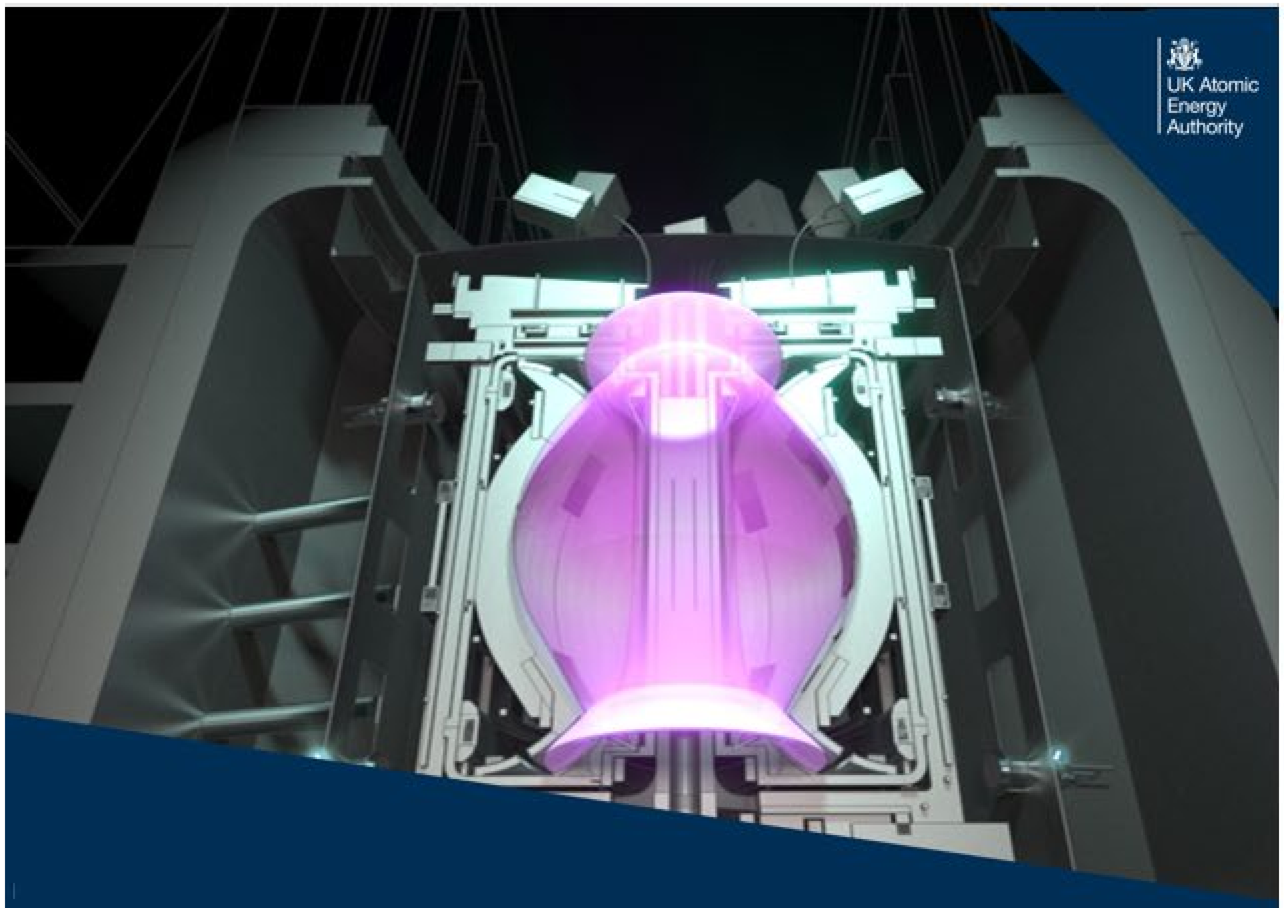


sCO2 in fusion

Jack Acres
STEP Power Infrastructure Lead
UKAEA

Tokamak Energy

Chris Clements
Head of Power Generation

Agenda

UK Atomic Energy Authority

1. Fusion: What, Why, and How
2. Who is doing fusion
3. Fusion Power plants
4. Fusion challenges and sCO_2 solutions

What is fusion?

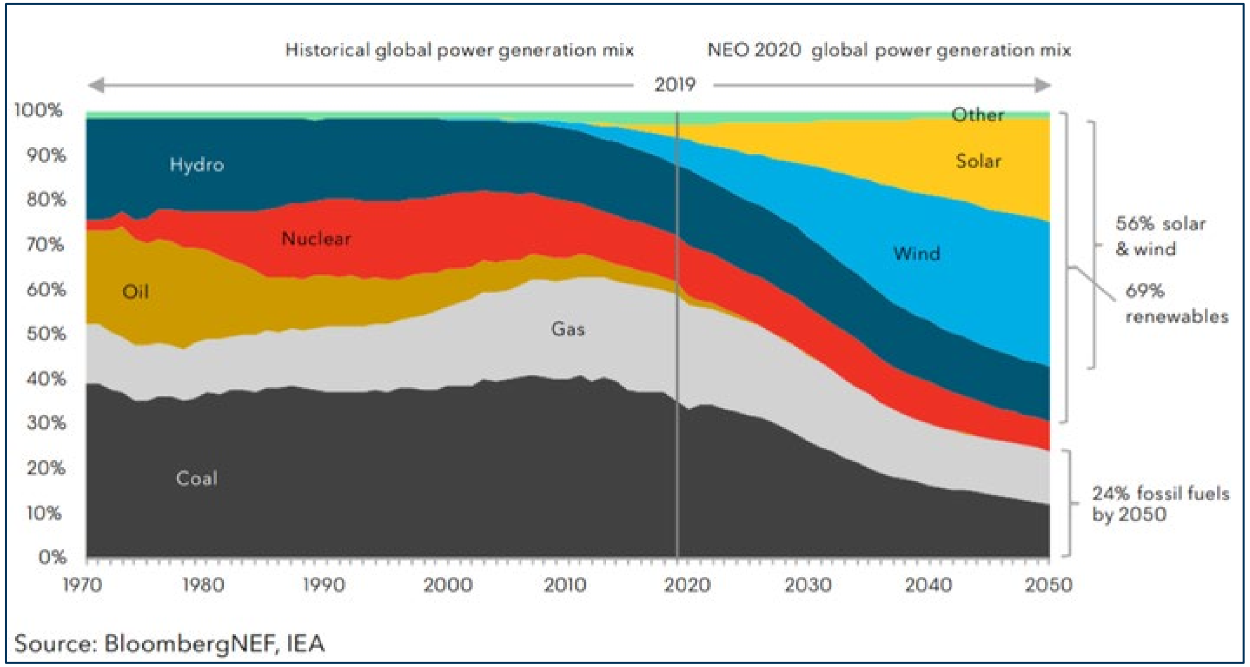
- Fusion is the process that powers the sun and stars by fusing hydrogen at the core

- Unlike its fission counterpart, fusion relies on fusing two lighter atomic particles. The mass deficit of the subatomic particles releases energy ($e=mc^2$)

