IAEA
International Atomic Energy Agency

Overview of Nuclear Energy Department Fusion Activities

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Nuclear Power Technology Development Section
Department of Nuclear Energy
International Atomic Energy Agency

Overview of IAEA Fusion Activities

1. **FUSION ENERGY DEVELOPMENT AND DEPLOYMENT FRAMEWORK**

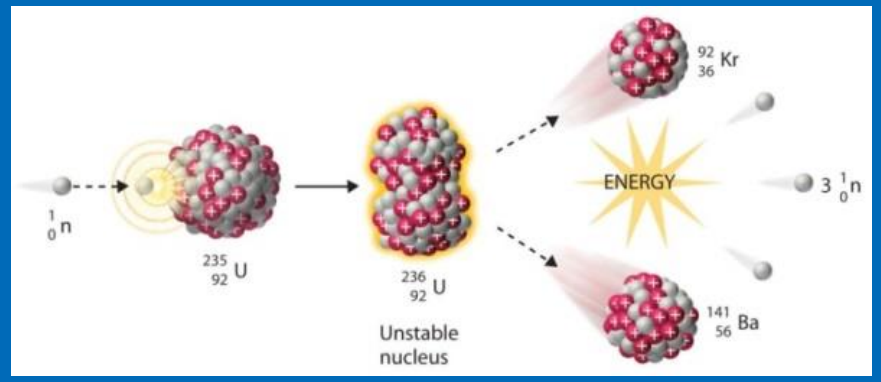
2. **FUSION GENERAL DESIGN CRITERIA AND RELEVANT CODES AND STANDARDS**

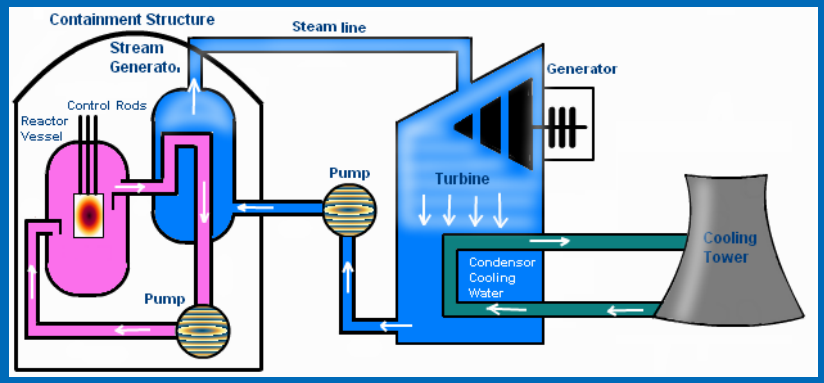
3. **SYNERGIES IN TECHNOLOGY DEVELOPMENT BETWEEN NUCLEAR FISSION AND FUSION FOR ENERGY PRODUCTION**

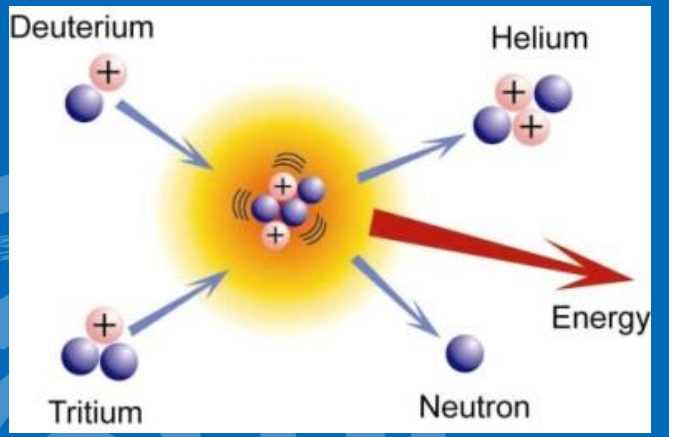
4. **OTHER ONGOING NUCLEAR ENERGY ACTIVITIES**

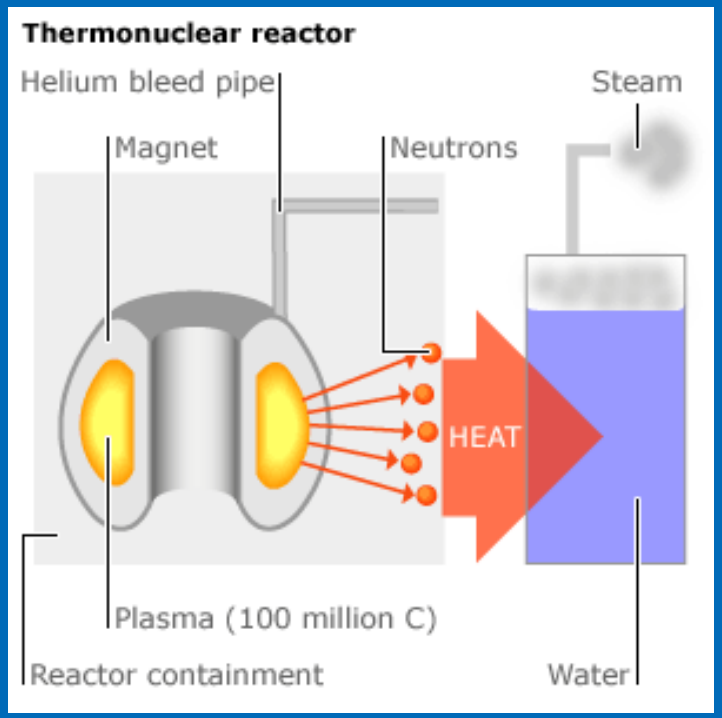
The Nuclear Age

Major breakthroughs in understanding the physics of nuclear reactions during 1st half of XX century
Nuclear technology first developed during World War II for military applications and shortly after as energy source. Fission supplies 5% of primary energy worldwide









Fusion Power Plant

1 gram of fusion fuel = 8 tons of oil

$^{2}D^{+} + {}^{2}D^{+} \xrightarrow{50\%} T^{+}\ (1MeV) + p^{+}\ (3MeV)$

$^{2}D^{+} + {}^{2}D^{+} \xrightarrow{50\%} {}^{3}He^{++}\ (0.8MeV) + n^{0}\ (2.5MeV)$

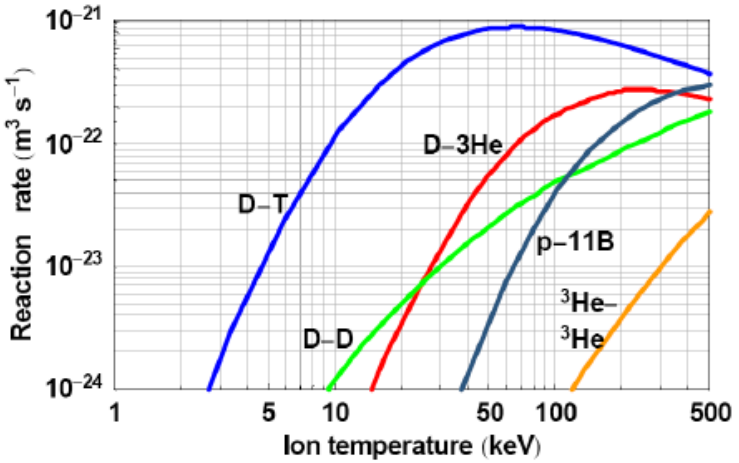
$^{2}D^{+} + {}^{3}T^{+} \longrightarrow {}^{4}He^{++}\ (3.5MeV) + n^{0}\ (14MeV)$

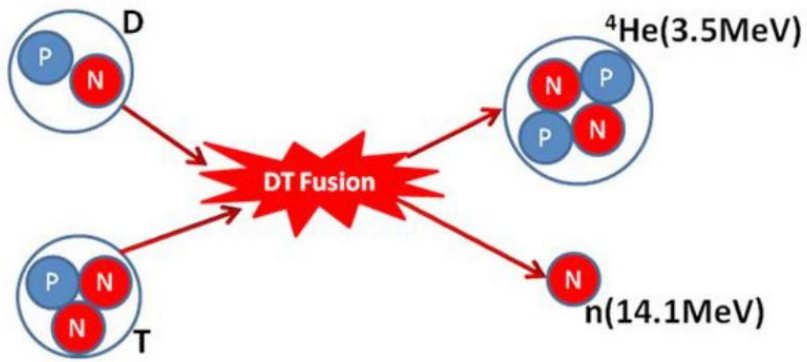
$^{2}D^{+} + {}^{3}He^{++} \longrightarrow {}^{4}He^{++}\ (3.6MeV) + p^{+}\ (15MeV)$

Basics of Fusion

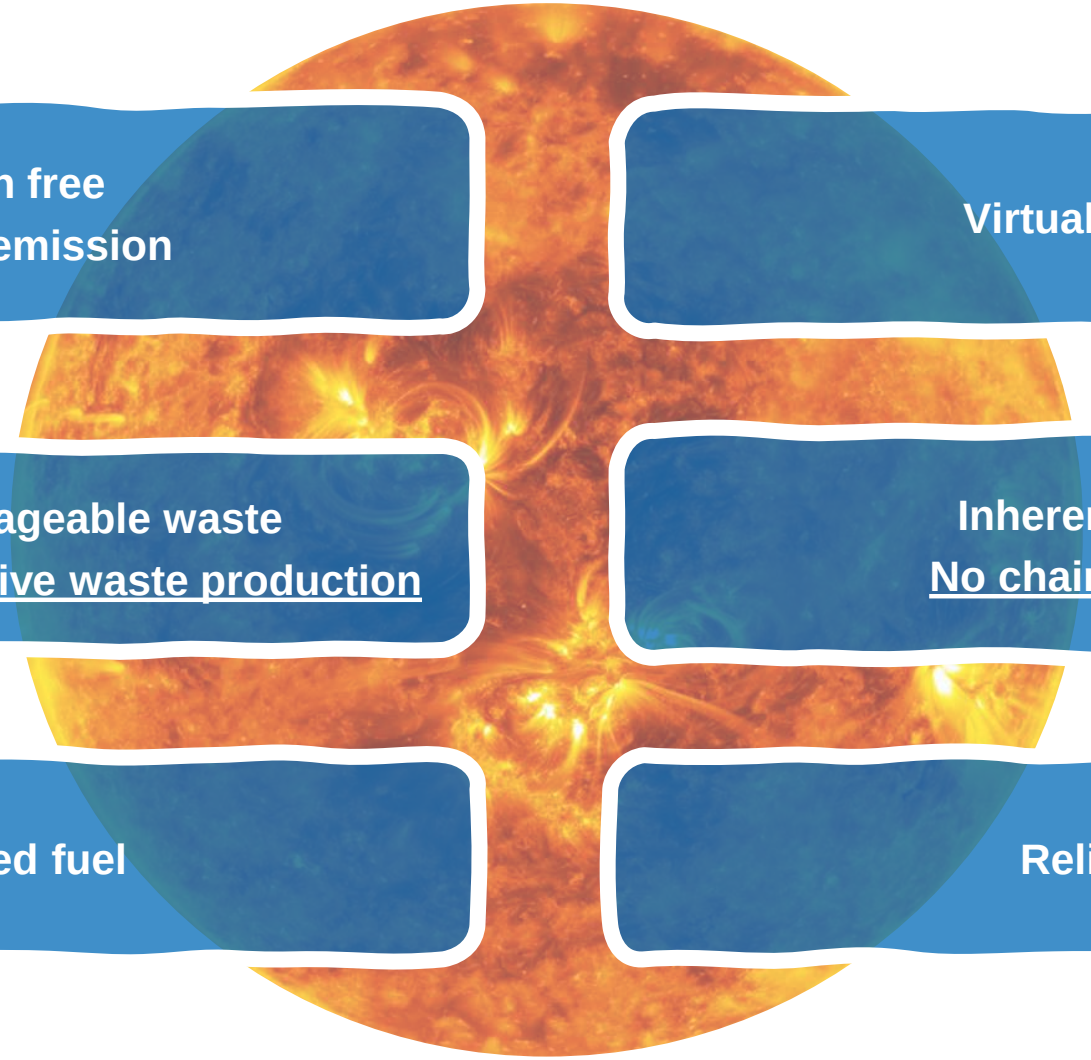
- Possible **fusion** reactions, **which lead to gain of energy**

