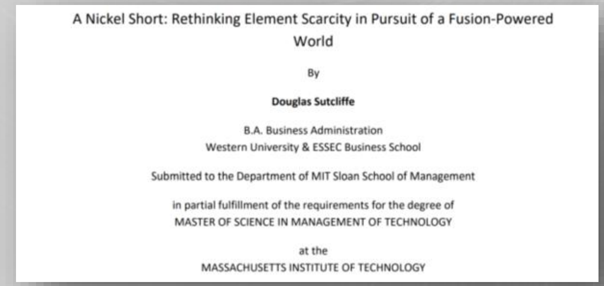
Douglas Sutcliffe
MS, Management of Technology (Fusion) at MIT | 6 Sigma | PSM II

3x founder, Fortune 500 product leader, driving over $1B in annual revenue, thesis on mineral sufficiency for fusion energy.



A Nickel Short: Rethinking Element Scarcity in Pursuit of a Fusion-Powered World

By

Douglas Sutcliffe

B.A. Business Administration
Western University & ESSEC Business School

Submitted to the Department of MIT Sloan School of Management

in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE IN MANAGEMENT OF TECHNOLOGY

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MODULE12

AS SEEN IN:

International Business Times

Entrepreneur

HACKERNOON

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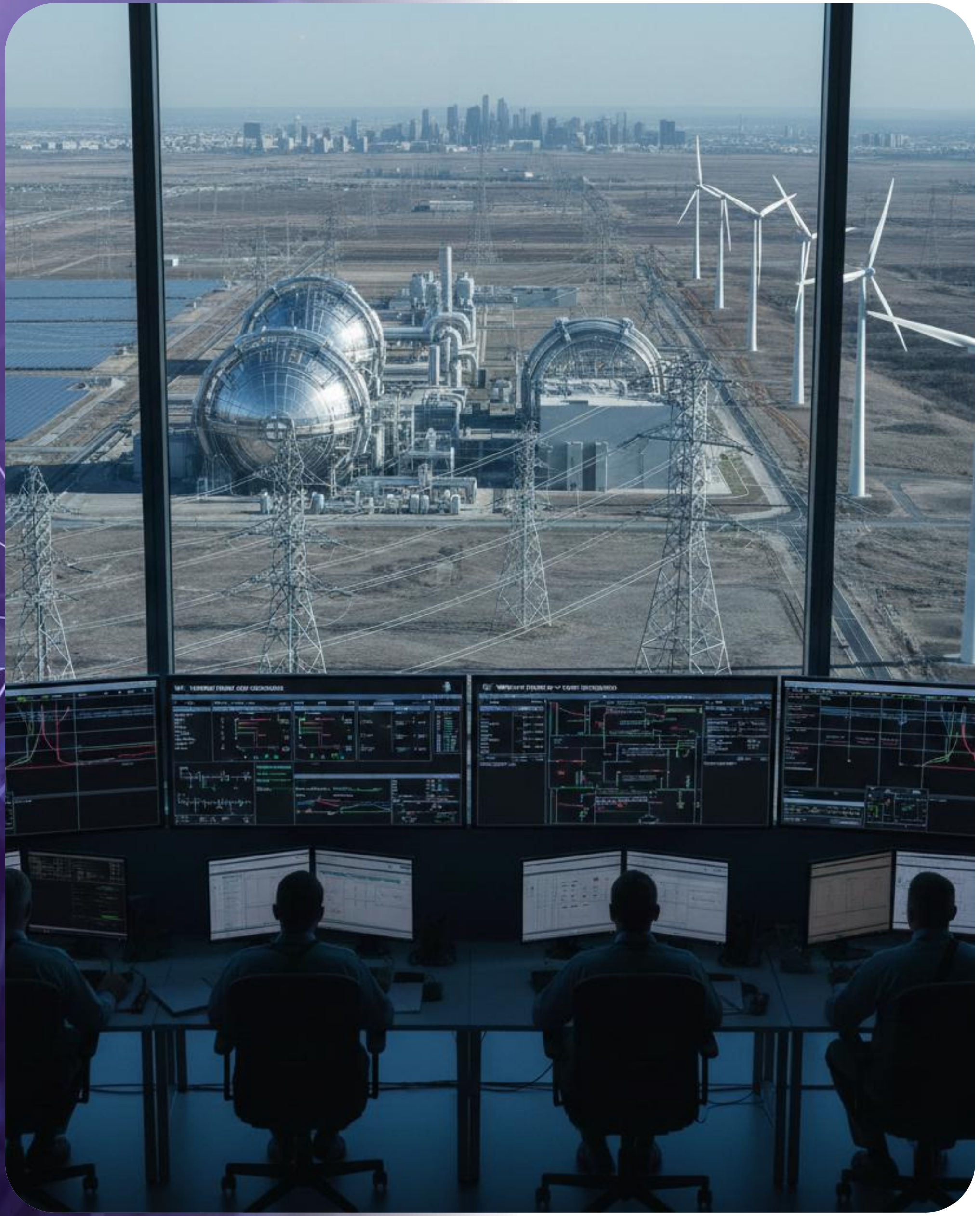


Part 3

Execution: Constraints and Strategies

Practical Limits: Scientific Challenges

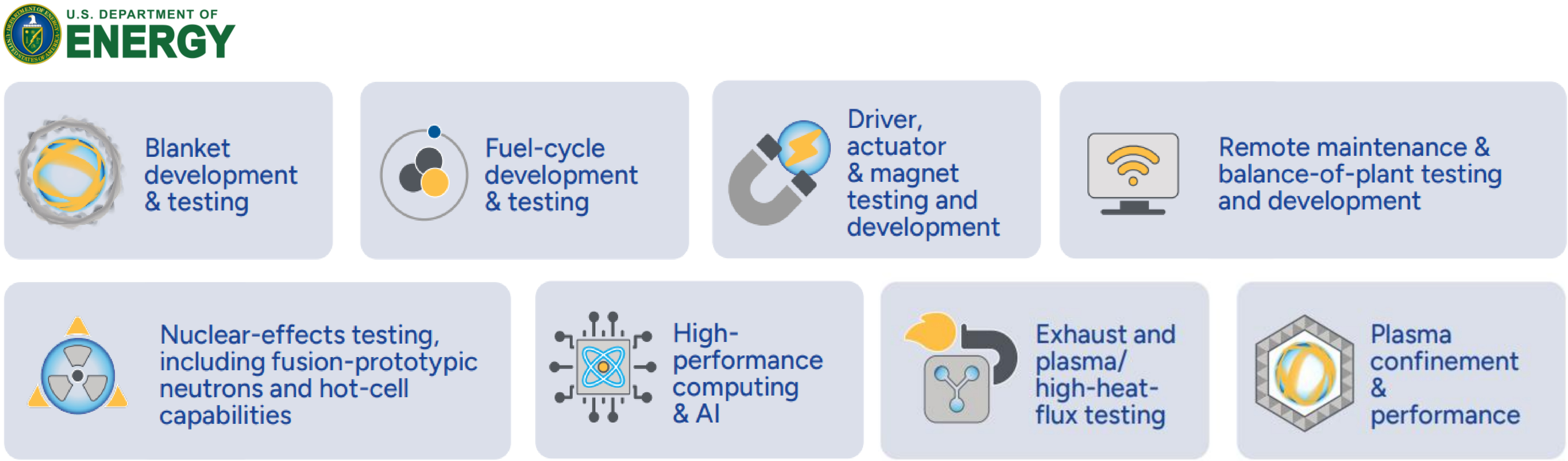
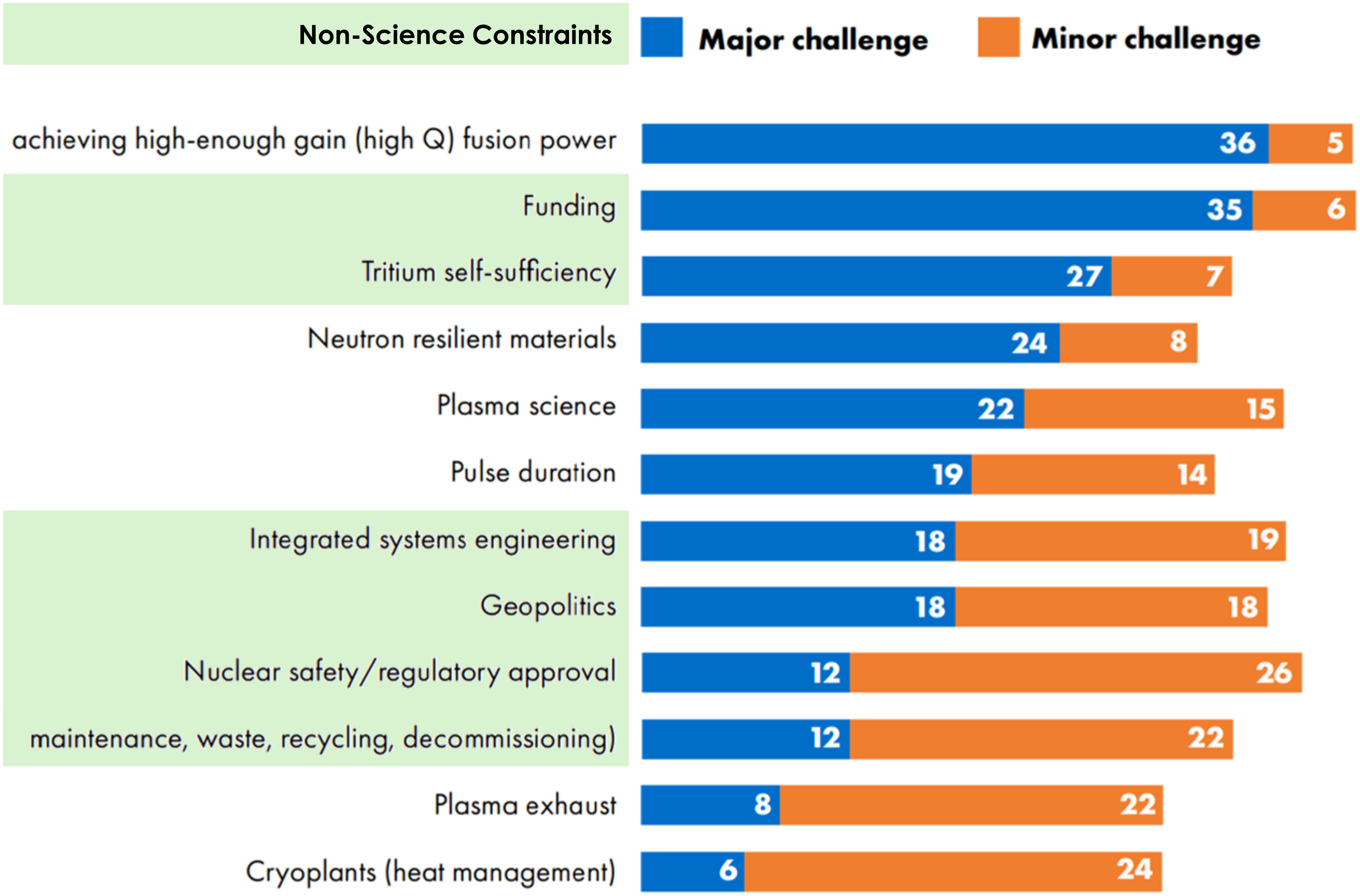


