Private customer – Completed gyrotron tube FAT, ready for shipment

Exporting Kyoto Fusioneering’s Gyrotrons to the UK

YouTube: https://youtu.be/zFboF2EUxdg?si=OHjUuRv2bXujgQd6

ECH/Gyrotron: R&D Activities

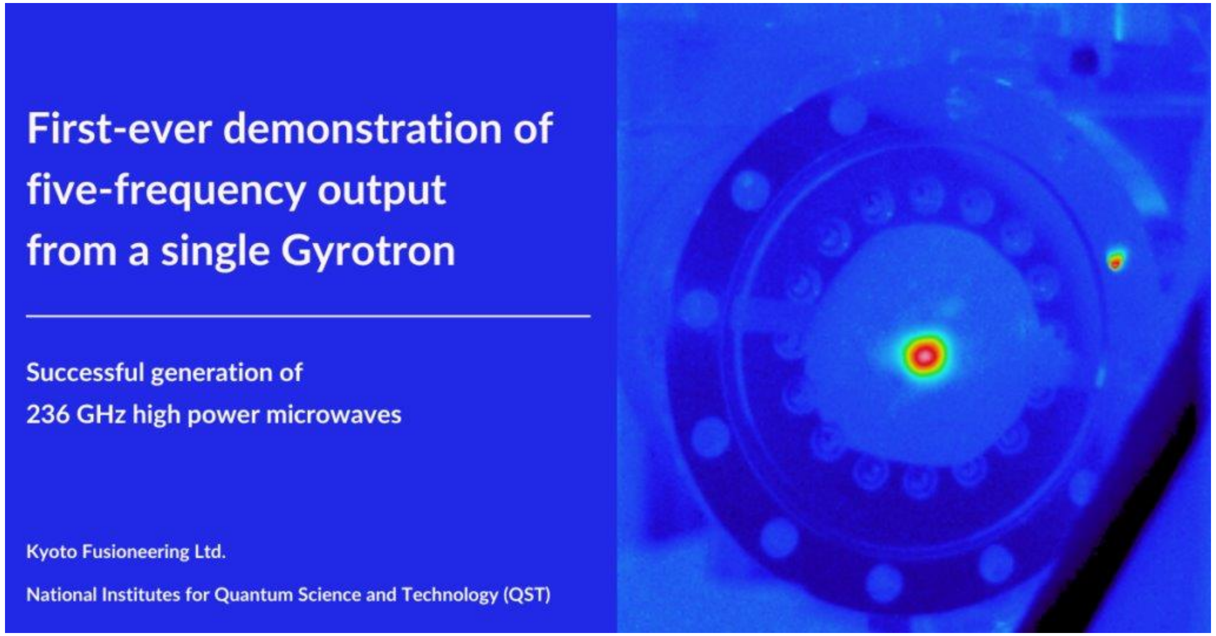
HV main power supply - Signed procurement agreement with Nichicon, after nearly a year tender & clarification process.

2024
Start of the procurement

2025
Completion of detail design, long lead item procurement

2026
Installation to new R&D site

236GHz development - A single gyrotron produces five separate frequencies of electromagnetic beam output [link]



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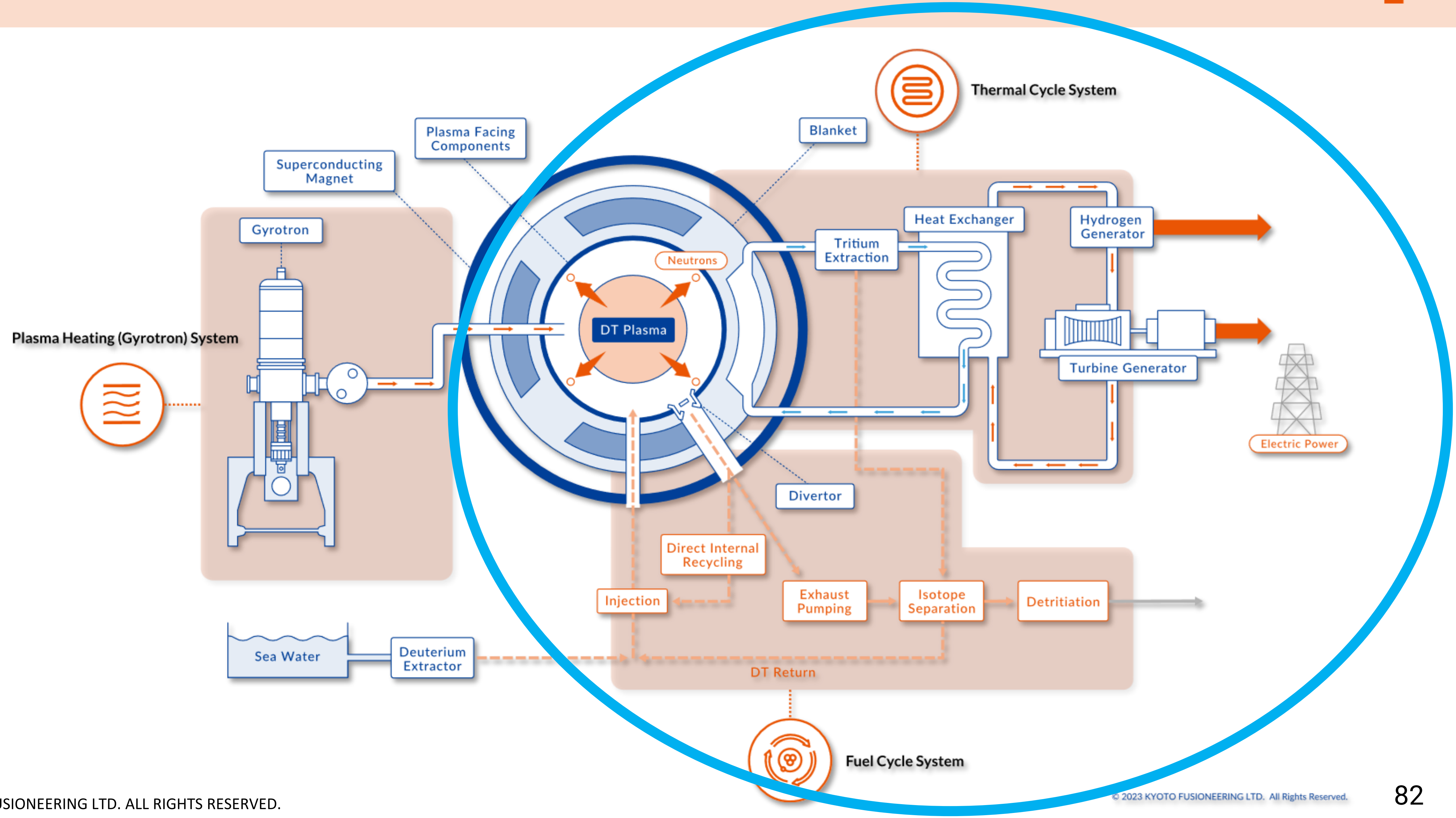
Activities & Key Projects Pt.2: Thermal & Tritium Fuel Cycles

Closing the gap to commercial fusion with the UNITY Programme

Refresher



Thermal Cycle System
Plasma Facing Components
Blanket
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Gyrotron
Heat Exchanger
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Divertor
Direct Internal Recycling
Injection
Exhaust Pumping
Isotope Separation
Detritiation
Sea Water
Deuterium Extractor
DT Return
Fuel Cycle System
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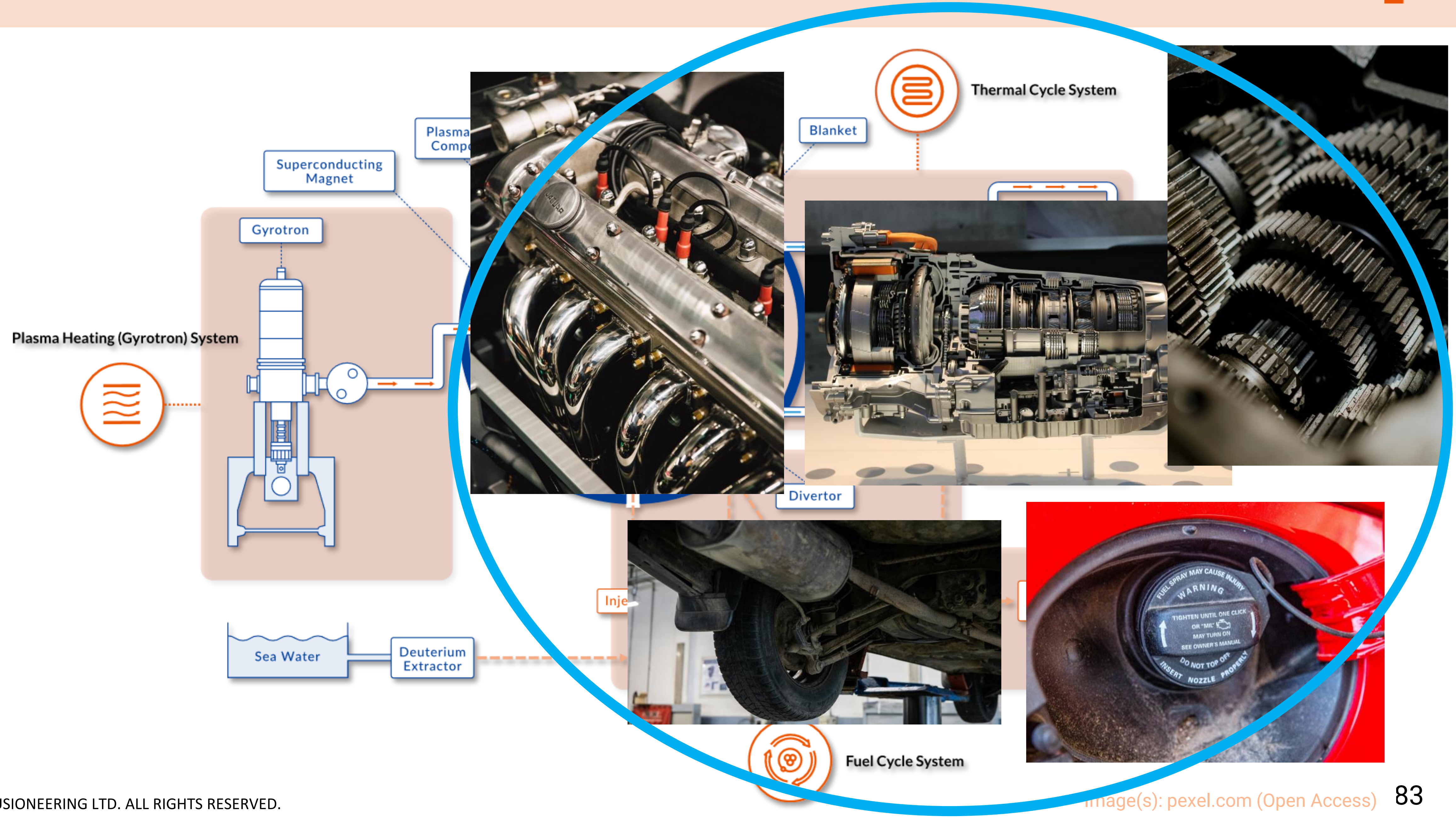
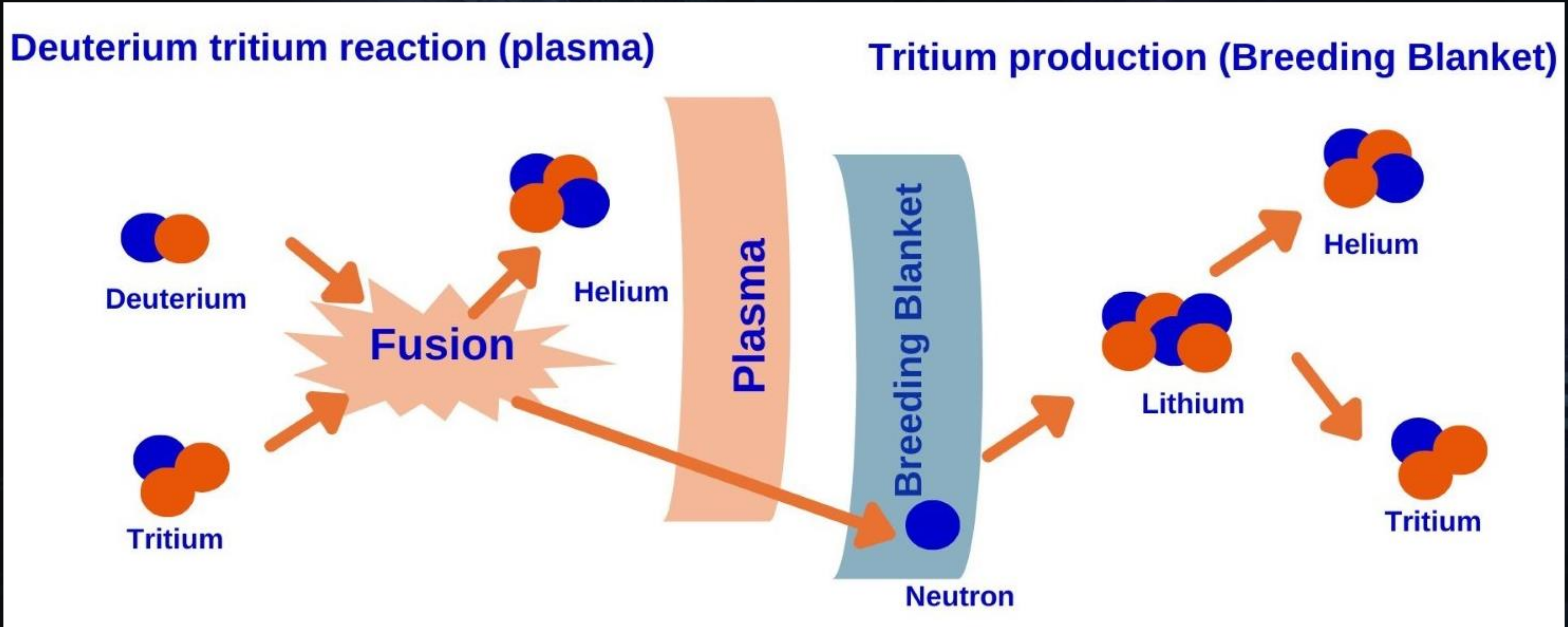
Refresher