Reaction name (fuel)	Reaction equation (energy out)	
DT	**D + T → ^{4}He (3,5 MeV) + n (14,1 MeV)**	**ITER, NIF, tokamaks + stellarators**
DD	D + D → ^{3}He (1,8 MeV) + n (2,5 MeV) → T (1,0 MeV) + p (3 MeV)	
TT	T + T → n + n + ^{4}He …… 11,3 MeV	
D-^{3}He	D + ^{3}He → ^{4}He (3,7 MeV) + p (14,6 MeV)	**Helion**
p-^{6}Li	p + ^{6}Li → ^{4}He + ^{3}He …… 4,0 MeV	
p-^{11}B	p + ^{11}B → 3 ^{4}He …… 8,7 MeV	**TAE, Marvel Fusion**





MERITS OF FUSION



Carbon free
Zero gas emission

Virtually clean

Low level, manageable waste
No long-lived radioactive waste production

Inherently safe
No chain reaction

Unlimited fuel

Reliable

Fusion Development Challenges

ITER

Designed

- to produce burning plasma
- to test systems and elements needed in a fusion machine
- to setup the fusion supply chain

Support facilities

- R&D on materials and components
- Plasma performance

DEMO

- Demonstration of electricity generation
- Qualification of components and processes
- Test self-production of fuel, closed fuel cycle
- Licensing

New private enterprises

- Advanced technologies
- New approaches and concepts

Challenges

- Confining the plasma at T~10 times hotter than the center of the Sun
- Neutrons damaging the structural materials
- Exhausting extreme heat fluxes
- Breeding and handling Tritium
- Need for remote handling and maintenance
- Waste management

Fusion Power Plant

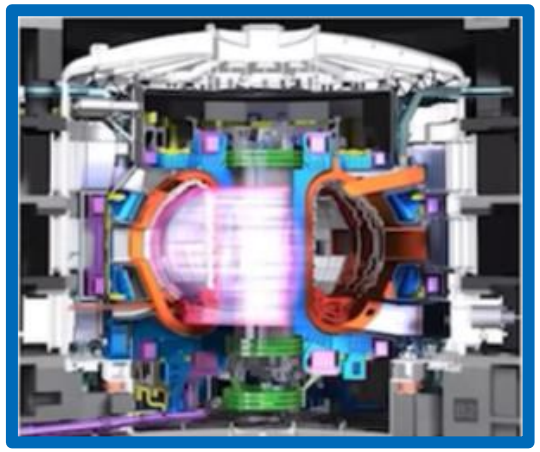
Market Conditions Becoming Attractive for Fusion

2 Paths to Fusion

Market pull

Climate emergency very high in public consciousness

Public



https://www.iter.org/mach/tokamak

Technical demonstration

ITER and DEMO will demonstrate the low field path to fusion…

Complimentary to one another

Lessons Learned on ITER have contributed to the private investment

Private

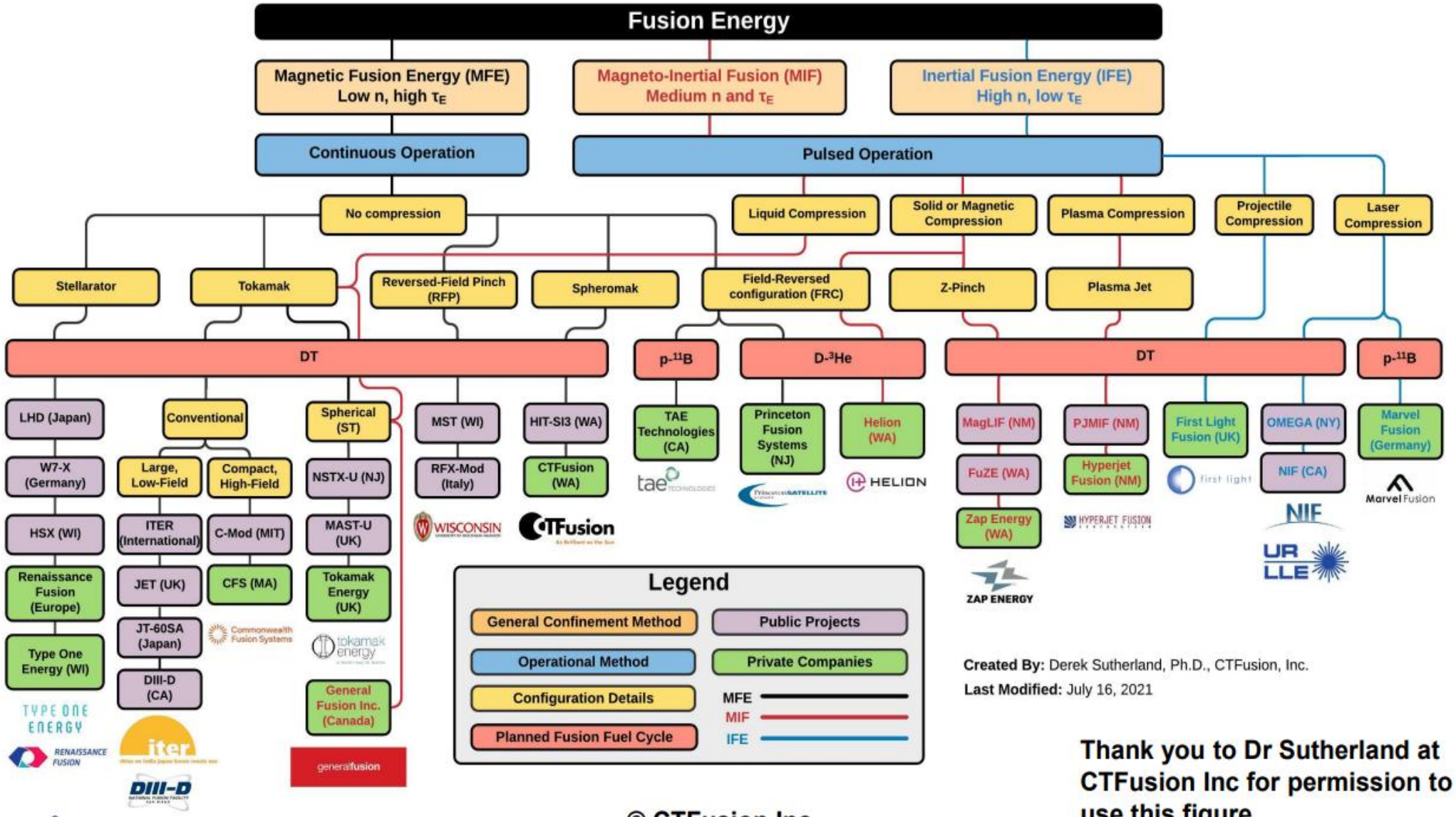
Private investment

>$6.2 Bn invested and committed in 43+ Start-Ups (FIA 2023)