Why fusion? Fusion power in a global demand for clean energy

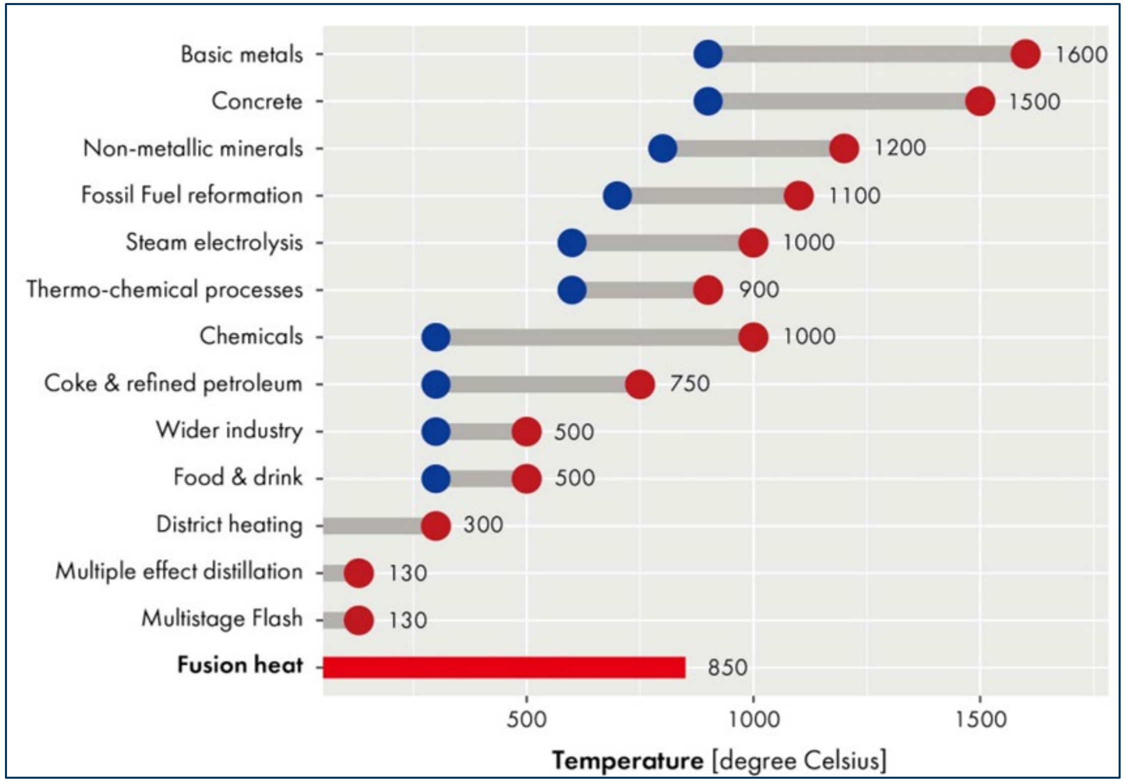
UK Atomic Energy Authority

Global electricity mix



New Energy Outlook Projects Massive Energy Sector Shift Through 2050 - forbes.com - Robert Rapier https://www.forbes.com/sites/rrapier/2020/10/31/new-energy-outlook-projects-massive-energy-sector-shift-through-2050/

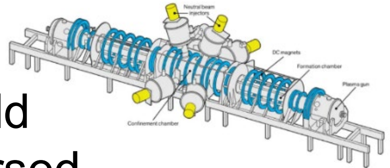
Temperature distribution of heat driven industrial processes



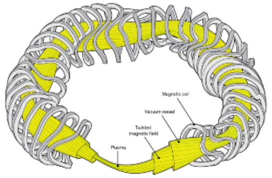
The commercialisation of fusion for the energy market: a review of socio-economic studies
Thomas Griffiths, Richard Pearson, Michael Bluck and Shutaro Takeda

Fusion energy will address a global demand for reliable, dispatchable, and safe clean energy – allowing us to reach net zero

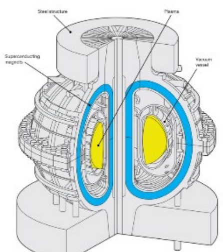
General confinement methods



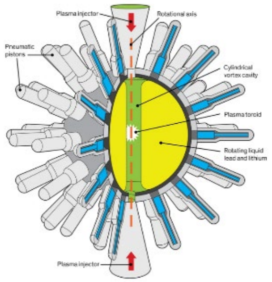
Field Reversed



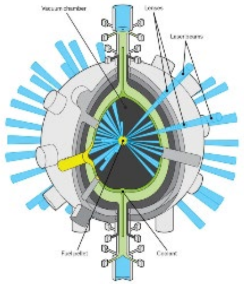
Stellarator



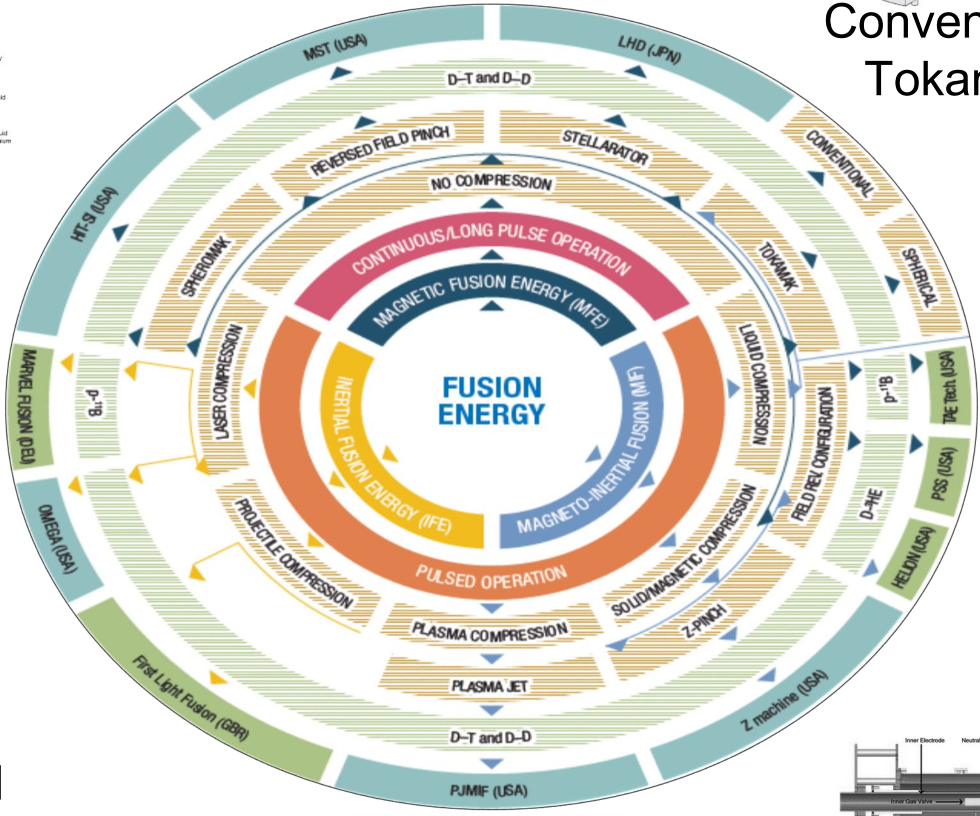
Conventional Tokamak

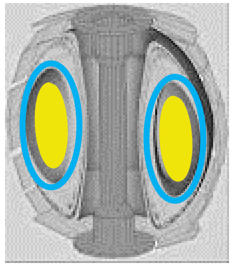


Inertial Confinement

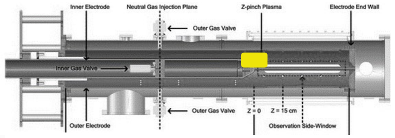


Magnetized Target



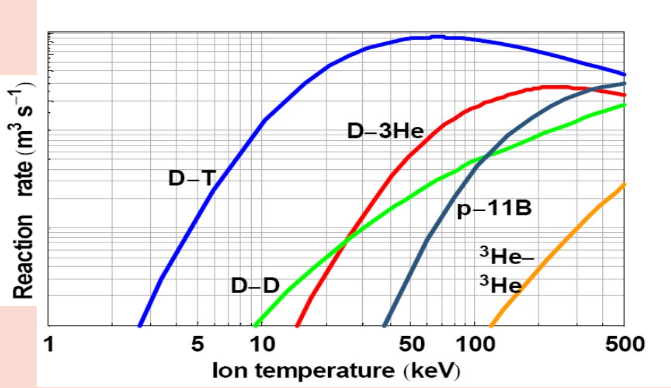


Spherical Tokamak



Z-pinch

WHY TOKAMAK TECHNOLOGIES



“The vast majority of past fusion plasma **experience** is from magnetic confinement in a **tokamak** design using deuterium–deuterium (**D–D**) fuel.”
IAEA Outlook 2023

