EUROfusion

EUROfusion R&D Activities Towards a Fusion Demonstration Power Plant (DEMO)

R. Kamendje

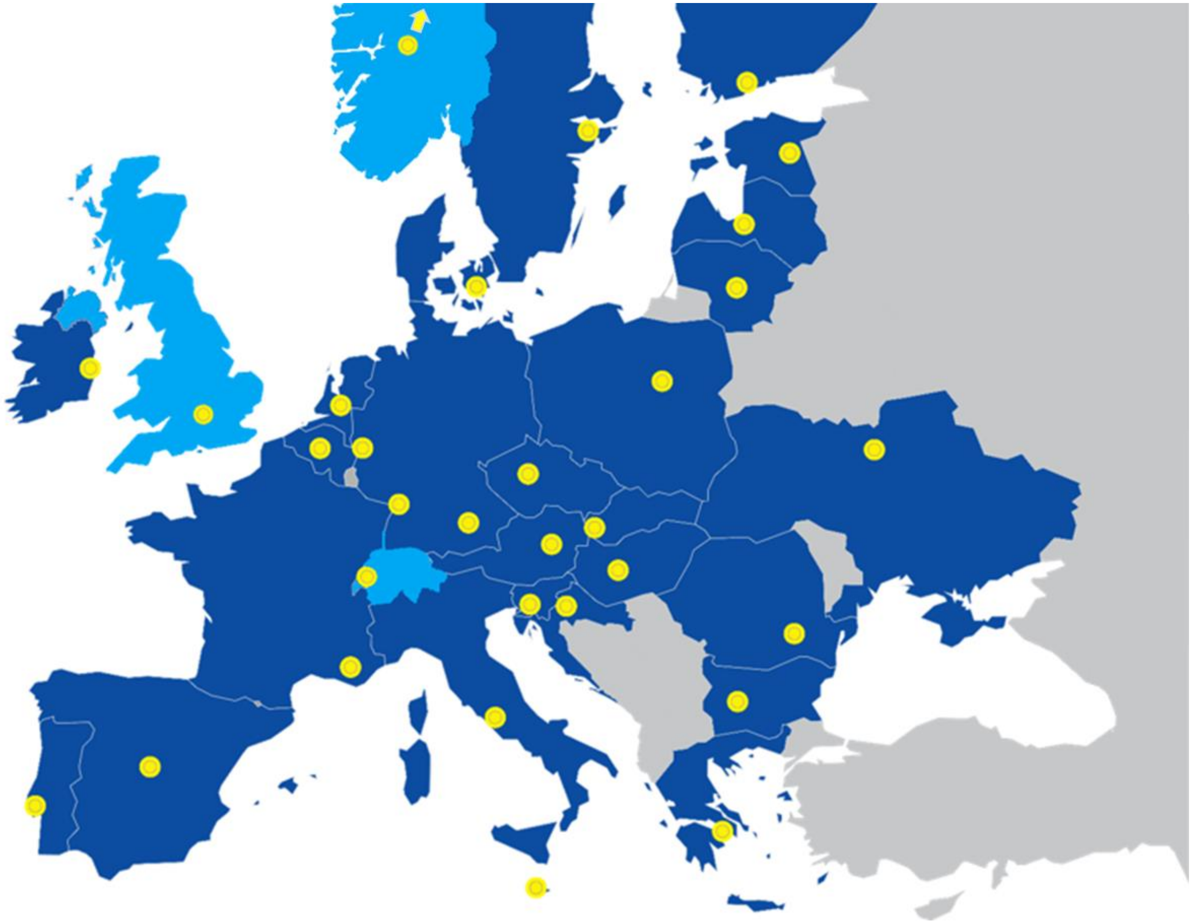
IAEA Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission reactors
30 October – 03 November 2023