Image(s): pexel.com (Open Access)


Deuterium tritium reaction (plasma)
Tritium production (Breeding Blanket)
Deuterium
Tritium
Fusion
Helium
Plasma
Breeding Blanket
Neutron
Lithium
Helium
Tritium

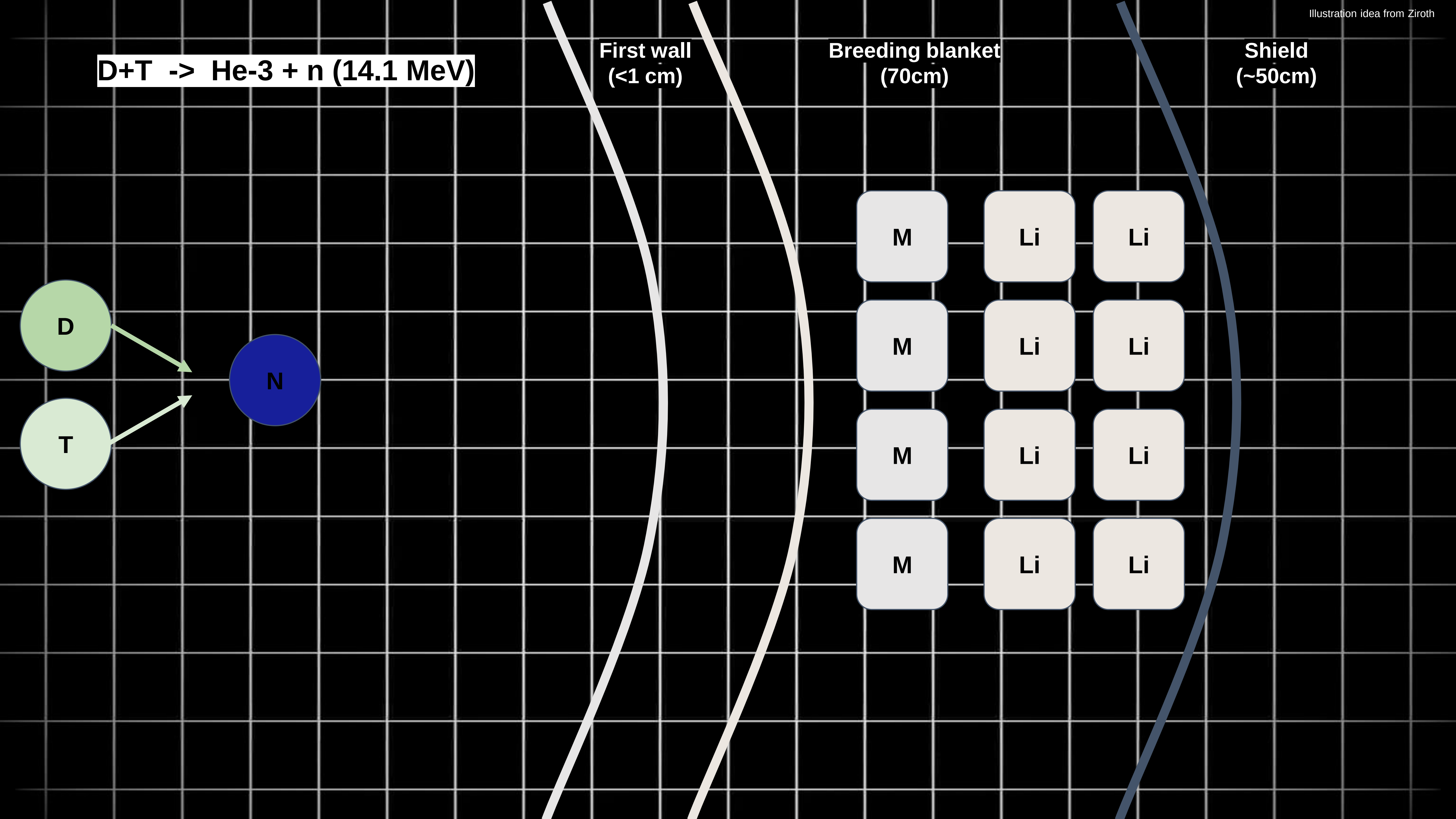
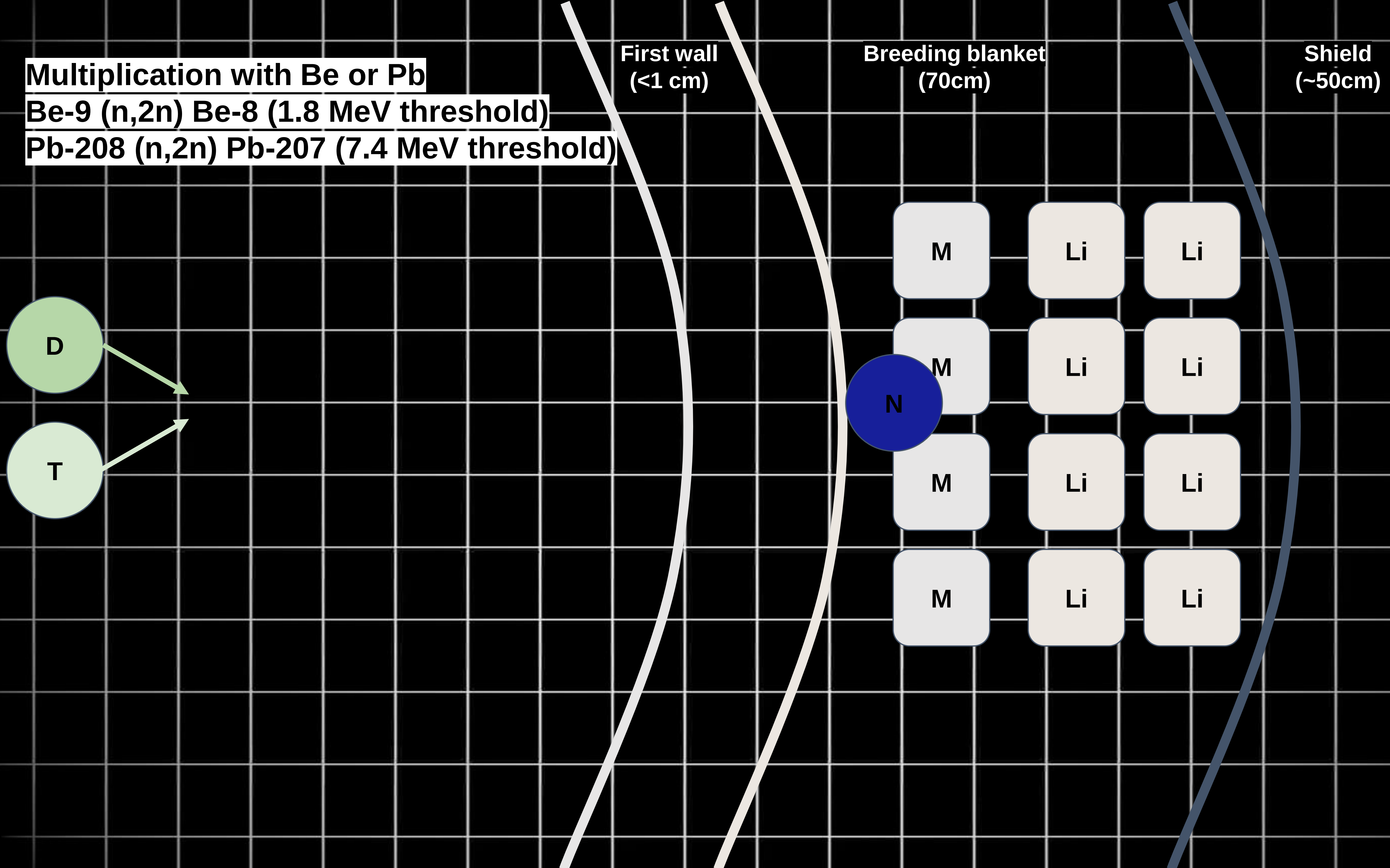


Illustration idea from Ziroth
D+T -> He-3 + n (14.1 MeV)
First wall
(<1 cm)
Breeding blanket
(70cm)
Shield
(~50cm)
D
T
N
M
Li
Li
M
Li
Li
M
Li
Li
M
Li
Li

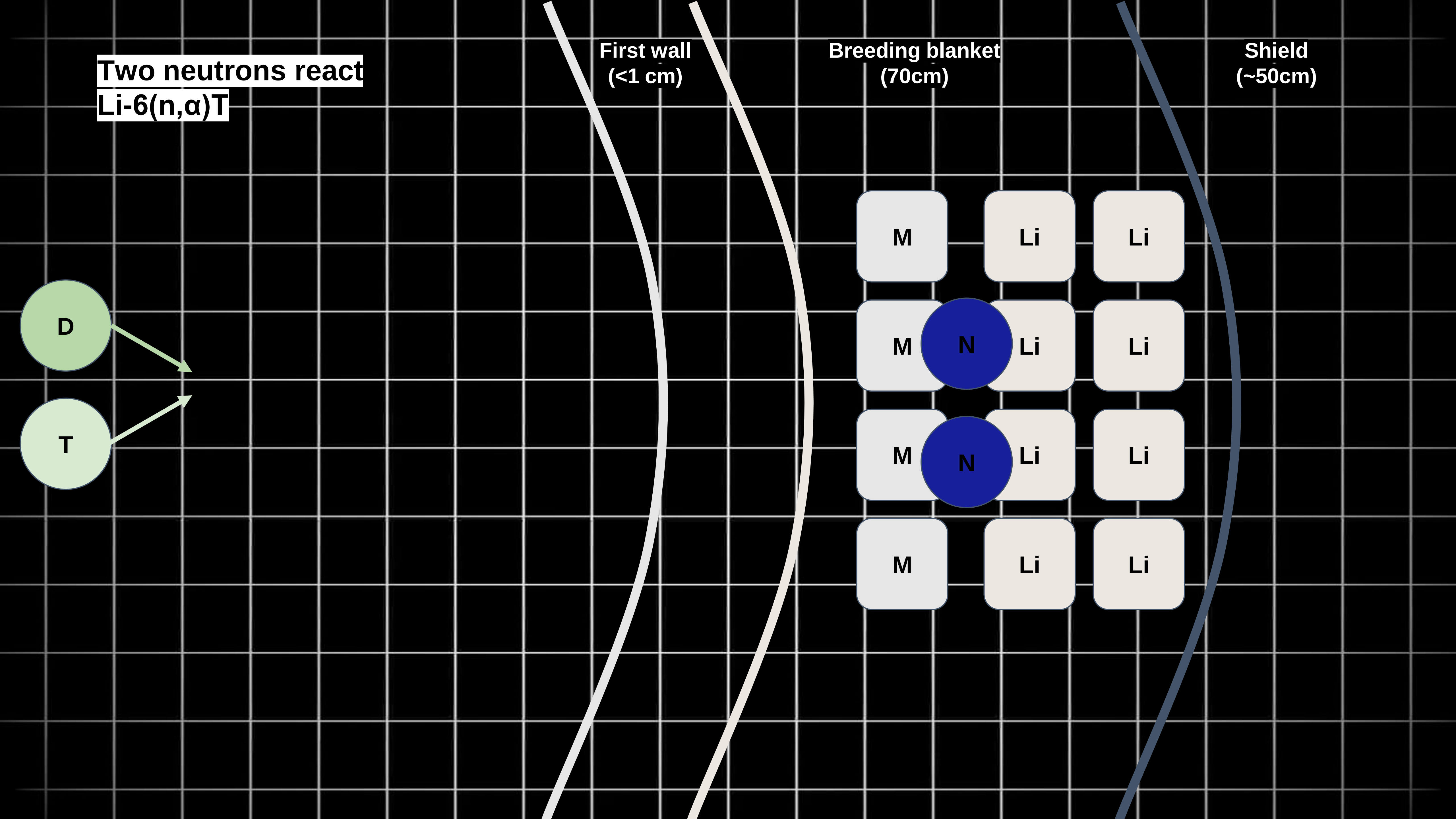
Multiplication with Be or Pb

Be-9 (n,2n) Be-8 (1.8 MeV threshold)