The global fusion industry in 2022, Fusion Industry Association

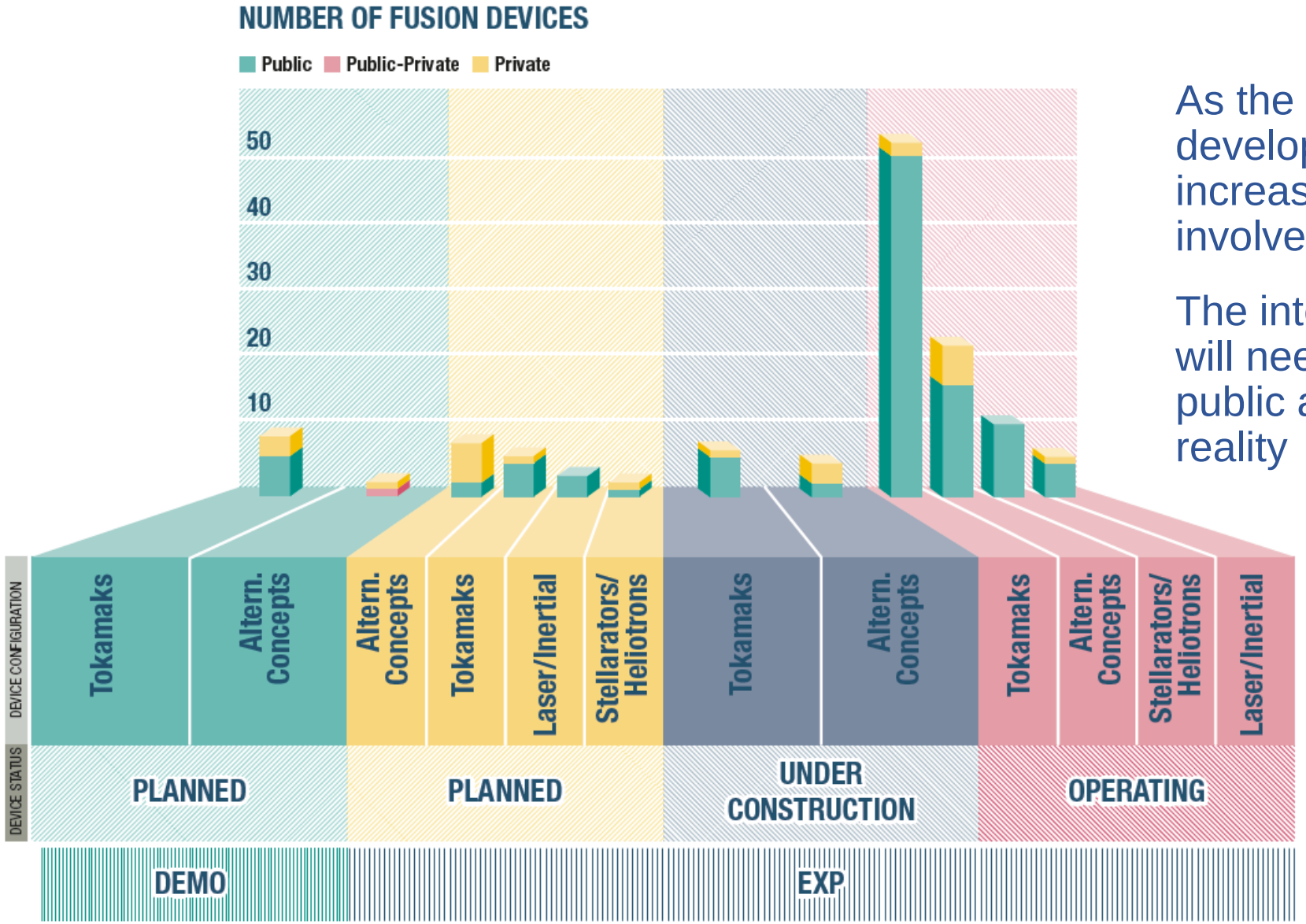
Overview of fusion technologies

CTFusion scheme



Thank you to Dr Sutherland at CTFusion Inc for permission to use this figure

Paths to Fusion

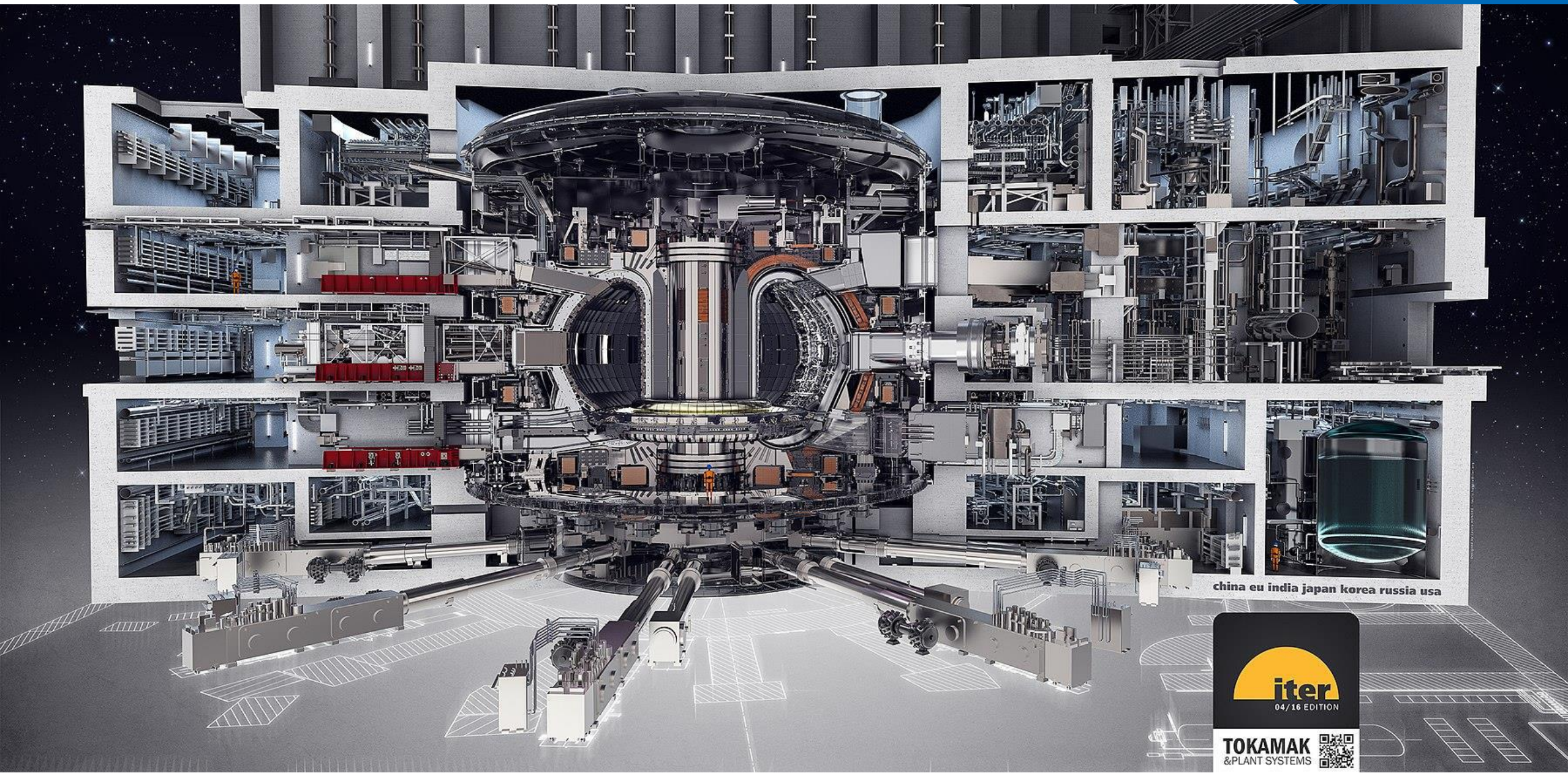


As the number of devices in development and/or construction increase, so is the need for IAEA involvement

The international fusion community will need to come together both public and private to make fusion a reality

The ITER Tokamak – Magnetic Confinement

D-T Fuel



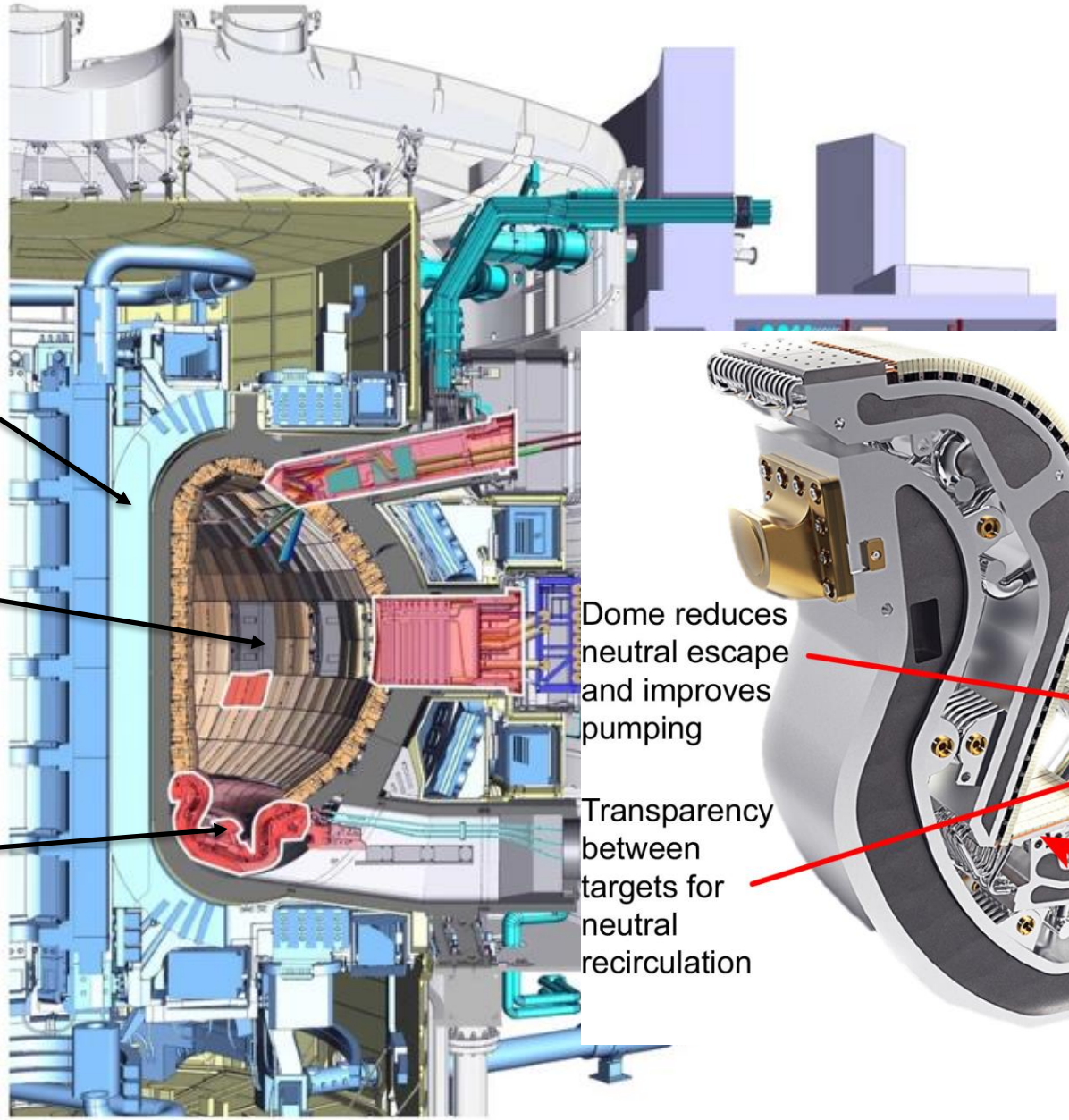
The ITER Tokamak

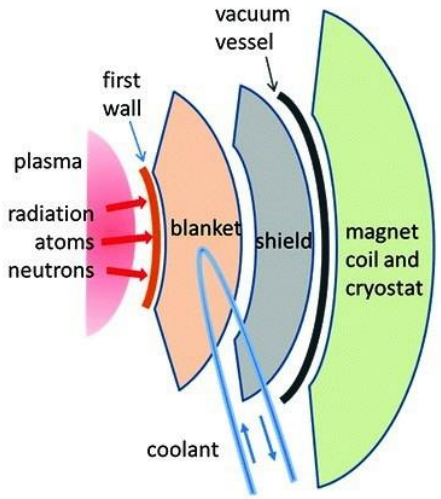
Temperature Range
-270˚ to 150M˚C

TF Coils @ -270˚C

Plasma @ 150M˚C

PFCs @ 500 - 800˚C
W melts @ 3422˚C

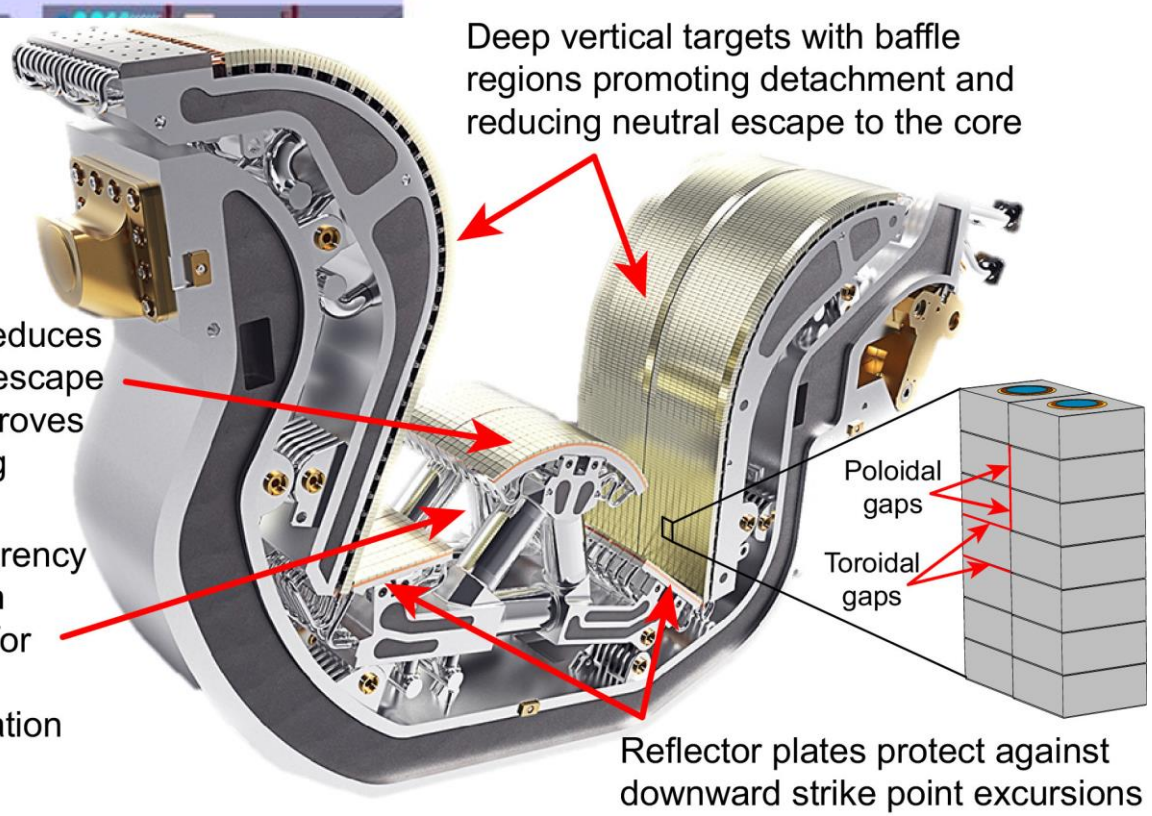




Deep vertical targets with baffle regions promoting detachment and reducing neutral escape to the core