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

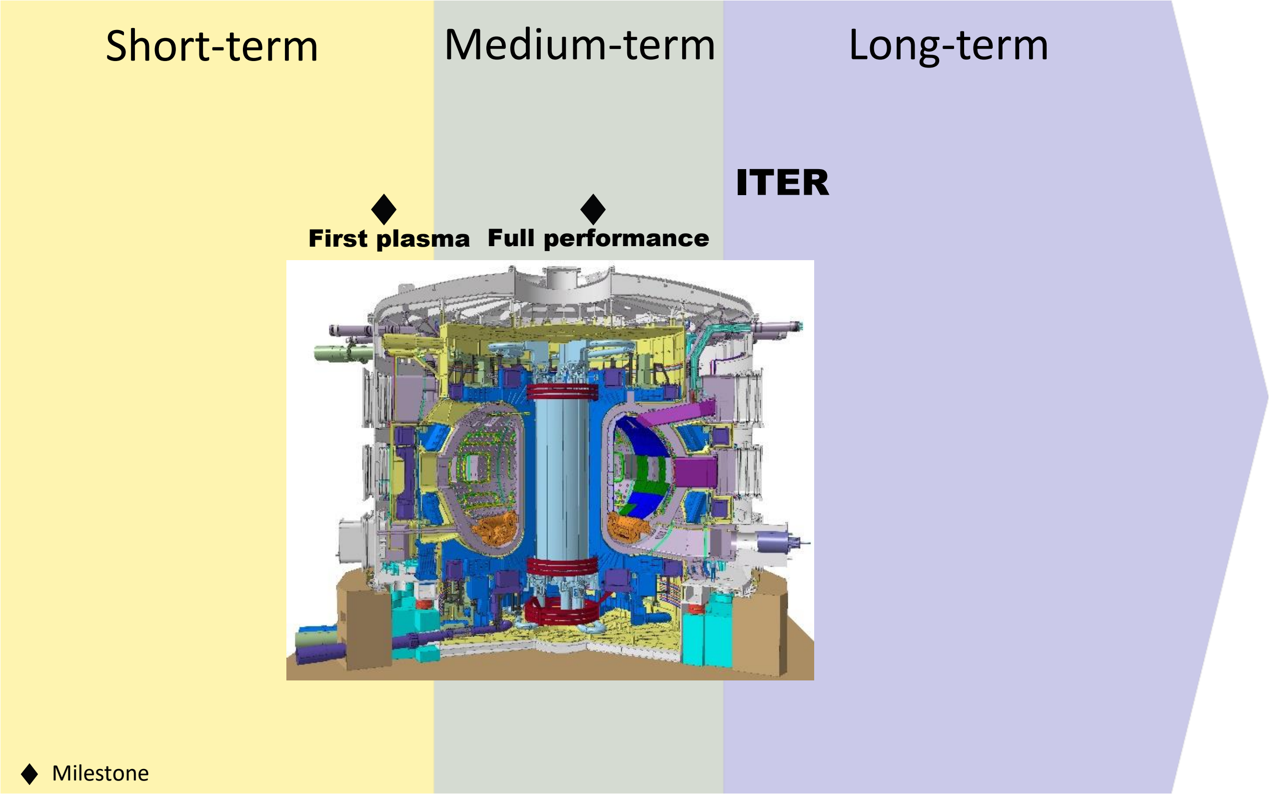
EUROfusion in 2023

EUROfusion integrates R&D in fusion science and technology

29	Countries
31	Research Institutions
150	Universities
800	MSc and PhD students
4000	Fusion Researchers & Support Staff



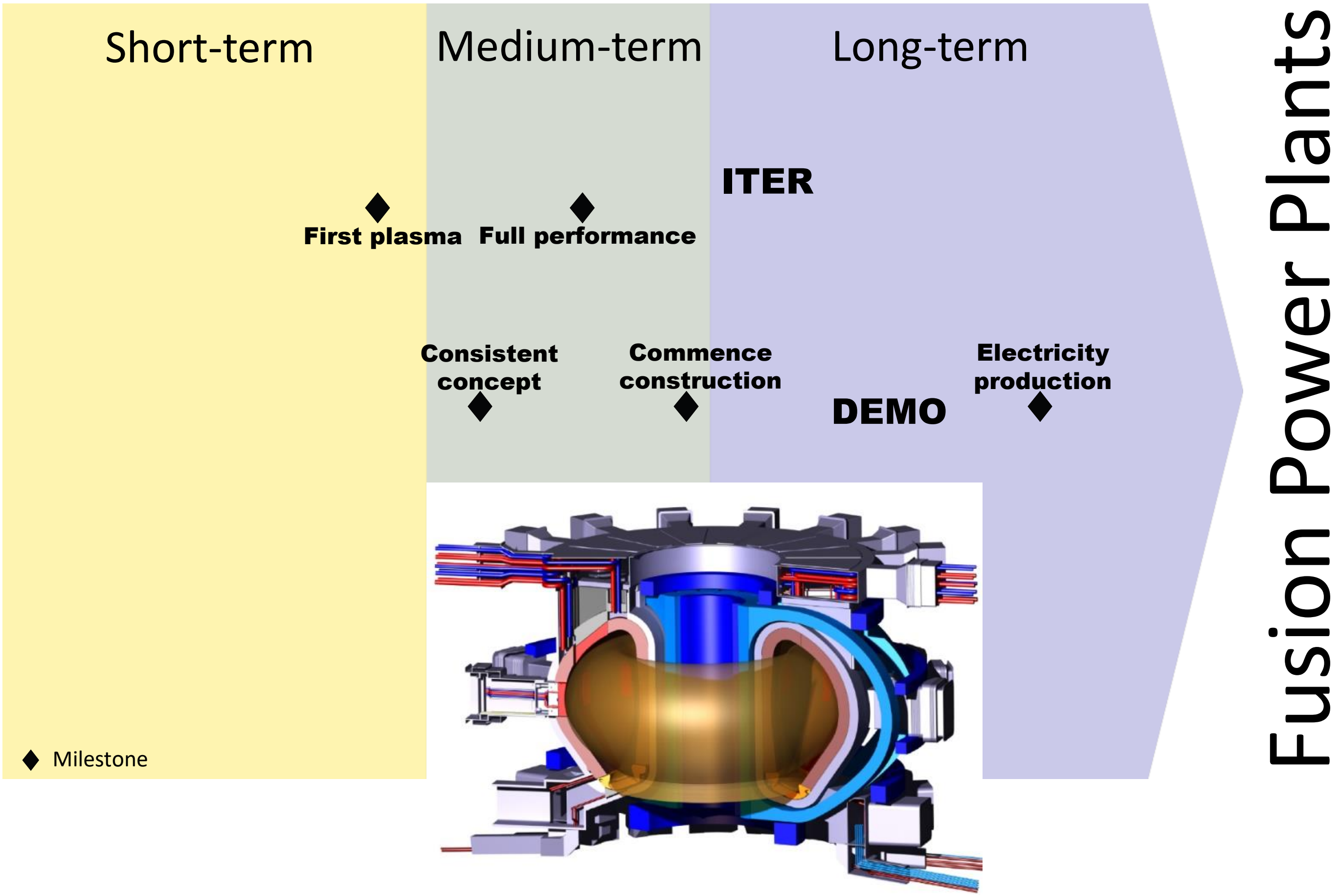
EUROfusion research is prioritised along the Fusion Roadmap



