EUROfusion

Energie de fusion et perspectives

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JET termine sa seconde campagne D-T (DTE2) avec succès !

Objectif : 10 MW de puissance fusion stationnaire pendant environ 5 secondes atteint

- **DTE1 en 1997 avec des parois en carbone → DTE2 en 2021 avec des parois Be-W « ITER-like » = nouvelles données pour l'opération d'ITER**

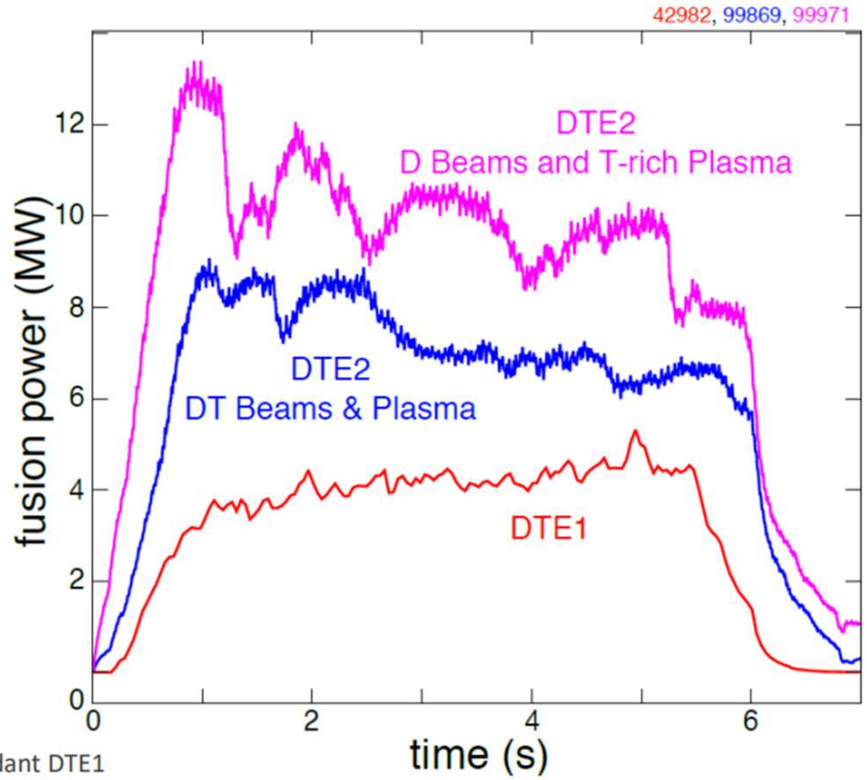
- **Fin du contrat d'opération avec la CE (NJOC) le 31 octobre 2021 → machine nationale UK**

- **Prolongation jusqu'en 2023 dans le cadre du WP-Tokamak Exploitation (WPTE) → sujette à la contribution de l'UK à EUROfusion**
  - Informations additionnelles pour ITER : accès mode H en hélium, faible disruptivité et caractérisation SPI, caractérisation de l'interaction plasma-paroi dans les scénarios avec injection d'impuretés (N, Ne), caractérisation de l'inventaire tritium en surface

- **Démantèlement par UK à partir de 2024…**

JET (UK)

Plus de 10^{20} neutrons (280 MJ d'énergie fusion) produits le 21 décembre 2021 et 10.3 MW moyenné sur 5s



*Communiqué de presse international pour célébrer la campagne DTE2 de JET prévu le **9 février 2022***

JET

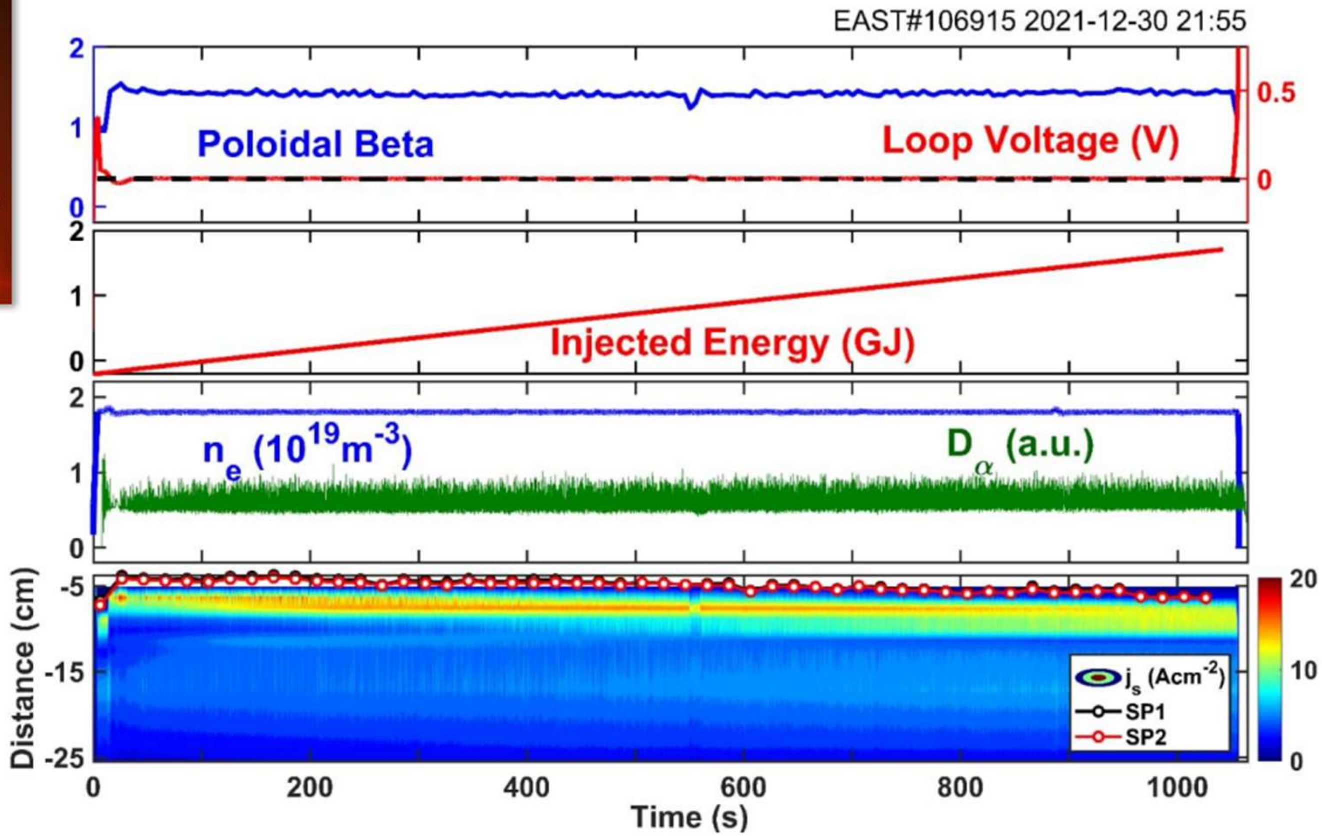
*22 MJ obtenus pendant DTE1

CHINA

Nouveau record de durée plasma pour EAST !

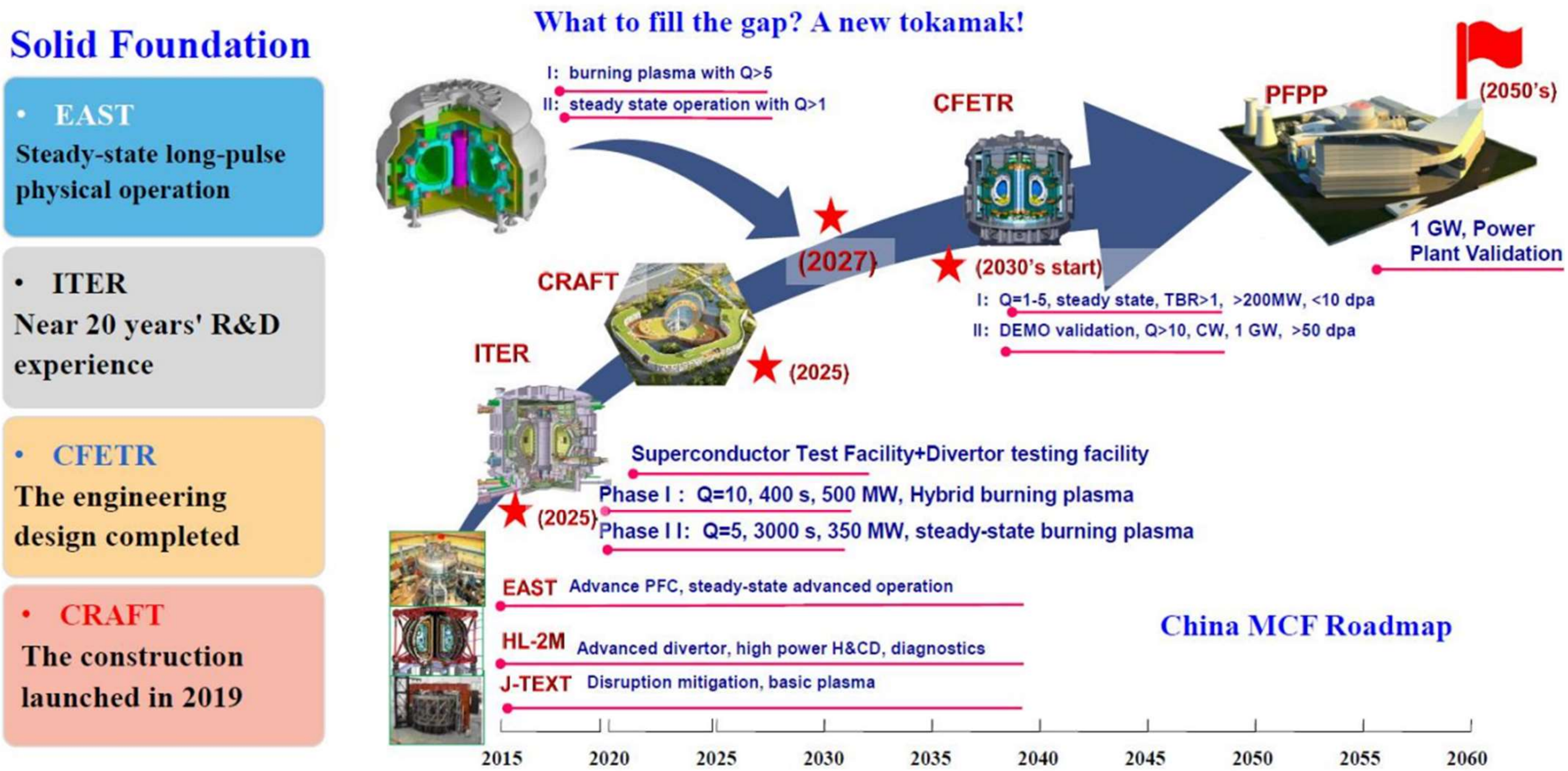
…et un nouveau record d'énergie injectée avec ~1.75GJ

avec **1MW de LH et 0.55MW d'ECRH** pour un I_p de 336kA



CFETR (Chine)