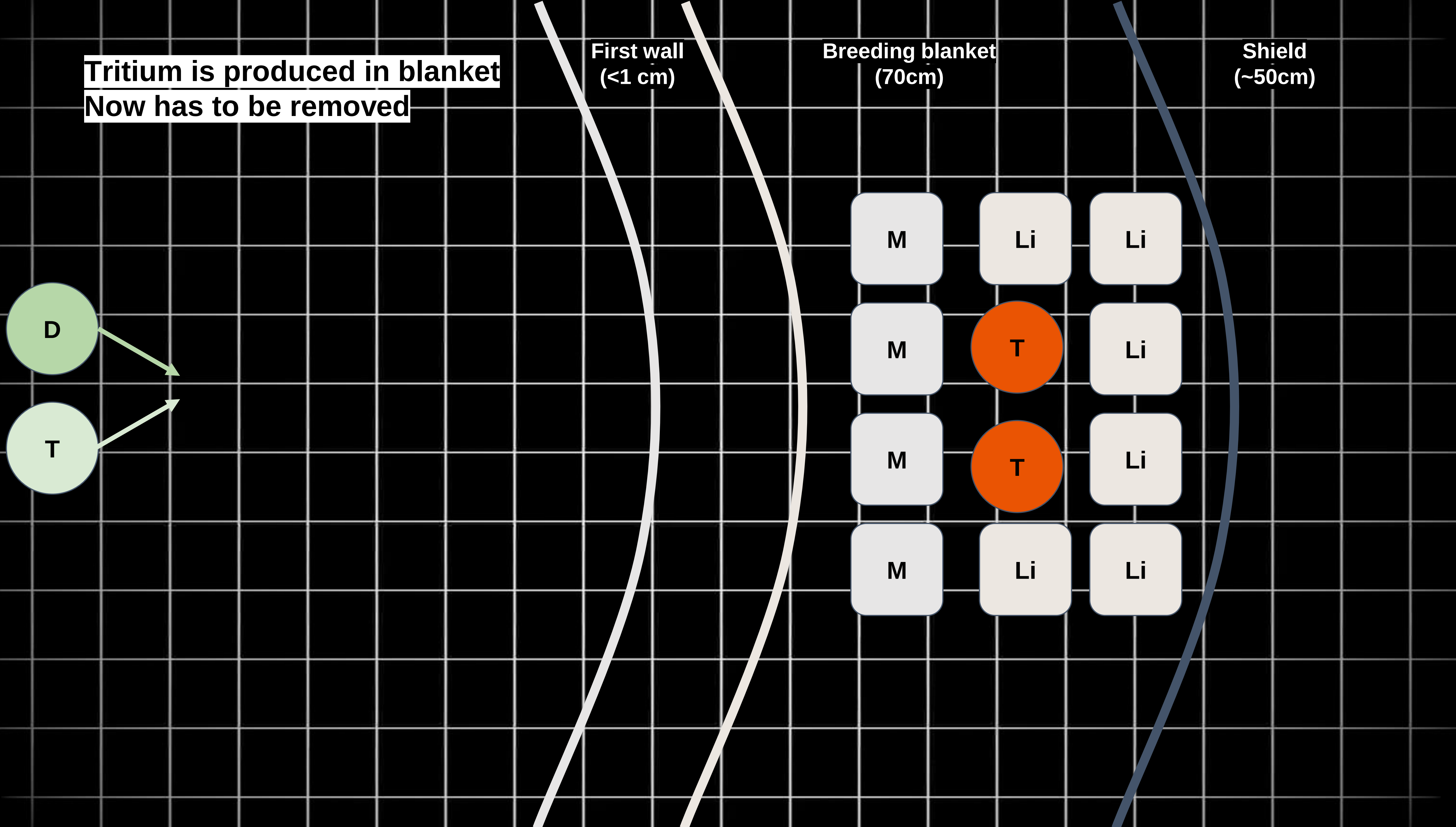
Pb-208 (n,2n) Pb-207 (7.4 MeV threshold)



Two neutrons react
Li-6(n,α)T

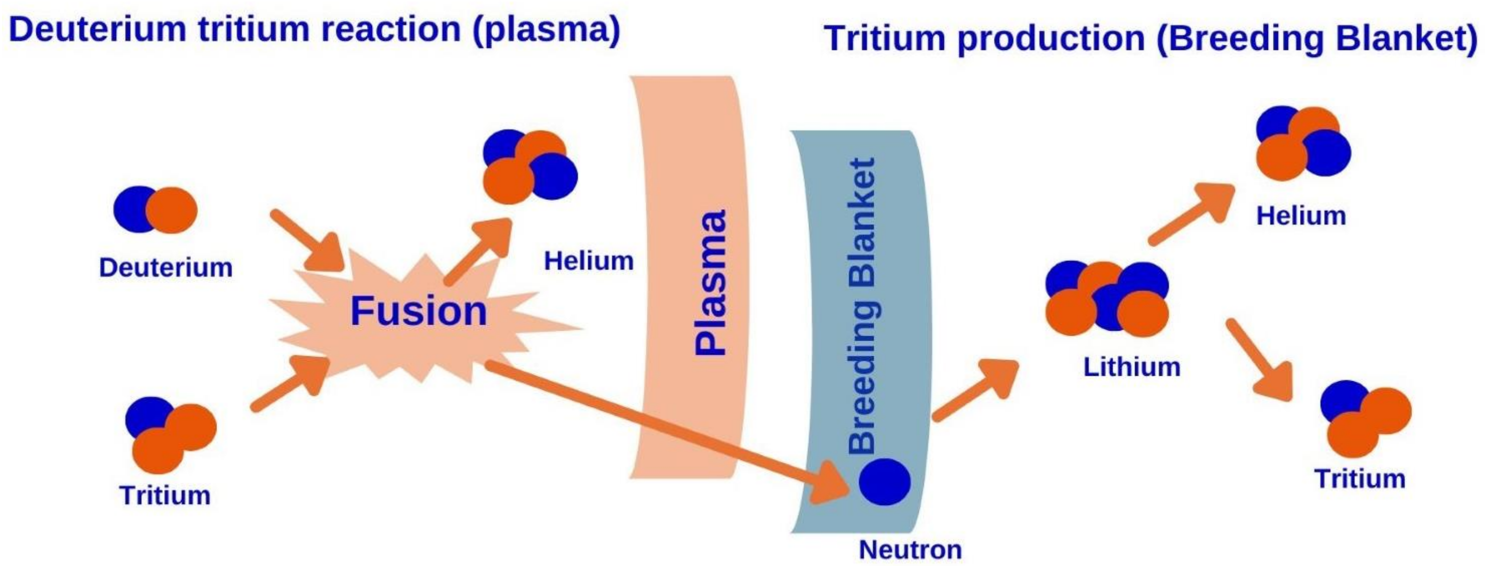


Tritium is produced in blanket
Now has to be removed



Tritium (Thermal and Fuel cycle): Central to Accelerating Commercial Fusion

- Tritium is a **critical path challenge** for all approaches. It affects **every major system**, in terms of performance, safety and cost. As development efforts accelerate, **tritium will apply the brake**.
- The tritium fuel cycle is **not something to "bolt-on"** after first net power gain; **it cannot be an afterthought**, it is essential for it to be integral in early development.
- While some facilities have provided valuable insights on the tritium fuel cycle, **major progress is needed for commercial Fusion Power Plants (FPP)**. The path is challenging…



Tritium (Thermal and Fuel cycle): Central to Accelerating Commercial Fusion

- There are a range of **technical**, **strategic** and **commercial** challenges, which are complex both individually, and when intertwined (system integration).
- Requires multifaceted solutions from **materials science**, to **regulatory policy and safety**, to **training of a competent workforce**.

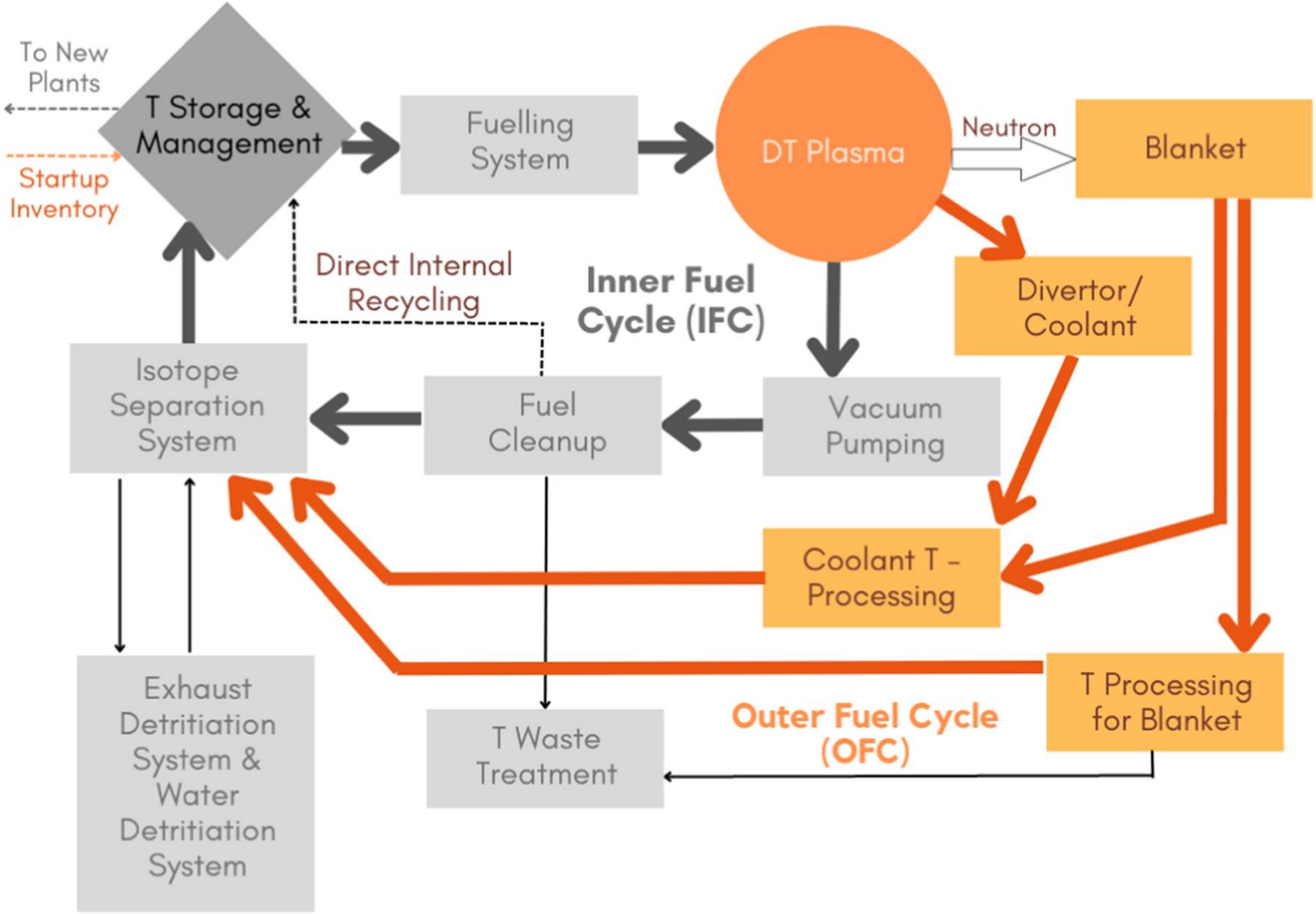


Image: Baus et al., *J. Fusion Energy* 42.1 (2023)