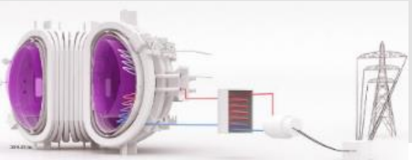
Fusion Power Plants

https://www.euro-fusion.org/eurofusion/roadmap/

EUROfusion research is prioritised along the Fusion Roadmap



DEMO Staged design approach



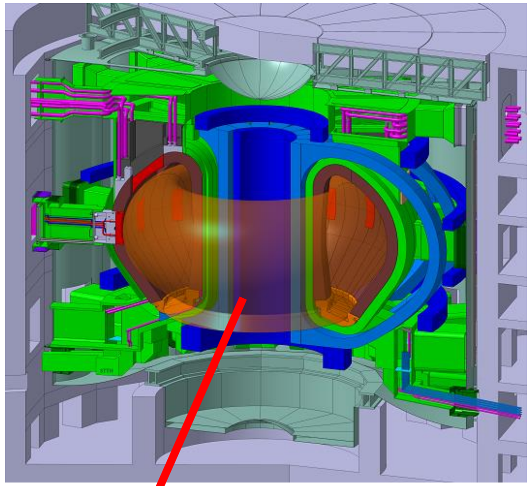
- Developing and evaluating system designs in the context of the wider integrated plant design (a more systems-orientated approach has brought clarity to a number of critical design issues and has provided a clear path for urgent R&D).
- Targeting technology R&D and system design studies that are driven by the requirements of the DEMO plant concept and respond to critical design feasibility and integration risks.
- Evaluating multiple design options in parallel investigations for systems and/or technologies with high technical risk or novelty (e.g., the choice of tritium breeding blanket technology and coolant, power exhaust solution and configuration, Balance of Plant and Power Conversion System, etc.).
- Evaluating the design and technology readiness of the foreseeable technical solutions, together with a technology maturation and down-selection strategy to bound development risks by adopting structured and transparent gate reviews, occurring at the critical decision points of the design phases.

EU DEMO Preconceptual design completed

Preconceptual DEMO design activities from H2020 have been published in a special issue of Fusion Engineering and Design

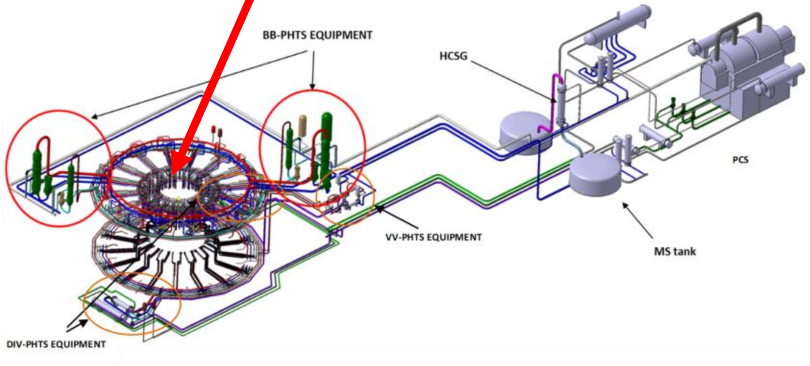
G. Federici et al., Fusion Eng. and Des. 173 (2021) 112959

https://www.sciencedirect.com/journal/fusion-engineering-and-design/special-issue/10RRZQ6LW4H