Figure 4. Eight distinct infrastructure streams critical for progress towards the development of fusion power plants have been identified.

https://www.energy.gov/sites/default/files/2025-10/fusion-s%26t-roadmap-101625.pdf

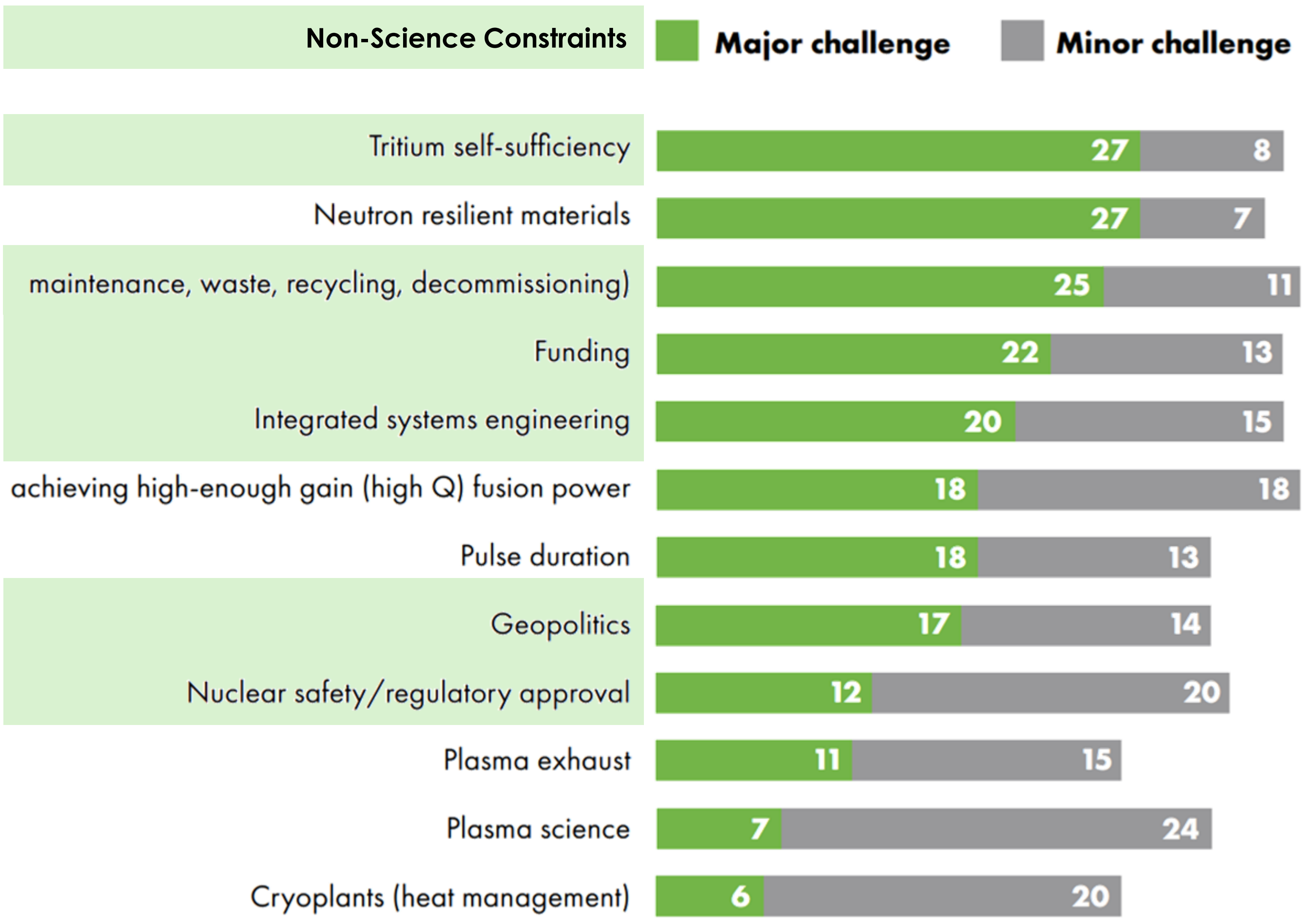
Practical Limits From Now Till 2030



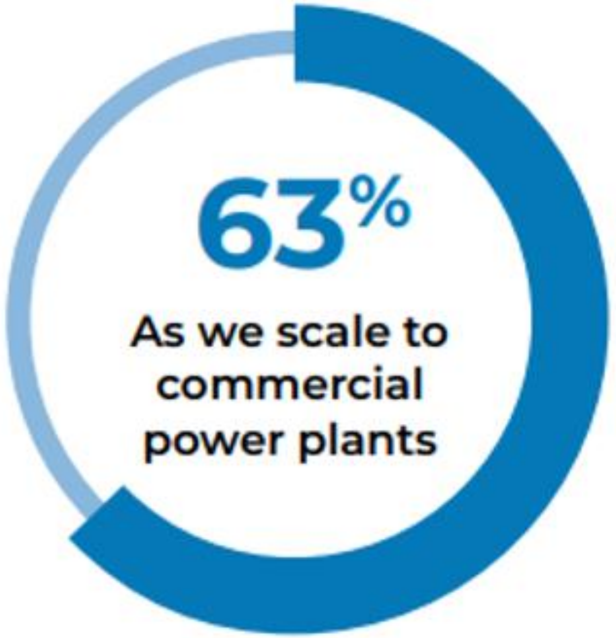
% of Industry players **concerned** about **sufficient** specialist **suppliers**

https://www.fusionindustryassociation.org/wp-content/uploads/2025/06/FIA-2025-Supply-Chain-Report.pdf

practical limits: Top Concerns After 2030



% of Industry players **concerned** about **sufficient** specialist **suppliers**



https://www.fusionindustryassociation.org/wp-content/uploads/2025/06/FIA-2025-Supply-Chain-Report.pdf

A Timeline of Critical Hurdles:

2026: Financing

Fusion is **expensive, risky, and slow** to return investment, a significant amount of capital is essential, but **current funding** models are **not a perfect fit.**

D-T

2030: Feed Stock Sufficiency

Early fusion machines will consume **tritium** long before starting to breed it. With **<30KG on earth** this won't last long. Once operational, regulations may limit enriched feed-stocks like **lithium** and **tritium**. (A similar constraint exists for H3)

2040: Demand Driven Cost Cycle

As operational energy providers, **price** becomes crucial. Fusion must compete with traditional **energy sources**. Metrics like **maintenance down time** and **capacity factor** become critical.