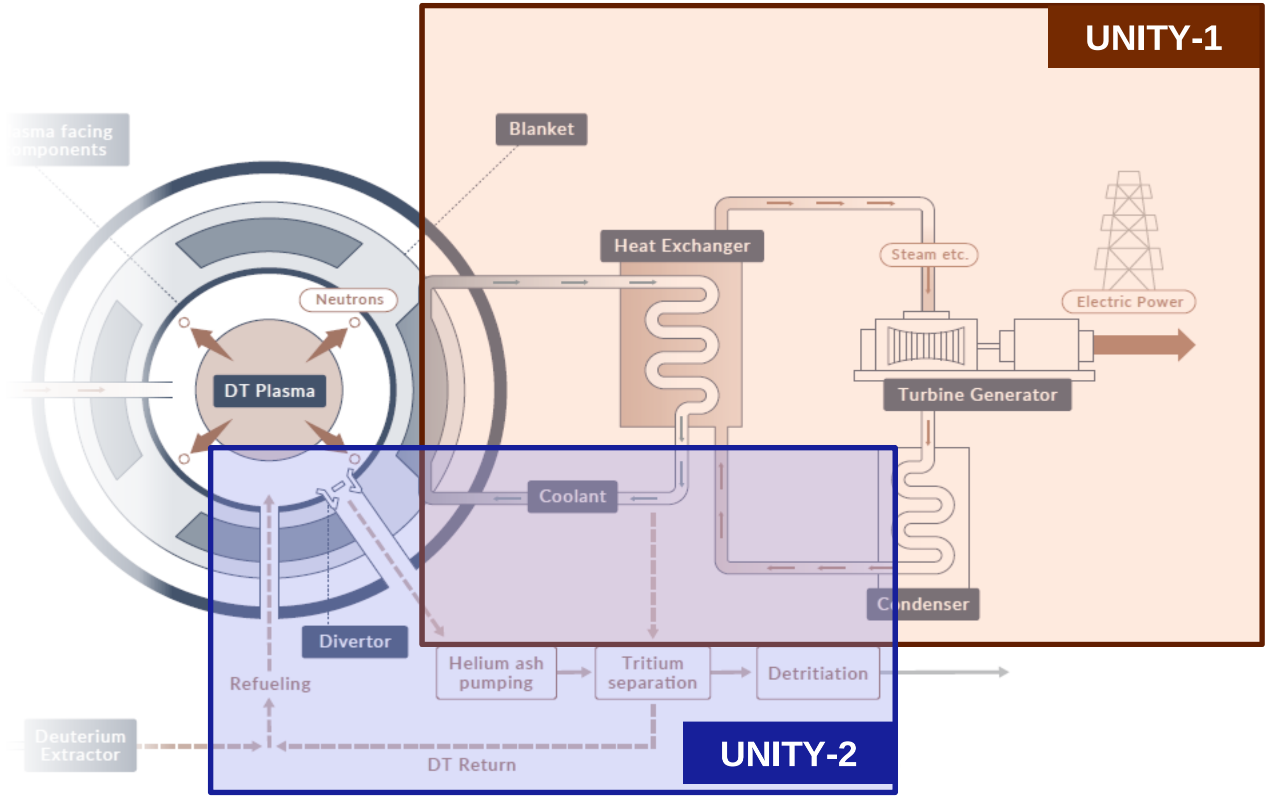
Fusion Fuel Cycle – *Get in touch if you want to know more!*

Keynote presentation on the tritium fuel cycle

SOFT 2024, Dublin, Ireland (September 2024)

Unique Integrated Testing Facility (UNITY) Projects

KF and its partners are designing and developing facilities to "crack" the fuel cycle, with UNITY-1 and -2



In partnership with Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

UNITY-1

Blanket Component Test Facility (BCTF)

Located at our Kyoto Research Centre, UNITY-1 is dedicated to advancing the Thermal Cycle System, crucial for harnessing fusion's power. It simulates high-temperature and magnetic conditions of a fusion plant to test various power generation systems, employing components like a blanket for heat extraction, liquid metal loops, and an advanced heat exchanger—all without radioactive materials.

UNITY-2

Fuel Cycle Test Facility (FCTF)

Located at Chalk River Laboratories in Ontario, UNITY-2, in strategic alliance with Canadian Nuclear Laboratories, focuses on the complete deuterium-tritium fuel cycle. This test loop will pioneer global standards in fuel exhaust, pumping, and tritium handling, among other critical operations.

Together, these facilities underscore our commitment to accelerating R&D to support fusion commercialization.

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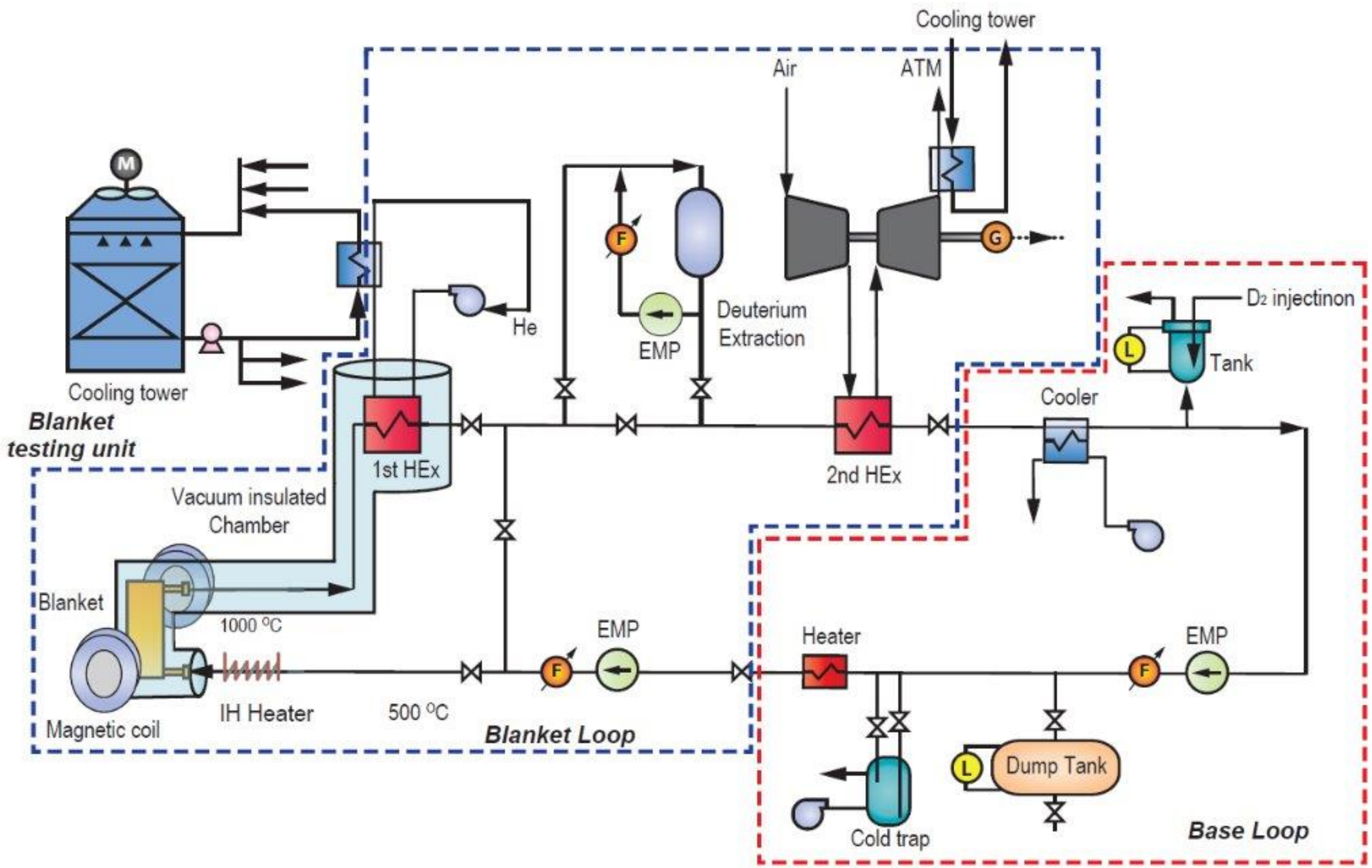
UNITY-1: Fusion Thermal Cycle

A closer look

UNITY-1 Facility (Kyoto Fusioneering)

Developing the thermal cycle system, to simulate the integration of the thermal and outer fuel cycle



Location: Kyoto, Japan

Thermal Cycle:

- Blanket test section (1000°C LiPb, Li, FLiBe)
- 250 L LiPb inventory
- 4T NbTi magnet
- IH heating and surface heating for blanket module
- Two heat exchangers and power conversion (first electricity generation from a blanket module)

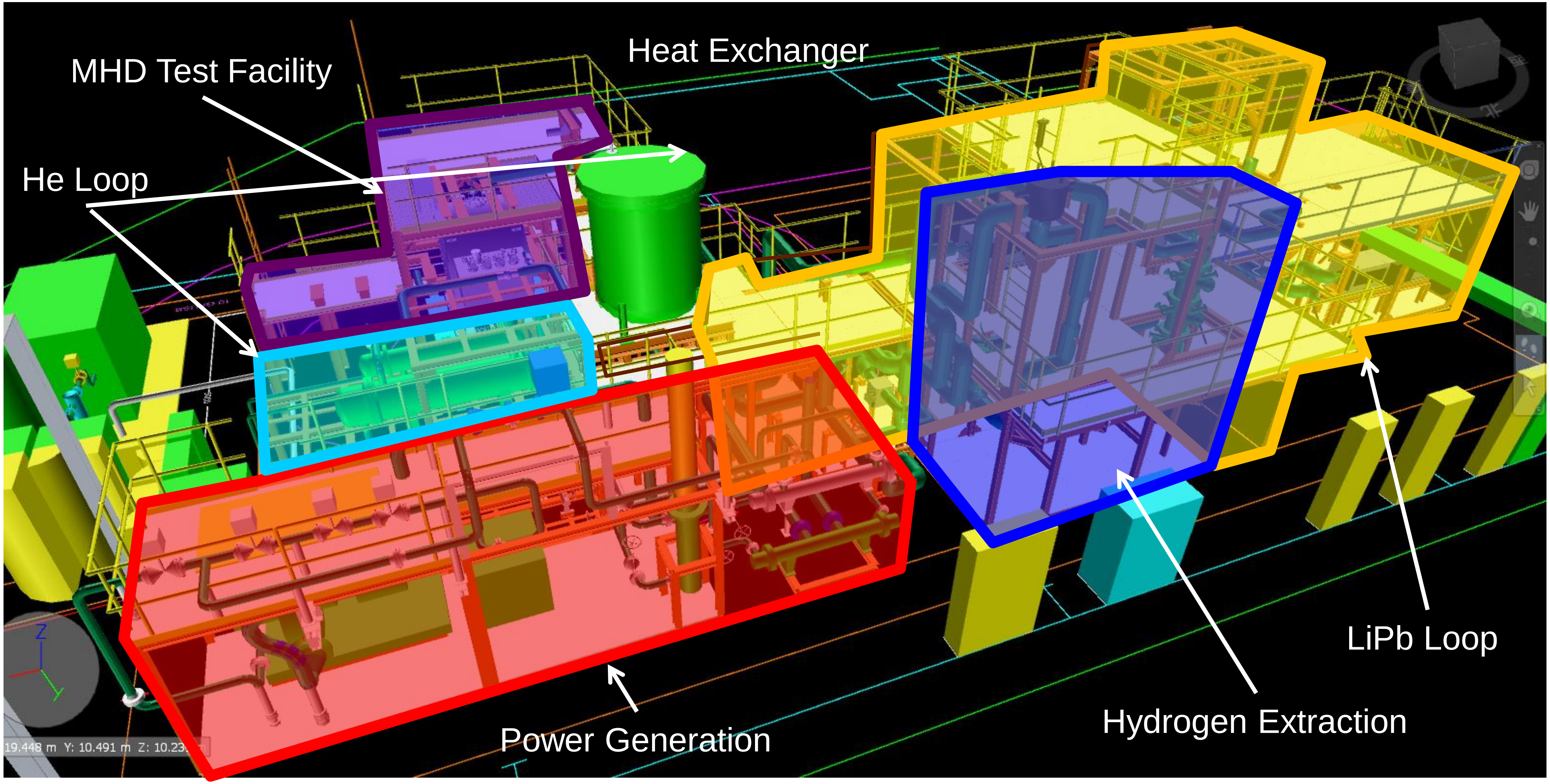
Fuel Cycle:

- Deuterium injection as proxy for tritium
- H isotope extraction via VST, electrochemical
- Exhaust pumping from vacuum vessel (pump train)
- DIR testing with proton conductor pump