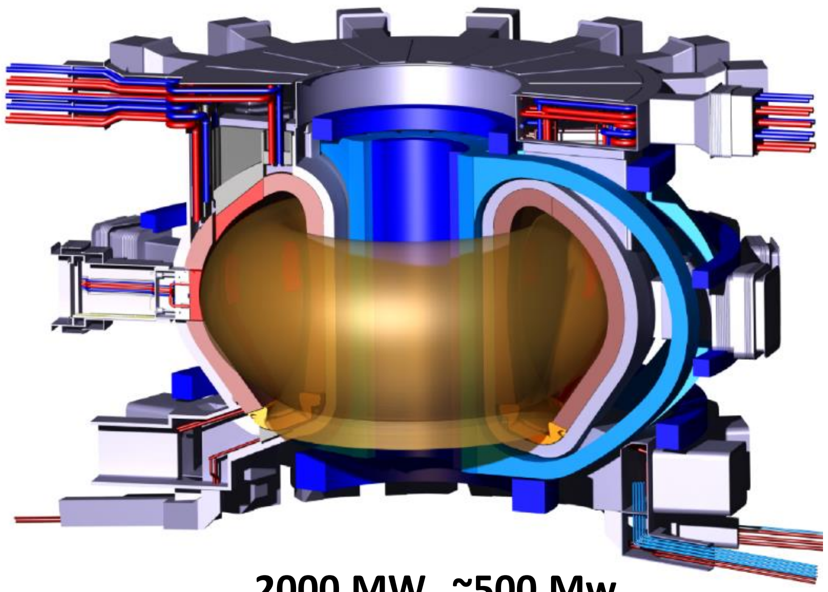


An extensive Gate Review process was organised to agree on the starting point of the Conceptual Design Stage

G. Federici et al., Nucl. Fusion 59 (2019) 066013.



EU DEMO : General design features current baseline (evolving!)



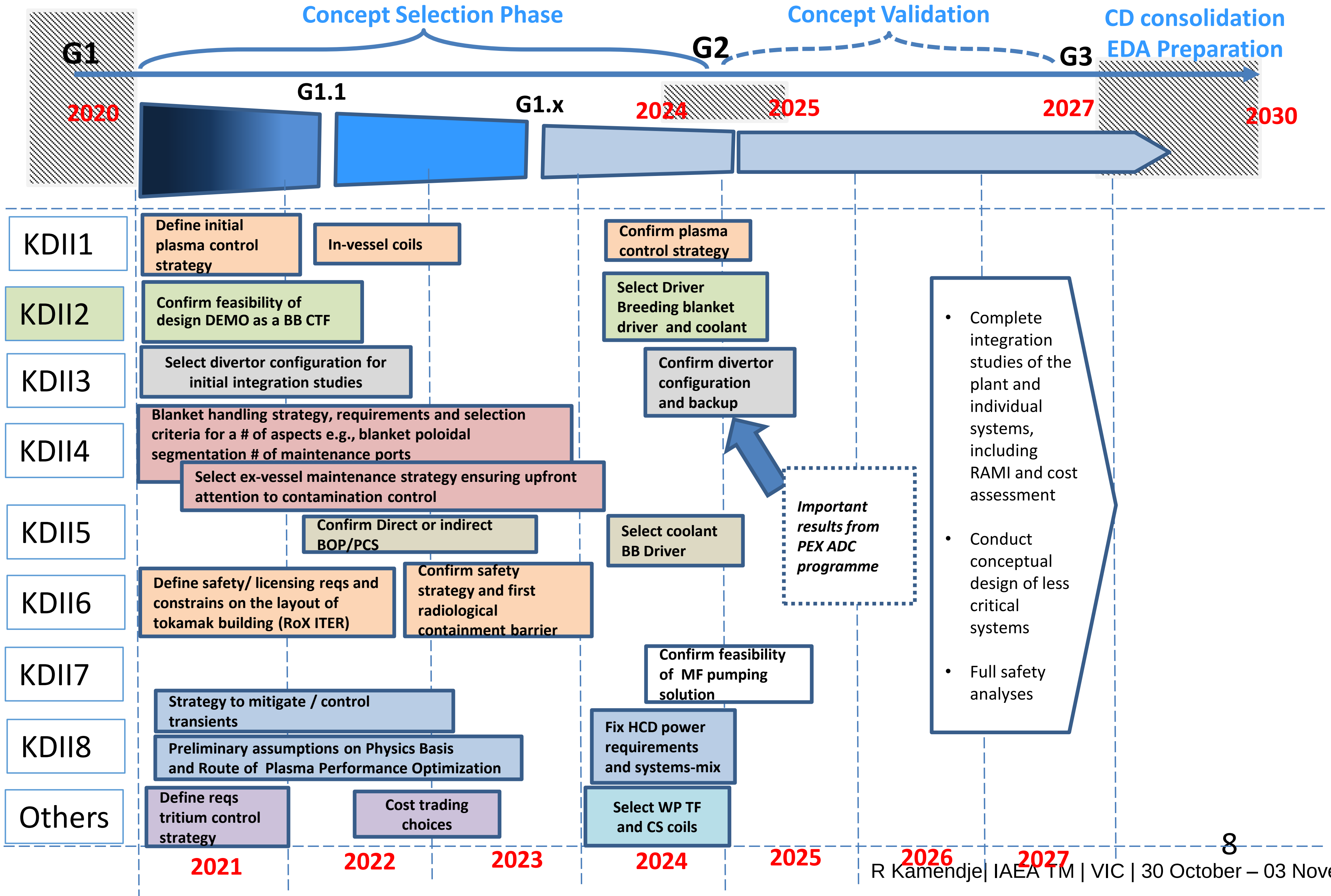
2000 MW_{th}~500 Mw_e

Open Choices:
- Plasma operating scenario
- Breeding blanket design concept
- Primary Blanket Coolant/ BoP
- Divertor configurations
- Remote maintenance and the blanket segmentation and extraction