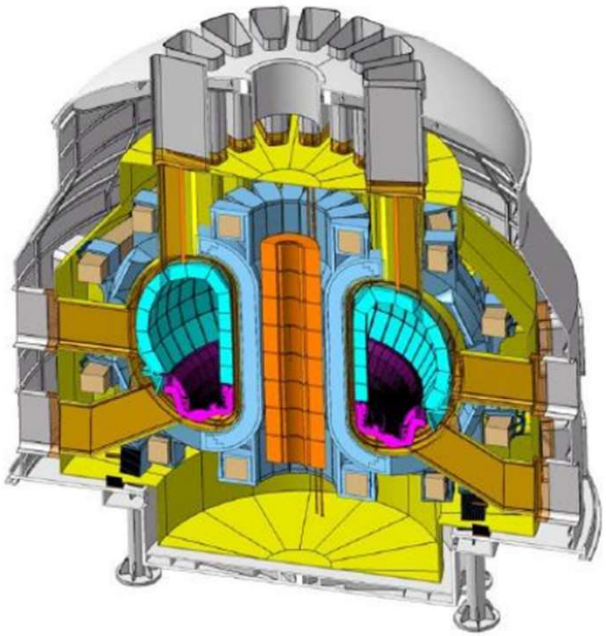
Le projet BEST vient consolider la roadmap chinoise



BEST : “Burning plasma Experiment Superconducting Tokamak”

Obtenir un plasma en combustion à coût réduit (construction et opération)

- Etudier le comportement des particules alpha et leur contrôle dans les plasmas en combustion
- Maîtriser le contrôle intégré des scénarios continus



Performance

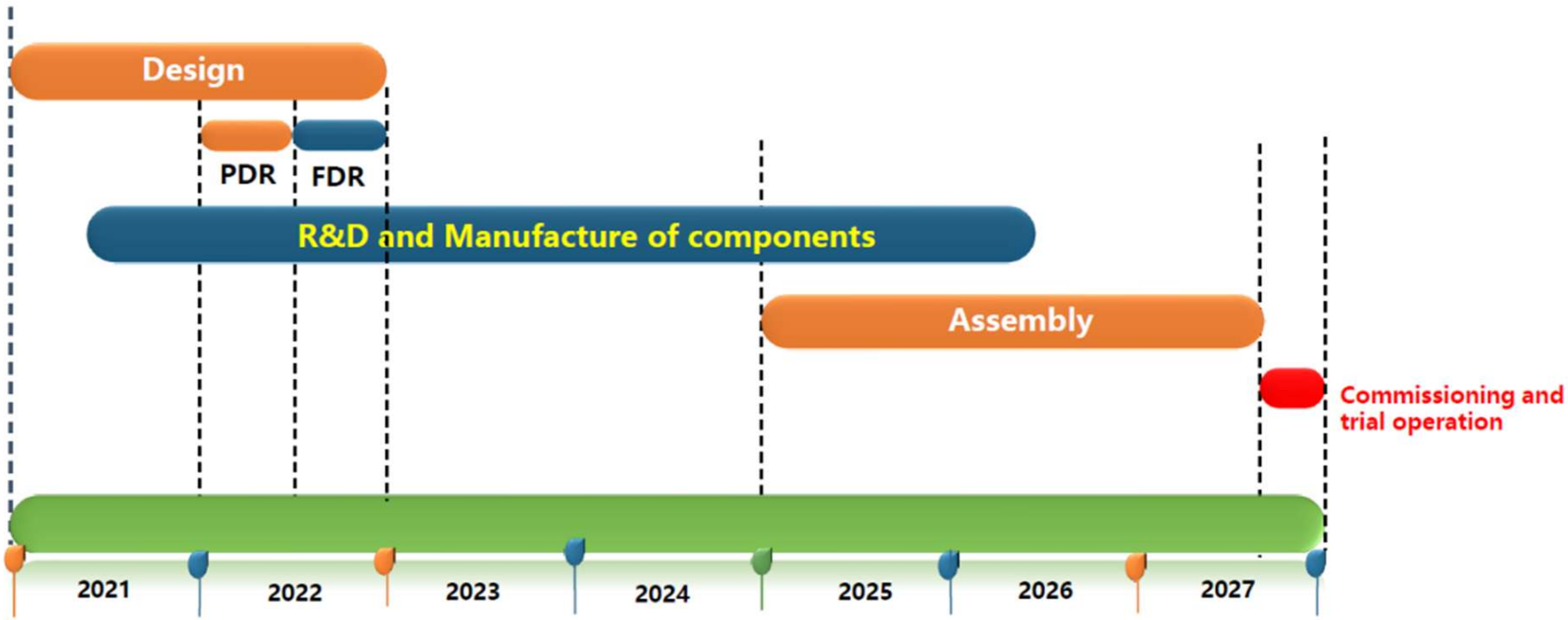
- Beta ↑
- Plasma Current ↑
- Advanced Divertor ↑
- Heat Flux ↑

Main parameters	
Plasma current	I_p=4-7 MA
Major radius	R=3.3 m
Minor radius	a=1 m
Elongation	Ƙ=a/b=1.9
Trianglularity	δ=0.49
Toroidal field	B_T=6.4 T
Fusion power	P_{fusion}=40-300 MW

Et développer les technologies clés pour le futur réacteur de démonstration

BEST : mitigation des risques pour la construction et l'opération de CFETR

Un planning très ambitieux : vers une **phase D-T dès 2030** !



- Le 30 décembre 2021, les chercheurs et ingénieurs de l'Institut de Physique des Plasmas de l'Académie des Sciences à Hefei en Chine, ont réussi à maintenir un plasma de fusion à une température de 70 millions de degrés pendant plus de 17 minutes (1056 secondes) dans le tokamak EAST.

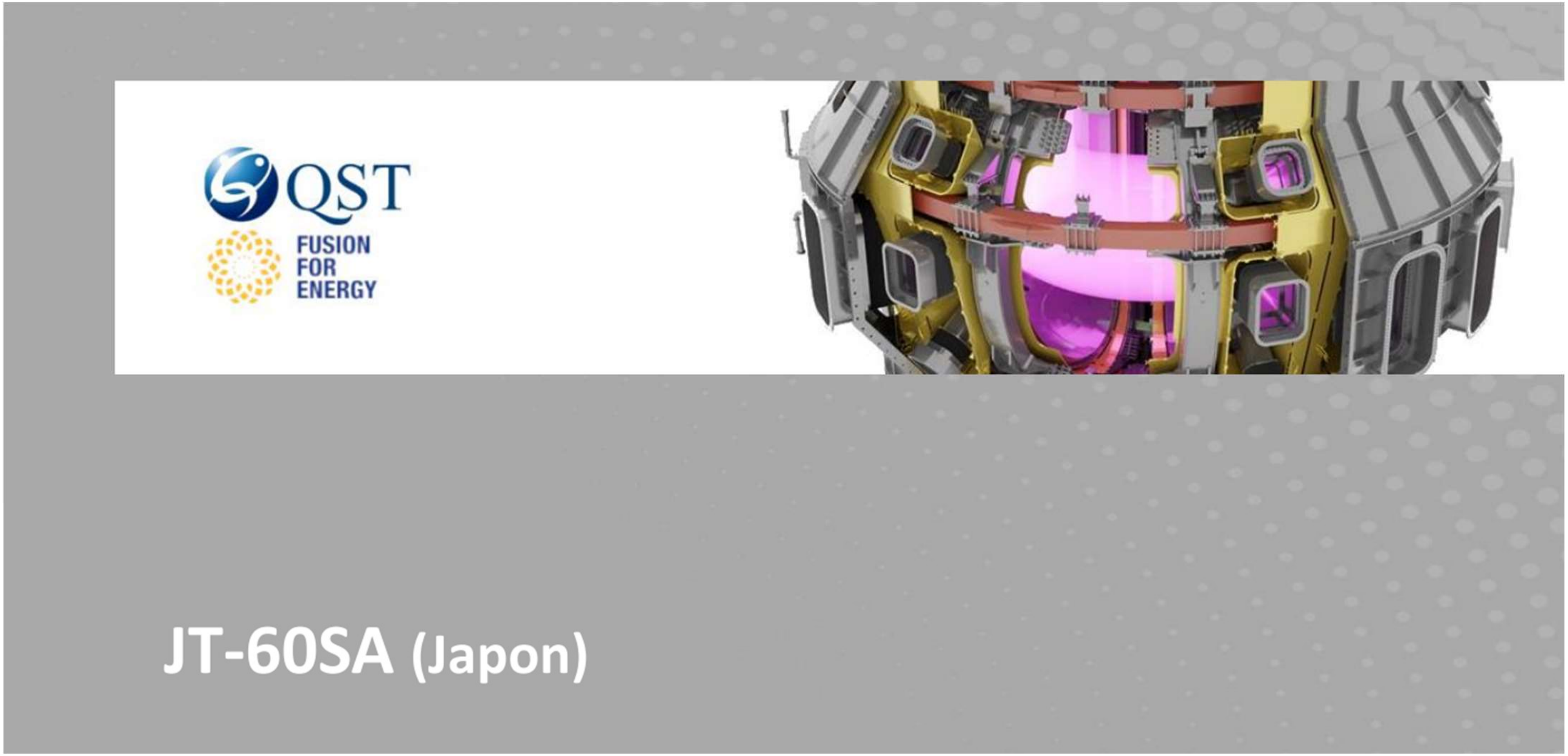
- deux tokamaks principaux en Chine sont East, et HL-2M situé à Chengdu qui a démarré fin 2020.