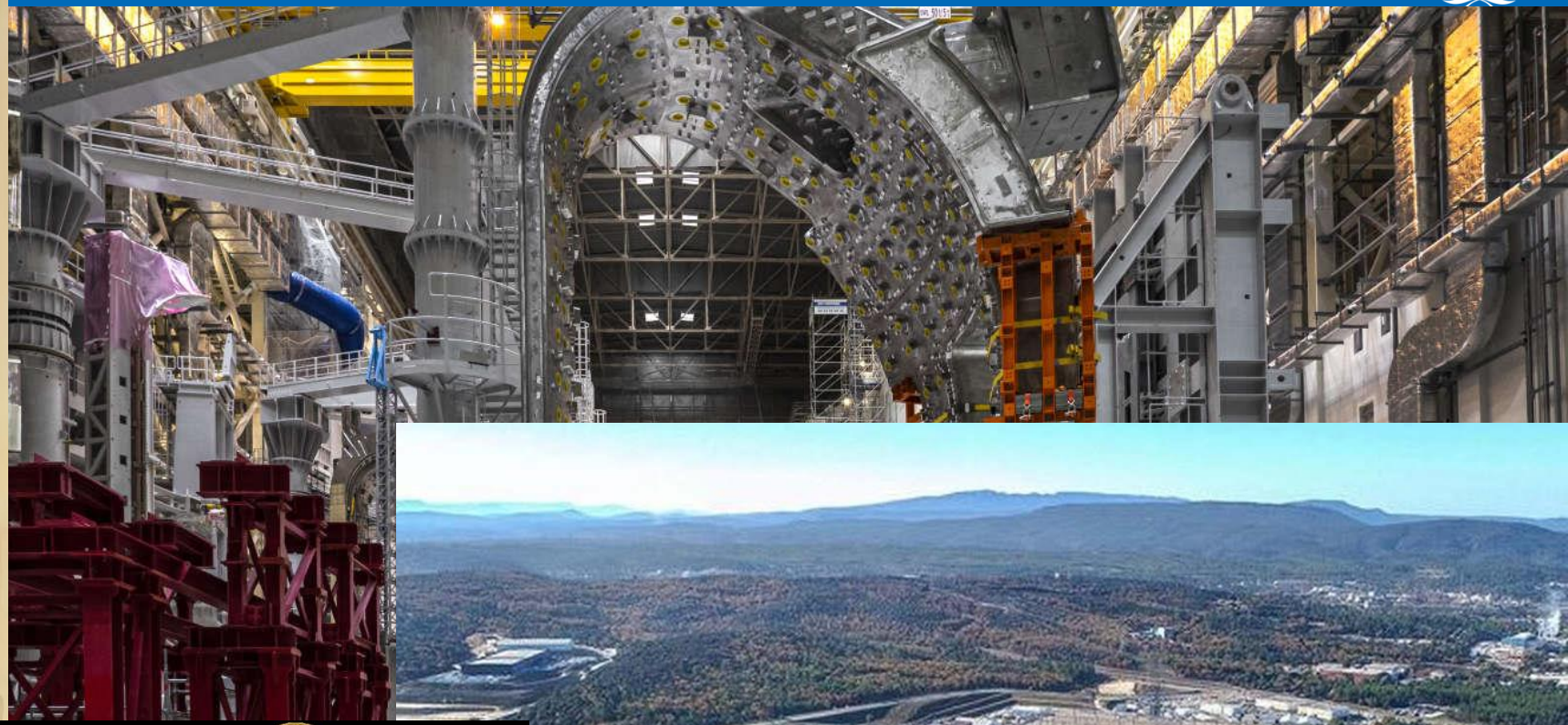
Dome reduces neutral escape and improves pumping

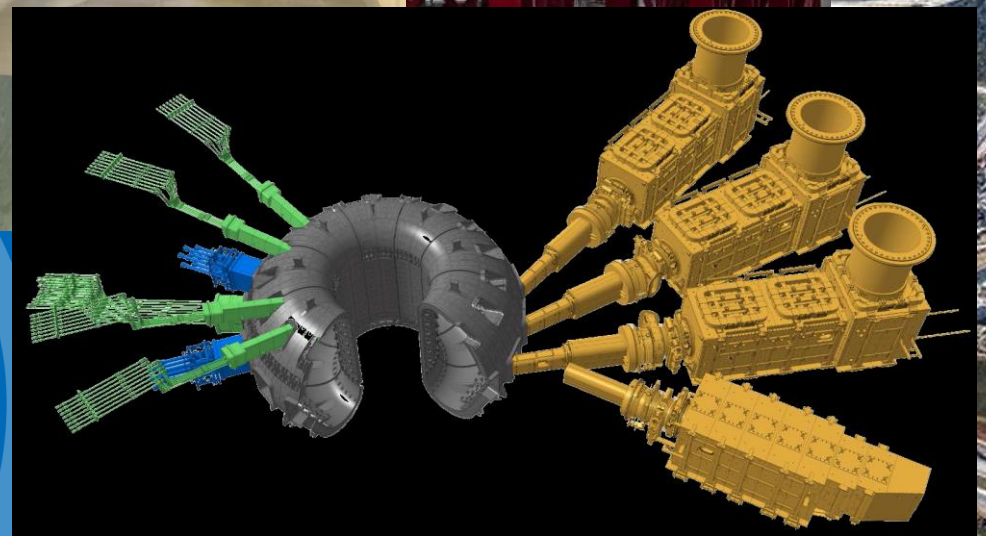
Transparency between targets for neutral recirculation



Reflector plates protect against downward strike point excursions

ITER Construction





Commercial Fusion – over $6B invested

Commonwealth Fusion Systems

Magnetic Confinement
D-T Fuel

The SPARC Tokamak

The ARC Tokamak

SPARC Construction

Devens Rendering
~June 2021

[Italy's Eni and CFS speed up plans for fusion energy]

[Commonwealth Fusion Systems Selected by U.S. DOE for Milestone Program to Accelerate Commercial Fusion Energy]

Devens Reality
27 October 2023

Helion Field Reversed Configuration

Magneto-Inertial Fusion

D – He^3

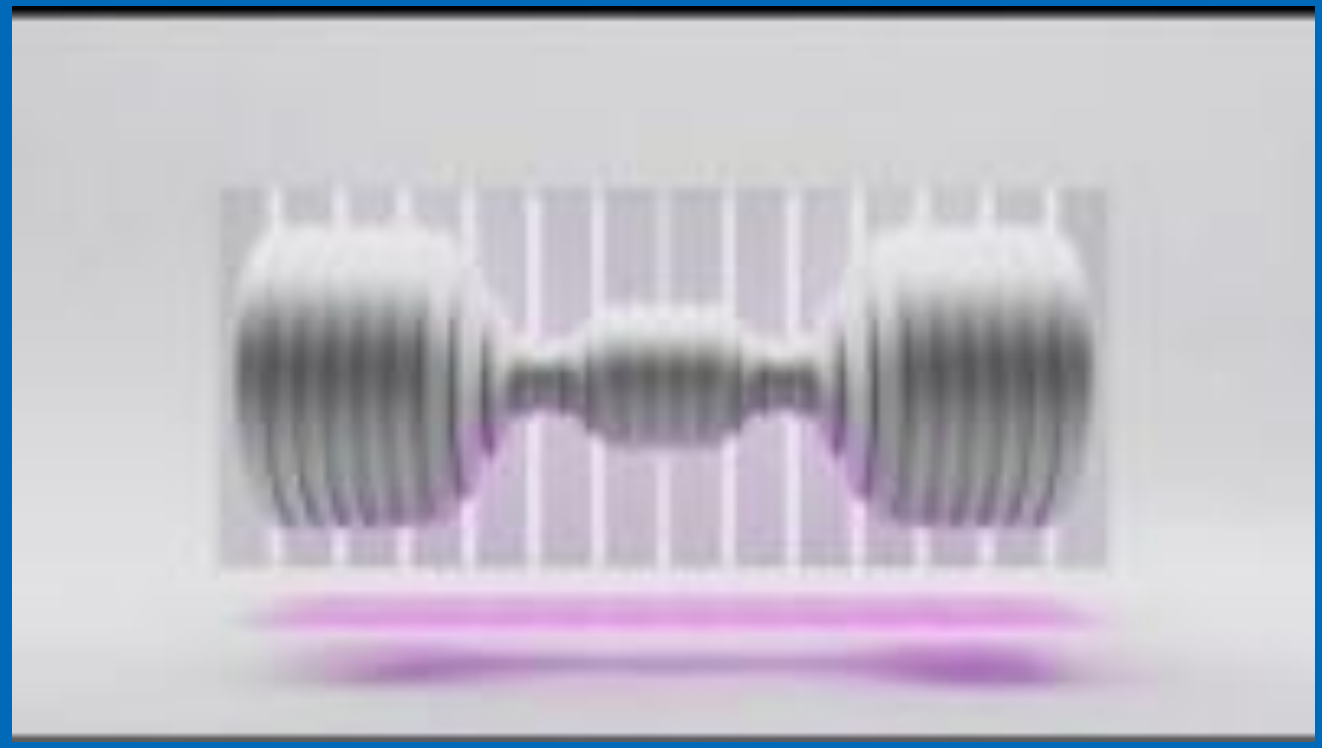
Everett Washington
27 July 2021

[Microsoft agrees to buy electricity generated from Sam Altman-backed fusion company Helion in 2028]

[Microsoft signs power purchase deal with nuclear fusion company Helion]

[Nucor and Helion to Develop Historic 500 MW Fusion Power Plant (prnewswire.com)]

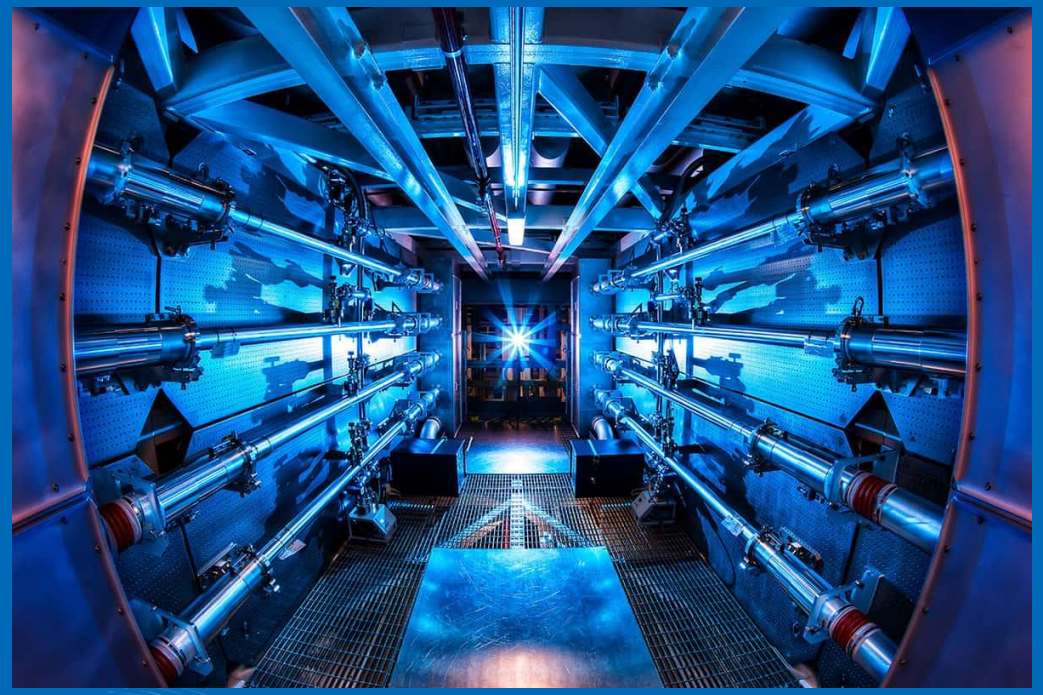
How it works.