“To obtain **viable fusion energy**, deuterium–tritium (**D–T**) fuel is the most common choice for future fusion power plants and the majority of fusion development activities continue in variation of this design.”
IAEA 2023 Outlook

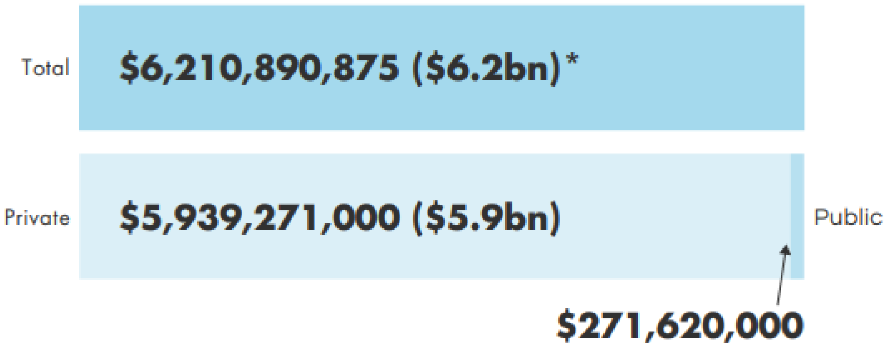
IAEA World Fusion Outlook 2023, © IAEA, 2023, page 46
https://doi.org/10.61092/iaea.ehyw-jq1g

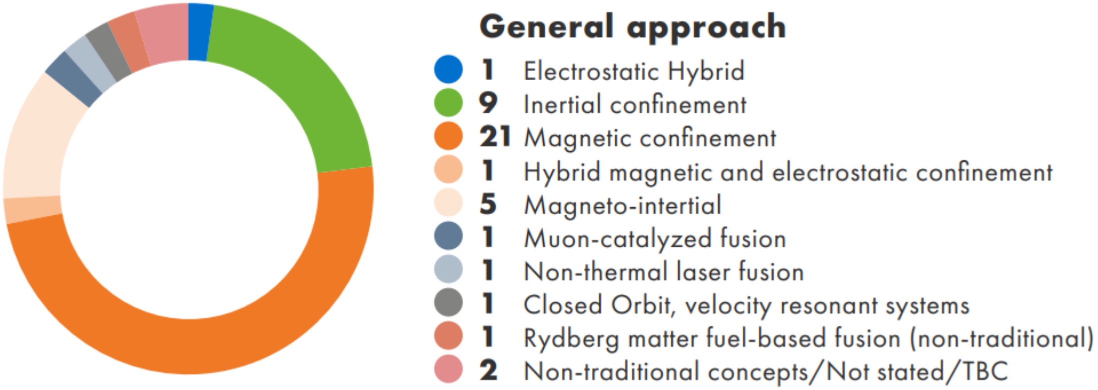
Who is doing Fusion?

Rapidly expanding private sector

In the last 2 years, private sector funding has outstripped public spending for the first time in history

Funding for fusion companies

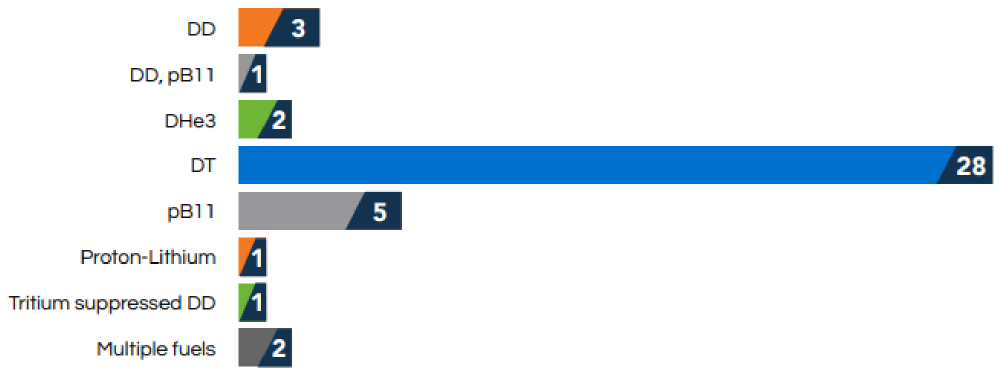




Location

By primary HQ

Fuel Source



AND chosen to be part of U.S. Government's decadal fusion vision

U.S. DOE Milestone-Based Fusion Development Program

DOE Milestone Program

- Public/private collaboration
- $46M initial U.S. Govt. funding

Tokamak Energy INC.

- Work began in phase 1 in Q4 2023
- Key partnerships with U.S. National Labs

Oak Ridge National Laboratory · PPPL Princeton Plasma Physics Laboratory · SRNL Savannah River National Laboratory · INL Idaho National Laboratory

UKAEA and STEP

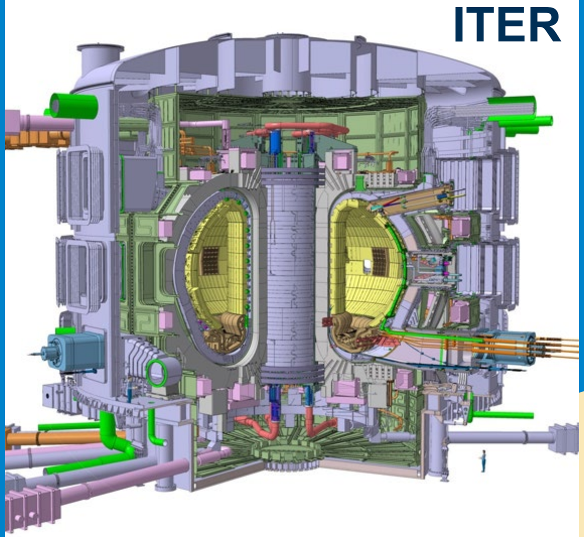
Who is doing fusion: Global Public Fusion Roadmap

UK Atomic Energy Authority

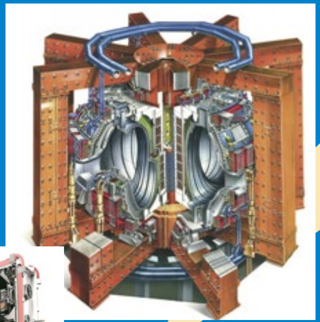
2020 **2030** **2040** **2050**

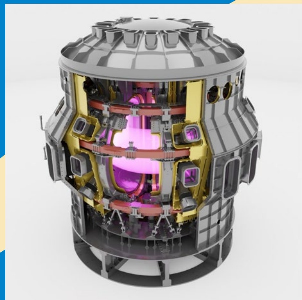
EXPERIMENTAL DEVICES

ITER

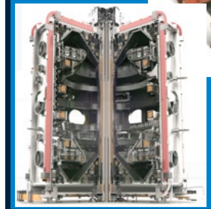


JET





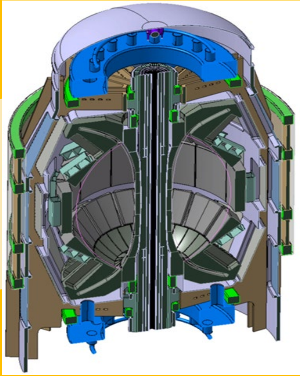
JT-60SA
& others
supporting ITER…



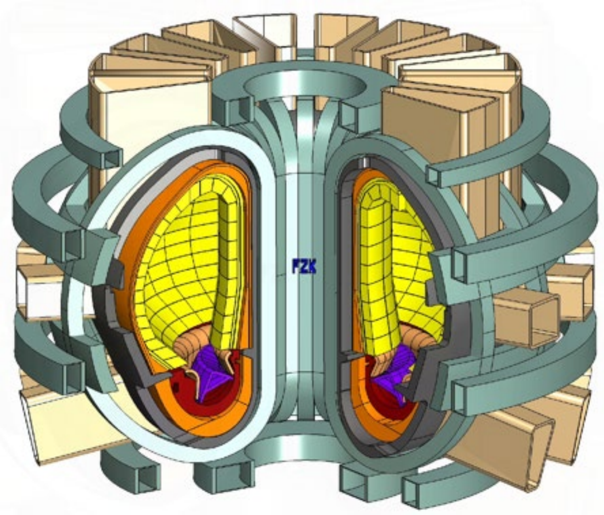
MAST-U

POWER PLANTS

STEP



DEMO



DOE BOLD DECADAL VISION

- *Inertial Laser* – Xcimer Energy Inc.
- *Magnetic Mirror* – Realta Fusion
- *Z-pinch* – Zap Energy Inc.
- *Inertial Laser* – Focused Energy
- *Stellarator* – Type One Energy Group
- *Spherical Tokamak* – Commonwealth Fusion Systems
- *Spherical Tokamak* – Tokamak Energy Inc.
- *Stellarator* – Princeton Stellarators Inc.