- Mis en service en 2006, East est équipé de bobines supraconductrices et l'une de ses missions est justement de développer des plasmas très longs et de servir de banc de test pour Iter en termes de physique et de technologie.

- East a notamment démontré en 2021 l'obtention d'un plasma en mode-H (le mode de confinement privilégié pour Iter) de 101 secondes avec une température de 120 millions de degrés.

- East est une installation expérimentale n'utilisant pas de tritium, et qui donc n'a pas vocation à générer de l'énergie ; ce n'est donc pas un réacteur

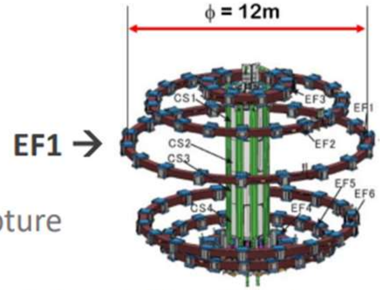
JAPAN

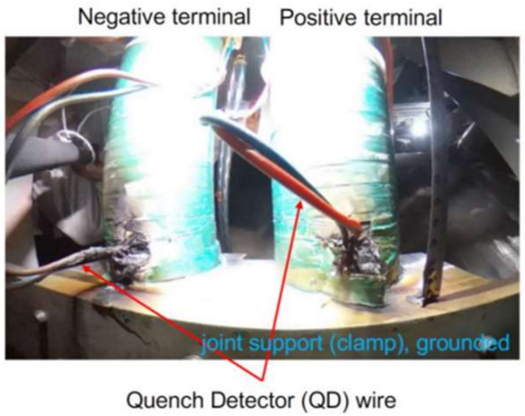


JT-60SA programme (1/2)

Machine status

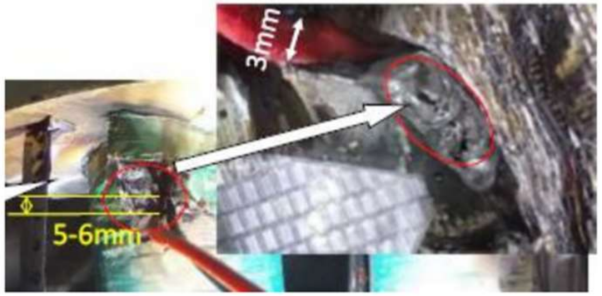
- **Commissioning stopped** on March 9, because of an incident on feeders of coil EF1
- **First report** on incident and root causes produced and elaboration of a **recovery plan**
- **Foreseen delay of exploitation: 15 months →** plasma commissioning **summer 2022**; start of first scientific campaign: **Oct. 2024**





EF1 incident

- **Over current at the EF1 feeding detected**
- TF and PF cryogenic system pressure increased and a rupture disc **released He into the torus hall**
- **Cause:** arcing started between the positive terminal joint and metallic support, then a second arc at the negative terminal → **short circuit** via arcs and support



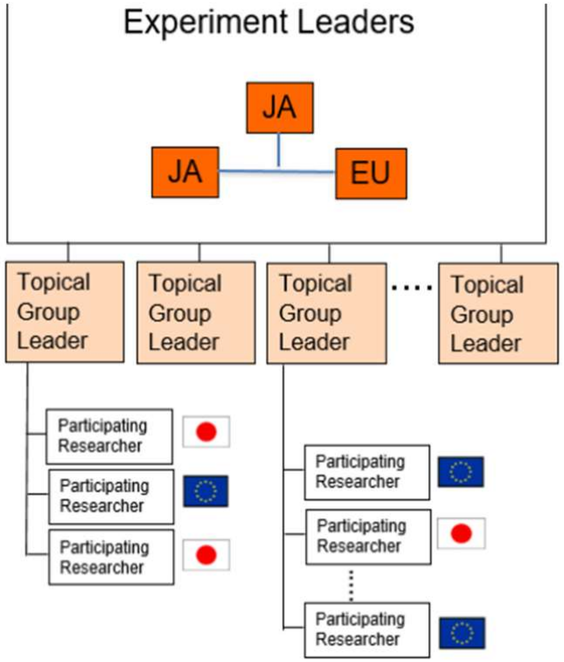
Lessons learned and consequences

- **design** of feeders and quench detection cables **insulations** was not adequate
- **voltage holding problems** also on other coils, including TF
- insulations must be re-manufactured and **Paschen-tested** on mockups
- **stricter quality measures** in manufacturing and operation **enforced**

JT-60SA programme (2/2)

Experiment Leaders from Japan and from Europe appointed

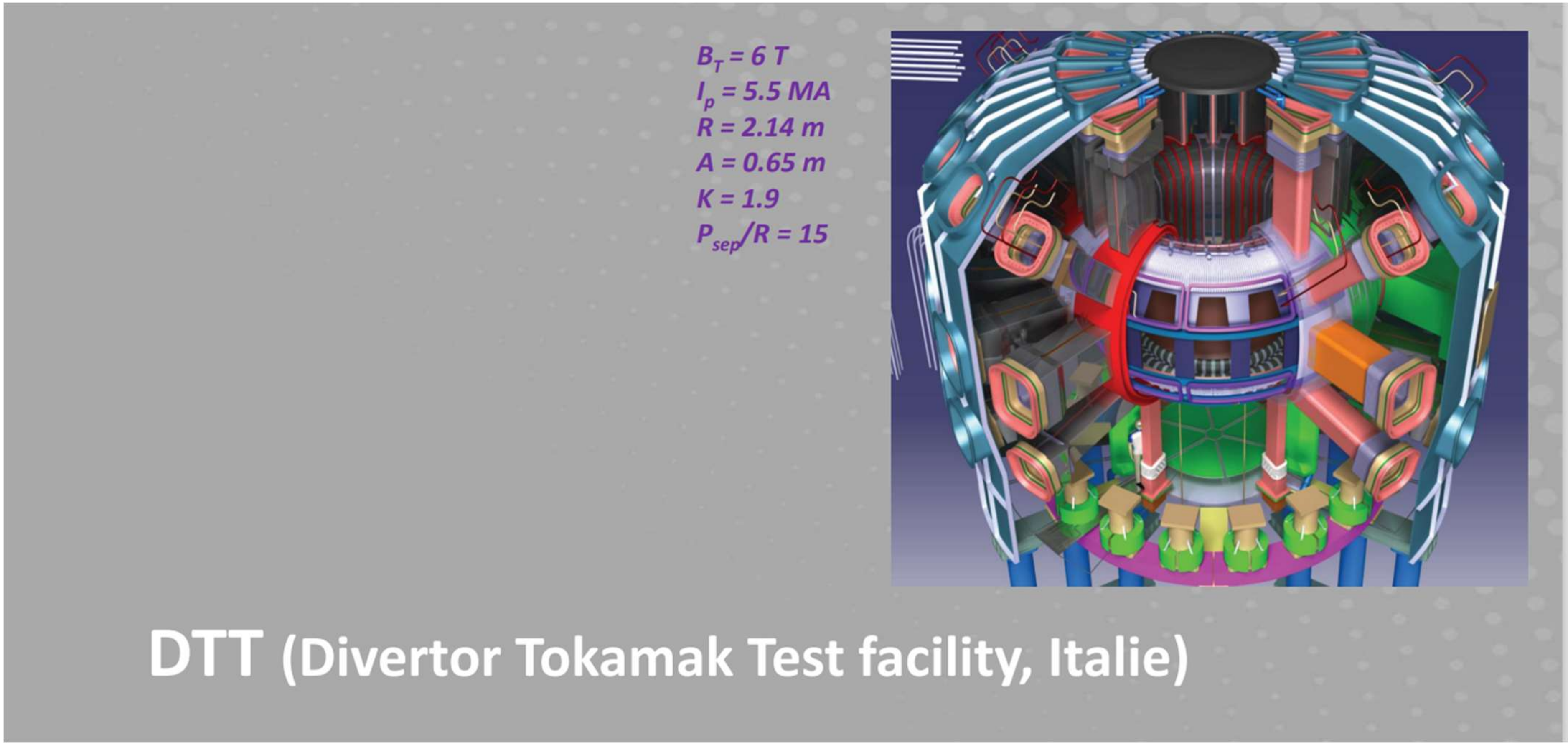
- **Maiko Yoshida (QST) → coordinator**
- **Hajime Urano (QST)**
- **Jeronimo Garcia (CEA/IRFM)**
- **CQMS document** specifies the function and related organization of the Experiment Team (document elaborated by S. Ide and E. Joffrin)
- The **Experiment Leaders** implement the JT-60SA experiment, organize the related analyses, modelling and simulation and can propose enhancements



JT-60SA International Fusion School (JIFS)

- **School charter** written and approved. **Advisory Board** appointed.
- **Co-directors appointed** (Kamada & **Giruzzi (CEA/IRFM)**)
- **Programme of 1st edition** drafted and thoroughly discussed
- JIFS victim of its success: **EU Commission and MEXT** want a joint declaration at **governmental level**, inauguration with top-level politicians etc. → **1st edition delayed to 2022**

ITALY


B_T = 6 T
I_p = 5.5 MA
R = 2.14 m
A = 0.65 m
K = 1.9
P_{sep}/R = 15
DTT (Divertor Tokamak Test facility, Italie)