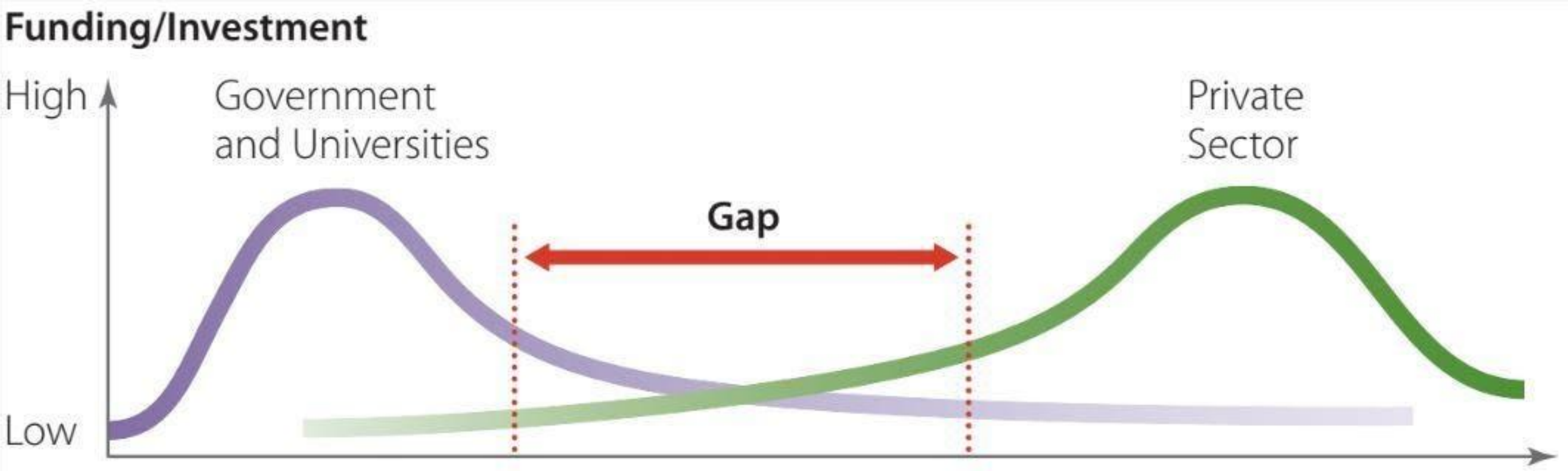
2050: Supply Limitations and Supporting industries

As more power plants are deployed, consumption drives up **prices** of **fusion-specific** materials, while broader market trends drive **demand** for other **critical inputs.** Development of a **supply chain industry** will be essential to balance rising material costs.

Talent

As with any new and highly technical industry, especially one as vertically integrated as fusion, **talent shortages** will exist at **many stages** of fusion's evolution. Critically, with each step in it's growth, the **needs evolve**, exacerbating the difficulty of this critical challenge.

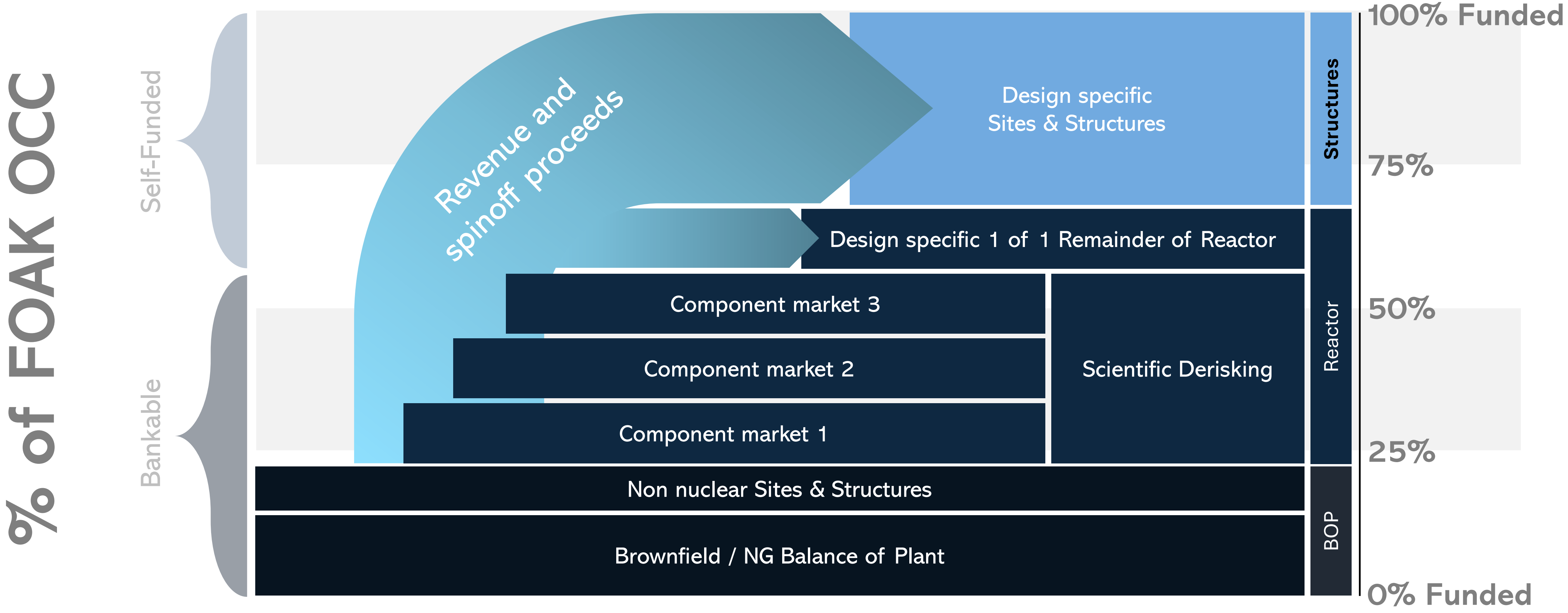
Practical Limits: Financing



mismatch between timescale, risk, and investment size of fusion vs current capital structures (Grants, VC, PE, Lenders, etc.)

https://www.forbes.com/sites/energyinnovation/2019/02/28/how-clean-energy-rd-policy-can-help-meet-decarbonization-goals/

Commercial Pathways



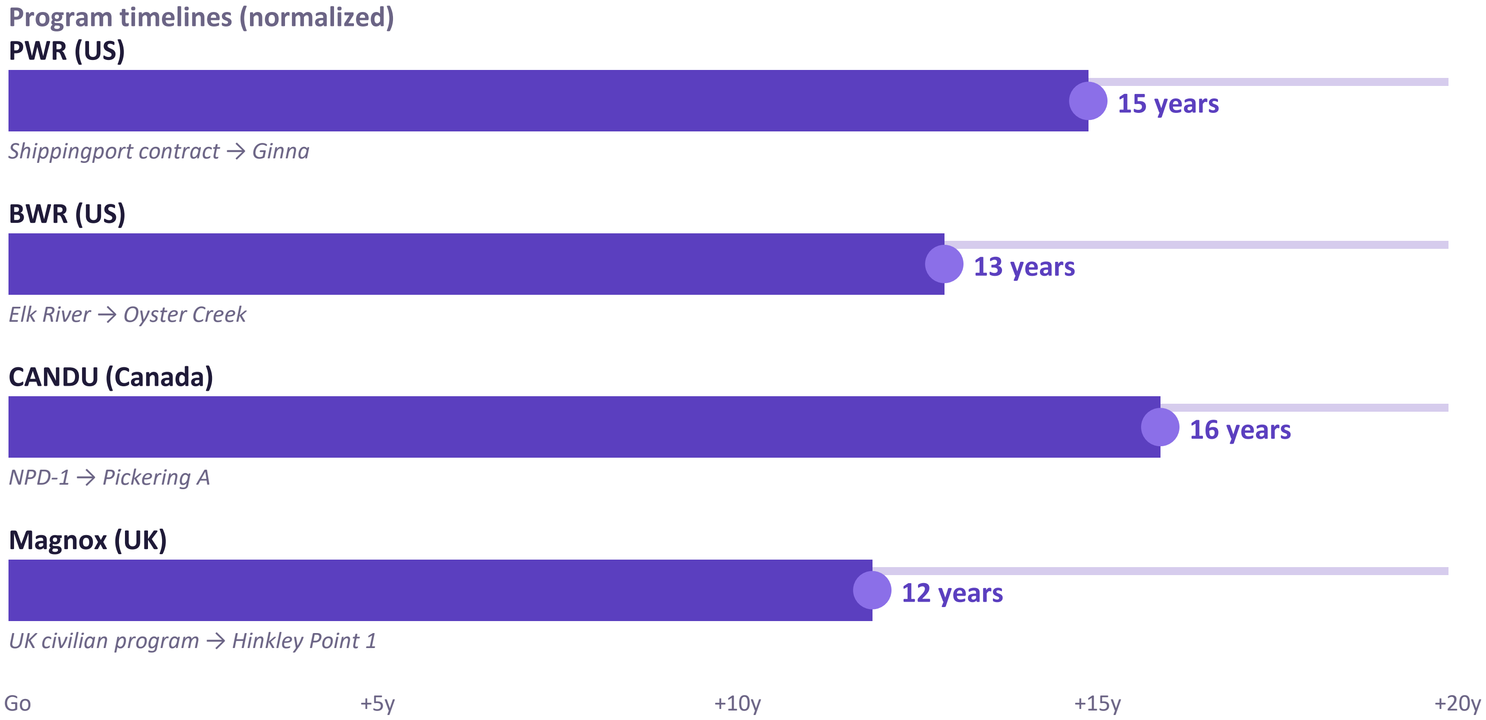
Every successful program took 12-16 years to commercialize