What is STEP?

STEP = Spherical Tokamak for Energy Production

Mission = Deliver a UK prototype fusion energy plant, targeting 2040, and a path to commercial viability of fusion.

A prototype spherical tokamak based fusion power plant with a commercially driven design basis:

- Predictable net electricity production
- Fuel self-sufficiency
- Credible maintenance solution
- Spherical tokamak design – potentially lower cost than other tokamak design types – due to the compact nature.

STEP Schedule*:*

Phase 1 – develop concept design and select a site by 2024

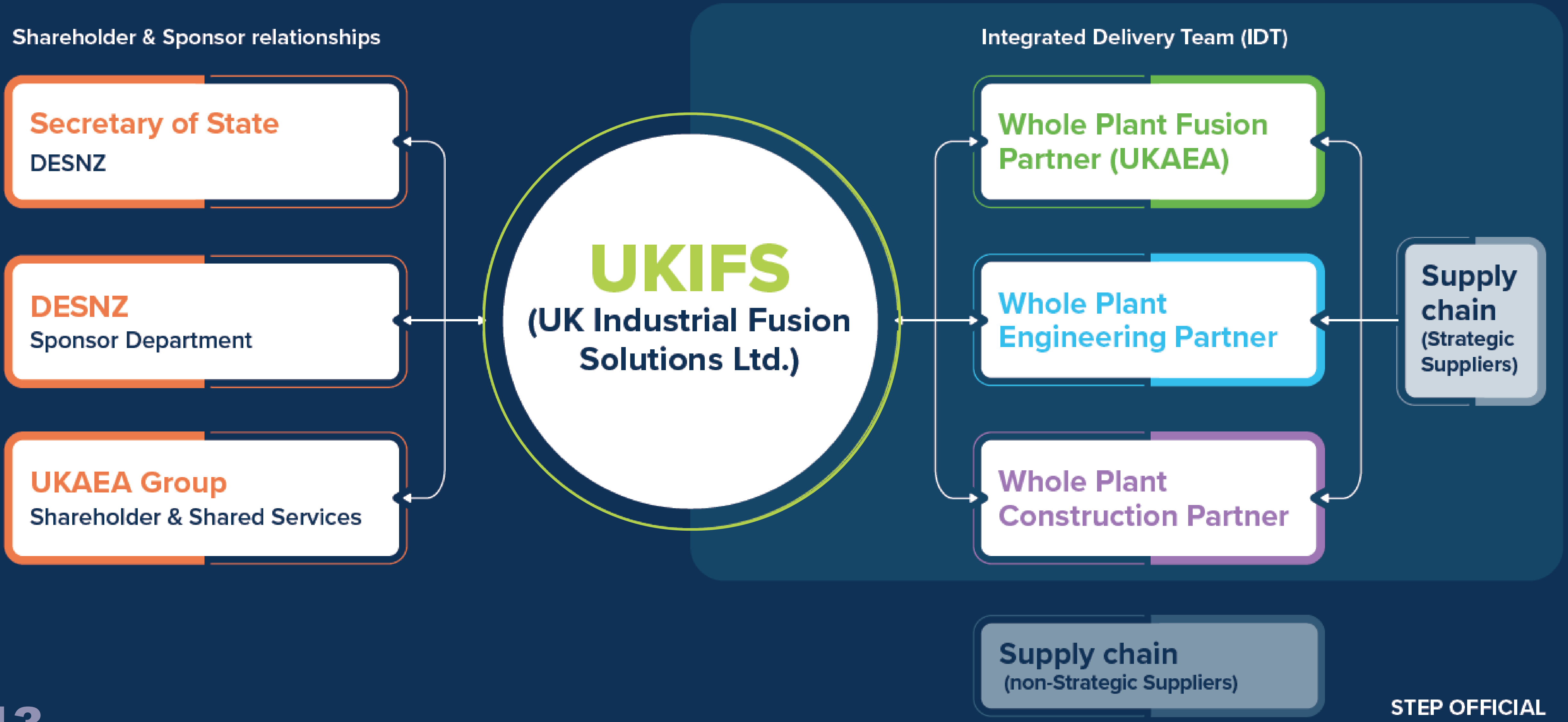
Phase 2 – detailed engineering design and permissions and consents as well as pre-construction works by early 2030s

Phase 3 – manufacturing and construction – targeting operations around 2040.

UK Atomic Energy Authority

Delivering STEP

UK Atomic Energy Authority



STEP OFFICIAL

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The Fusion Powerplant

A tokamak powerplant needs to …

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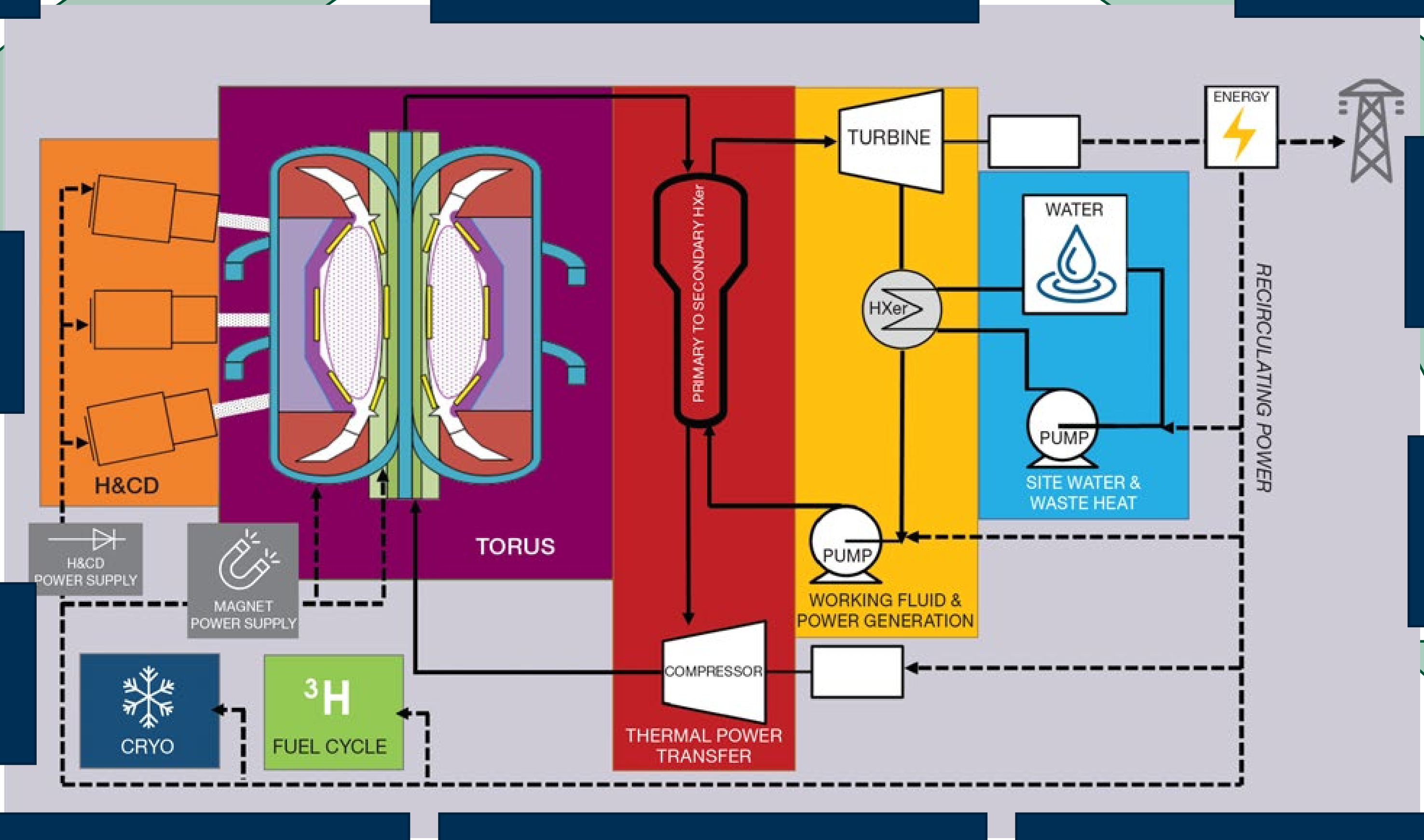
Manage Coolants
Develop solutions for efficient heat removal from reactor and coolant chemistry management