EUROfusion

The European Roadmap – DEMO Development Programme

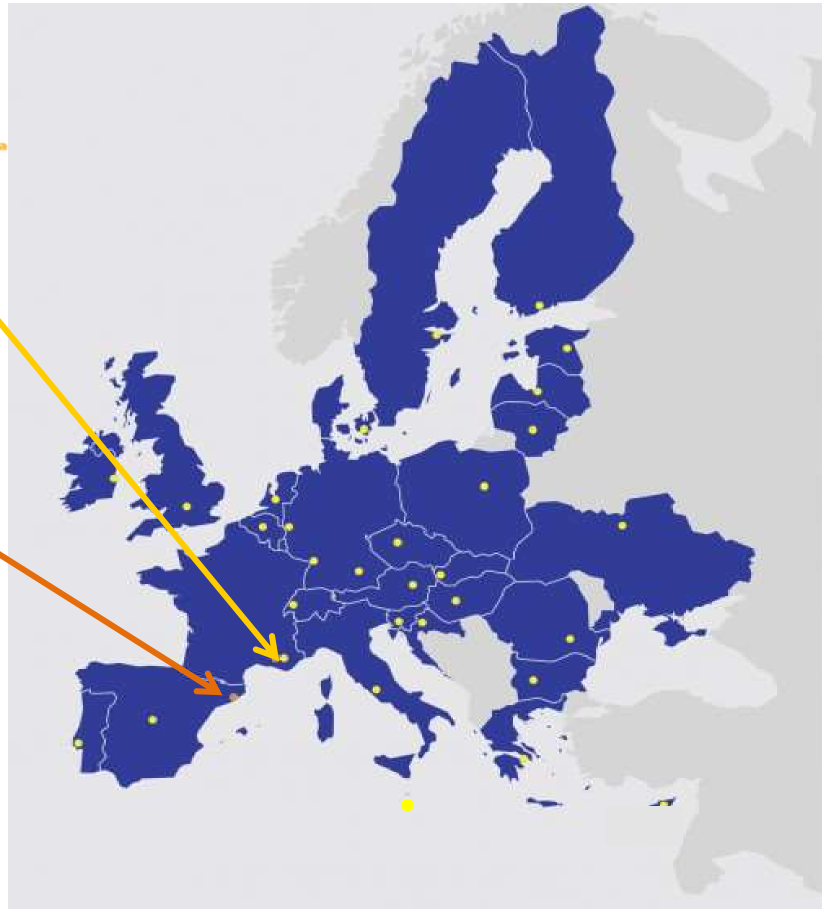
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

EUROfusion

FUSION FOR ENERGY

iter

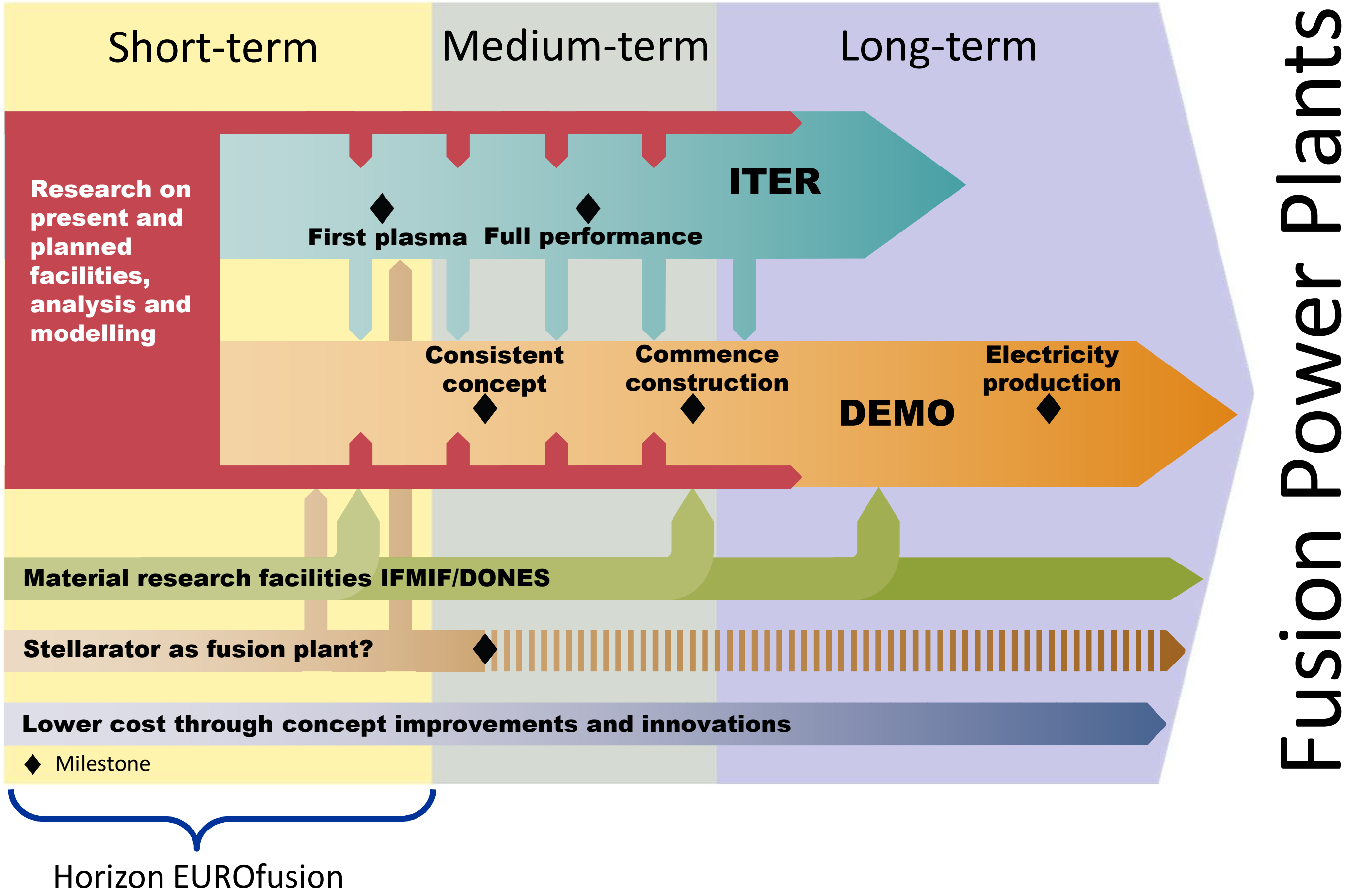
china eu india japan korea russia usa



EUROfusion

30 National Research Institutes & 150 universities
28 European countries working together to achieve the ultimate goal of the Fusion Roadmap:
Fusion electricity

European Fusion Roadmap



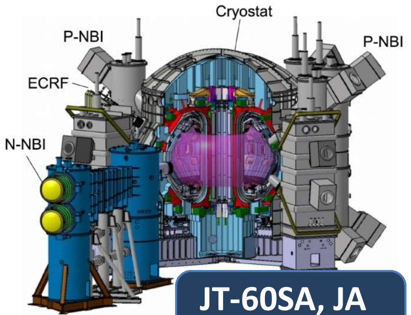
Eight Roadmap Missions – Mission 1

1

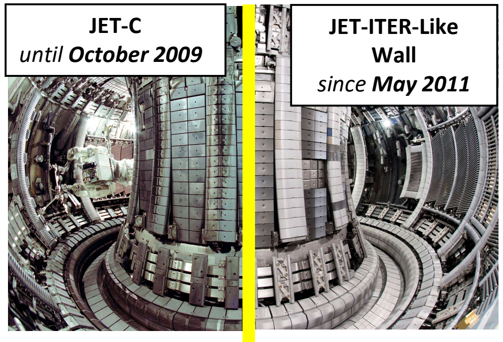
- Plasma Regimes of Operation

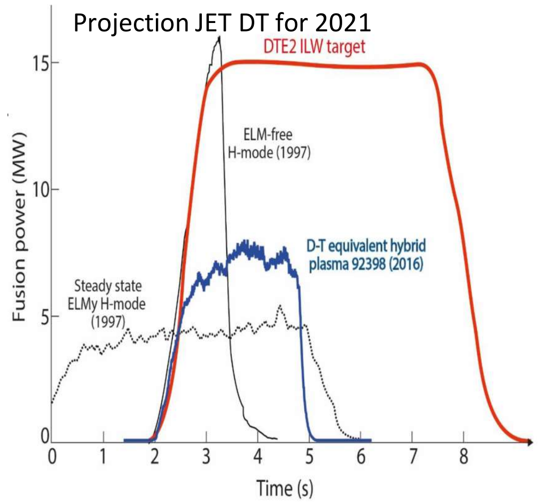
JET, UK

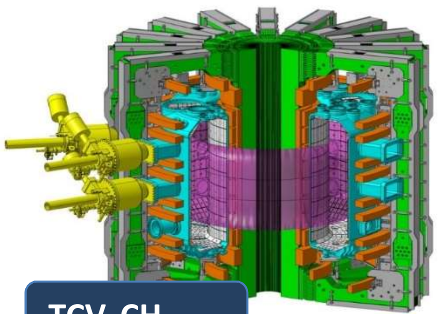
ASDEX Upgrade, Munich, DE



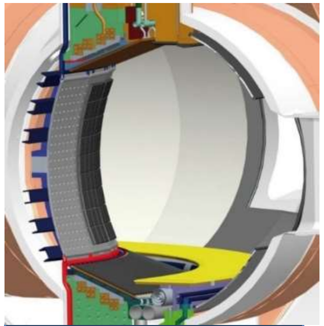
JT-60SA, JA (Start in 2022)