Across four reactor families and three countries — a remarkably tight range.

2-4

years on average

Operational proof between each stage

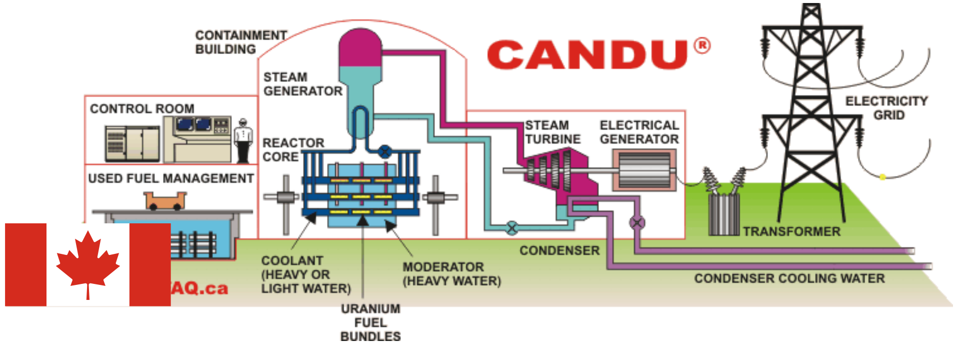


Success Factors

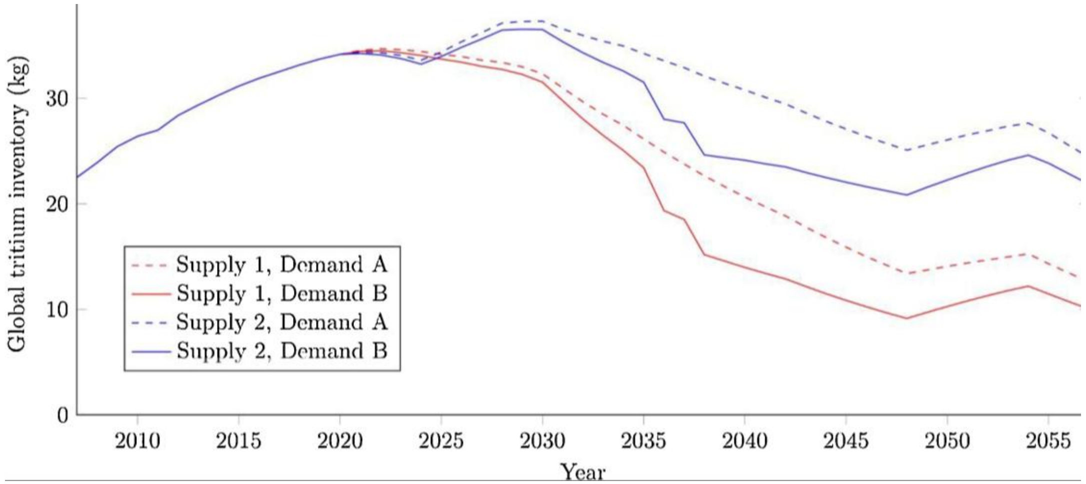
- Successful programs had a clean derisking ladder
- Most failures were execution failures, not physics failures
- Operational reliability mattered more than novel performance
- Industry crowded in for proven steps; government supported for novel ones