Manage & Integrate Heat
Integrate different sources of heat into a thermodynamic cycle, in an efficient manner

Generate Power
Ensure efficiency is maximised in the generation of power to ensure net power is delivered to the grid.

Supply high voltage/high current DC power
Design for significant electrical power demand from H&CD and Magnets, within highly dynamic scenarios



Interface with grid & environment
Ensure the power plant is compliant with external interface regulators.

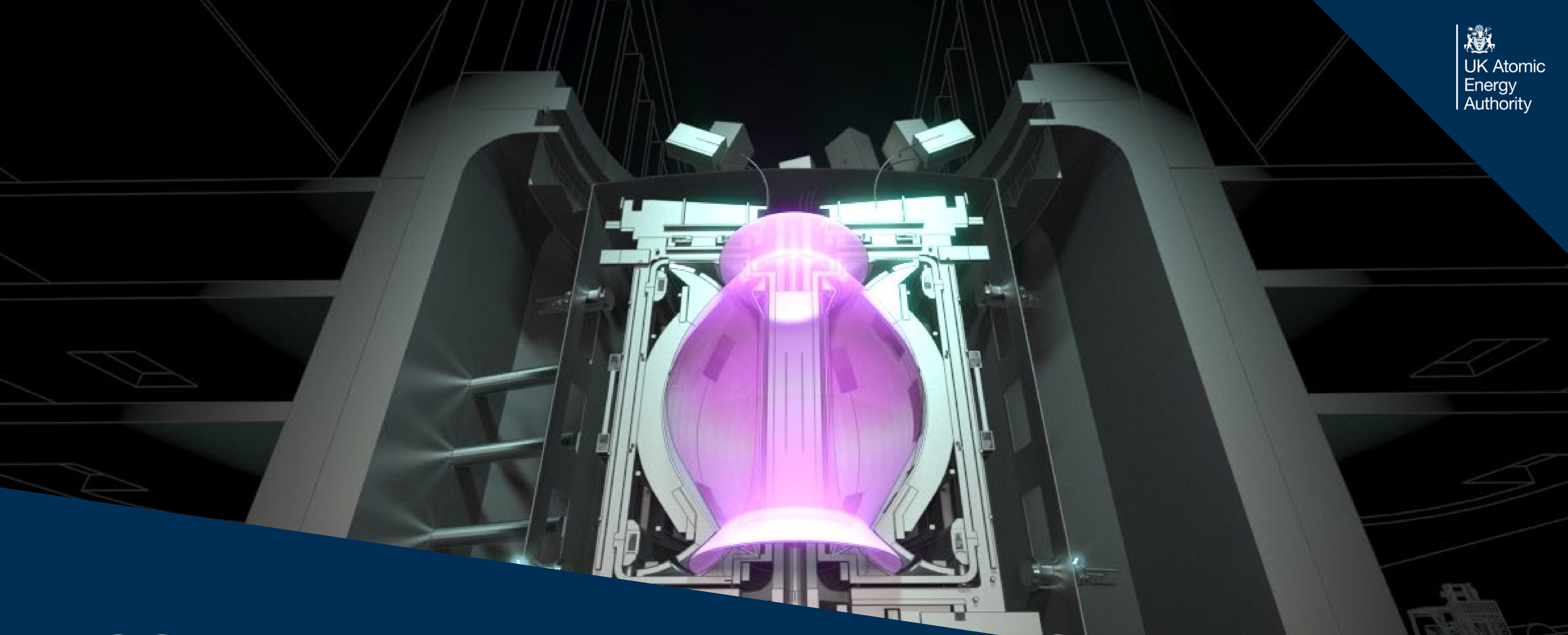
Ensure Safety
Ensure a safe design and appropriate tools are used to evaluate safety throughout design and operations lifecycle.

Manage Cold
Using core thermodynamic principles, design cryogenic systems to cool superconducting magnets

Manage Fuel
Manage the breeding of its own fuel and recover it, ensuring self-sufficiency.

Store energy
Develop holistic design that can meet the tokamak and power supply requirements within constraints set by grid

Distribute Power
Manage power and energy distribution to parasitic load management efficiently



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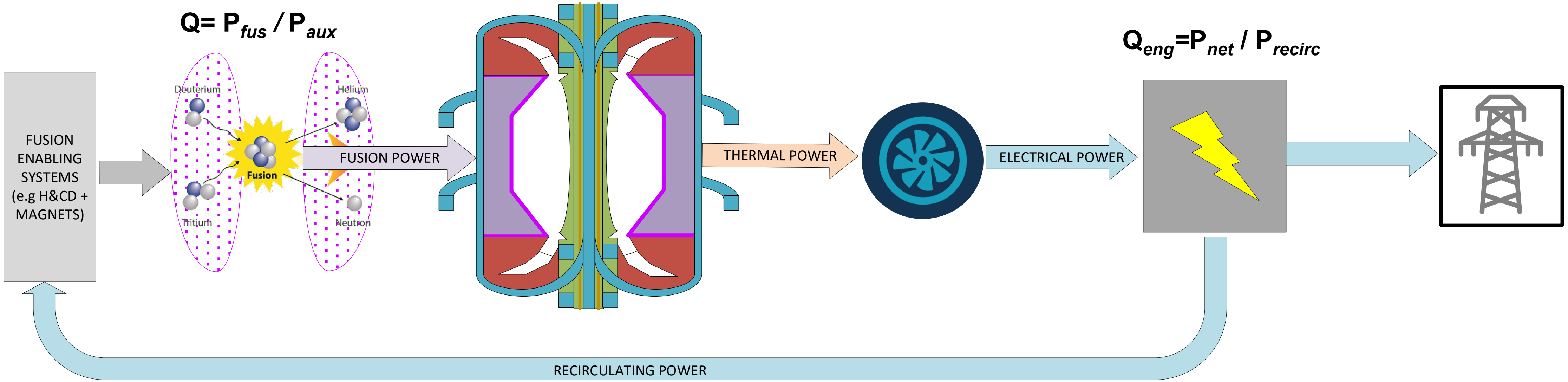
sCO_2 uniquely poised to answer fusion power generation challenges?