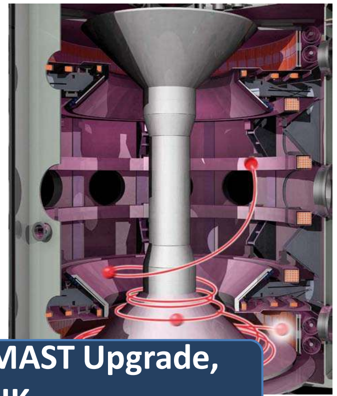




TCV, CH



WEST, FR

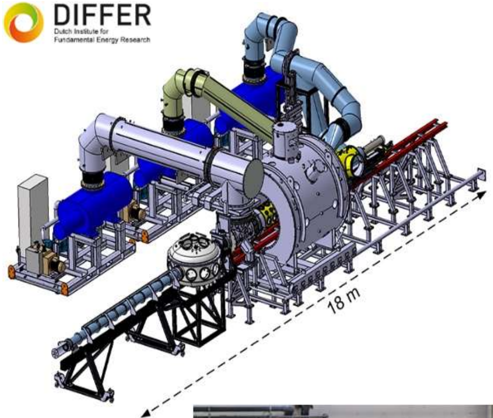


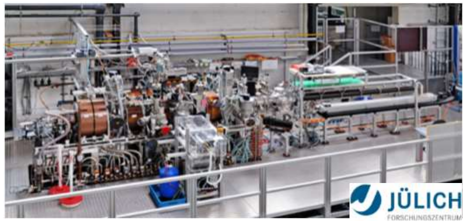
MAST Upgrade, UK

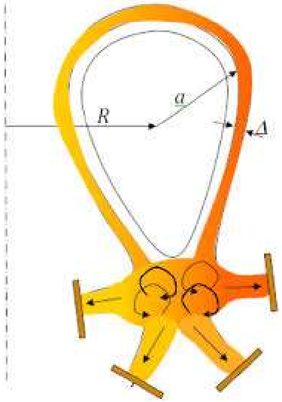
Eight Roadmap Missions – Mission 2

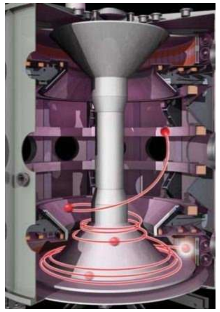
1 • Plasma Regimes of Operation

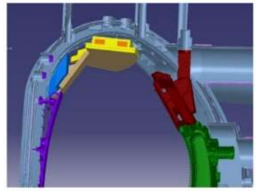
2 • Heat Exhaust Systems

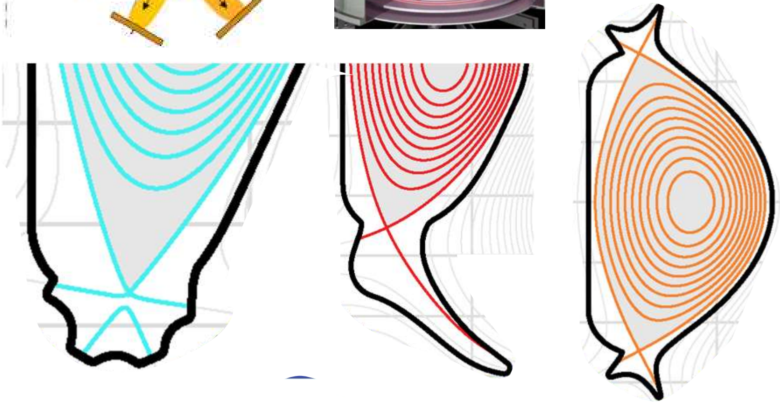










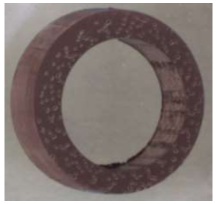


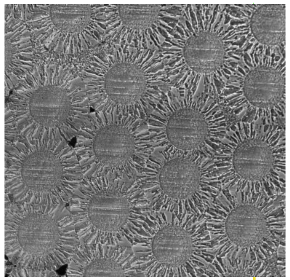
Eight Roadmap Missions – Mission 3

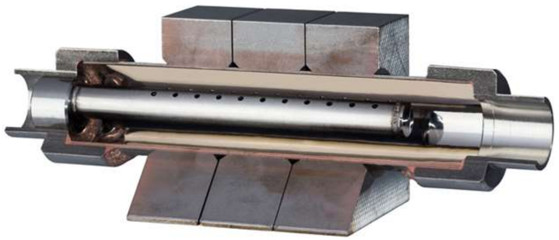
1 • Plasma Regimes of Operation

2 • Heat Exhaust Systems

3 • Neutron-Resistant Materials

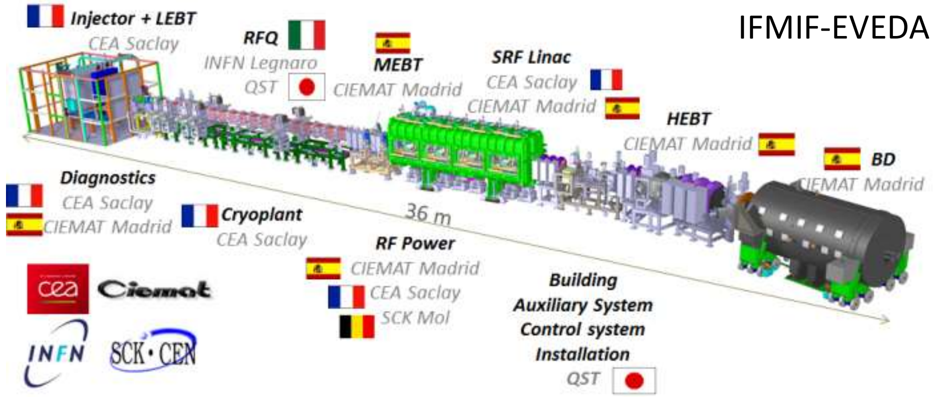




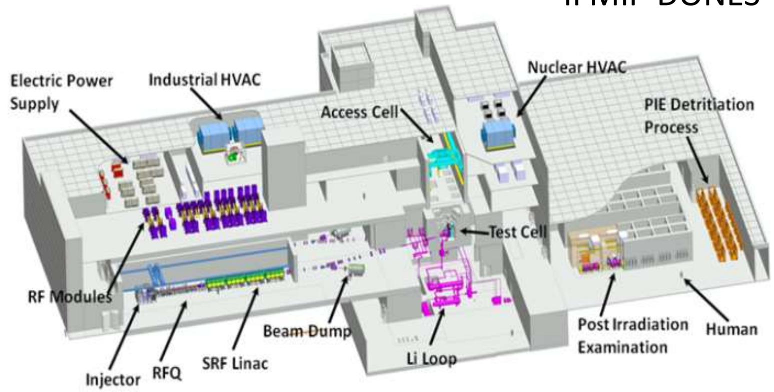


See also talk by Ángel Ibarra

IFMIF-EVEDA



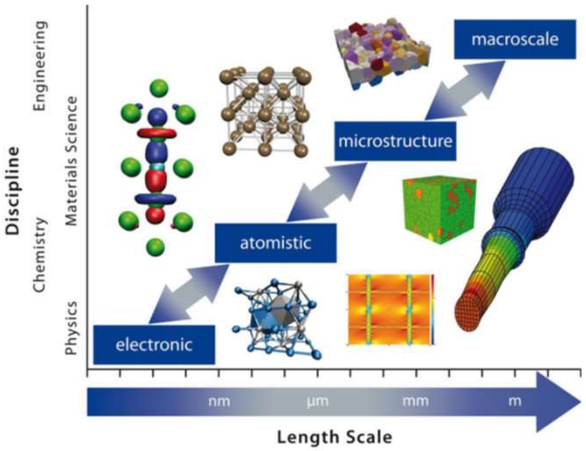
IFMIF-DONES



Eight Roadmap Missions – Mission 3

1. Plasma Regimes of Operation
2. Heat Exhaust Systems
3. **Neutron-Resistant Materials**

Model multi-scale problem



Challenges and opportunities

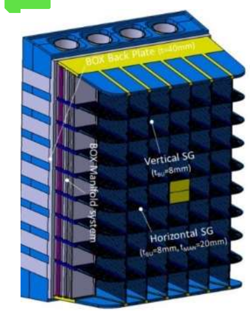
- Embrittlement and operating temperature of steels esp.
- Functional materials (breeding, coatings etc)
- Activation: decay heat, waste, recycling
- Design rules and licensing with sparse data (esp. 14MeV)

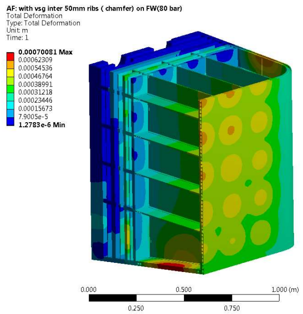
Basic approach:

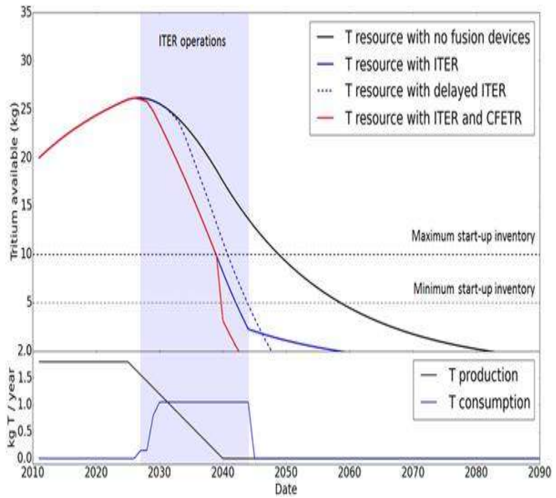
- EUROFER97, tungsten, CuCrZr for in-vessel structures
- Use MTRs, advanced analysis and modelling for design rules (20dpa, ~2fpy)
- IFMIF-DONES for validation and >20dpa
- Alternate & advanced materials, composites: back-up/improved