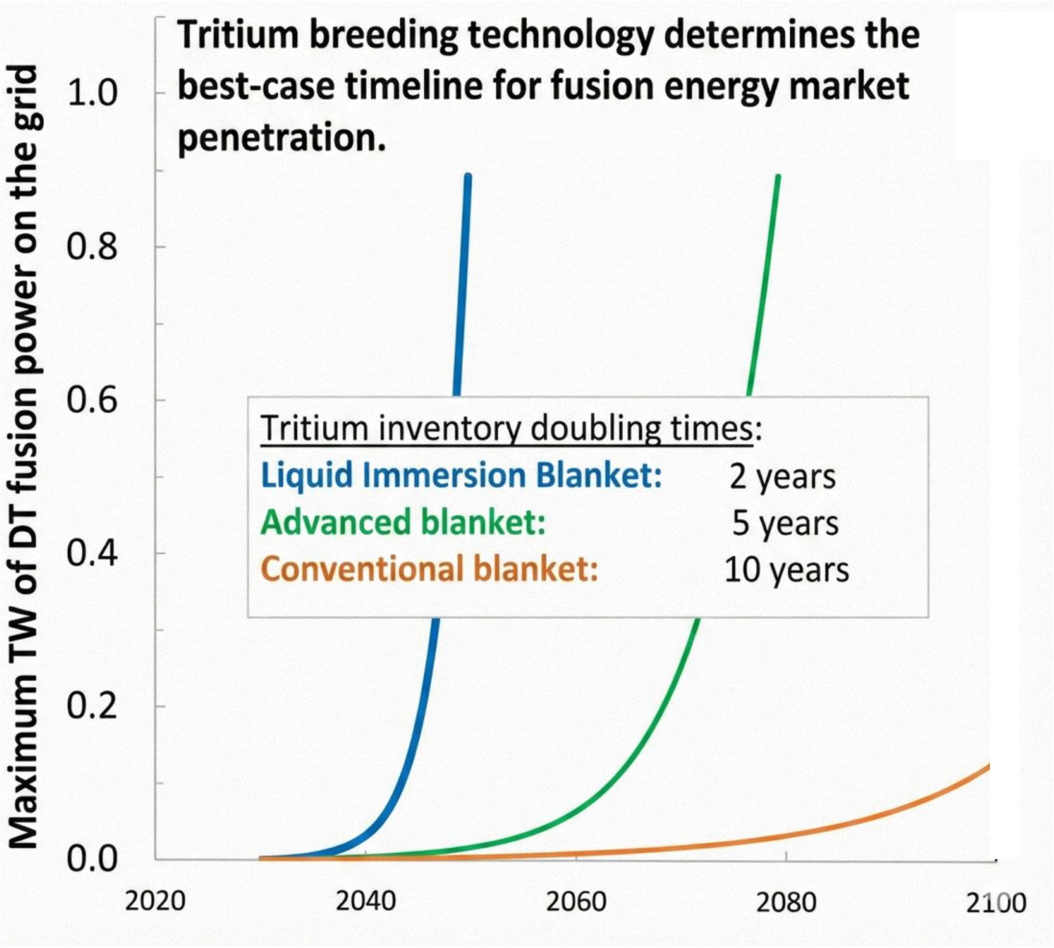
Practical Limits: Feed Stock

D-T



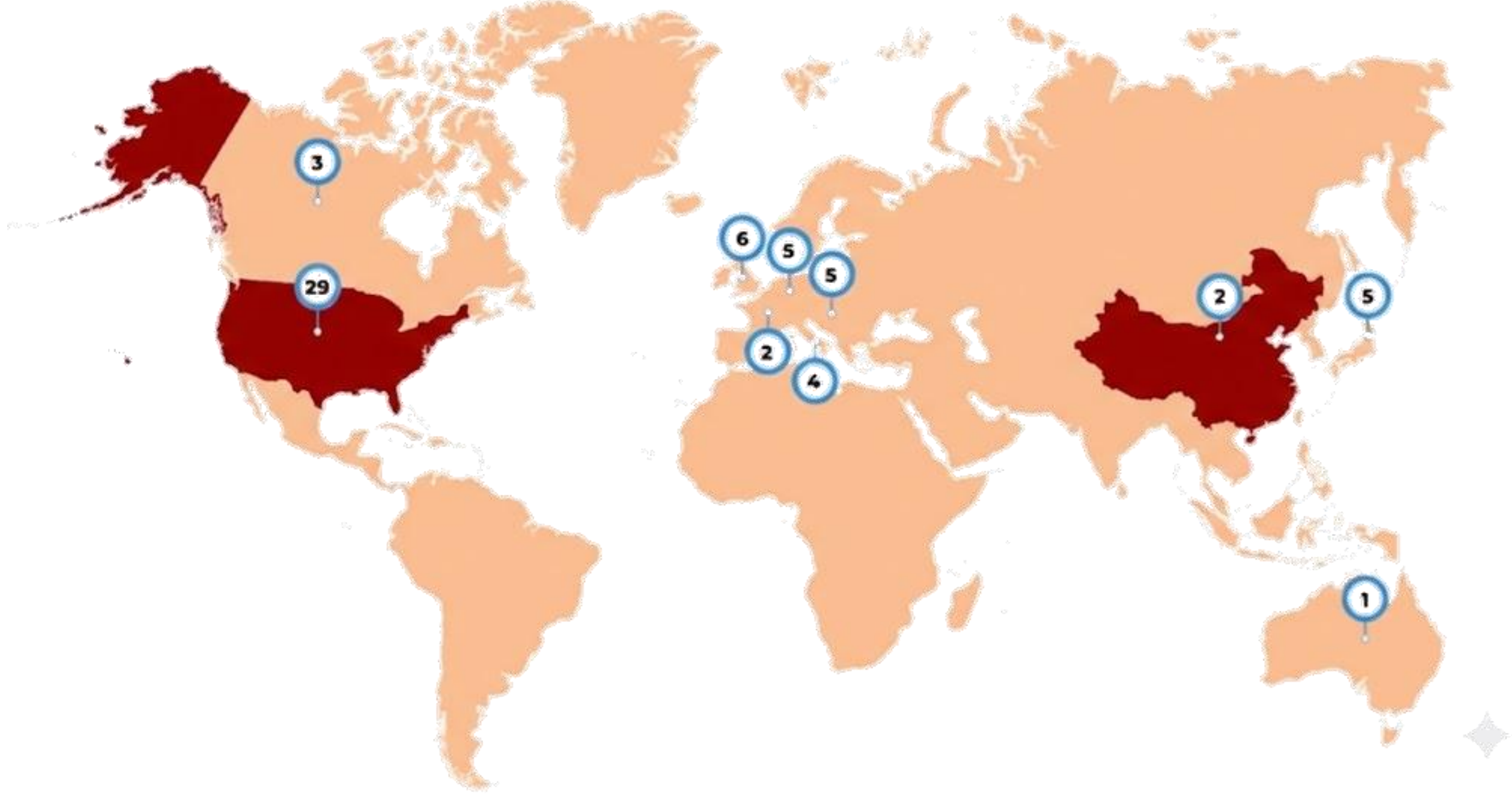
Tritium Half-life: 12.5y Global Inventory: ~25 kg





https://www.sciencedirect.com/science/article/pii/S092037961830379X

Practical limits: Supply Limitations Geographic Concentration & Geopolitics



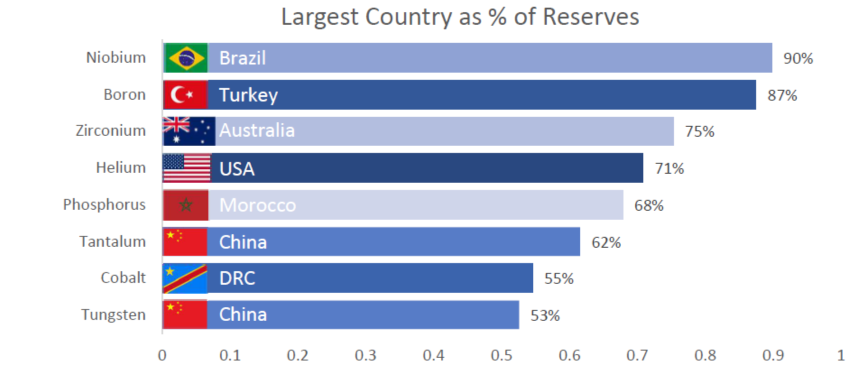


Figure 6: Largest countries by % of reserves per mineral.

7.5 Top-Country Dependence Dramatically Increases Supply Risk

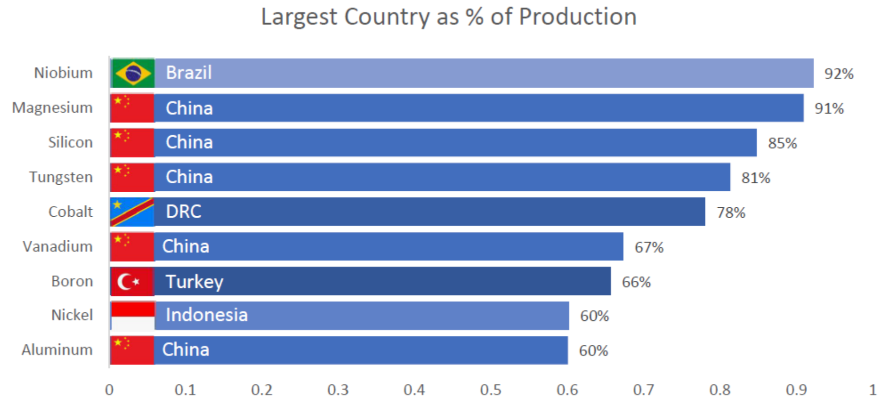
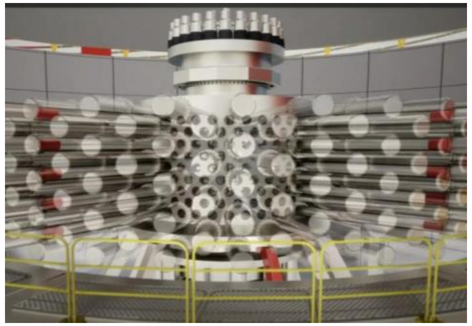


Figure 5: Largest Countries as % of Production by Mineral

https://www.fusionindustryassociation.org/wp-content/uploads/2025/06/FIA-Supply-Chain-2025-Report.pdf

Supply Limitations - Critical Minerals – Solutions, research & mitigation



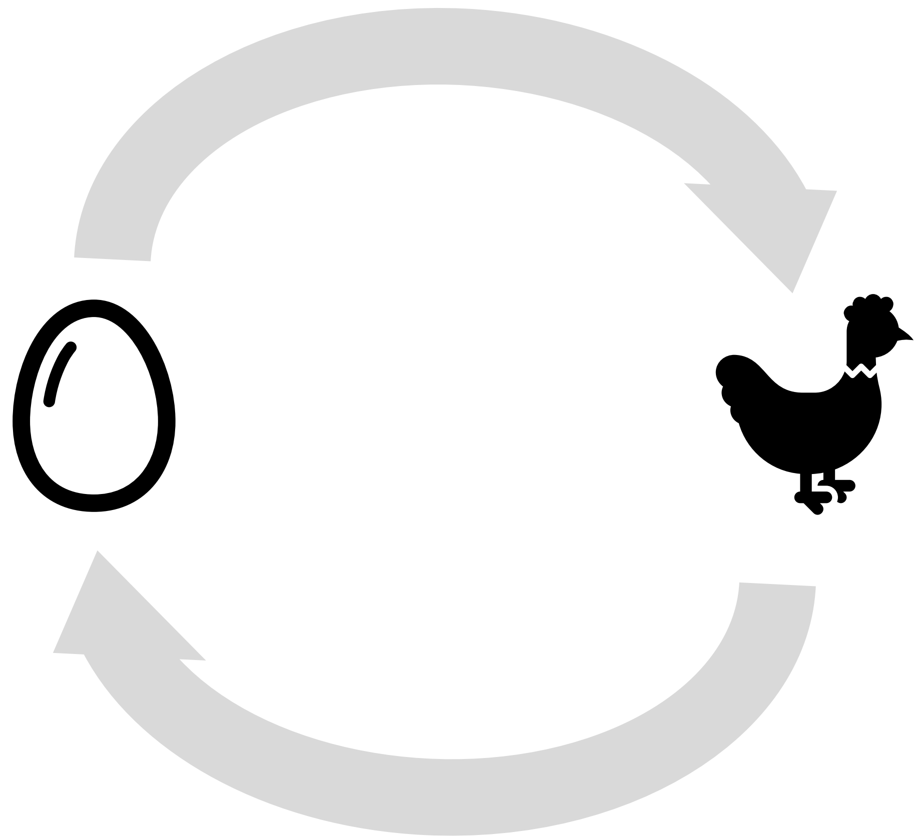
1. **Material Strategy (Design-Level)**
    - Replace scarce materials with alternative alloys or blanket concepts
    - Best when fusion demand alone exceeds reserves and substitutes meet performance needs
2. **Isotopic & Functional Optimization**
    - Reduce dependence on scarce isotopes via blanket and neutron-economy redesign
    - Best when scarcity is isotope-specific and efficiency gains are achievable