National Ignition Facility

Inertial Fusion

D-T Fuel



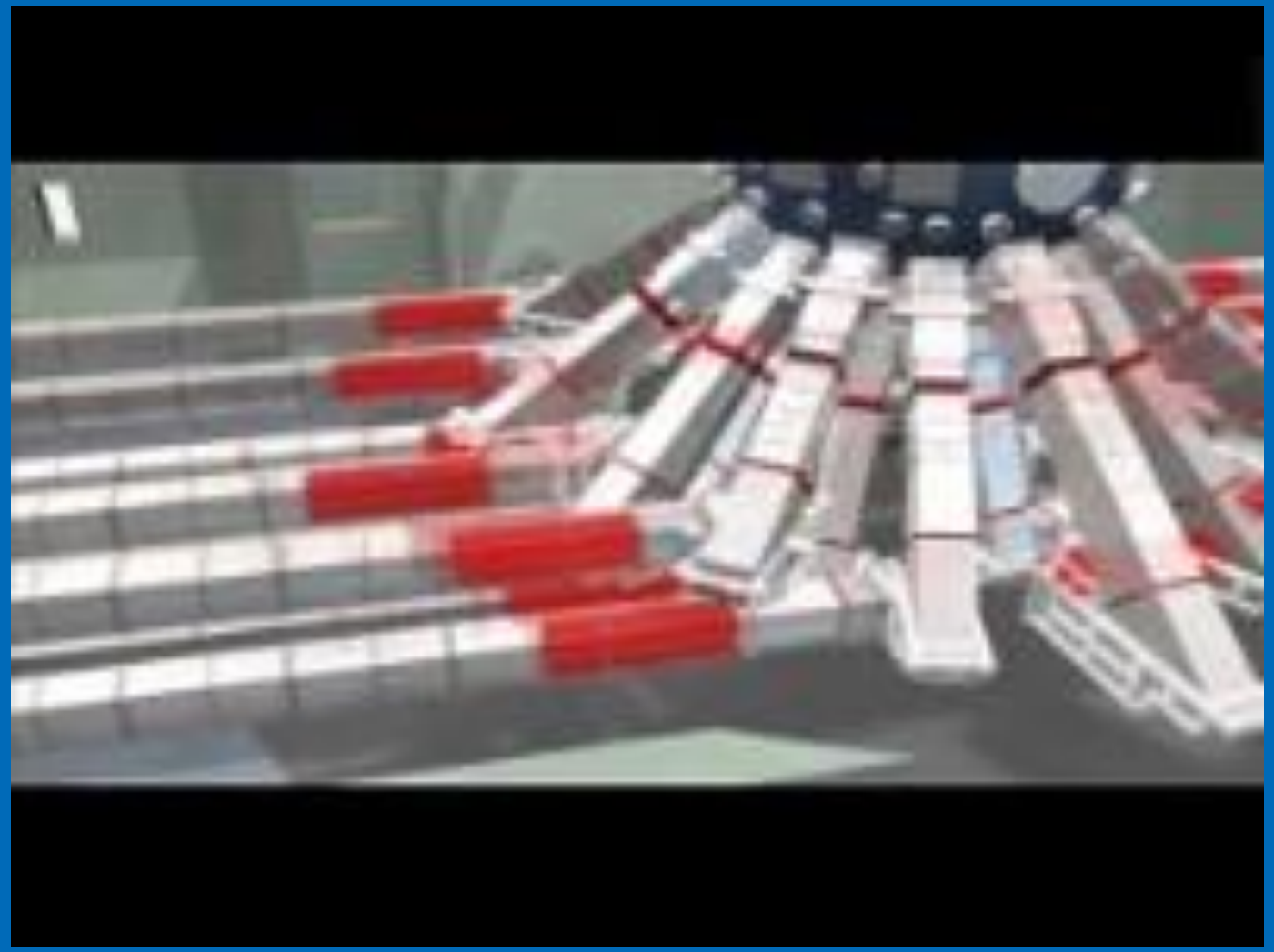
Q>1 on 5 December 2022

[Feds confirm historic fusion ignition at Lawrence Livermore National Laboratory - CBS San Francisco (cbsnews.com)]

[Breakthrough in nuclear fusion energy announced - BBC News]

[US scientists reach long-awaited nuclear fusion breakthrough, source says | CNN Politics]

How it works.

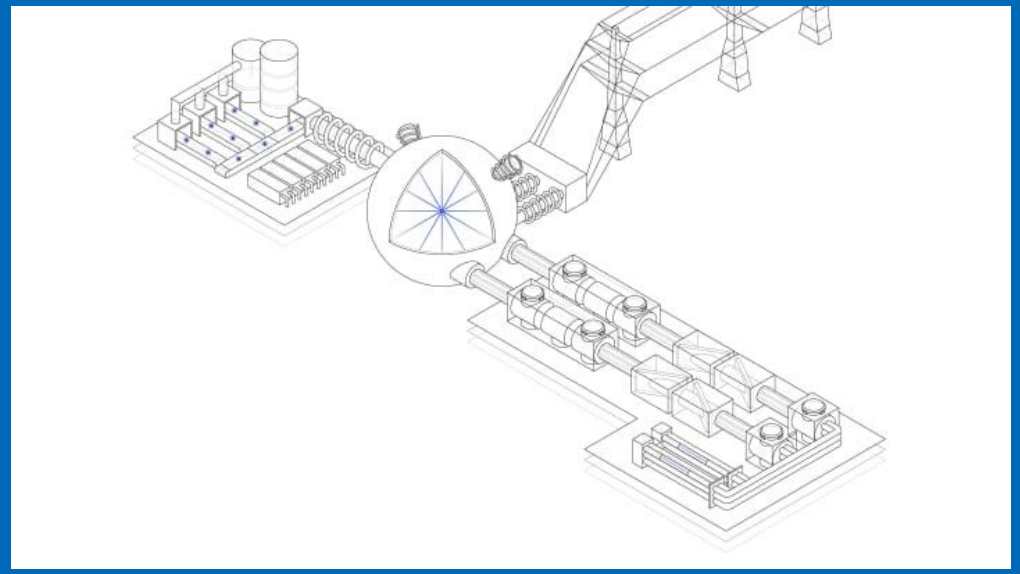


Other approaches

ZAP ENERGY (Sheared Flow Stabilized Z-Pinch):
Zap Energy - YouTube
How It Works: Making a Z Pinch - YouTube

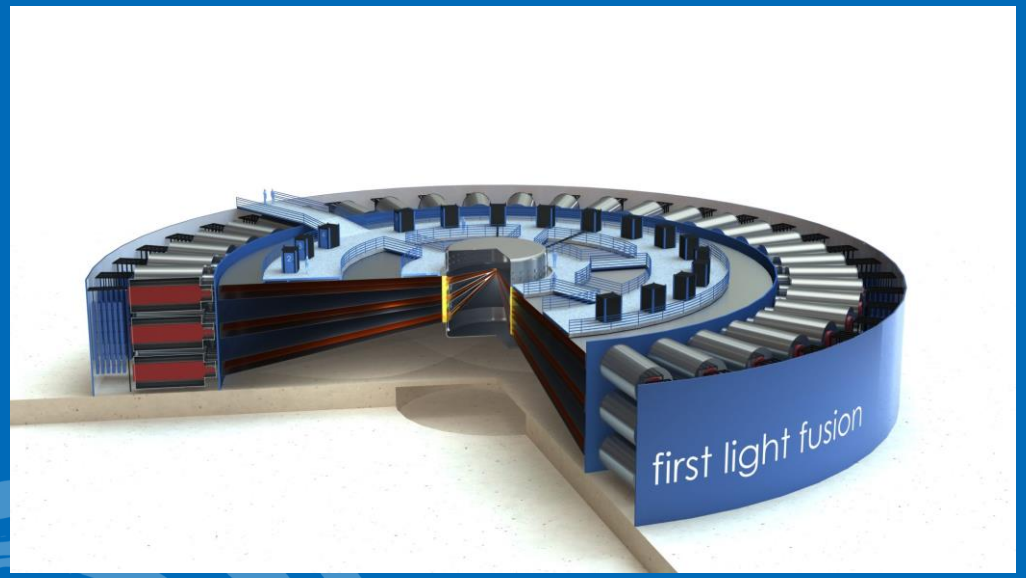
MARVEL FUSION (Inertial Fusion p-B^{11} fuel):
German start-up Marvel Fusion invests in US, laments lack of support in Europe | Clean Energy Wire

CSU and Marvel Fusion partner on groundbreaking $150M laser facility (colostate.edu)

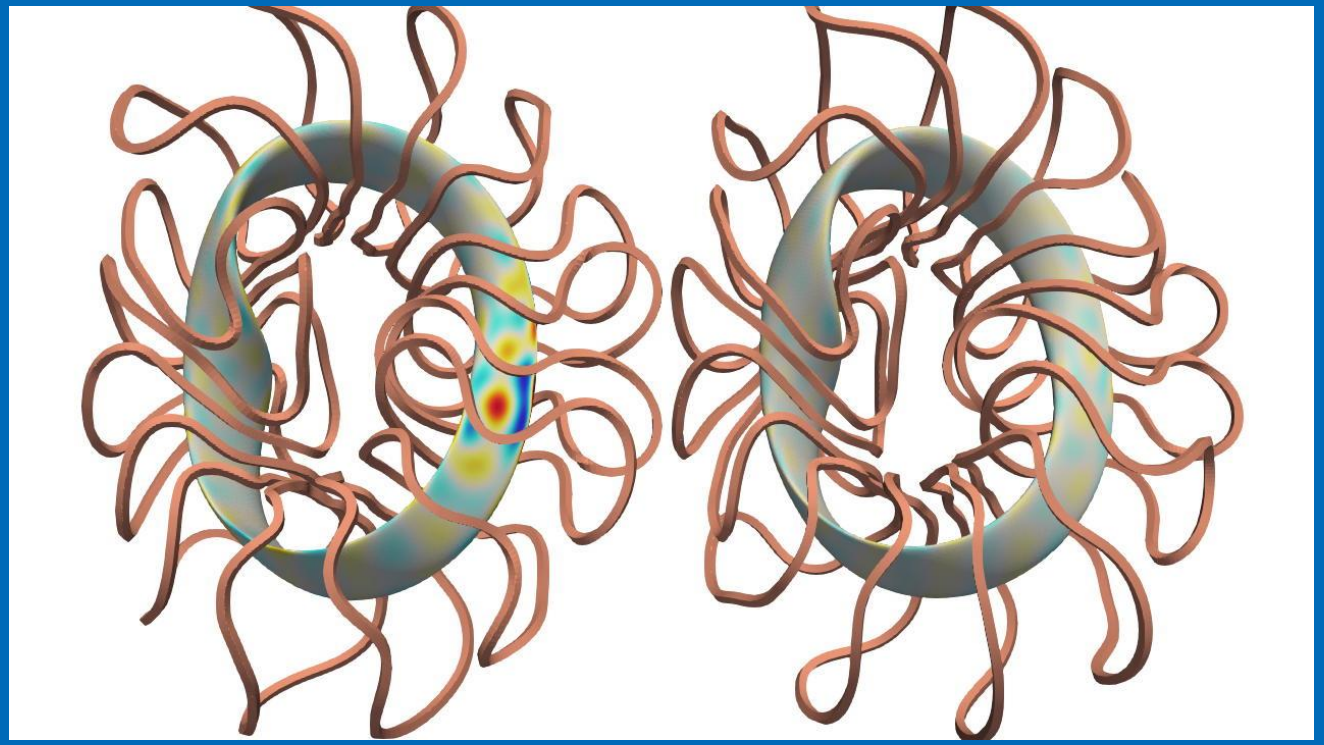


Other approaches

FIRST LIGHT FUSION (Projectile Fusion:
First Light reactor concept – YouTube
Projectile fusion – YouTube