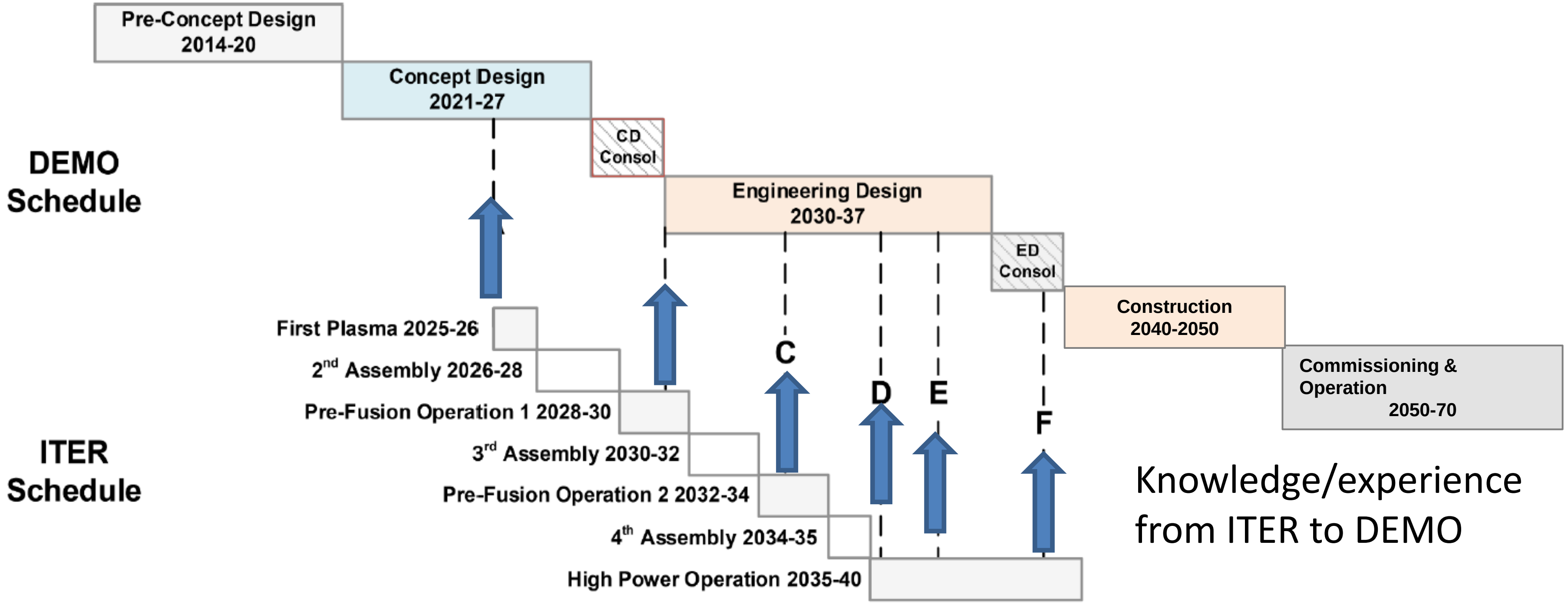
R_0 = 9 m; a= 2.9m
B_0 = 5.9 T, I_0 = 18 MA; q_{95} = 3.6
κ_{95} = 1.66; δ_{95} = 0.33
H=1.1
P_{fus}=2000 MW, P_{aux}=<100 MW, P_{el}=500 MW
NWL = 1 MW/m^2
Still exploring the available design space !!

- Pulsed tokamak: pulses > 2 hrs
- Divertor coolant: water
- PFC armour: W
- LTSC magnets Nb_3Sn (grading)
- B_{max} conductor > 12 T (depends on A)
- RAFM (EUROFER) as blanket structure
- VV made of AISI 316
- Blanket vertical RH /
- Lifetime: starter blanket: 20 dpa (200 appm He); 2nd blanket 50 dpa; divertor: 5-10 dpa (Cu)