Supply Limitations - Critical Minerals – Solutions, research & mitigation

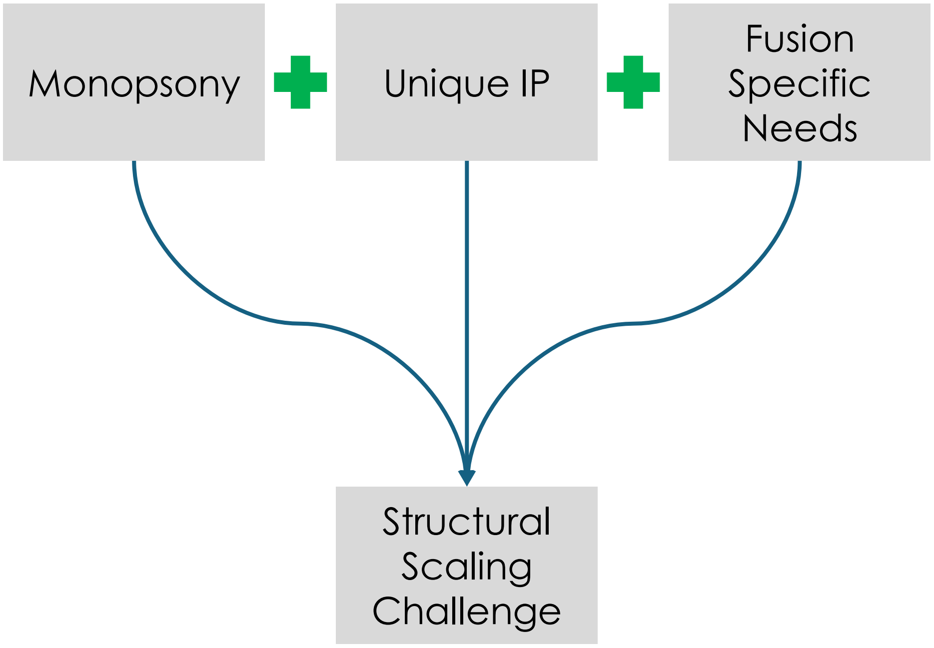
3. **Hedging & Stockpiling**
    - Lock in supply via futures contracts or low-volume physical stockpiles
    - Best when fusion demand is small but price volatility threatens project economics

4. **Recycling & Circular Supply**
    - Expand recycling to reclaim high-value metals and reduce primary extraction
    - Best when shortages stem from combined fusion and non-fusion demand

Practical limits: Supply Chain Risk Concentration

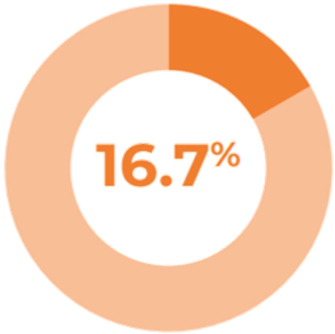


Practical limits: Supply Chain Risk Concentration

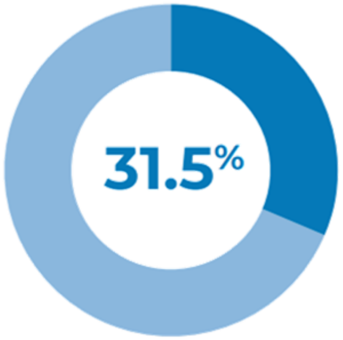


Requires Standardization, Alignment, and Risk Sharing

Not positioned to scale capacity



Want to scale capacity but **can't** absorb **any risk**



Already investing to scale capacity

Prepared to take on some scaling risk **if shared** with customers

https://www.fusionindustryassociation.org/wp-content/uploads/2025/06/FIA-Supply-Chain-2025-Report.pdf

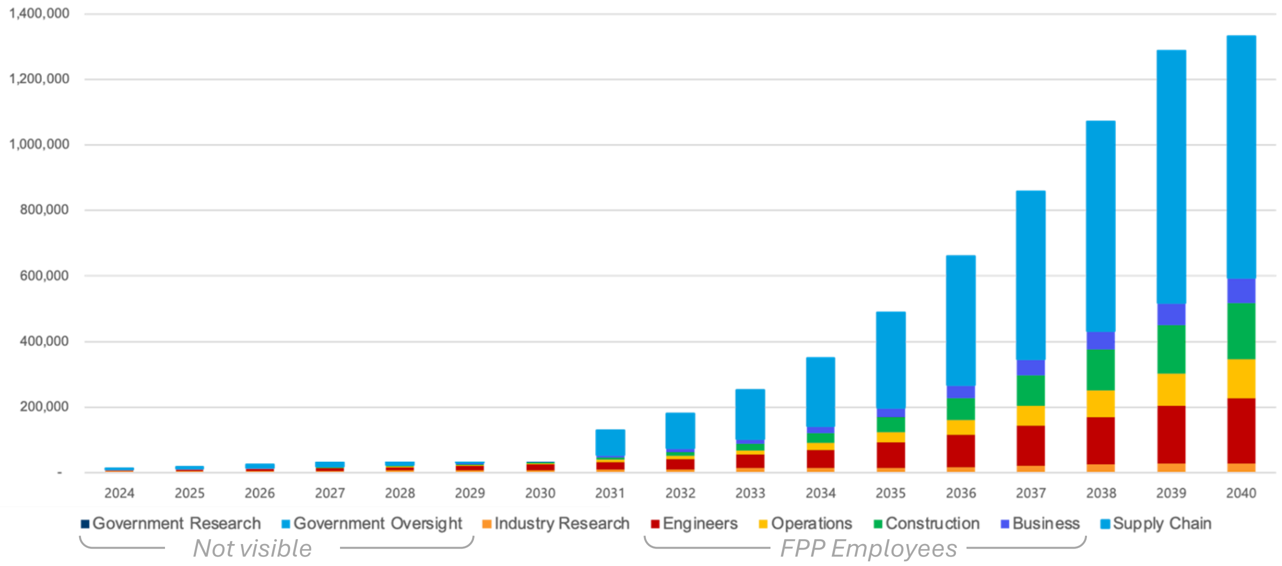
Practical limits: Talent Gaps – Supply Chain

“Today, 75% of fusion workers are scientists or engineers, and 38% hold PhDs”

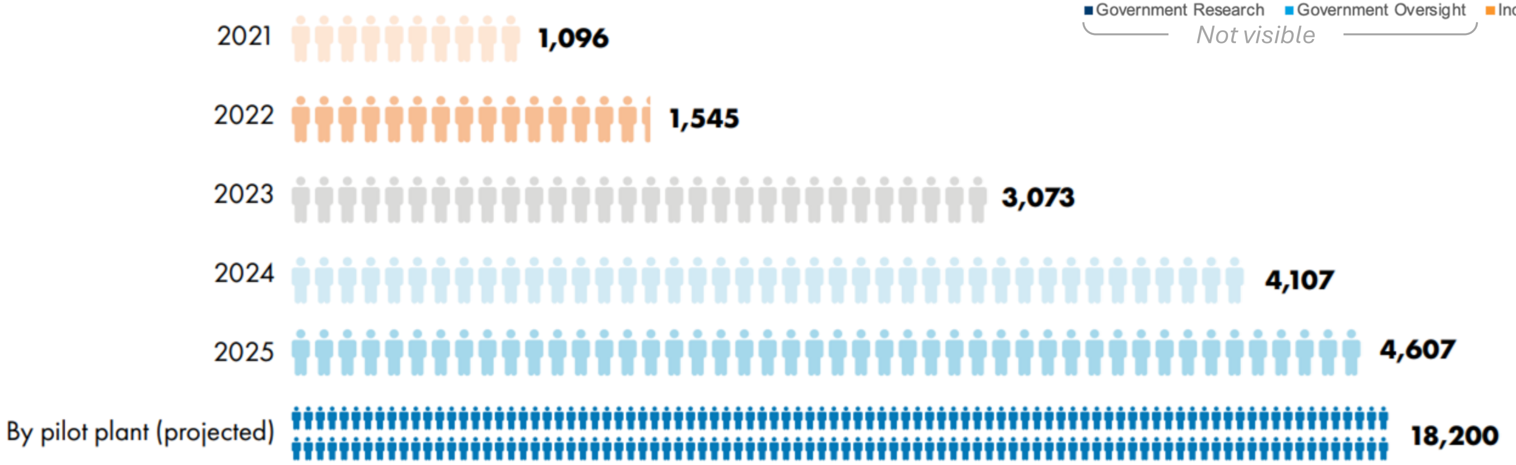
“Over the next 10 - 15 years, the demand for PhDs will decline, while the need for hands-on engineers, project managers, and technicians will surge”