Materials

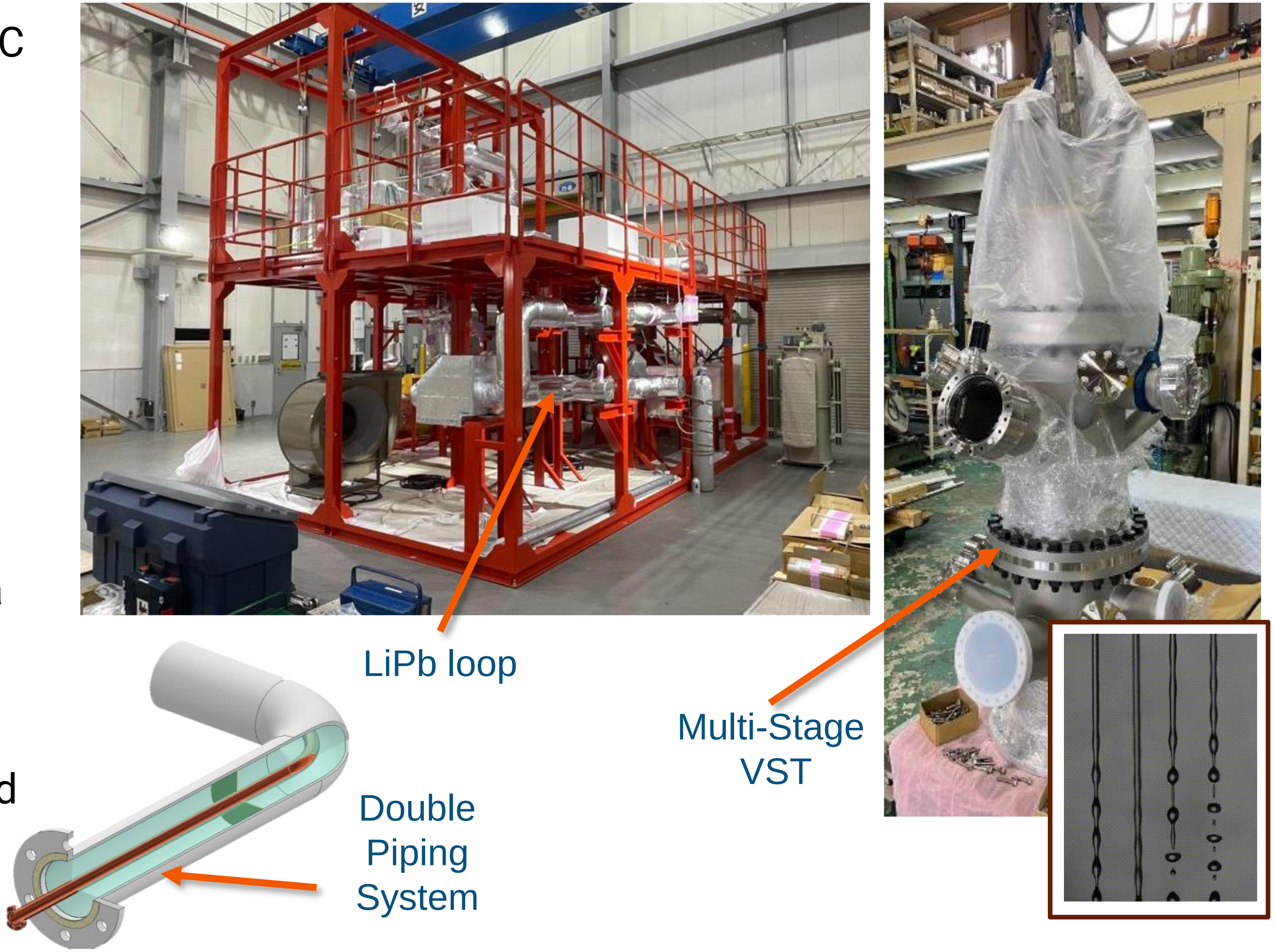
- Compatibility in flow conditions (up to 50 L/min via 3 EMPs)
- FLibe and Li piping material tests
- MHD testing with SiCf/SiC insulators

UNITY-1: 3D Schematic



UNITY-1 Progress

- **Commissioning Completed:** 250L LiPb base loop operational, achieving 300-500°C with a flow rate of up to 50 L/min.
- **Tritium Management:** Construction of a VST-based tritium extraction system underway.
- **Magnetic Field Integration:** Testing setup for blanket systems with >1T magnetic field.
- **Heat Exchanger Development:** Installing a heat exchanger with a 140 kW capacity to facilitate high-temperature operations.
- **Future Operations:** Preparing for advanced material testing at temperatures up to 1000°C.



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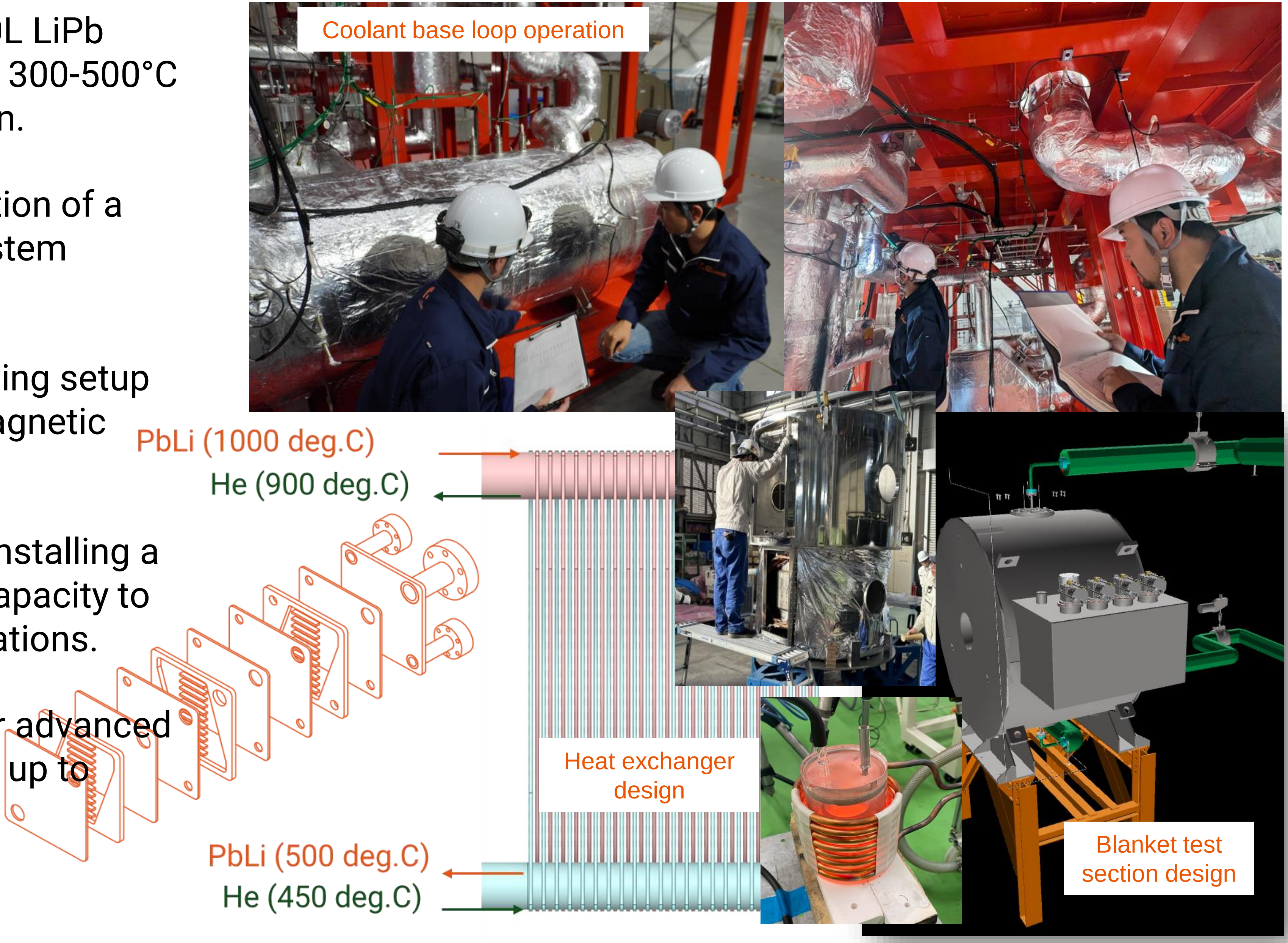
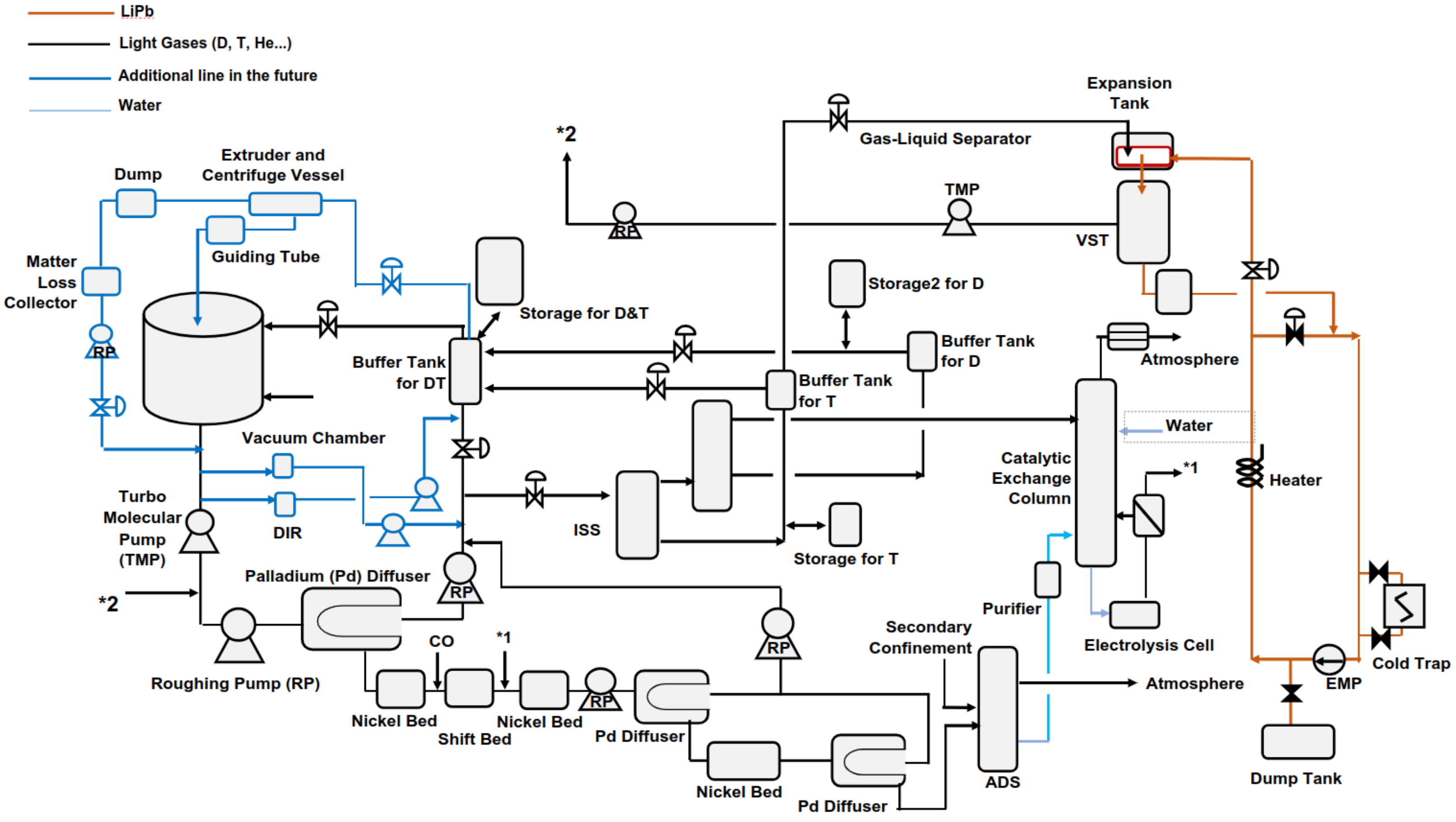


UNITY-2: Fusion Fuel Cycle

A closer look

UNITY-2 Facility (Kyoto Fusioneering + Canadian Nuclear Laboratories)

UNITY-2 is leading the way in fuel cycle testing through the unique partnership between CNL and KF.



Location: Chalk River, ON, Canada (CNL)

Components:

- **Build on TSTA's "everything but the plasma" Legacy**
- **No plasma? No problem**
- **Tritium Handling and Separation**
- **Integrated Tritium Extraction**
- **Focus on Tritium Safety**
- **Tritium Extraction and Handling:** Testing with real tritium (up to 10-40 g), dual storage (dU, ZrCo), and dual ISS systems (TCAP, CD) for optimized tritium processing and safety.
- **Reactor-like Conditions:** Mimics fusion reactor environments including vacuum chambers, PEG gases, and centrifugal pellet injection systems for fuelling.
- **Outer Cycle Systems:** Incorporates WDS, ADS, and DIR to manage tritium safely through external handling systems.
- **Fuel Cycle Modelling:** Dynamic modelling of the entire fuel cycle, including coolant and breeder inventory, pumps, Pd diffusers, and DT delivery mechanisms.
- **Advanced Fuelling Capability:** Capable of fuelling vacuum chambers at ~2.6 Pa m3/s under operational conditions.

Fusion Fuel Cycles (FFC) Inc.

FFC is dedicated to delivering an optimal fuel cycle that boosts fuel efficiency, cuts tritium inventory, and maximizes heat transfer for power, enabling safe, high-performance fusion energy systems from design to full operation.

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Private

Brings speed, agility, market incentives, commercial thesis, private capital, and more.

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Public

Brings licensed lab, track-record with regulator, tritium-handling capabilities, and more.

FUSION FUEL CYCLES INC.