Critical Decisions Leading up to Gate 2



EU DEMO benefits from the experience gained from ITER



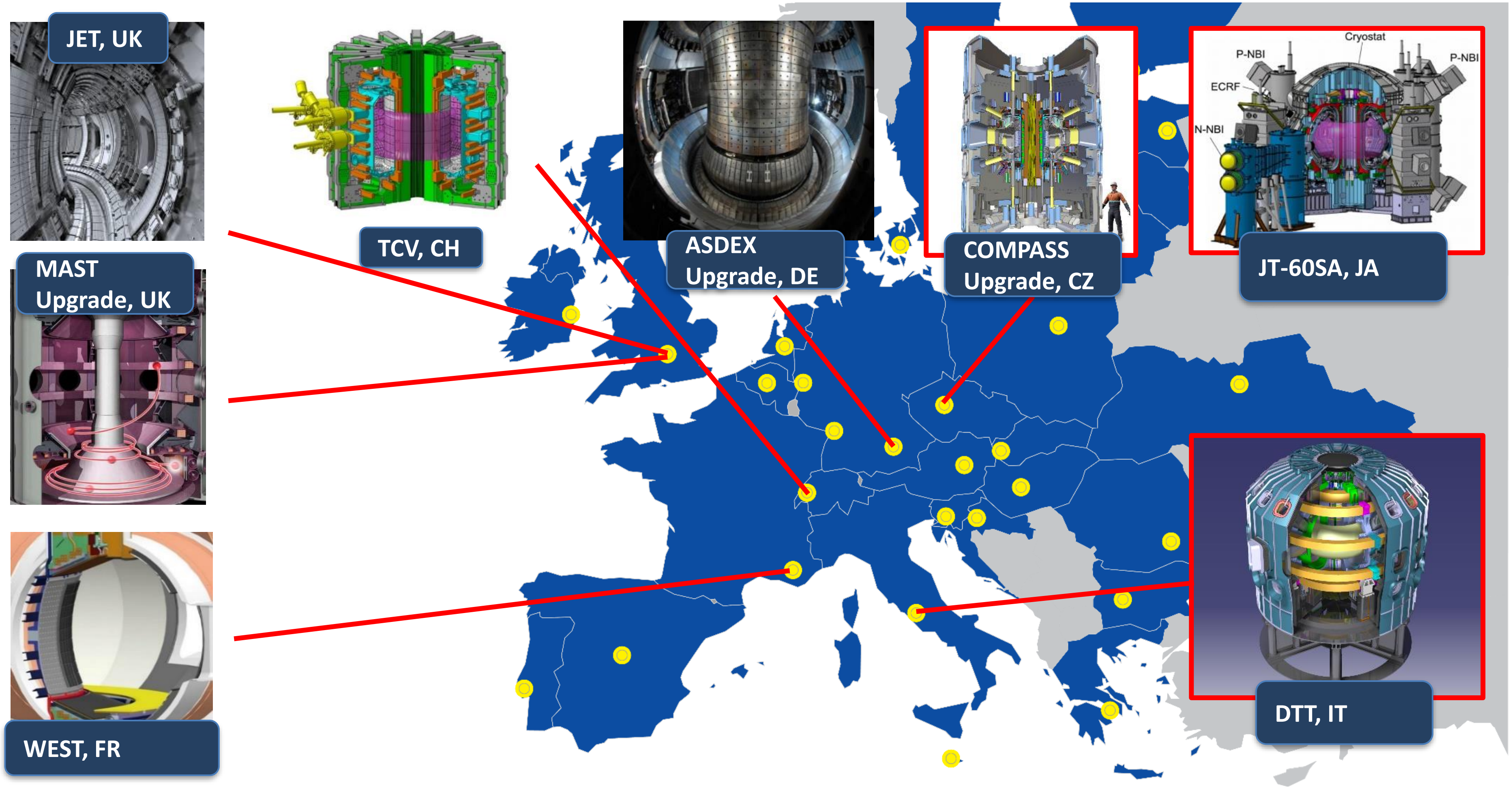
- **ITER is crucial for validation of the DEMO physics and part of the technology**
- RoX from ITER emphasises the importance of safety and licensing, design integration, quality, shielding, fabricability, costs, RH
- These play an important role in the design of DEMO