Eight Roadmap Missions – Mission 4

1. Plasma Regimes of Operation
2. Heat Exhaust Systems
3. Neutron-Resistant Materials
4. **Tritium self-sufficiency**







Eight Roadmap Missions – Mission 5-6

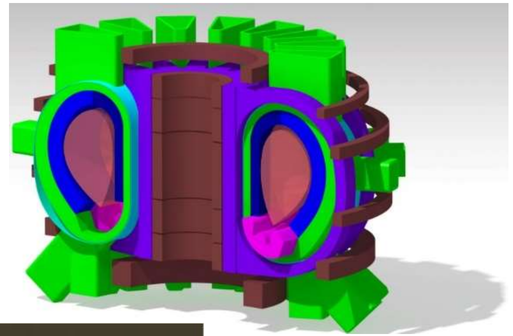
1
- Plasma Regimes of Operation

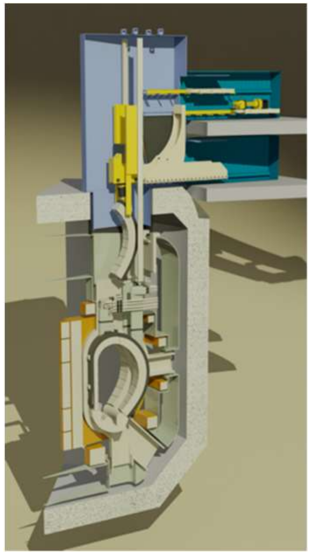
2
- Heat Exhaust Systems

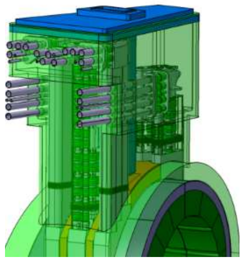
3
- Neutron-Resistant Materials

4
- Tritium self-sufficiency

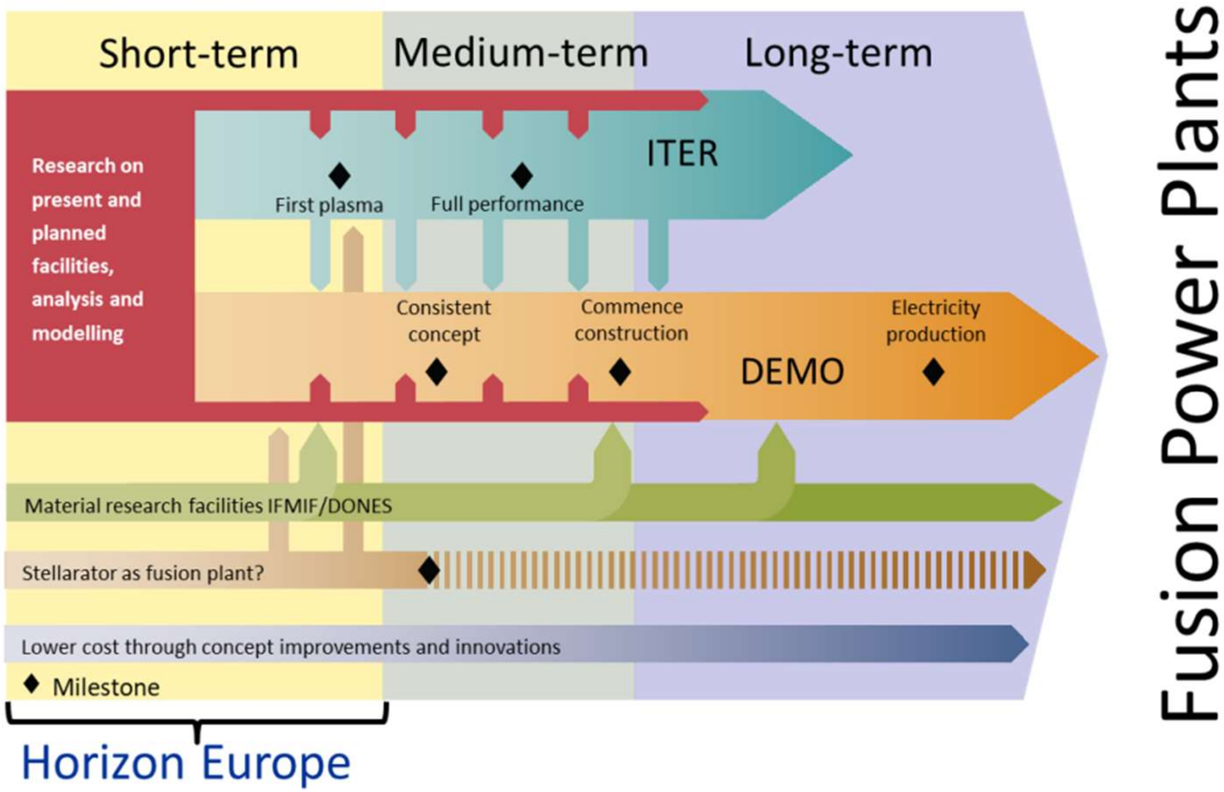
5, 6
- Implementation of Safety Features
- Integrated DEMO Design







La feuille de route fusion européenne



"DEMO represents the last step driven by the research community"

"After DEMO, industry will lead fusion power plant production with limited involvement of the research community"

2 additional goals compared to ITER
- Electricity production
- Tritium self-sufficiency

Not addressed by the EU-DEMO
- Neutron-tolerant materials → IFMIF-DONES

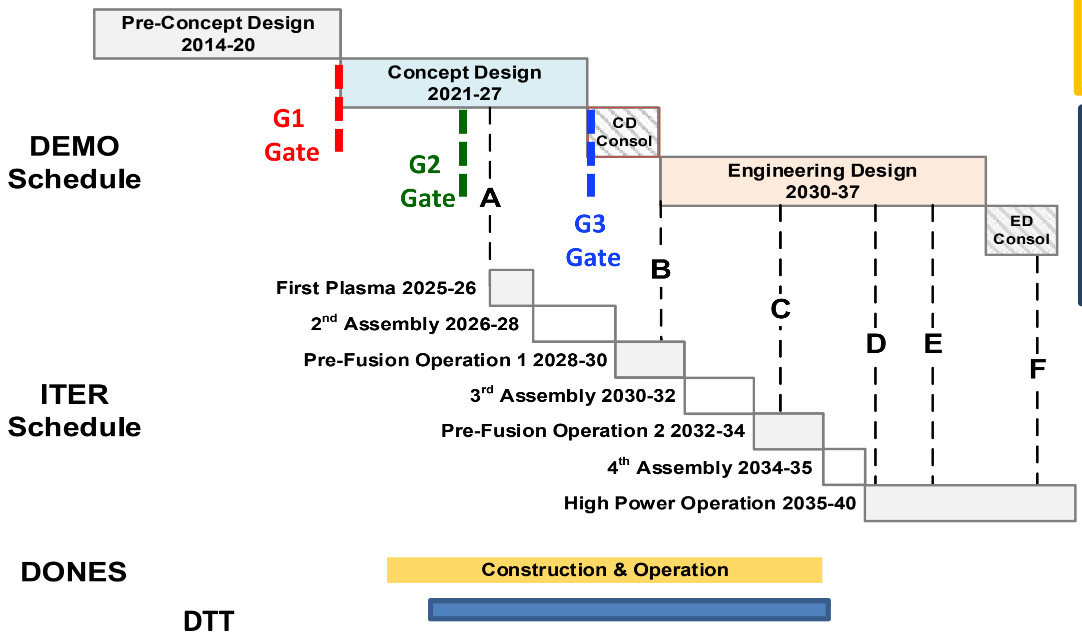
Main Differences ITER and EU DEMO

ITER	DEMO
Experimental device with physics and technology development missions	Nearer to a commercial power plant but with some development missions
No tritium breeding requirement (except small quantity in TBMs)	Tritium breeding needed to achieve self-sufficiency
Conventional 316 stainless steel structure for in-vessel components	Nuclear hardened, novel reduced activation materials as structure for breeding blanket
Very modest lifetime n-fluence, low dpa and He production	High n-fluence, significant in-vessel materials damage
Cooling system optimized for minimum stresses and sized for modest heat rejection	Cooling system optimized for electricity generation efficiency (e.g. much higher temperature)

Staged design approach for DEMO

- Pre-Concept Design Phase 2014-20 - Horizon 2020
- Concept Design Phase 2021-27 - Horizon Europe

Advance the technical basis of DEMO to a stage at which assessments of technical feasibility, safety, licensing issues and life-cycle costs can be undertaken for approval at G3.



EU DEMO mission requirements

- **DEMO Net electricity (~500 MWe)**
- **Makes its own fuel (TBR>1)**
- **Reliable operation**
- **Reasonable plant availability**
- **Allow extrapolation to a FPP**
- **Test facility for advanced BB concepts**

High Level Requirements agreed with DEMO External Stakeholders (e.g., industry, utilities, grids, safety, licensing, funding bodies)

A. Validated **Assembly**, **Integrated Design**, Testing & **Commissioning** (2025)
B. Integrated systems **validation**, (2028-2030)
C. ELM control & disruption mitigation (2032-2034)
D. Burn **scenarios**, bootstrap fraction, first wall heat loads, tritium plant validation, full H&CD validation (2035-2040)
E. TBM Validation, Operational scenario refinement, Q=10 (short pulse)
F. Q=10 (long pulse) (2035-2040)

Eight Roadmap Missions – Mission 7

1
- Plasma Regimes of Operation

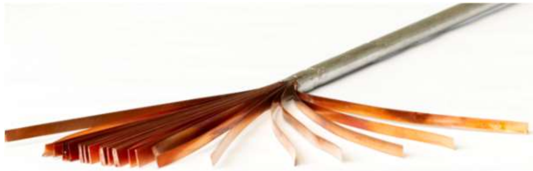
2
- Heat Exhaust Systems

3
- Neutron-Resistant Materials

4
- Tritium self-sufficiency

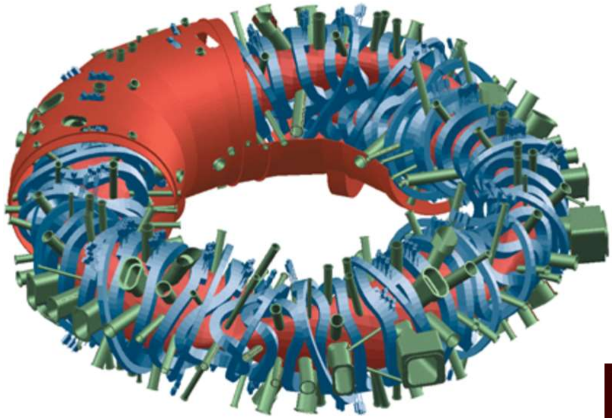
5, 6
- Implementation of Safety Features
- Integrated DEMO Design