FFC will:

- **Deliver UNITY-2**, fuel cycle test facility.
- **Operate UNITY-2** as user facility.
- **Elevate TRL** of D-T fuel cycle components.
- **Design** fuel cycle for fusion developers.
- **Supply** fuel cycle components and integrated systems.

and more…

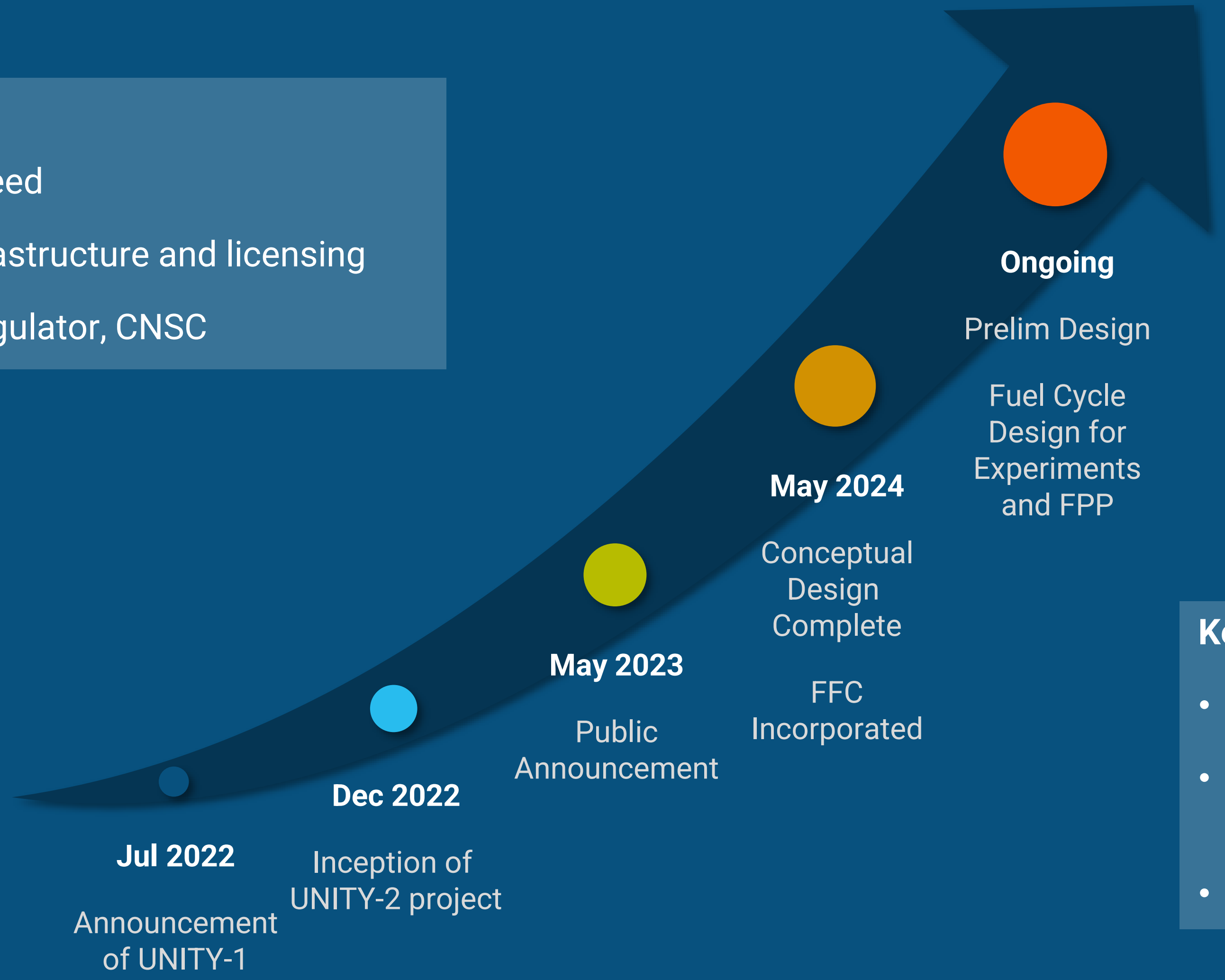
UNITY-2: Closing Key Technology Gaps on a BOLD Timeline

FFC

First fusion power plant relevant fuel cycle test facility, in terms of both scope and speed.

Enablers of Success:

- Private sector speed
- Public sector infrastructure and licensing
- Full support of regulator, CNSC



Key Motives:

- Lab-scale testing is not enough
- Need to demonstrate fusion-specific tech in prototypic environment now
- Tech-to-market is not the job of labs

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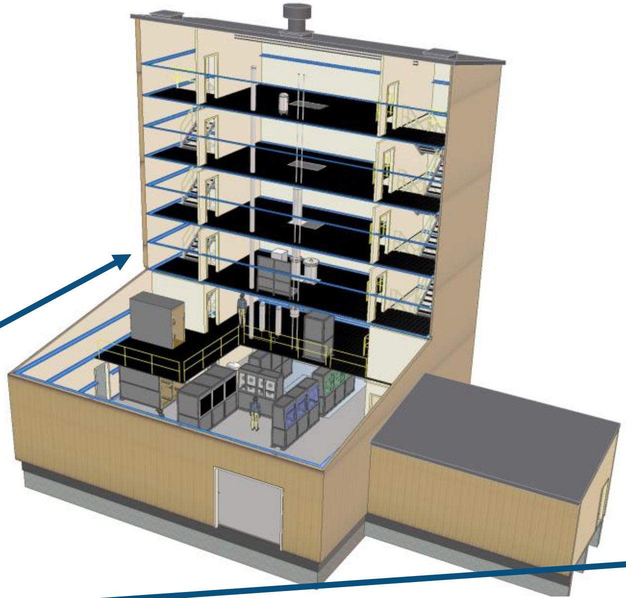
UNITY-2 Progress: Conceptual Design Finalised & 3D layout in progress

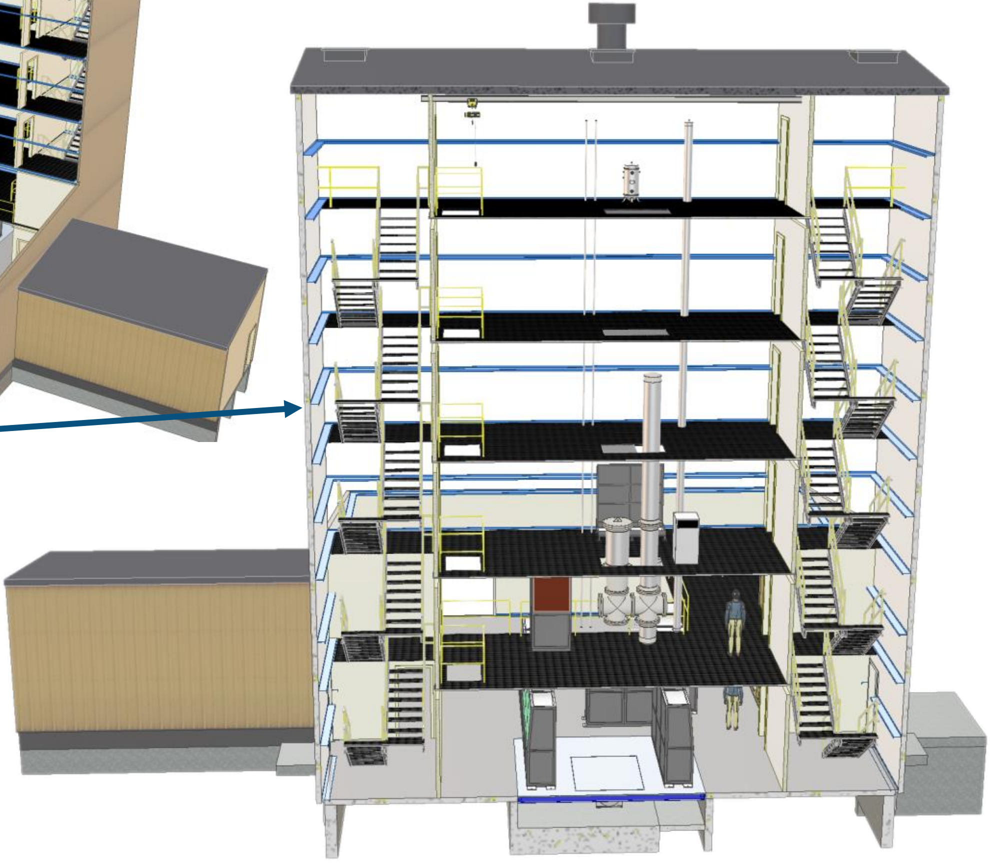
FFC

- UNITY-2 fits within tritium facility operating license at Chalk River, ON.
- Current license allows **up to 100g in process** and **up to 250g immobilized**.
- The precious space is being carefully allocated. **Potential user input being considered now**.

Building B215 at Chalk River, Ontario
Licensed for 100g of Tritium

Location of UNITY-2





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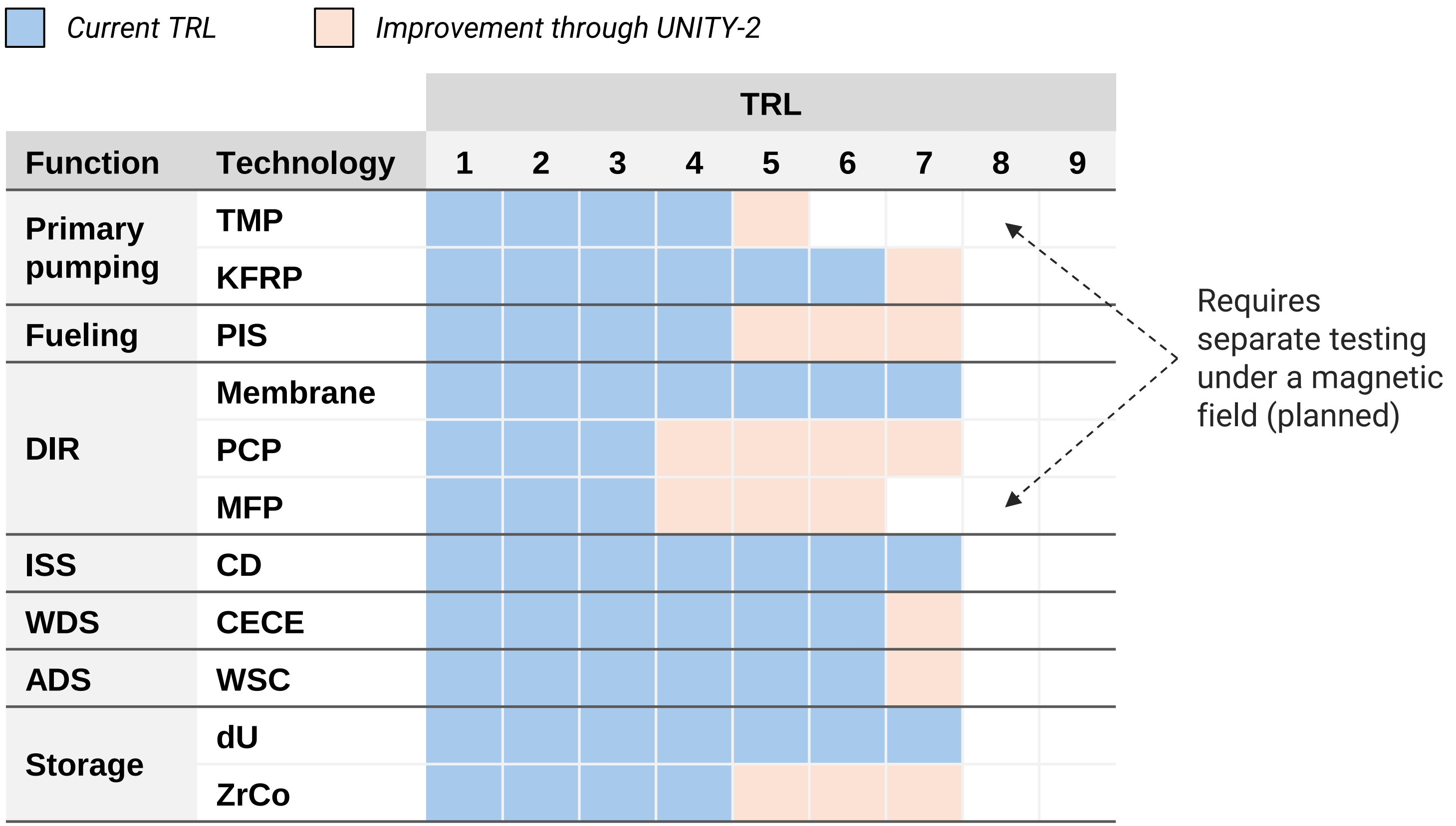
UNITY-2 Progress: Charting Fuel Cycle Technology Readiness