Magnetically Confined Fusion – A Unique Power Source

UK Atomic Energy Authority

Challenge 1: Need for efficiency

Challenge 2: Need for heat integration



Challenge 3: Need for flexibility

Challenge 4: Needs to be viable

Challenge 1: Efficiency

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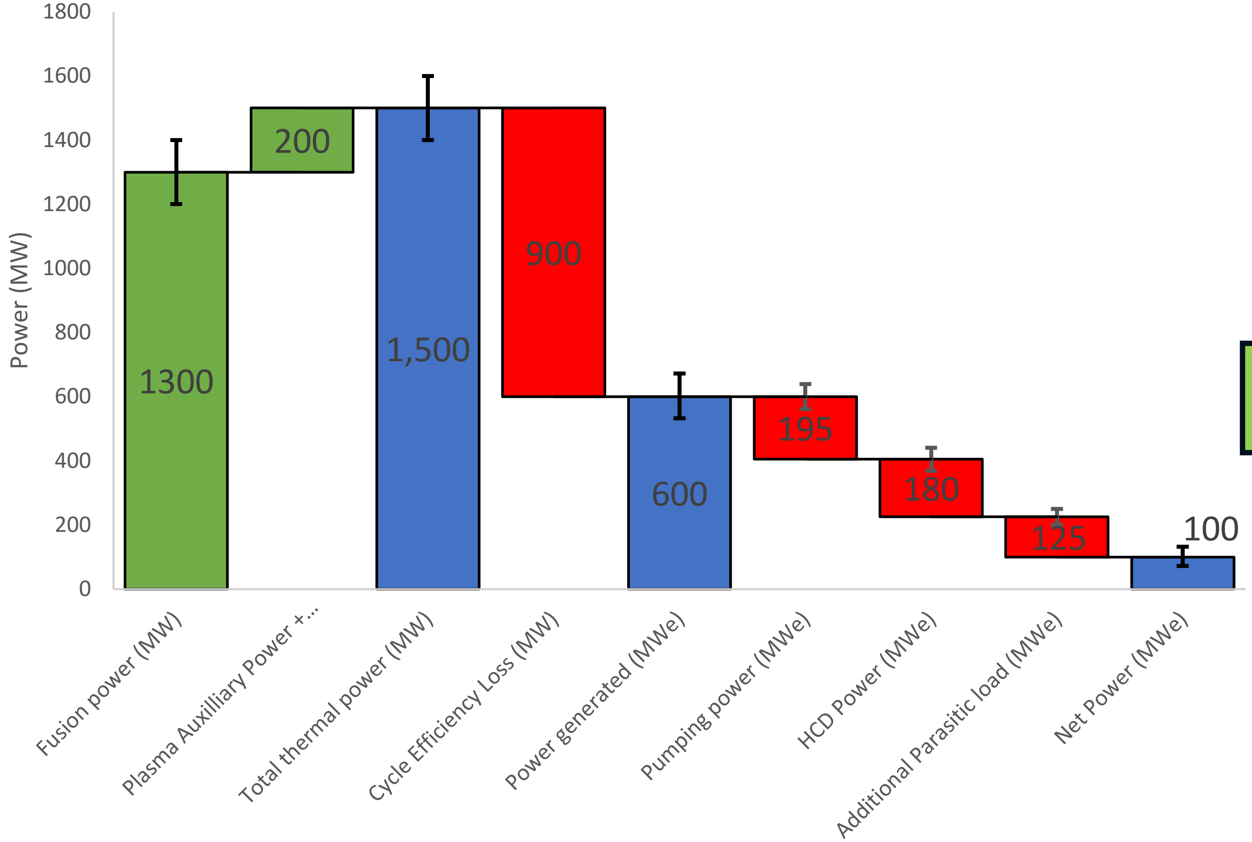
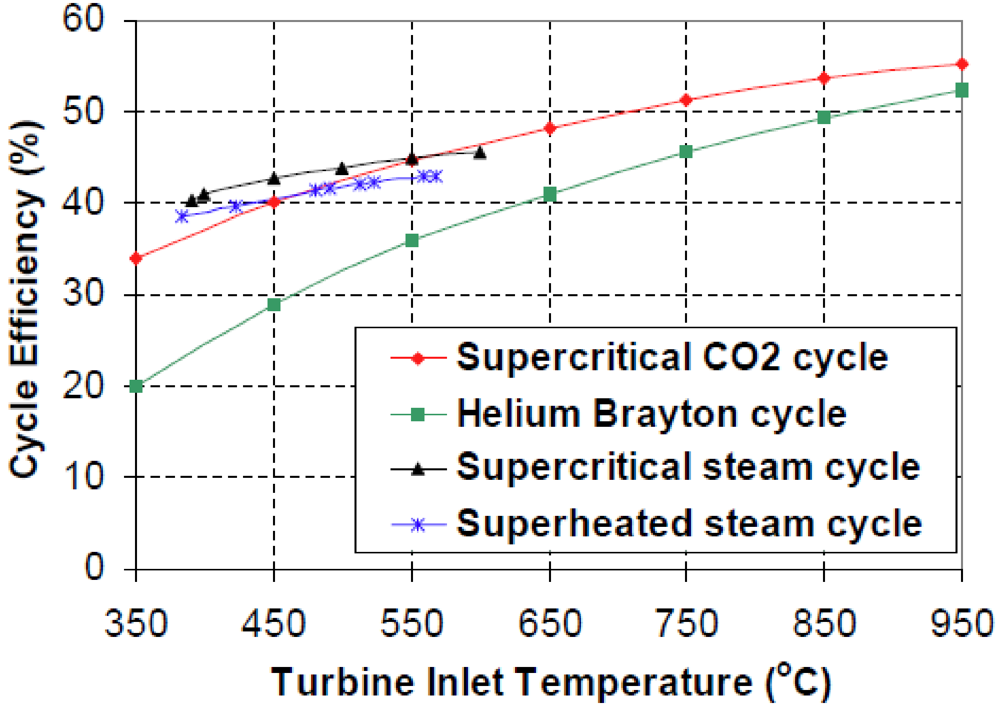
Tokamak prototype powerplant indicative power balance with uncertainties





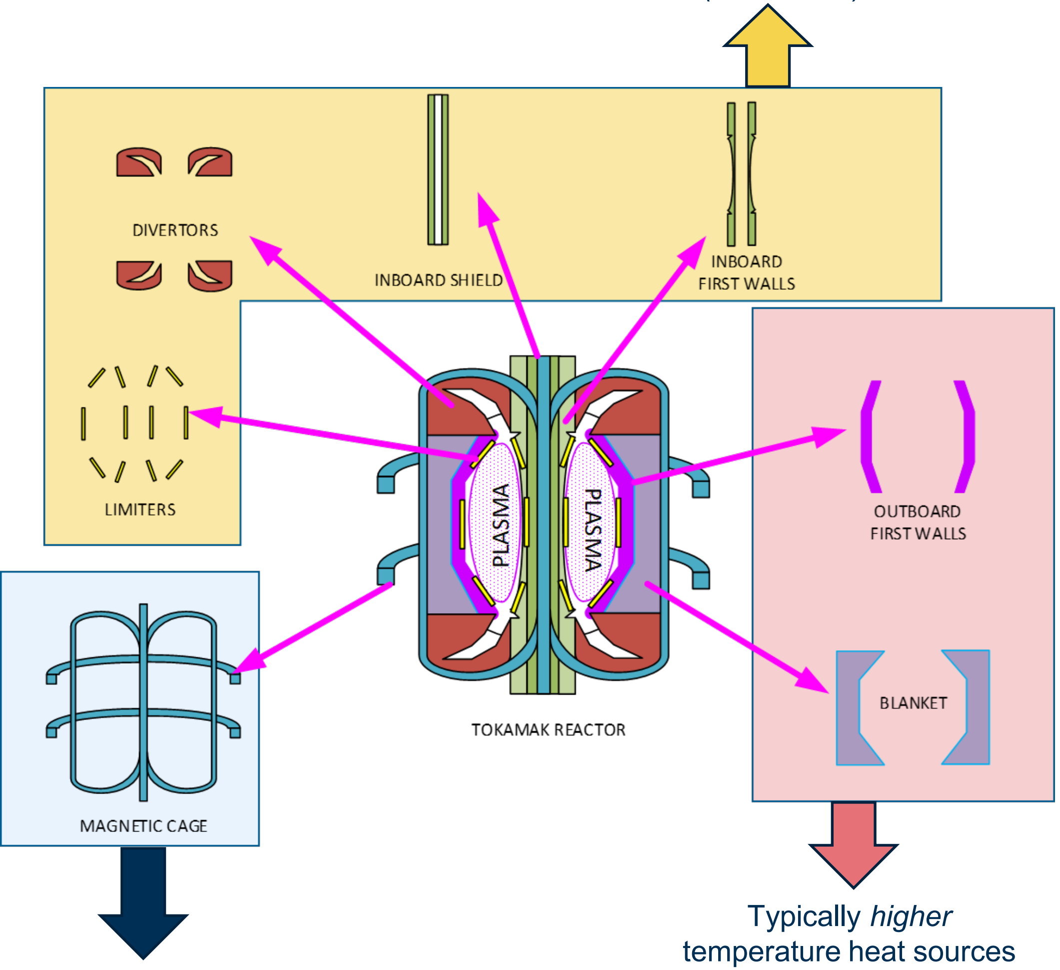
Dostal, Vaclav, Michael J. Driscoll, Pavel Hejzlar. "A supercritical carbon dioxide cycle for next generation nuclear reactors." PhD diss., Massachusetts Institute of Technology, Department of Nuclear Engineering; 2004.