Ad-hoc technical meetings with ITER

IO (and F4E) experts are invited to attend DEMO reviews

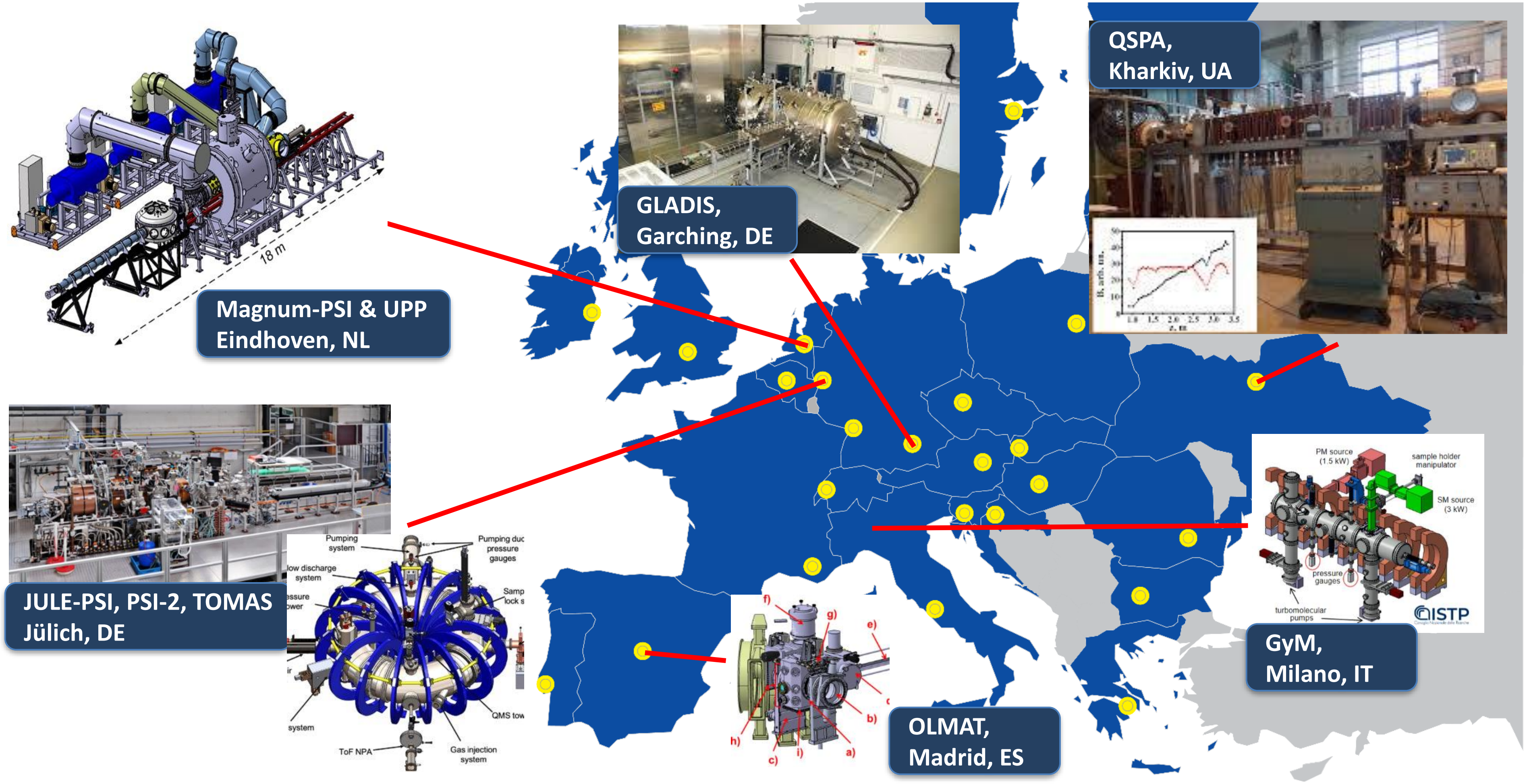
Contribute to training young engineer grantees