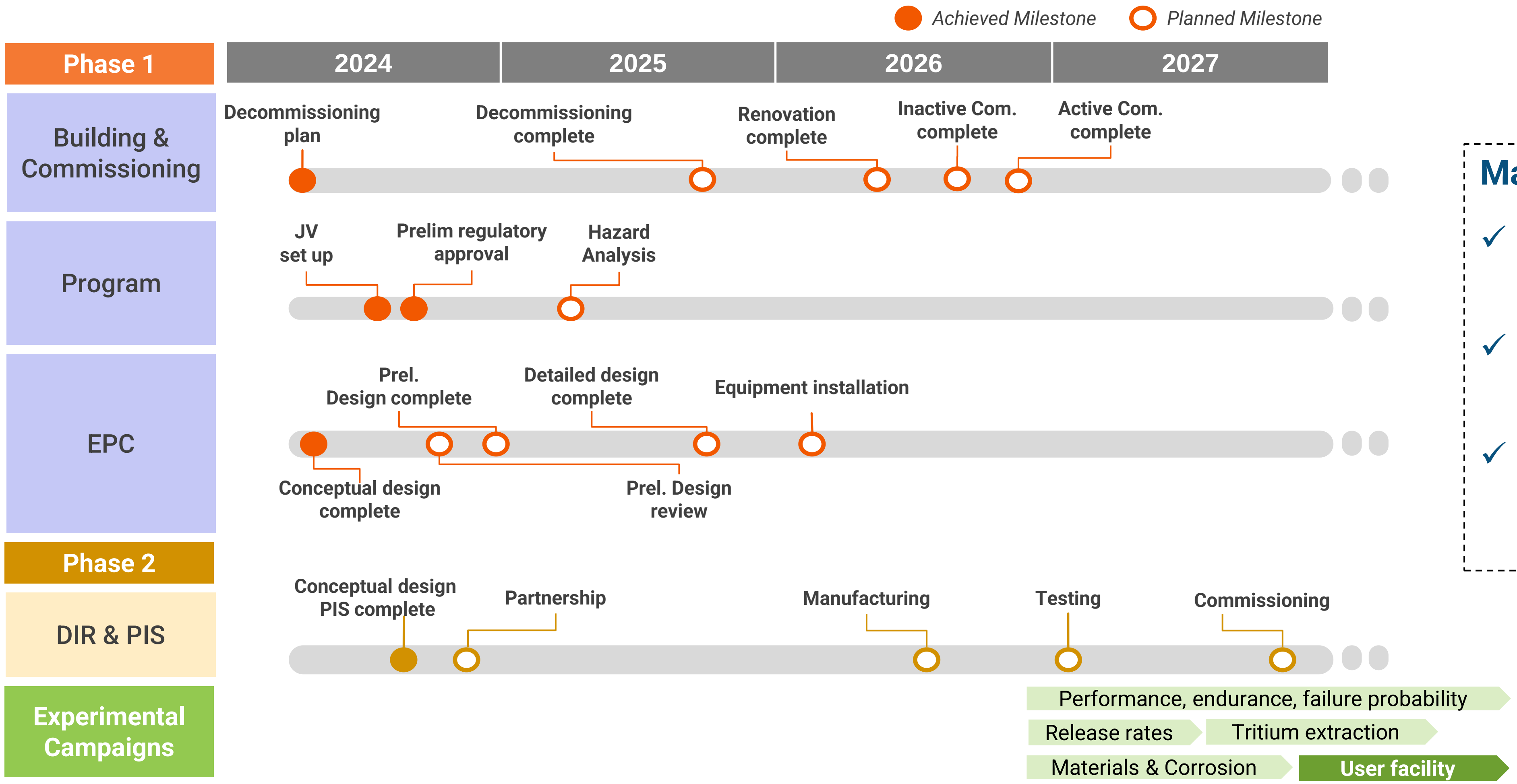
Significant advances to Technological Readiness Level (TRL) planned.
Several key tritium technologies essential for both the inner and outer fuel cycle will be tested and validated.



Adapted data from [Hörstensmeyer et al. 2018](#) for DEMO technology plus additions relevant to UNITY-2.
Aiming for TRL 7: "Brass board experiments with relevant component functions and tritium quantities"

UNITY-2 Progress: Project Schedule

Active commissioning scheduled for mid-2026 with experimental campaigns starting thereafter.



Major milestones achieved:

- ✓ **CNSC confirms scope is within existing license**
- ✓ Conceptual design complete
- ✓ Building decommissioning planned, funded, and set to start

Note: These are internal targets and subject to change

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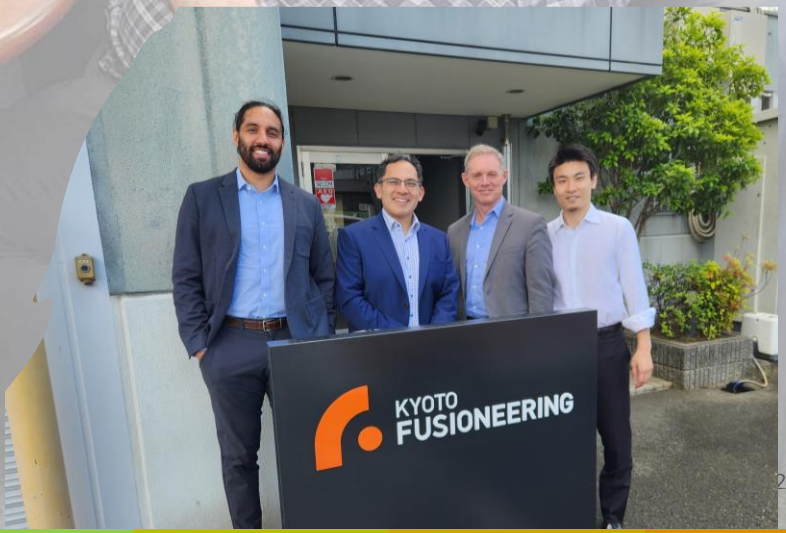
UNITY-2 Team

A global team of over 30 engineers – and counting!



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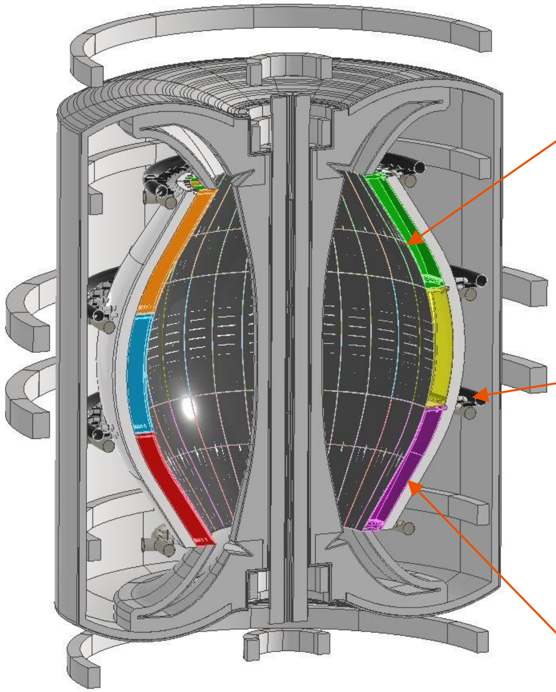
Tour the UNITY-2 site during Tritium 2025! (Sep 21-26, 2025)

Tritium 2025

Key supporting activities

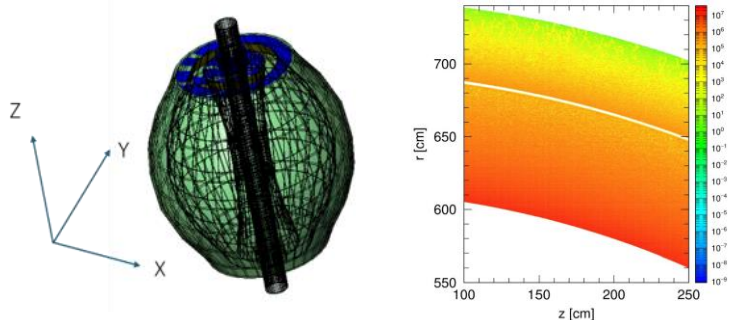
Plant System Design Activities

Liquid blankets: liquid metal and molten salt coolants

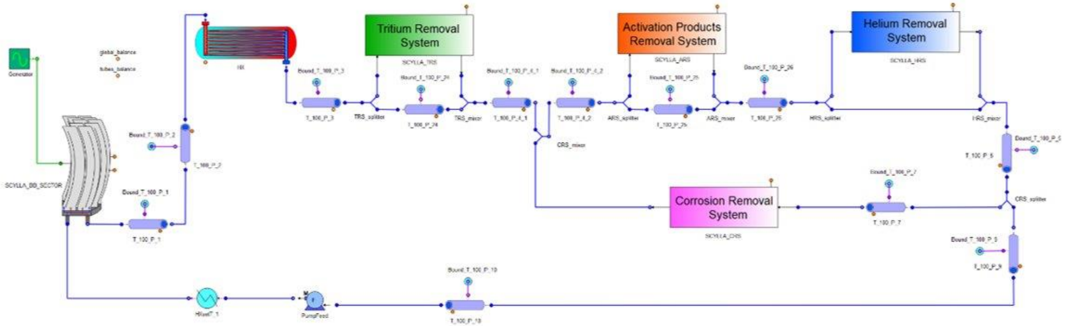


See: Pearson et al., 2022

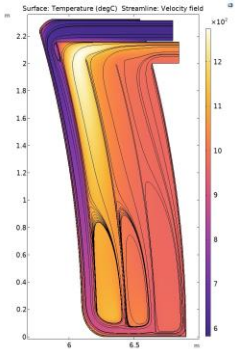
Neutronics



Tritium transport



Thermohydraulic and thermomechanical analysis

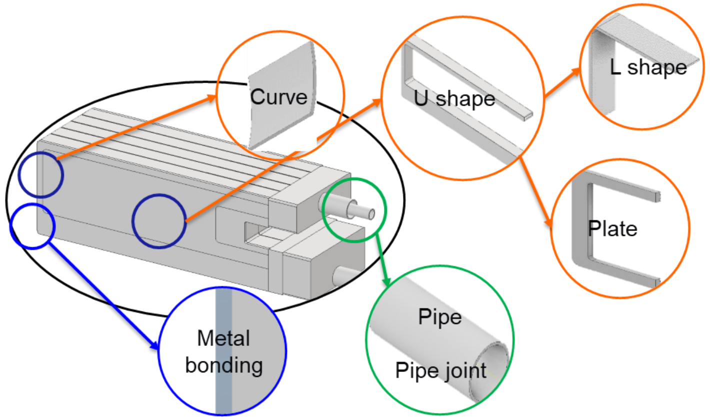


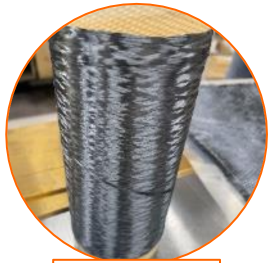
Activities include:
TRL assessments, RAMI, FMEA, FMECA, SDS, I&C and a long list of supporting R&D development

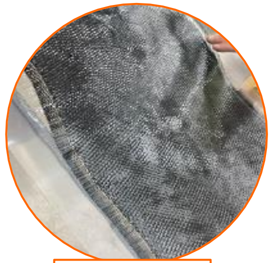
Materials Development

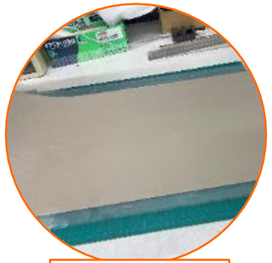
Novel materials development, including silicon carbide composits (SiCf/SiC), for high temperature operations.

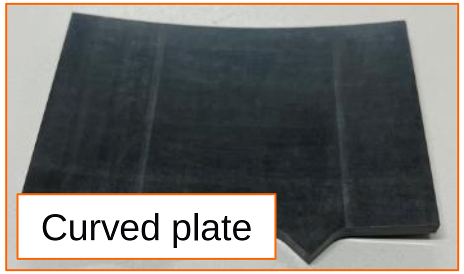
- To confirm **feasibility** of SiC/SiC composites for blankets
- To organize the **supply chain** to fabricate
- To confirm parts can be combined to make **larger** module

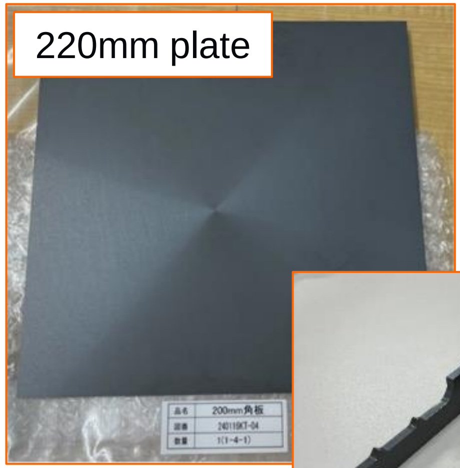


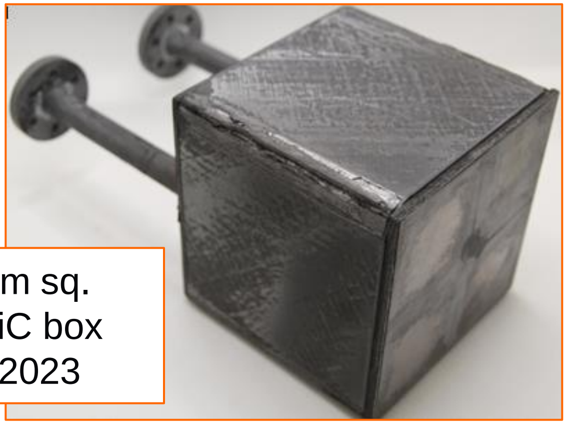

Fiber

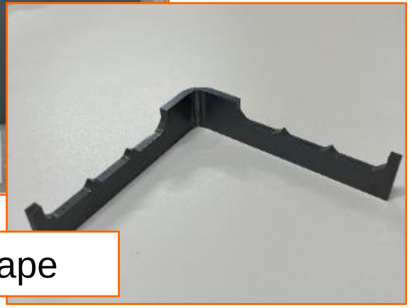

Fabric


Prepreg


Curved plate


220mm plate


100mm sq. SiC_f/SiC box Oct.-2023


L-shape

Kyoto Fusioneering UK

KF's technologies for the UK market.