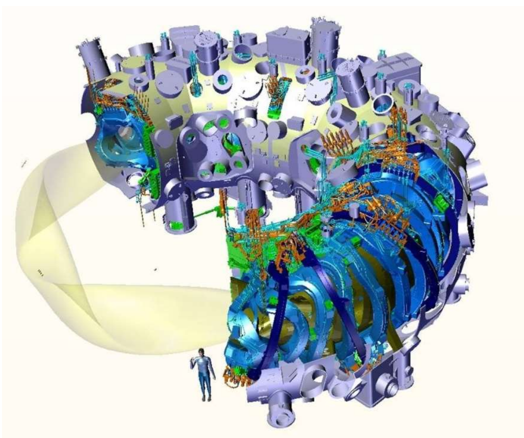
7
- Competitive Cost of Electricity

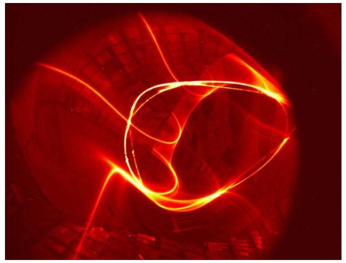


Eight Roadmap Missions – Mission 8

1. Plasma Regimes of Operation
2. Heat Exhaust Systems
3. Neutron-Resistant Materials
4. Tritium self-sufficiency
5, 6. Implementation of Safety Features; Integrated DEMO Design
7. Competitive Cost of Electricity
8. **Stellarator**







ture

The chase for fusion energy

An emerging industry of nuclear-fusion firms promises to have commercial reactors ready in the next decade.

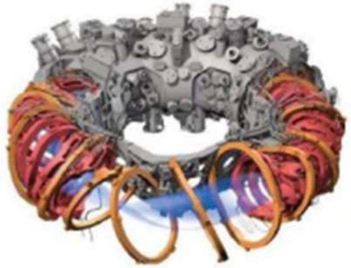
By Philip Ball
17 November 2021

Le discours des startups

generalfusion

Commercialization of fusion energy is accelerating…

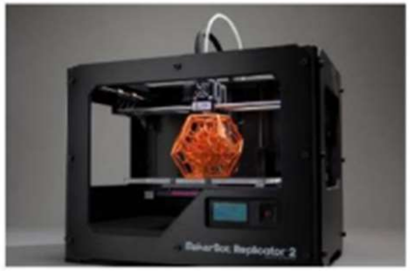
Progress of Fusion Science



- Plasma physics knowledge
- Advanced simulation codes (U.S. DOE Exascale Project)
- Experimental confirmation of fusion theory

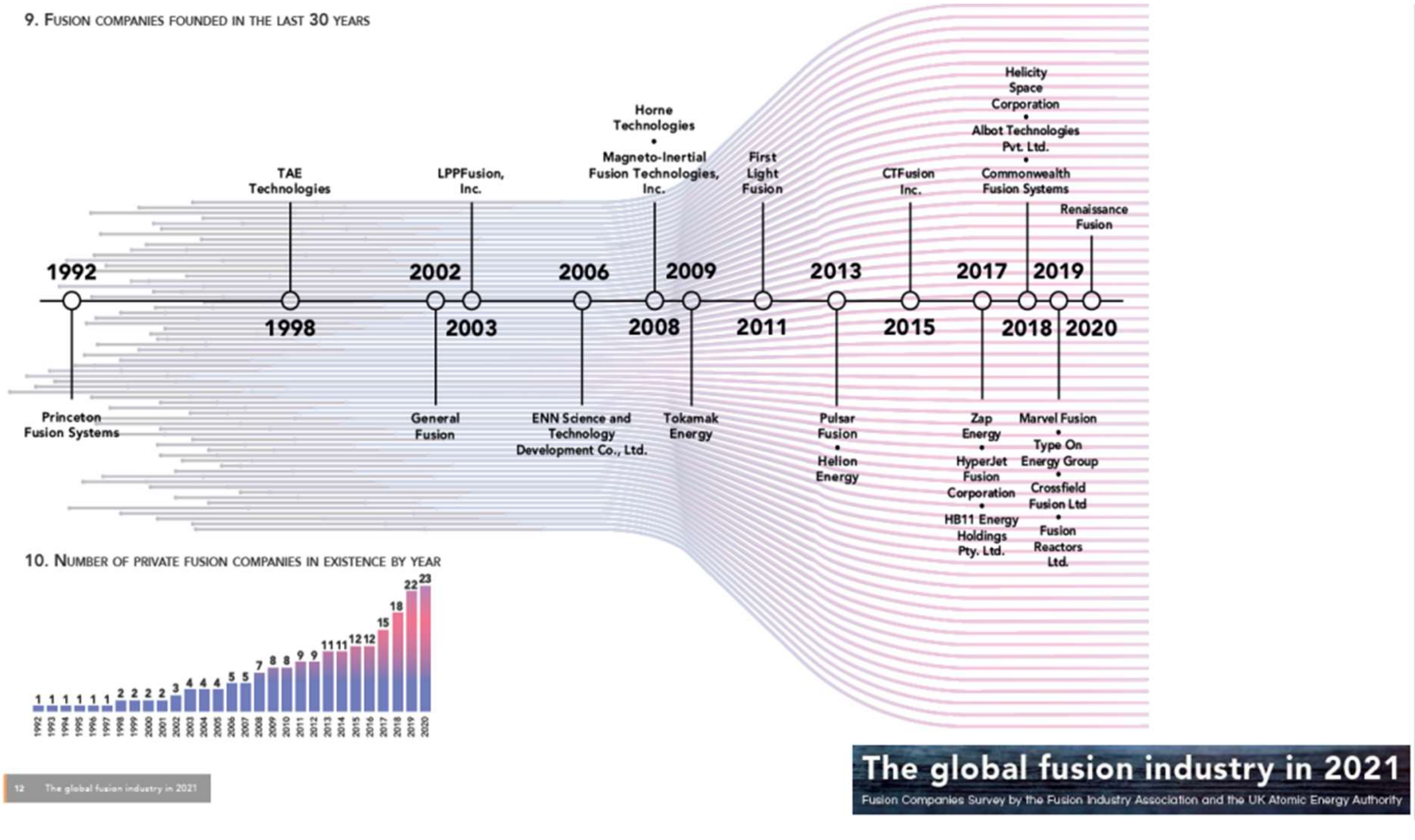
+

Maturing Enabling Technologies



- Advanced manufacturing (3D printing)
- Computational power and big data analytics
- High speed digital control systems
- High temperature superconducting magnets

6



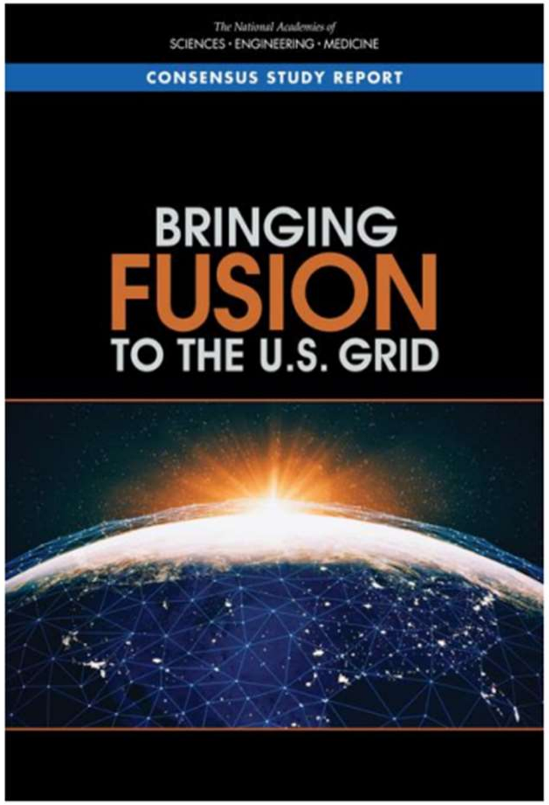
9. Fusion companies founded in the last 30 years
1992
Princeton Fusion Systems
1998
TAE Technologies
2002
General Fusion
2003
LPPFusion, Inc.
2006
ENN Science and Technology Development Co., Ltd.
2008
Horne Technologies • Magneto-Inertial Fusion Technologies, Inc.
2009
Tokamak Energy
2011
First Light Fusion
2013
Pulsar Fusion • Helion Energy
2015
CTFusion Inc.
2017
Zap Energy • HyperJet Fusion Corporation • HB11 Energy Holdings Pty. Ltd.
2018
Helicity Space Corporation • Albot Technologies Pvt. Ltd. • Commonwealth Fusion Systems
2019
Marvel Fusion • Type On Energy Group • Crossfield Fusion Ltd • Fusion Reactors Ltd.
2020
Renaissance Fusion
10. Number of private fusion companies in existence by year
12 The global fusion industry in 2021
The global fusion industry in 2021
Fusion Companies Survey by the Fusion Industry Association and the UK Atomic Energy Authority

Companies by location


PCAST Meeting: Climate Change, Energy, and the Environment
The National Academies of
SCIENCES
ENGINEERING
MEDICINE
Bringing Fusion to the U.S. Grid
R. J. Hawryluk
Presented to:
PCAST
October 19, 2021

"Bringing Fusion to the U.S. Grid" (2021 -US NAS)

Fait suite au : ***"Final Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research"* de 2019**



Key Takeaways

Recommendation: For the United States to be a leader in fusion and to make an impact on the transition to a low-carbon emission electrical system by 2050, the Department of Energy and the private sector should produce net electricity in a fusion pilot plant in the United States in the 2035—2040 timeframe.

Recommendation: DOE should move forward now to foster the creation of national teams, including public-private partnerships, that will develop conceptual pilot plant designs and technology roadmaps that will lead to an engineering design of a pilot plant that will bring fusion to commercial viability.