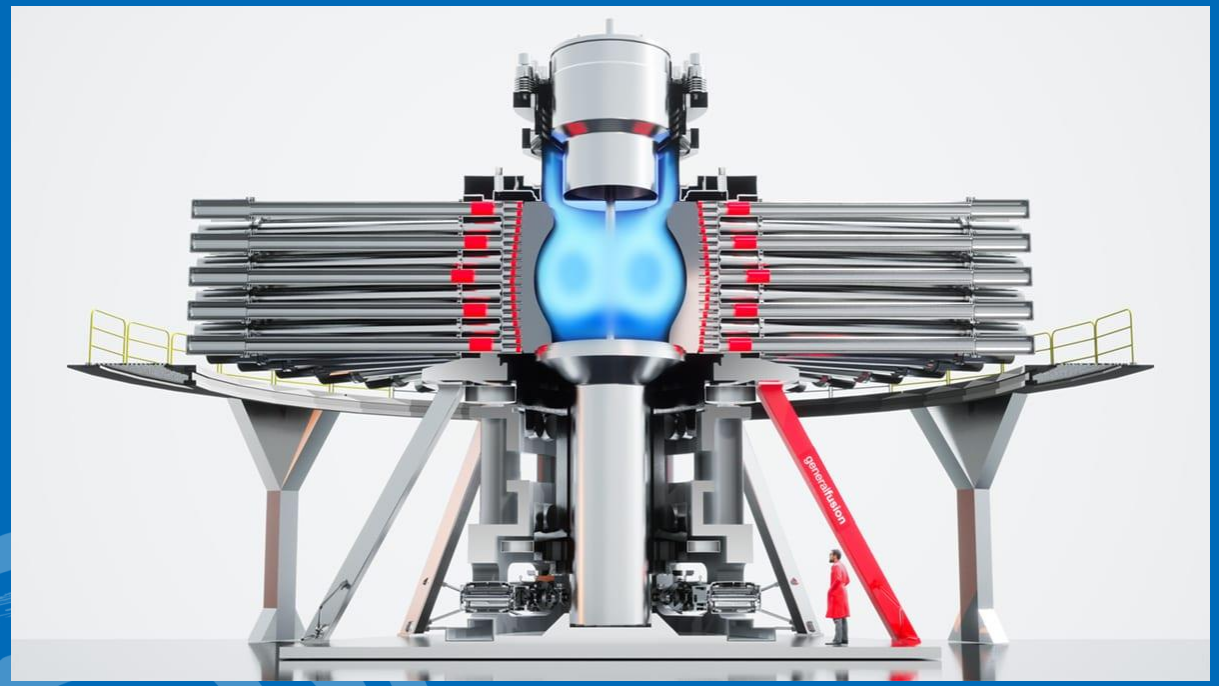


PROXIMA FUSION (Quasi-Isodynamic Stellerator):
Proxima Fusion starts cooperation with other merger startups - Munich Startup (munich-startup.de)

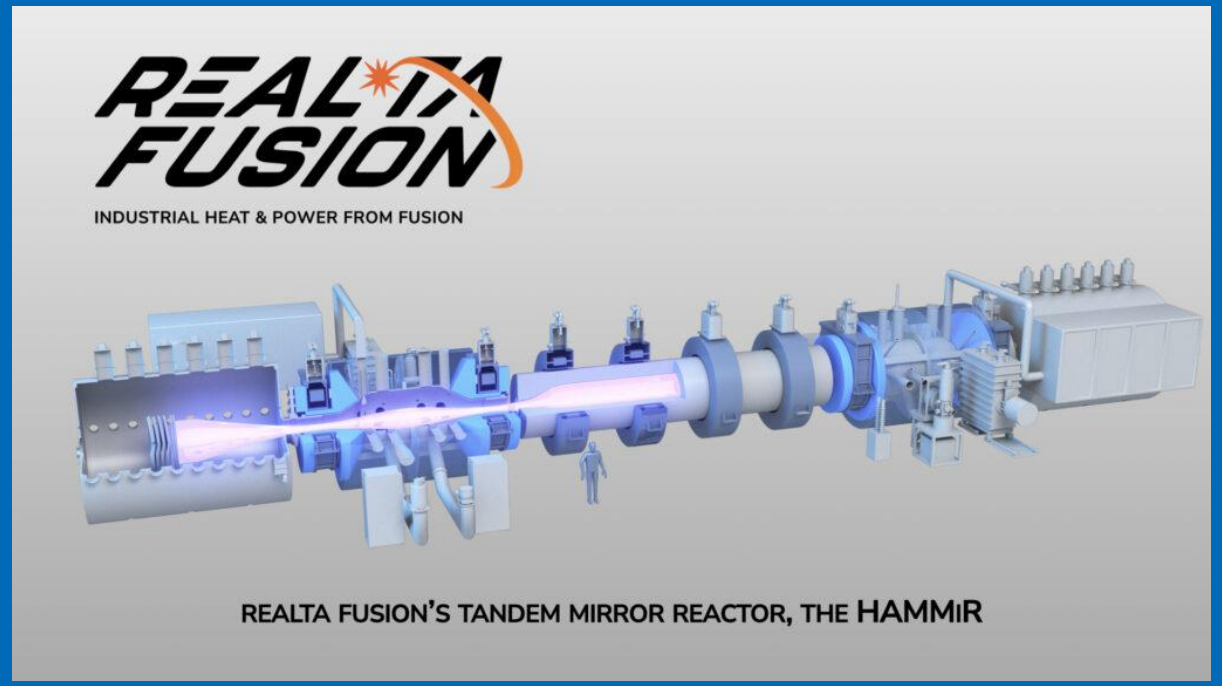


Other approaches

General Fusion: Magnetized Target Fusion Technology - YouTube



REALTA FUSION (High Field Magnetic Mirror): Realta Fusion Inc | Industrial heat and power from fusion energy



Fusion Industry Association

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1. **FUSION ENERGY DEVELOPMENT AND DEPLOYMENT FRAMEWORK**

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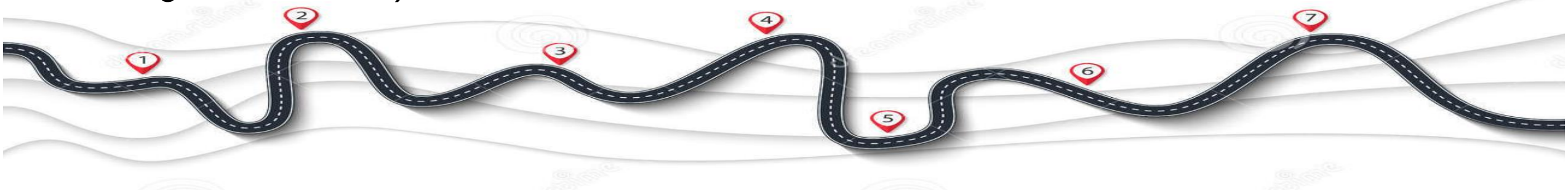
Fusion Energy Development and Deployment Framework

Topics include (not exhaustive):

- ***Fusion Key Elements*** (announced FEC2023)
- Guidelines for Fusion Safety Assessments and Regulatory Frameworks
- General Design Criteria and Applicable Codes and Standards
- Technologies and Fuel Cycles
- Fusion Economies and Financial Analysis
- Modelling and Simulation (neutronics, digital twins, etc.)
- Materials and Structures
- Knowledge Management (engineering, integration, construction LLs)
- Stakeholder Engagement
- Energy Justice and Social Licensing
- Program Development and Deployment
- Systems Integration and Construction
- Staffing and Training, Operations and Maintenance Requirements
- Fusion Facility Capacity and Integration with Grid (infrastructure)

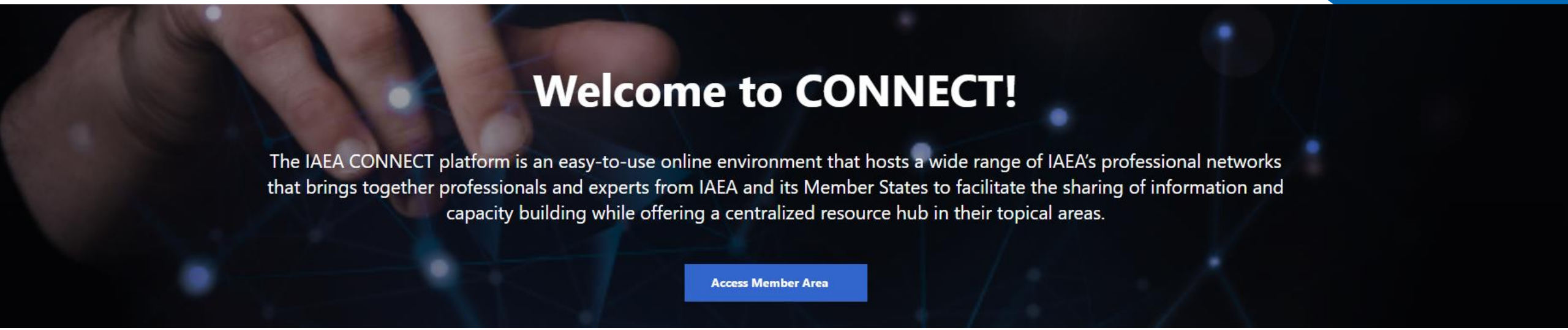


Fusion Framework

Fusion Power Plant Development and Deployment Framework

- Purpose is to provide subject modules to assist member states in developing fusion programs
- Web-based training will be provided for each module
- Fusion Advisory Services to be provided on request
- All framework modules will be managed in the Fusion CONNECT platform; international collaboration can be managed through access control

FUSION CONNECT Platform



bDN is a coordinated effort to create a Reference Database for beta-delayed neutron...
Database and SW Tools

Ofers the latest information on IAEA activities, guidance documents and examples ...
Capacity Building