$$Power\ generated = Total\ thermal\ power\ -\ Cycle\ efficiency\ loss$$

$$Net\ power = Power\ generated - Total\ parasitic\ load$$

Challenge 2: Heat Integration

Typically *lower*
Temperature heat sources
(150-300°C)

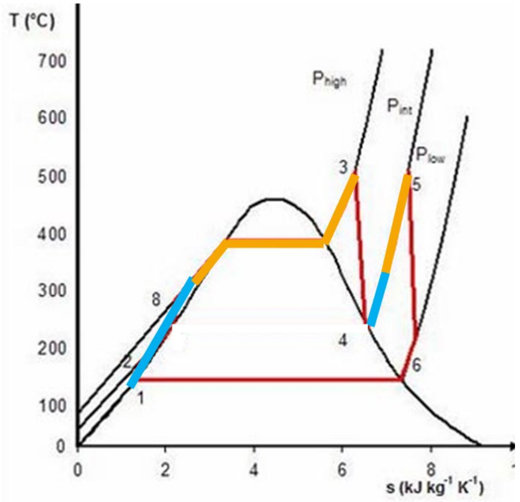


Cryogenically Cooled

Typically *higher*
temperature heat sources
(450°C+)
Accounts for over 60% of heat

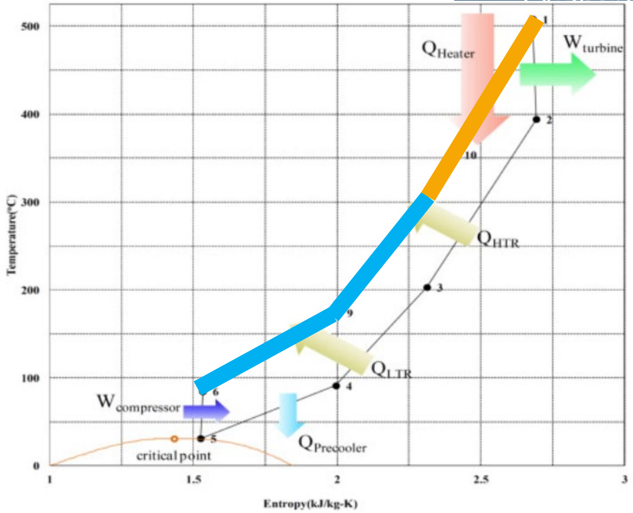
sCO_2 Solution

SRC T-S



https://www.scientificlib.com/en/Physics/Thermodynamics/RankineCycle.html

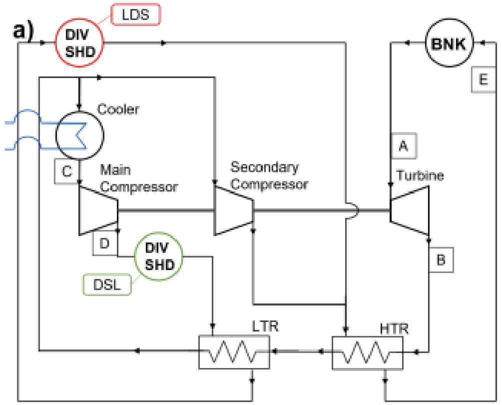
RCBC T-S



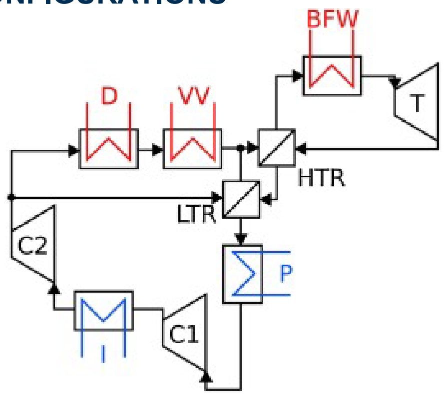
Y. Ahn, S.J. Bae, M. Kim, S.K. Cho, S. Baik, J.I. Lee, et al. Review of supercritical CO2 power cycle technology and current status of research and development Nucl Eng Technol, 47 (6) (2015), pp. 647-661

Higher Grade Heat Sink (>300°C)
Lower Grade Heat Sink (<300°C)

EU DEMO FUSION RCBC CONFIGURATIONS



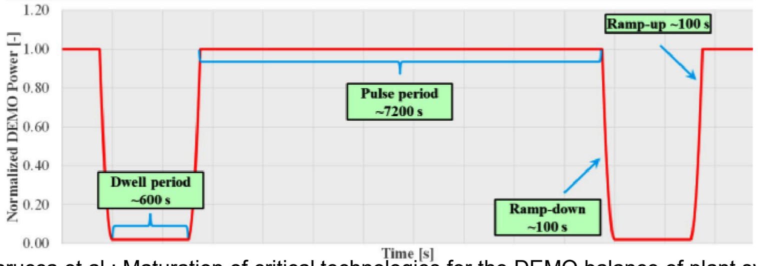
J. Hidalgo-Salaverri, P. Cano-Megias, R. Chacartegui, J. Ayllon-Guerola, E. Viezzer, Analysis of supercritical carbon dioxide Brayton cycles for a helium-cooled pebble bed blanket DEMO-like fusion power plant, Fusion Engineering and Design, Volume 173, 2021



Jan Stepanek, Slavomir Entler, Jan Syblik, Ladislav Vesely, Vaclav Dostal, Pavel Zacha, Parametric study of S-CO2 cycles for the DEMO fusion reactor, Fusion Engineering and Design, Volume 160, 2020

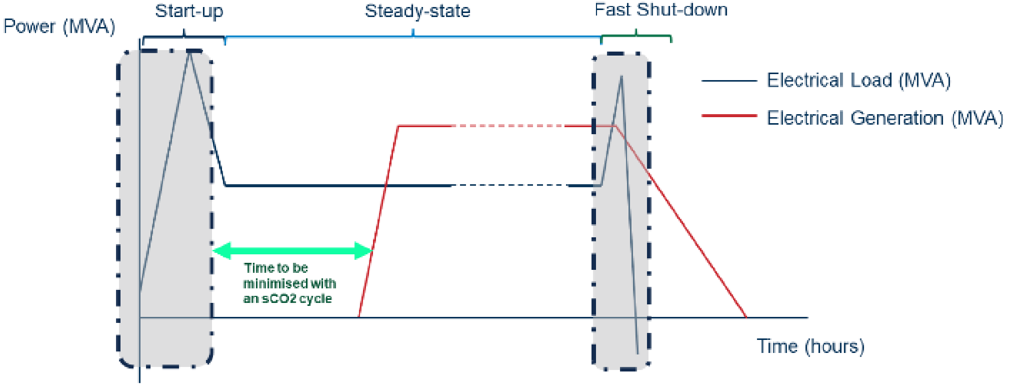
Challenge 3: Flexibility

1. Inherently pulsed

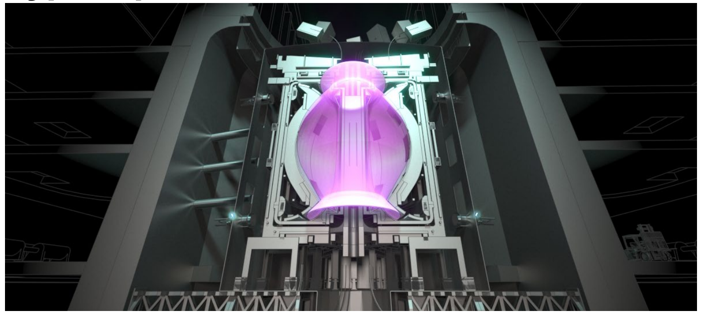


L. Barucca et al.; Maturation of critical technologies for the DEMO balance of plant systems, Fusion Engineering and Design, Volume 179, 2022