Conclusion: Successful operation of a pilot plant in the 2035—2040 timeframe requires urgent investments by DOE and private industry — both to resolve the remaining technical and scientific issues, and to design, construct, and commission a pilot plant.

The National Academies of | SCIENCES ENGINEERING MEDICINE

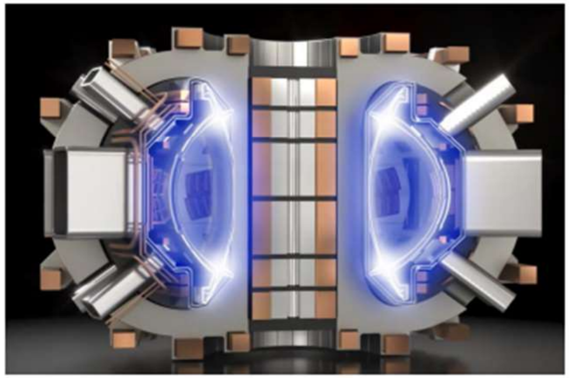
Le programme ARC* : la route des tokamaks forts champ (USA)

Commonwealth Fusion Systems (CFS), spin-off du MIT's Plasma Science and Fusion Center

01

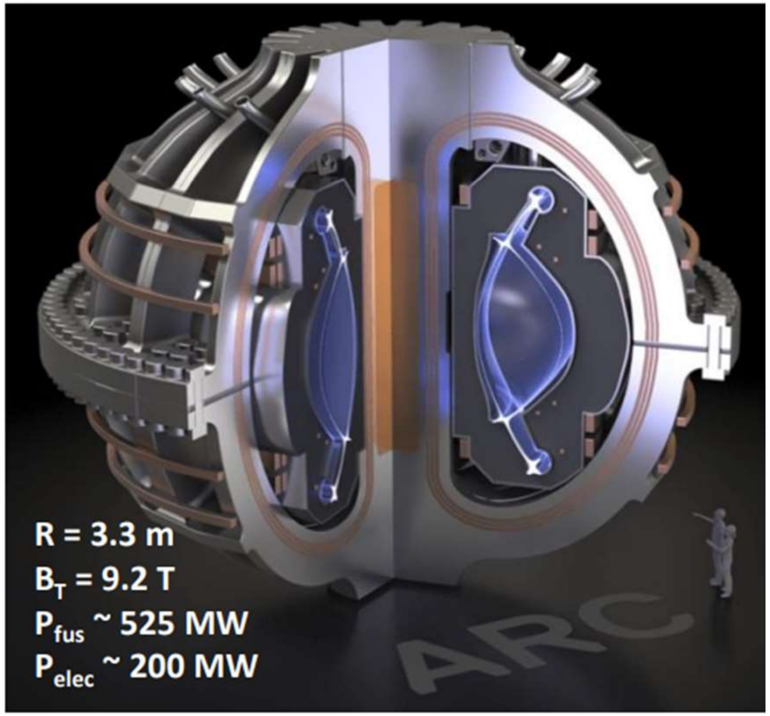
02

03



01	Alcator C-Mod: Plasma Physics Basis	Completed	↓
02	HTS Magnets: Enabling Technology	Done	↓
03	SPARC: Fusion Energy Demonstration	Starting in 2021	↓
04	ARC: Commercialization	Starting 2025	↓

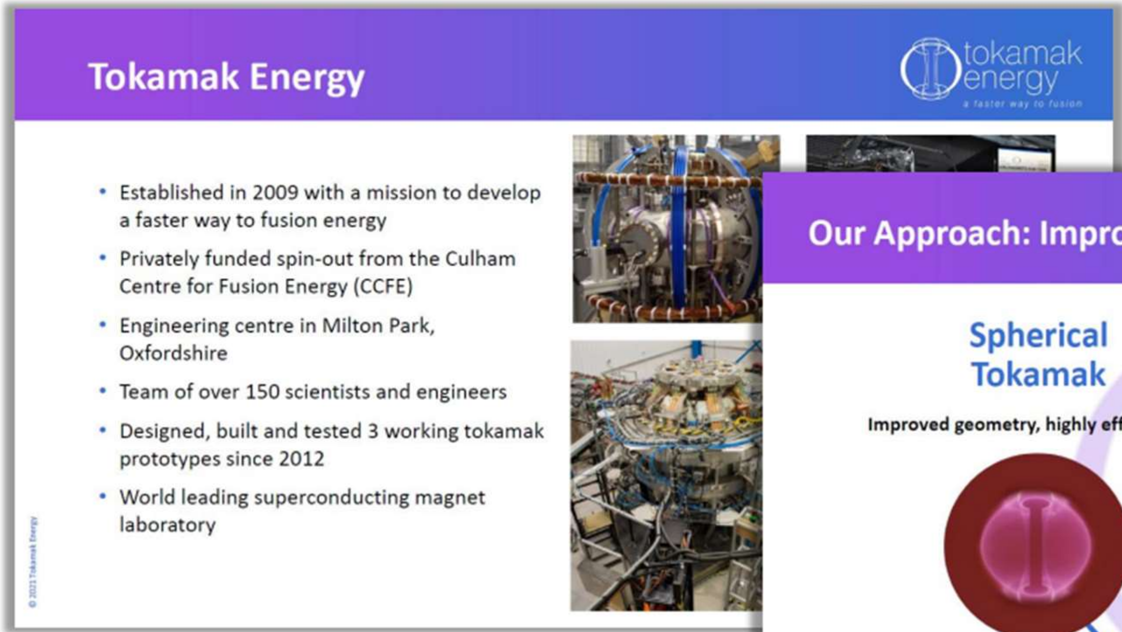
04

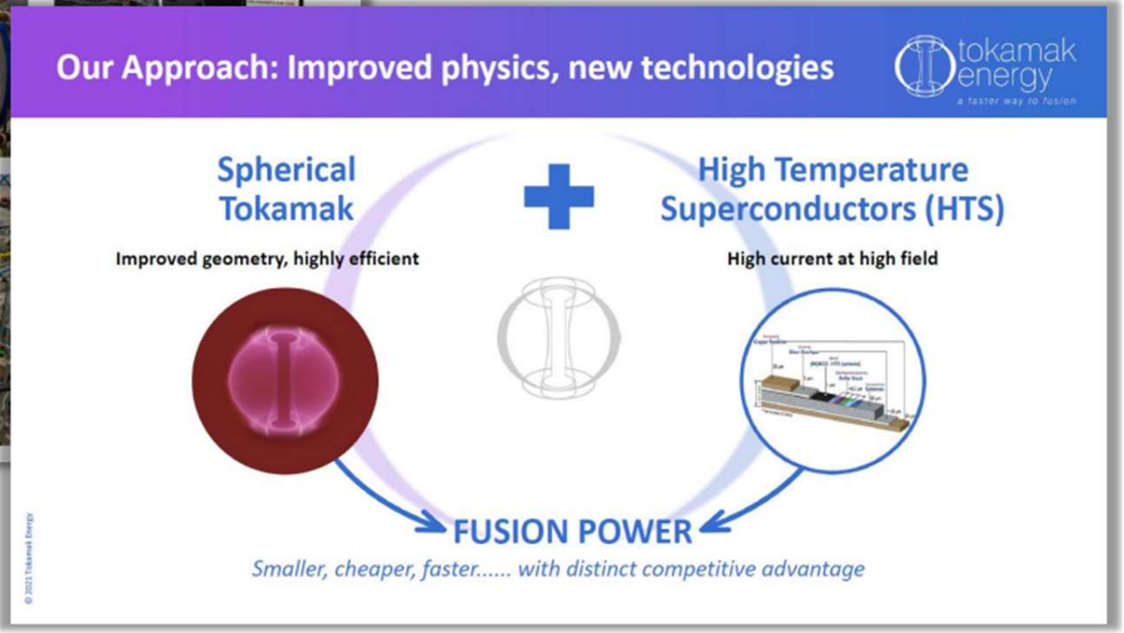


A.Q. Kuang et al.Fusion Engineering and Design 137 (2018) 221–242222

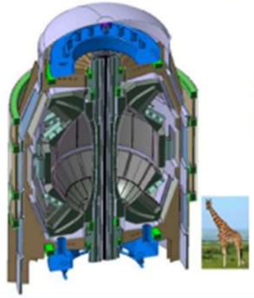
Tokamak Energy & STEP : la route des tokamaks sphériques (UK)

Tokamak Energy, spin-off du UKAEA's Culham Centre for Fusion Energy





Programme ambitieux pour concevoir and construire une centrale fusion prototype en visant une mise en service autour de 2040 → 5 sites en compétition pour accueillir le prototype, sélection en 2022



R = JET size (~3 m)
P_{fus} = GW scale

Fusion nucléaire : Jeff Bezos soutient le projet d'une première centrale près de Londres

La start-up canadienne General Fusion, qu'accompagne le patron d'Amazon, a annoncé jeudi qu'elle construirait sa première centrale nucléaire pilote à Culham, un petit village de l'Oxfordshire, situé à deux heures de voiture à l'ouest de Londres. Un projet à 400 millions de dollars.

Les Echos 17/06/2021

https://generalfusion.com/

Amanda Solloway said: *"This new plant by General Fusion is a huge boost for our plans to develop a fusion industry in the UK, and I'm thrilled that Culham will be home to such a cutting-edge and potentially transformative project. Fusion energy has great potential as a source of limitless, low-carbon energy, and today's announcement is a clear vote of confidence in the region and the UK's status as a global science superpower."*

17/06/2021

General Fusion CEO Chris Mowry, UK Science Minister Amanda Solloway and UKAEA CEO Ian Chapman

Conclusions

- De nombreuses activités expérimentales basées sur des tokamak
- Des avancées majeures expérimentales sur la maîtrise scientifiques et technologiques
- Une volonté politique d’accélérer la filière et la faire passer du stade experimental à un stade de production
- Une vraie attraction du secteur privé
- Une nouvelle réglementation nucléaire ?