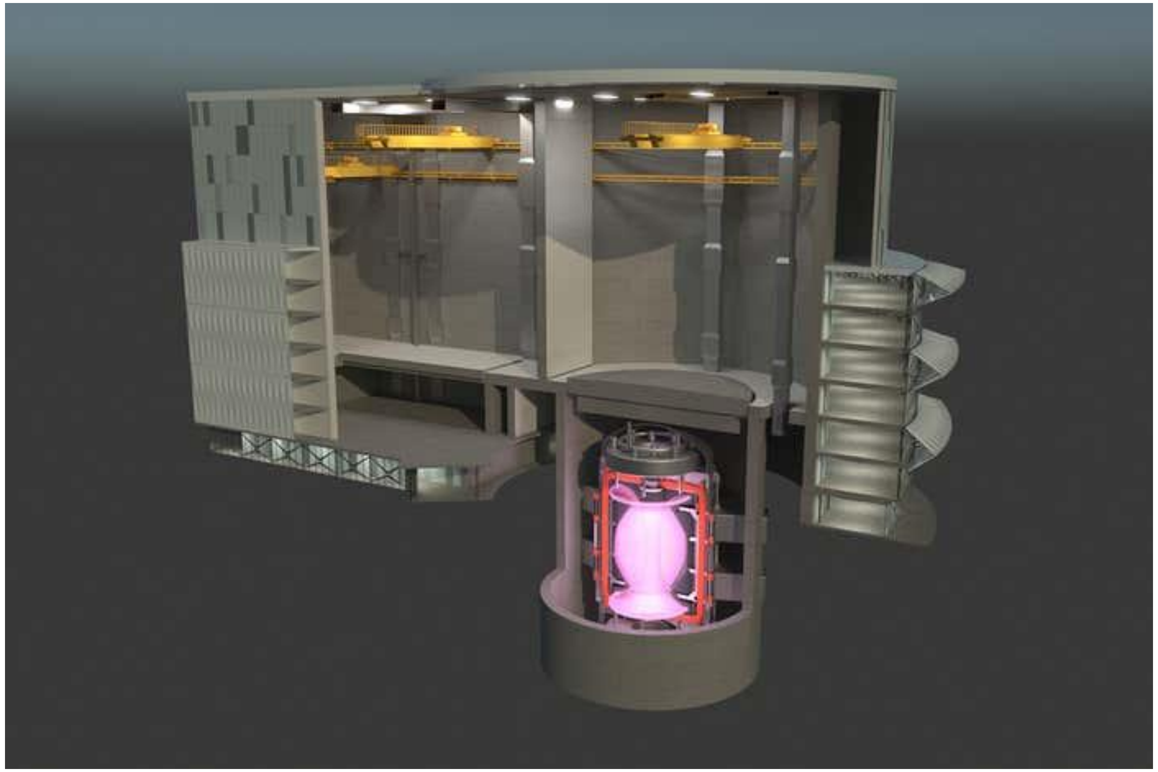
The UK Fusion Landscape

The UK is a world leader in fusion, supported by a strong national program and government commitment.

Key Milestones:

- **Past Successes:** UKAEA's legacy with JET and MAST-U, pioneering regulatory frameworks, and cutting-edge research.
- **Future Look:** The UK Government's **STEP program** (aiming for first plasma by 2040) and recent "Fusion Futures" funding (£650M), which has a remit to support industry innovation.

Global Collaboration: The UK has partnerships with international leaders, including the U.S. and Japan (fostered by KF), to enhance cross-border opportunities in fusion.



The UK National Programme: STEP (concept image)
Image source: UKAEA. (Public Domain).

Kyoto Fusioneering UK: Mission and Purpose

Our UK Mission: Launching formally in 2021, Kyoto Fusioneering UK was established to lead in fusion innovation and support the development of the UK market, by providing KF's engineering and technology deployment.

- **Business Development:** Sales of equipment like gyrotrons, tritium systems, as well as engineering services (blanket design, etc.).
- **Capability Growth:** Expanding engineering expertise and supporting global projects to ensure KF's technologies meet emerging UK and international market needs.

Our Purpose: Drive growth in the UK fusion ecosystem, leveraging KF's strengths to support fusion's transition from research to viable energy production.

Kyoto Fusioneering UK: Profile, Progress, and Achievements

Active Presence:

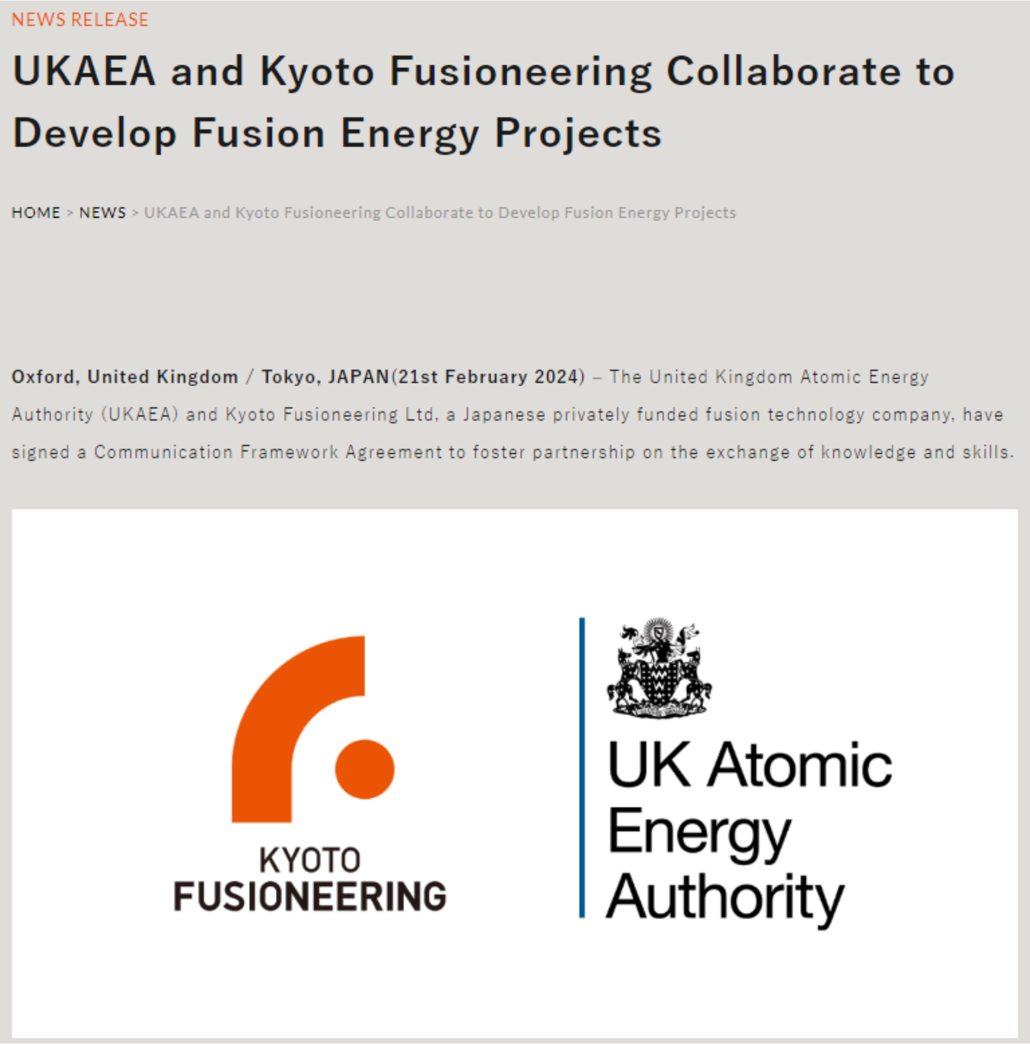
- **Strategic Contracts:** Awarded projects through government initiatives (Supplier to UKAEA on STEP Tritium Framework, UKAEA Engineering Design Services).
- **Collaborative Projects:** Formal framework with UKAEA on joint R&D (e.g., blanket engineering, tritium, and power technologies).

Growth & Engagement:

- Team Expansion: Grew from 4 to 12+ staff in 18 months, with new hiring to meet project demands.
- Government & Industry Connections: Engaged with key UK government bodies, industry associations, and educational initiatives (e.g., PhD projects).

Local Impact:

- Sited in Reading, 40 minutes from Culham—close to the centre of UK fusion.


NEWS RELEASE

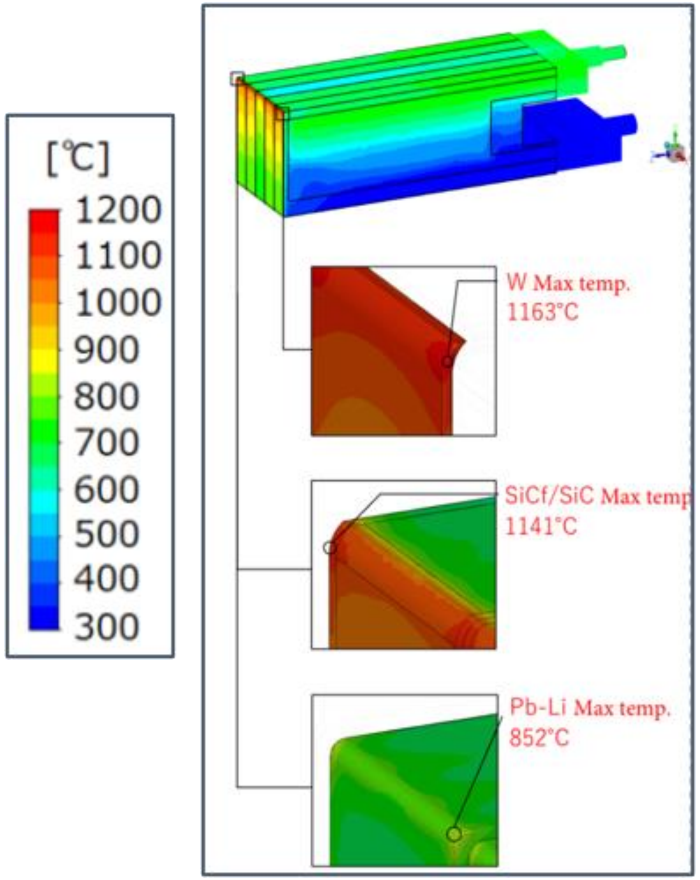
UKAEA and Kyoto Fusioneering Collaborate to Develop Fusion Energy Projects

HOME > NEWS > UKAEA and Kyoto Fusioneering Collaborate to Develop Fusion Energy Projects

Oxford, United Kingdom / Tokyo, JAPAN(21st February 2024) – The United Kingdom Atomic Energy Authority (UKAEA) and Kyoto Fusioneering Ltd, a Japanese privately funded fusion technology company, have signed a Communication Framework Agreement to foster partnership on the exchange of knowledge and skills.

UK: Blanket Engineering Focus

- **SCYLLA (Self-Cooled Yuryo Lithium Lead Advanced) type blankets**
  - Complete pre-conceptual design, including:
    - Technology readiness analyses and maturation planning
    - Safety analyses including functional and RAMI analyses
    - Breeder blanket system design including MHD analyses, tritium extraction system design and lithium-lead loop development.
- **DCLL (Dual Cooled Lithium Lead) type blankets**
  - Collaboration with UKAEA
- **UK-led project supported by – and informing the direction of – R&D activities in materials & component development in Japan**



Recap & Concluding Remarks

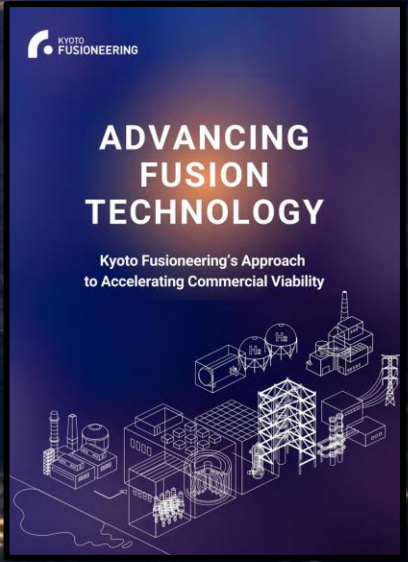
Recap & Concluding Remarks

- **Fusion: "Last Energy“ for Humanity?** A potential power source for the next millennium.
- **A Transformative Shift:** Recent scientific breakthroughs and the rise of private fusion developers are redefining the landscape. We have undergone a “paradigm shift”; a fundamental change in the approach to the problem.
- **Complex Path Ahead:** many organisations are focused on novel plasma machines, where challenges remain. KF is developing critical path technologies that provide immediate solutions while paving the way for future advancements.
- **Current Innovations:** KF is Deploying gyrotrons for plasma heating, developing key technologies for the thermal and fuel cycles through its UNITY program—supporting global developers today, also building out the next steps.

Our Commitment is "Fusion for the Future“ — we're building that future today.

KYOTO FUSIONEERING

Read Kyoto Fusioneering's report:
"Advancing Fusion Technology"



ありがとうございます

(Thank You Very Much!)

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