Through CGULS, the IAEA supports a network of national and international...
Environmental Management

DISPONET serves to enhance efficiency in sharing international experiences t...
Waste Management

DSRSNet is a forum for sharing practical experience, knowledge and internation...
Waste Management

Support organizations or Member States to make available the relevant...
Environmental Management

GIF is focused on the research, development, and demonstration of six select...
Nuclear Reactors

To raise skills and expertise levels to facilitate safe decommissioning of nuclea...
Decommissioning

The IPN is being established to increase efficiency in sharing international...
Waste Management

ISOP network is established to increase collaboration and experience sharing in the...
Innovation Management

The ITV Network is a community of international nuclear measurement...
Database and SW Tools

LABONET has been established to increase efficiency in sharing...
Waste Management

The International Network of Life Management of Nuclear Power Plants (LMNPP) ha...
Capacity Building

MSCQ goal is to facilitate and encourage enhanced co-operation and the exchang...
Capacity Building

NFE is to enhance Member States' knowledge and information sharing in the...
Knowledge Management

Fusion Energy Conference 2023

Announcement from the IAEA DG Grossi:

- During the Fusion Energy Conference 2023 in London, DG Grossi made several announcements

- A new IAEA event, the *World Fusion Energy Group*; bringing together scientists and engineers, policymakers, financiers, regulators and civil society as the "next leg of the fusion energy journey will get us from experiment to demonstration to commercial fusion energy production"

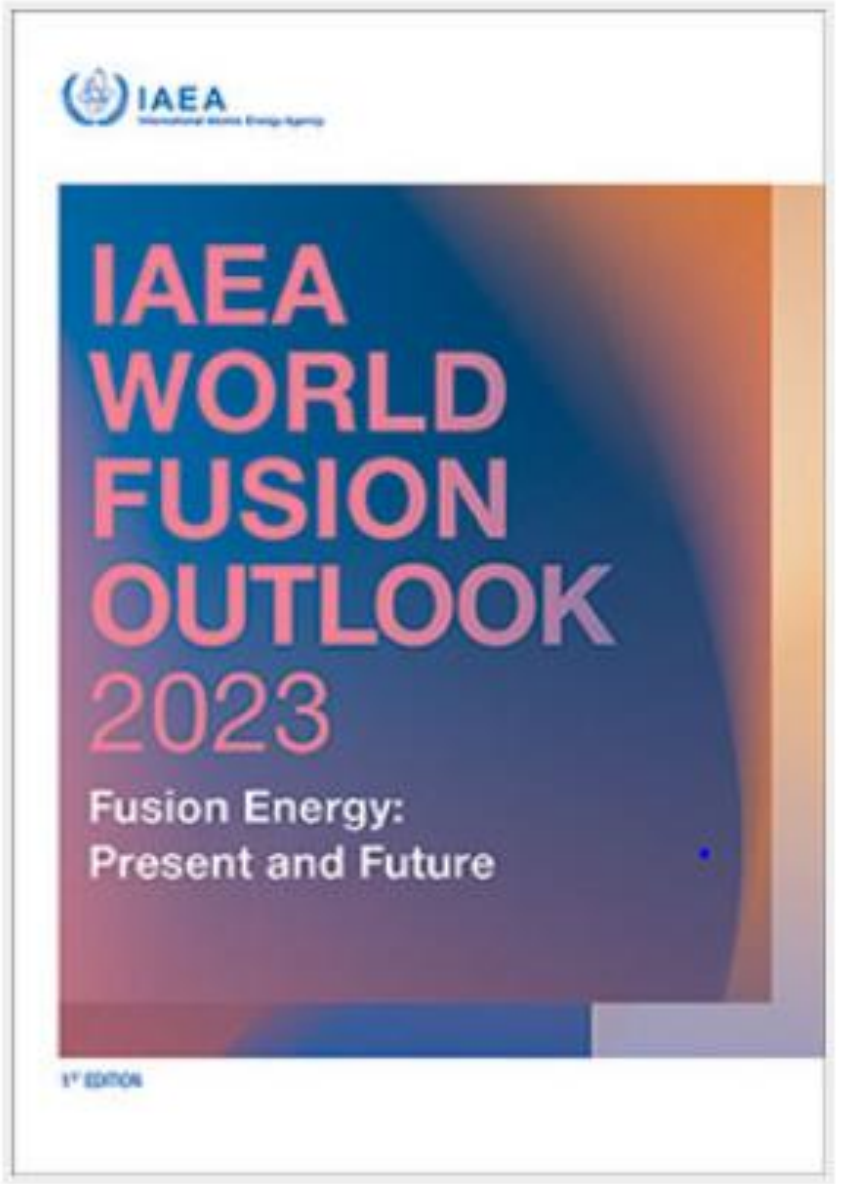
Fusion Energy Conference 2023

World Fusion Outlook:

- Intended it to be a regular publication providing "authoritative information and updates on fusion energy"
- and to become "a global reference for energy R&D, technology development and prospective deployment of fusion as a source of unlimited low carbon energy“
- *World Fusion Outlook*

Fusion Key Elements:

- "shortly invite fusion experts to work with the IAEA to outline Fusion Key Elements such as fusion-related definitions, characteristics and criteria for fusion energy to help develop common understanding among stakeholders essential for global deployment"



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CM on Pre-feasibility Study – GDC and C&S

General Design Criteria and Applicable Codes and Standards

- GDC and C&S should be technology neutral – or applicable to one technology over another – we've added attributes to different techs
- To the extent possible, codes and standards should be industrial (ex. IEC, ASME, IEEE…)
- Let's not re-invent the wheel; much work has already been done in this area, let's start with what's been done and identify gaps – in general, we'll review what's been done, but want to start with a clean slate
- An outcome of the meeting, should be to identify additional priorities of the members represented by this group

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How Fission can help Fusion

Fission

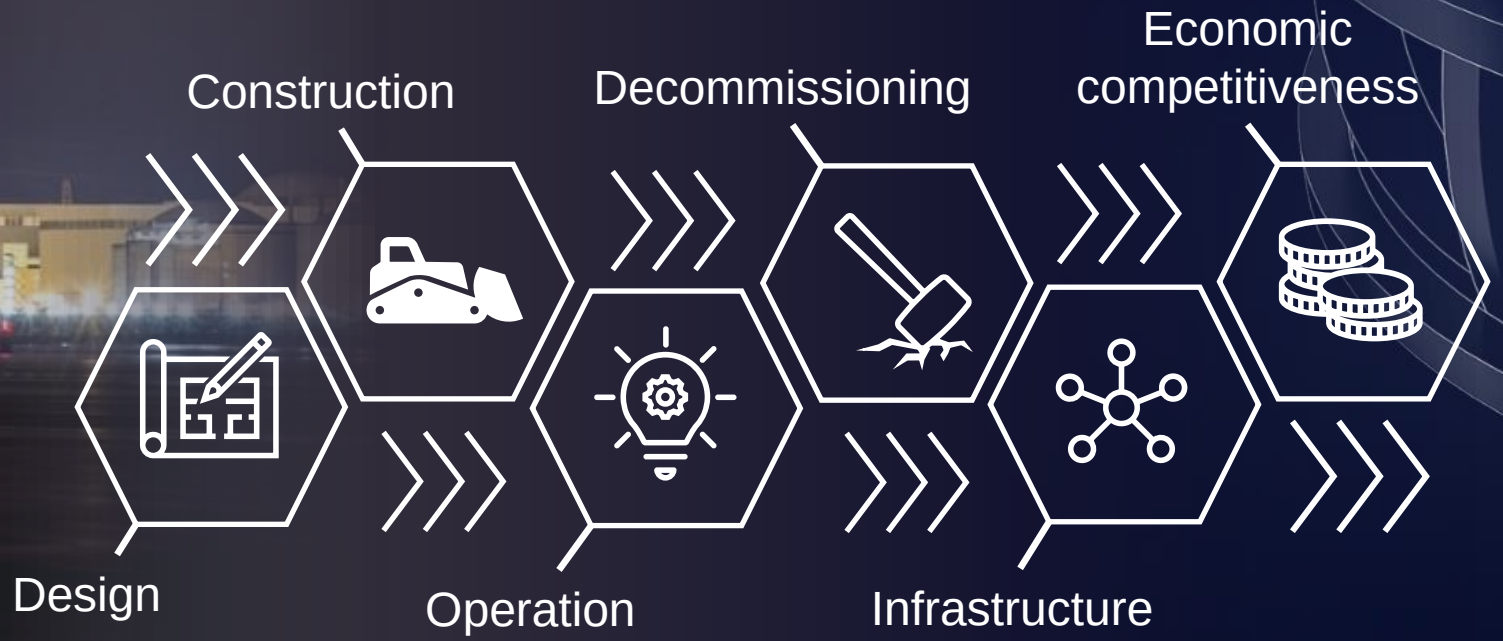
19,615
reactor years of operation

438
reactors in operation

58
nuclear power reactors under construction

10%
of world's electricity production

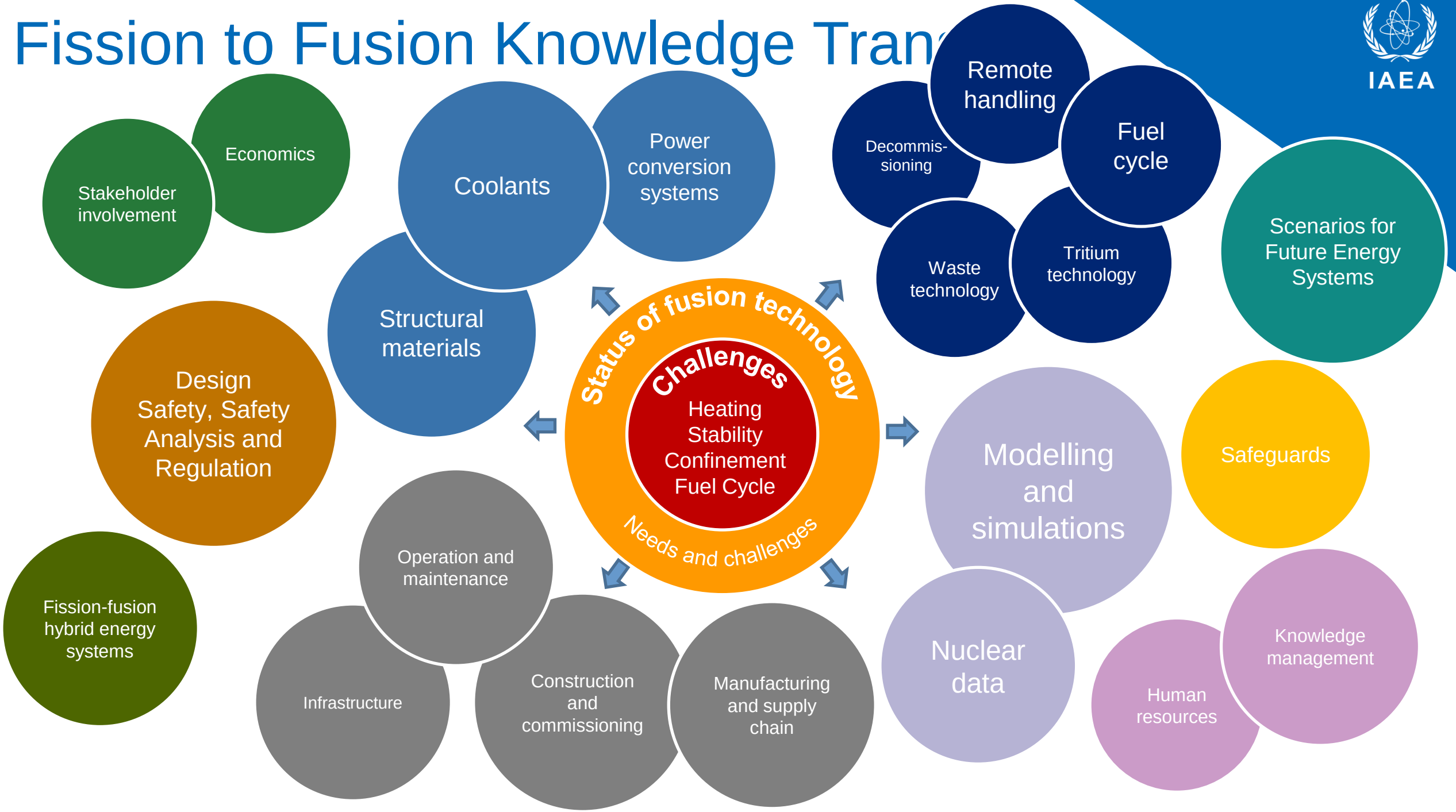
Many novel, innovative fission reactor designs under development, several expected for near term deployment.