- Securing the Fusion Workforce for the Future: The Talent Race to Power the Next Energy Revolution

Fusion Jobs Forecast - Whole Industry



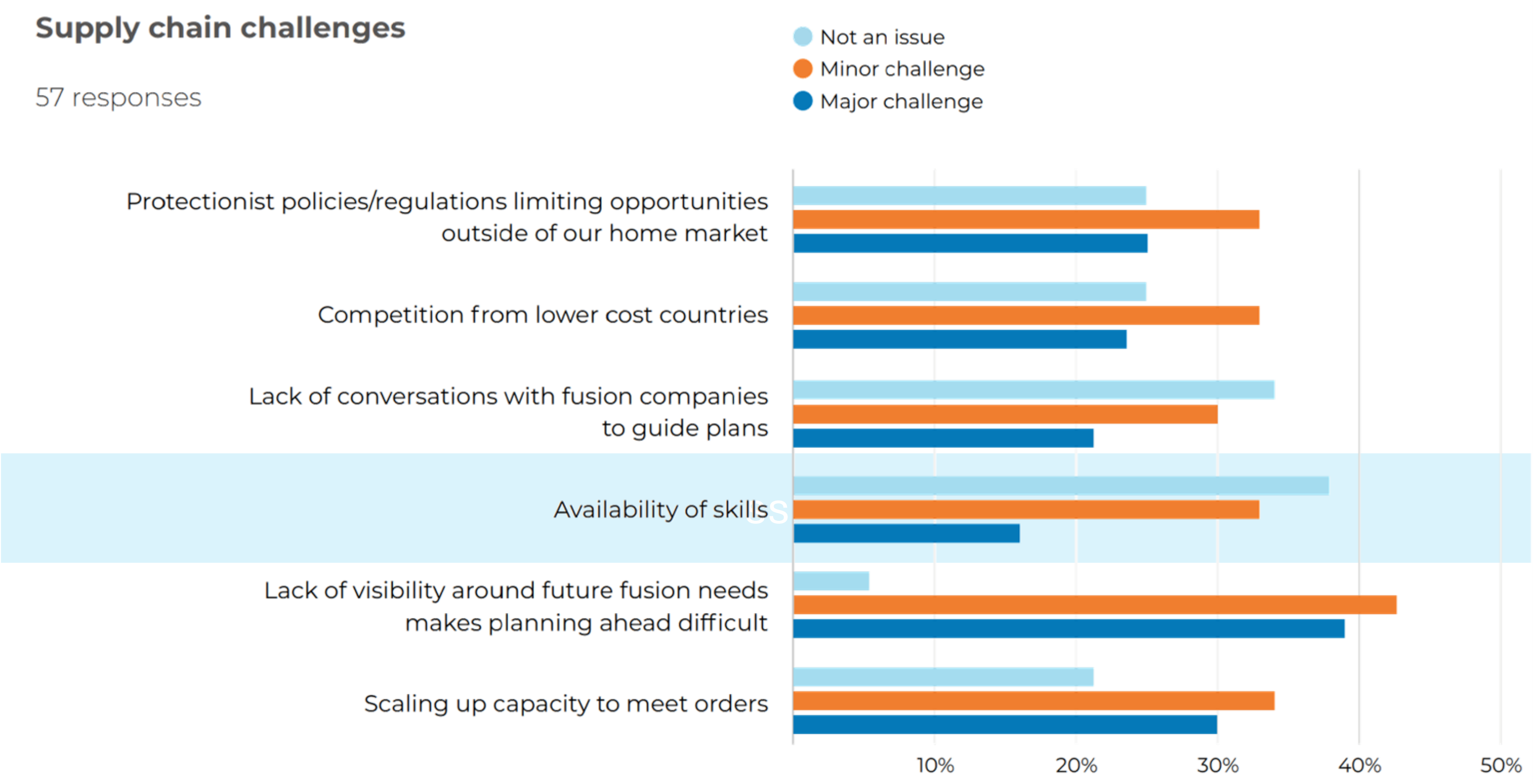
Fusion Jobs Forecast - Power Plant (FPP) Companies



https://www.peaknano.com/blog/1000000-fusion-energy-jobs-by-2050

Practical limits: Talent Gaps

Demand Will Not Be Driven By Component Supply Companies



So What Skills Are Needed?

STEM:

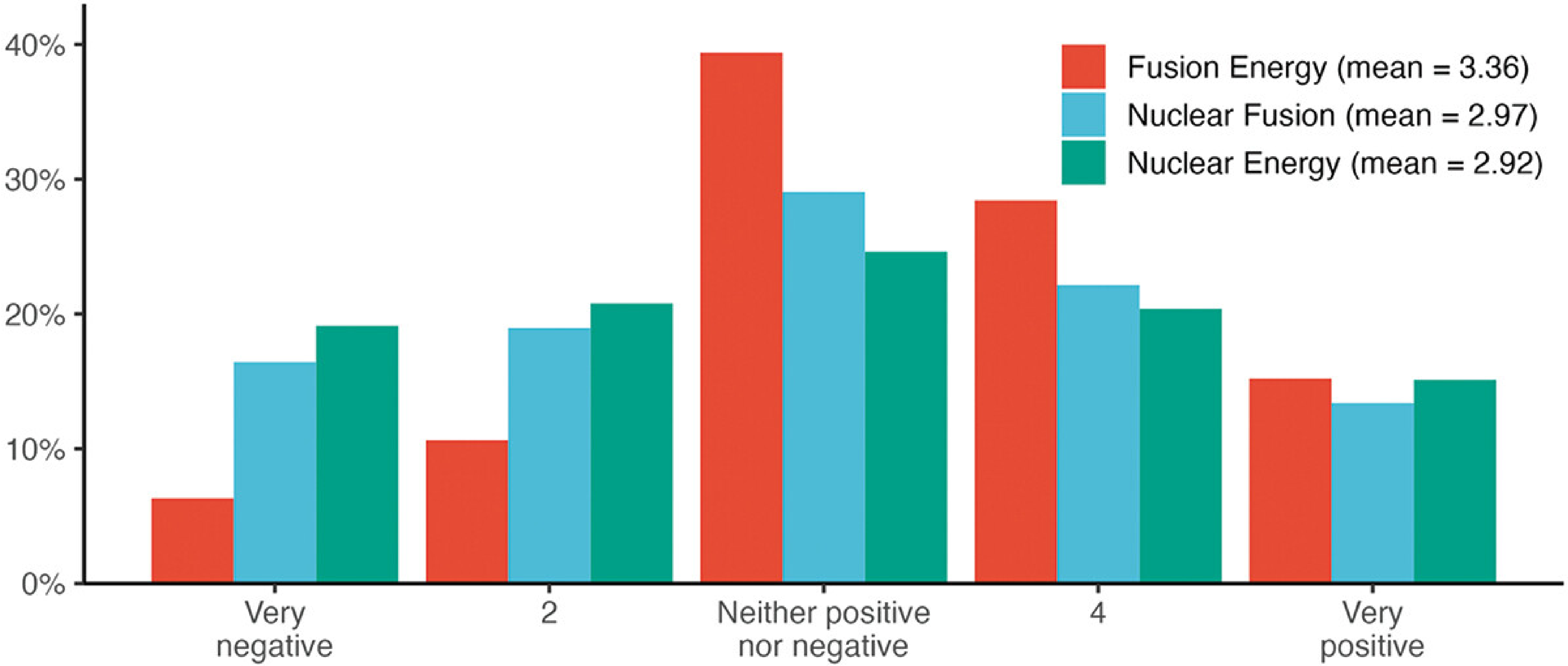
- Electrical and mechanical **engineering**
- Cryogenics and superconducting **magnet design**
- **Materials science** and neutron shielding
- **Robotics** and advanced manufacturing
- **AI, data science**, and real-time plasma control

Trades:

- Raw **material extraction** and processing (mining, refining, and forging)
- **Specialized fabrication** skills (electricians, welders, machinists, software engineers, and materials scientists)