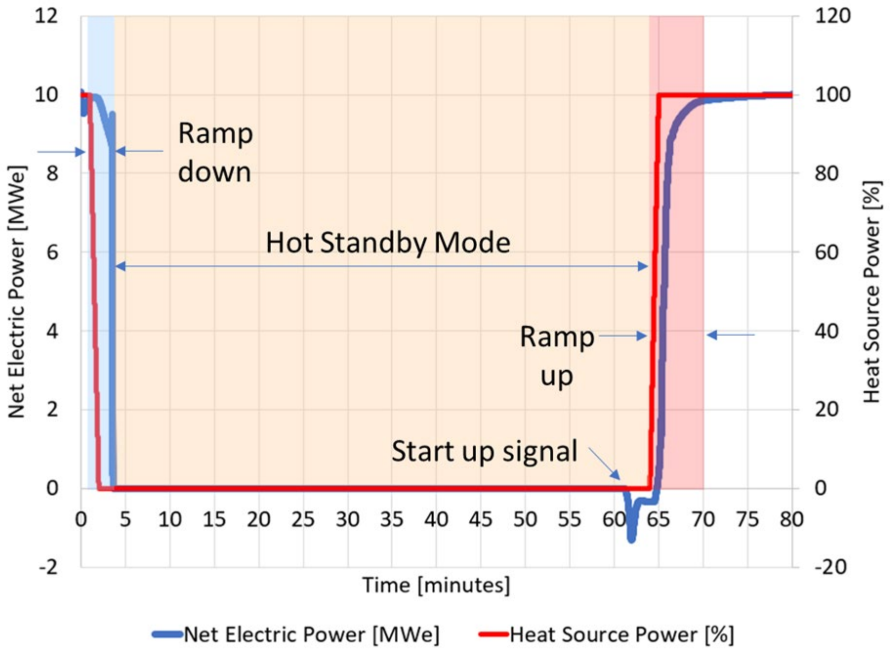
2. Rapid operational dynamics (startup/shut down)



3. Prototypic operations



sCO_2 Solution



Rapid ramp rates of the sCO_2 power cycle could effectively support challenging operating scenarios

Challenge 4: Commercial Viability

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Adaptability to larger fusion market

Regulatory approach

Power production ($Q + Q_{eng}$)

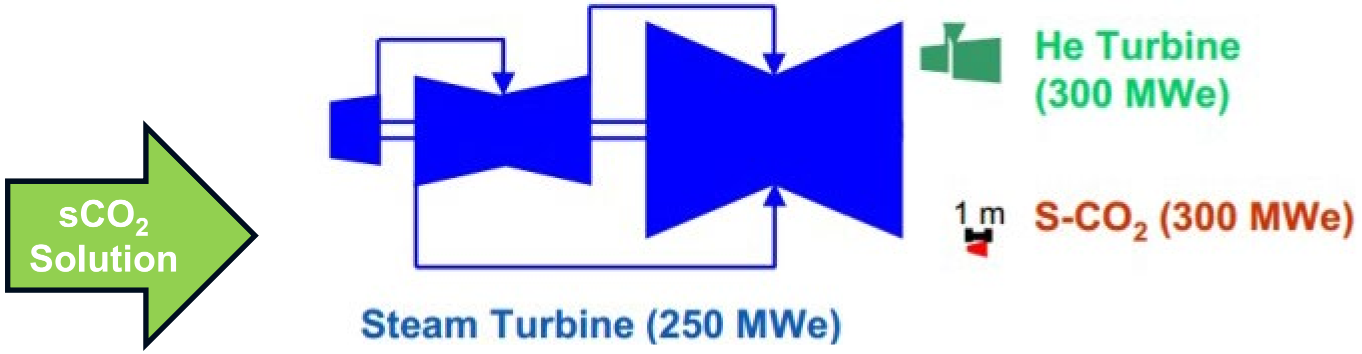
Power use

TRL development

Siting ability

Fusion CAPEX and OPEX drivers:

- Fuelling (High Power Density)
- Footprint and buildings
- Key equipment



Dostal, Vaclav, Michael J. Driscoll, Pavel Hejzlar. "A supercritical carbon dioxide cycle for next generation nuclear reactors." PhD diss., Massachusetts Institute of Technology, Department of Nuclear Engineering; 2004.

sCO_2 uniquely poised to answer Fusion power generation challenges?

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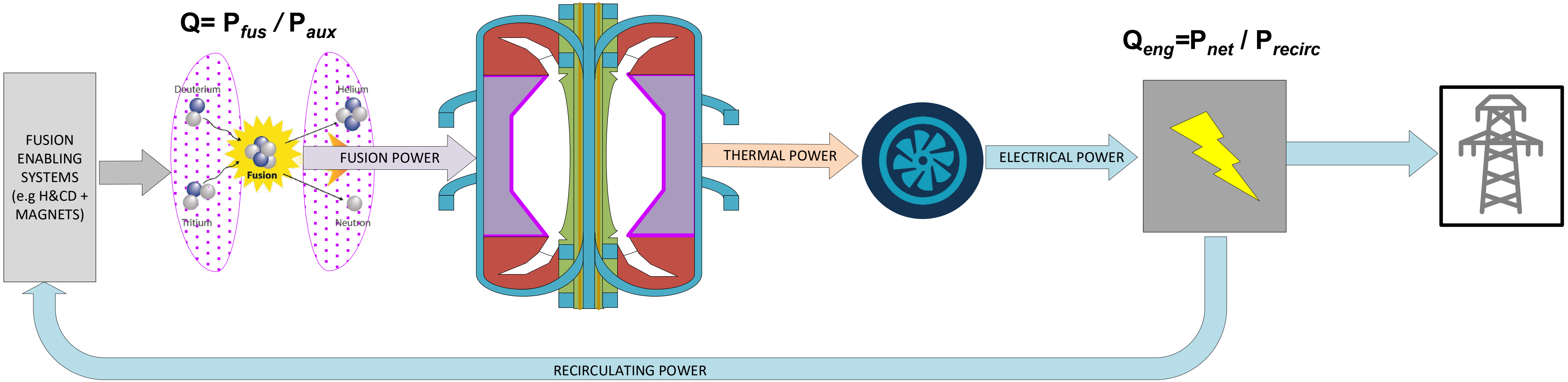
Challenge 1: Need for efficiency

sCO_2 solution: High efficiency

Challenge 2: Need for heat integration

sCO_2 solution: Able to integrate heat



Challenge 3: Need for flexibility

sCO_2 solution: Highly responsive

Challenge 4: Needs to be viable

sCO_2 solution: Compact and competitive

Q&A

UK Atomic Energy Authority

Thank you for listening any questions?

How to find out more…

On the web:

- www.ccfe.ukaea.uk
- www.euro-fusion.org
- https://step.ukaea.uk

By email: Communications@ukaea.uk

Follow @UKAEAofficial

Any Questions ?