Fusion

https://pris.iaea.org/pris/
https://unsplash.com/photos/C82jAEQkfE0

Fission to Fusion Knowledge Trans



Synergies in Technology Development between Nuclear Fission and Fusion for Energy Production

- Promote and facilitate the exchange of information on synergies between advanced nuclear fission and fusion technologies
- Summarize the **current status of cooperation** between fission and fusion technology development
- Discuss and identify **areas of development to bridge the gap** to deployment and to assess requirements in the field, leading to more focused efforts in specific areas
- Document the **discussions and major findings** among subject matter experts to support Member States to better understand and benefit from such synergies
- Serve as a **technical reference** for key technological aspects and related economic and human resource factors

The NES publication provides

- **insight on all these areas**
- **examples of good practices and lessons learned**
- **suggestions to accelerate the transfer of technology, knowledge and know-how from fission to fusion**

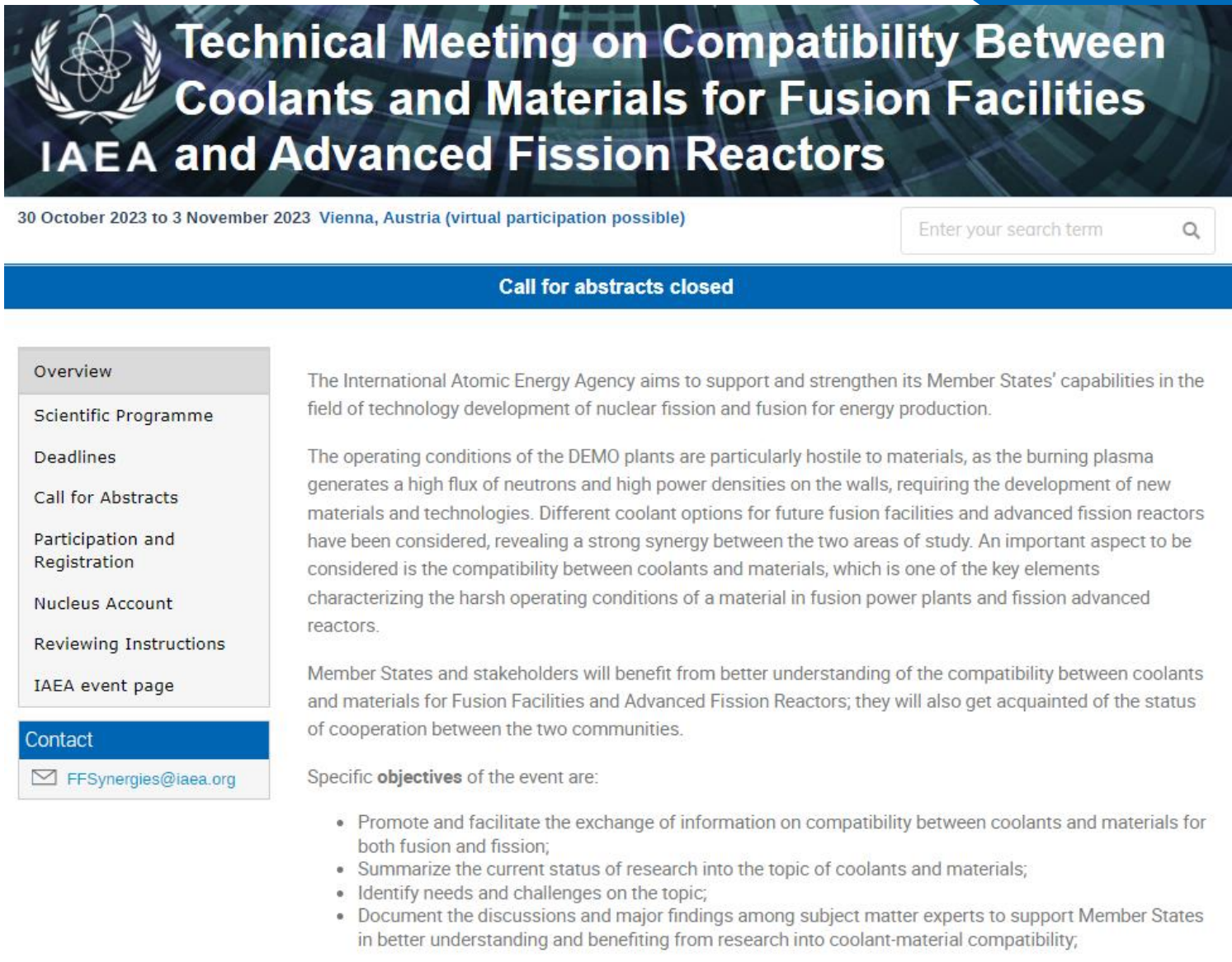
INTENDED AUDIENCE

NES document will be open to **all Member States** involved or interested in the research and development of fission and/or fusion technology and their synergies, including

- **government organizations** (policymakers, analysts, regulators and R&D agencies)
- **industry stakeholders** (vendors, engineering companies, plant operators and technology developers

Nuclear Energy Series on Fission-Fusion Synergies: Status and Activities

- NES on Fission-Fusion Synergies is in publication to be released in early 2024
- Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission Reactors is scheduled for:
  - 30 October – 3 November 2023
- Additional consultancy and technical meetings will be scheduled as needed, ex. Neutronics



IAEA

Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission Reactors

30 October 2023 to 3 November 2023 Vienna, Austria (virtual participation possible)

Enter your search term

Call for abstracts closed

Overview
Scientific Programme
Deadlines
Call for Abstracts
Participation and Registration
Nucleus Account
Reviewing Instructions
IAEA event page

Contact
FFSynergies@iaea.org

The International Atomic Energy Agency aims to support and strengthen its Member States' capabilities in the field of technology development of nuclear fission and fusion for energy production.

The operating conditions of the DEMO plants are particularly hostile to materials, as the burning plasma generates a high flux of neutrons and high power densities on the walls, requiring the development of new materials and technologies. Different coolant options for future fusion facilities and advanced fission reactors have been considered, revealing a strong synergy between the two areas of study. An important aspect to be considered is the compatibility between coolants and materials, which is one of the key elements characterizing the harsh operating conditions of a material in fusion power plants and fission advanced reactors.

Member States and stakeholders will benefit from better understanding of the compatibility between coolants and materials for Fusion Facilities and Advanced Fission Reactors; they will also get acquainted of the status of cooperation between the two communities.

Specific **objectives** of the event are:

- Promote and facilitate the exchange of information on compatibility between coolants and materials for both fusion and fission;
- Summarize the current status of research into the topic of coolants and materials;
- Identify needs and challenges on the topic;
- Document the discussions and major findings among subject matter experts to support Member States in better understanding and benefiting from research into coolant-material compatibility;

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3. SYNERGIES IN TECHNOLOGY DEVELOPMENT BETWEEN NUCLEAR FISSION AND FUSION FOR ENERGY PRODUCTION

4. **OTHER ONGOING NUCLEAR ENERGY ACTIVITIES**

Considerations of Technology Readiness Levels for the Fusion Technology Components

Technology Readiness Levels (TRL) TECDOC to be released in early 2024

- TRL frameworks consist of nine levels ranging from basic principles and observations (TRL1) to fully robust technologies validated for application in industry (TRL9)
- The scope of this TECDOC include five streams of TRLs related to critical technologies in fusion development:
  - Systems
  - Materials
  - Software
  - Manufacturing
  - Instrumentation

Decommissioning Considerations for Fusion Facilities

Fusion Decommissioning TECDOC in development

- Consultancy Meeting on considerations for decommissioning of fusion facilities held 2 – 6 October 2023
- Technical Meeting scheduled for 19 – 23 February 2024
- Table of Contents
  - Key Considerations for Decommissioning of Magnetic Fusion Devices
  - Regulatory Framework for Decommissioning of Fusion Facilities
  - Preparation for Decommissioning
  - Implementation of Decommissioning Activities
  - Management of Fusion-Specific Radioactive and Toxic Materials

Radioactive Waste Management for Fusion

- **Consultancy on the Management of Radioactive Waste for Fusion: Nov. 2019**

- **Workshop on Waste Management for Fusion in Oct. 2021**

CM Objective: identify key areas and priorities **for lifecycle radioactive waste management of fusion machines;**

- waste minimisation by design and during operations, maintenance and decommissioning;
- effective waste management techniques through characterisation processing, storage and disposal;
- integrating best practice into existing national programmes.

Output: Publication of IAEA TECDOC (in draft)

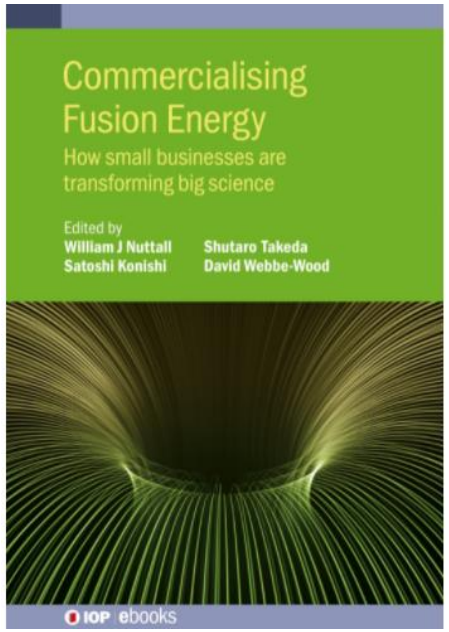
Organisation	Country
EUROfusion	Germany
ENEA	Italy
Wisconsin Univ.	USA
CCFE	UK
QST	Japan
QST	Japan
KIT	Germany
Andra	France
ITER	--
IAEA/NEFW	--
IAEA/NAPC	--

Economic Studies for Fusion

- 1st IAEA Workshop on Fusion Enterprises, held in 2018 in Santa Fe, Argentina

  TECDOC **New Pathways for Fusion Energy Systems** as Proceedings (submitted to Publication Committee)

- **2nd IAEA Workshop on Fusion Enterprises (July 2022, UK)**



- External Publication; released
  Book Chapter ***Considerations for Strategies for Fusion Commercialisation***
  Institute of Physics (IOP) Publications: London.

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Thank you