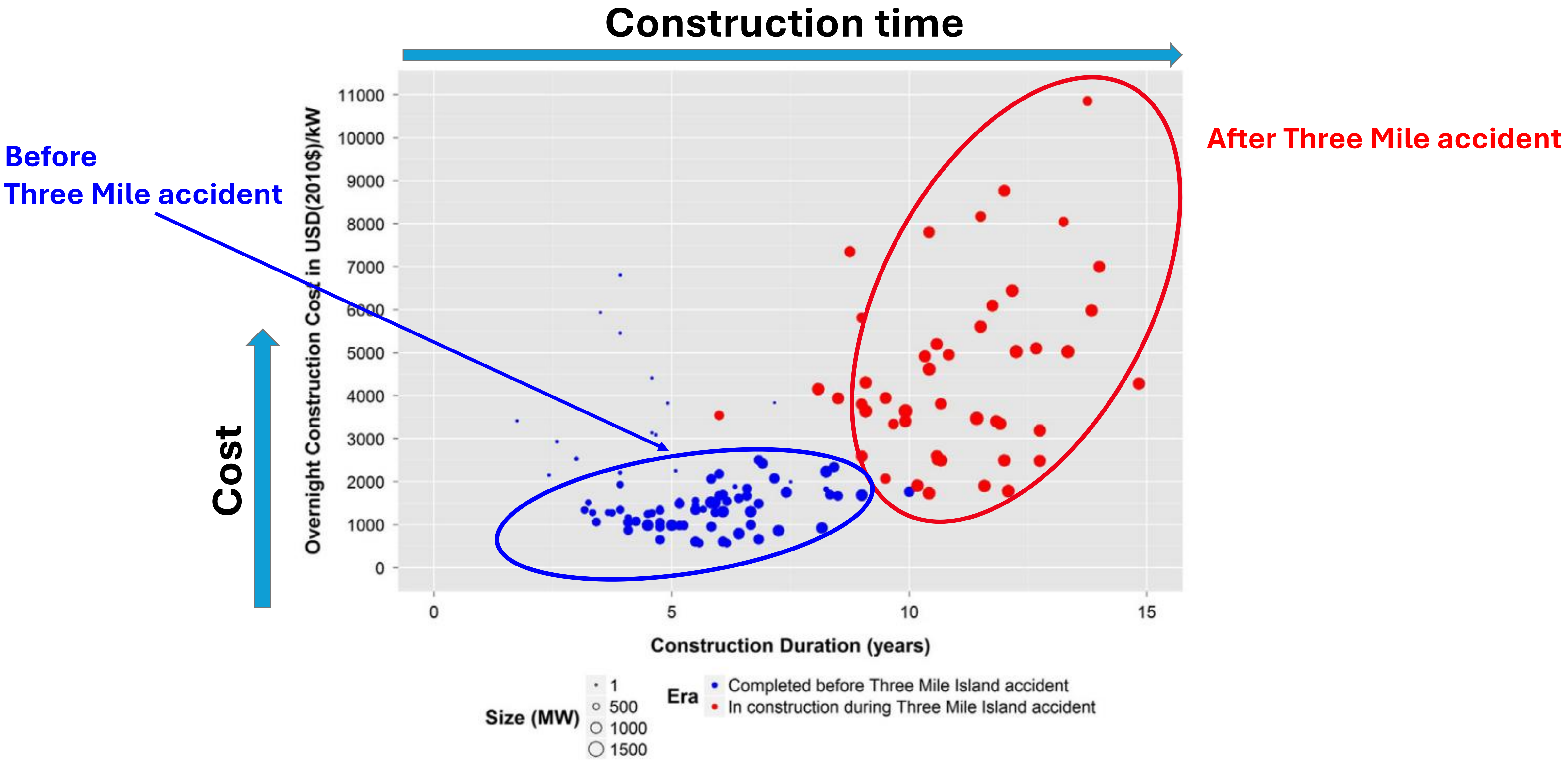
https://www.fusionindustryassociation.org/wp-content/uploads/2025/06/FIA-Supply-Chain-2025-Report.pdf
https://www.osti.gov/servlets/purl/3004770#:~:text=The%20industry%20anticipates%20the%20creation,3
https://www.powermag.com/building-a-fusion-ready-workforce-why-stem-and-trades-education-are-key-to-americas-energy-future/ https://www.rullion.co.uk/insights/Securing-the-Fusion-Workforce-for-the-Future/

practical limits to scaling fusion: Public Sentiment



https://www.tandfonline.com/doi/full/10.1080/15361055.2024.2328457#d1e634

Regulators and policymakers



Historical construction costs of global nuclear power reactors. Jessica R. Lovering, Arthur Yip, Ted Nordhaus

REGULATORS & POLICY MAKERS

Global landscape of fusion regulation is evolving

INDEPENDENT REGULATORS

Only **two countries** have regulated fusion **independently from Fission**

USA & UK

These countries have established frameworks to regulate fusion energy as a distinct and separate category.

EMERGING REGULATORS & POLICY MAKERS

Other **major players** are building **dedicated** regulation, but currently **treat fusion like fission**

These nations are developing policies and regulatory approaches to integrate fusion into their clean energy future.

Clear, fit-for-purpose regulation will be critical to accelerate innovation, investment, and safe commercialization of fusion energy worldwide.

European Union. Plans

European Commission

EN

Energy, Climate change, Environment

Energy

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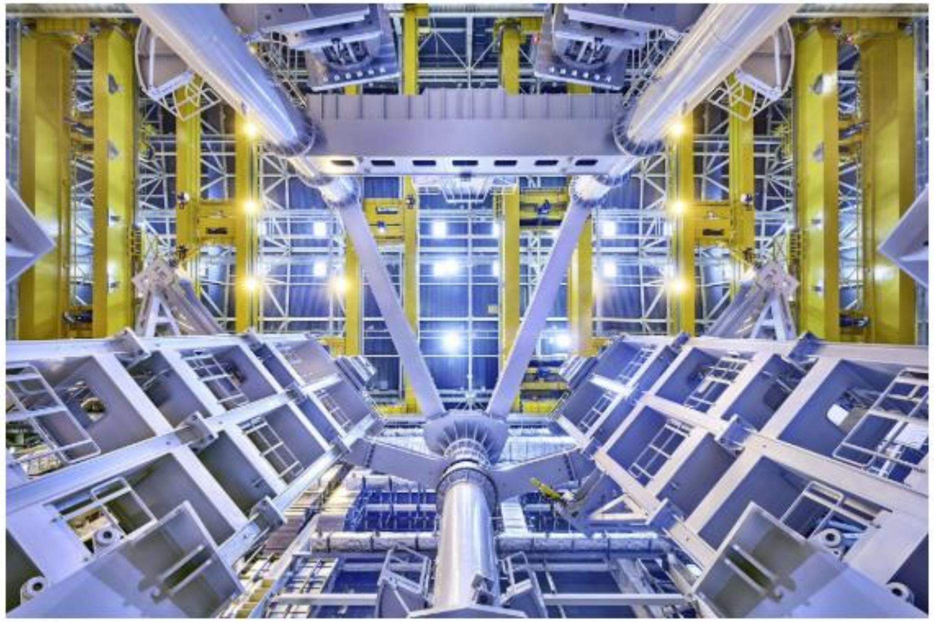
NEWS ANNOUNCEMENT | 6 June 2025 | Directorate-General for Energy | 2 min read

Commission launches Call for Evidence to support first-ever EU-wide Fusion Strategy



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China

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China to revise atomic energy law to promote nuclear power development, Xinhua says

By Colleen Howe

April 23, 2024 1:57 AM EDT · Updated April 23, 2024

Japan

Japan uses one of the world's strictest regimes for fission, but regulates fusion through radiation protection and facility safety rules, significantly lighter than nuclear reactor law, with no fusion-specific legislation yet.

Japan Fusion Energy Council

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Reuters

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Nuclear power at heart of new Japan prime minister's energy policy

By Katya Golubkova and Yuka Obayashi

October 22, 2025 4:39 AM EDT · Updated October 22, 2025

Aa

Canada

Canada's nuclear regulator (CNSC) runs a robust, internationally aligned fission licensing regime; fusion is currently regulated under existing radiation / research safety rules and is expected to develop a dedicated CNSC pathway as commercial projects mature

Français

Government of Canada Gouvernement du Canada

Search the website

MENU

Canada.ca > Canadian Nuclear Safety Commission > Nuclear safety - Acts and regulations

Fusion energy technology

The Canadian Nuclear Safety Commission (CNSC) regulates nuclear fusion through its responsibilities under the *Nuclear Safety and Control Act*. With increasing national and international interest in fusion energy, it is updating its regulatory framework to ensure that it has the appropriate tools to protect the environment and the health and safety of people.