Joint operation of tokamaks in support of ITER & DEMO



Addressing:
- Plasma operating scenarios
- Divertor configurations & transients

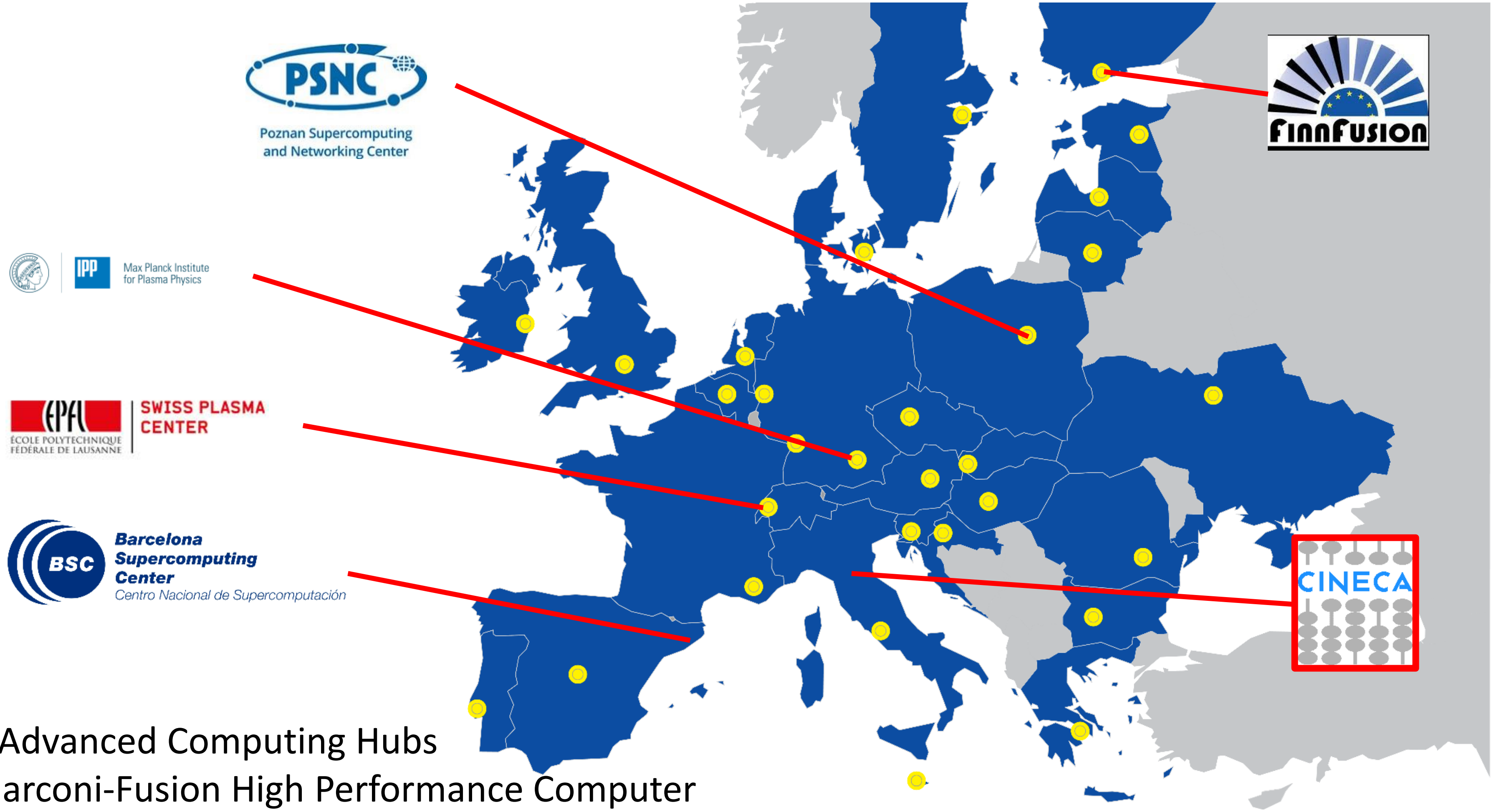
Joint operation of linear plasma devices



Addressing:

- Plasma-material interactions

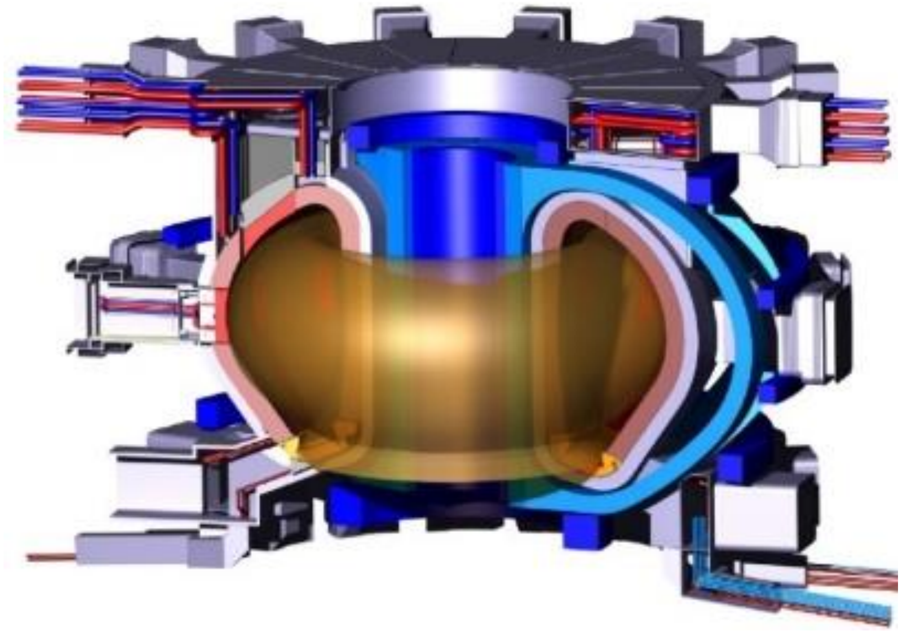
Integrated Theory and Simulation activities



5 Advanced Computing Hubs
Marconi-Fusion High Performance Computer

Addressing:
- All aspects of physics, engineering and design

Design Activities today (1)



MISSION / OBJECTIVES

- ✓ Electricity production
- ✓ Tritium self-sufficiency (TBR>1)
- ✓ Reasonable plant availability towards the end of operation

P_{fus}=2 GW, P_{el}=0.5 GW
Pulse duration=2 hr
R= 8.5 m, a = 3 m
B_o=5.9 T, B_{leg}=13 T
I_p=20 MA
NWL= 1 MW/m^2,
Fluence = 20+(50) dpa

- Advancing the DEMO concept design by addressing main technical issues emerged during the Gate Review G1
- Studies to try to expand the DEMO design and operating space, which is heavily constrained by physics and technology limits
  - Use of HTS
  - Configurations with low A

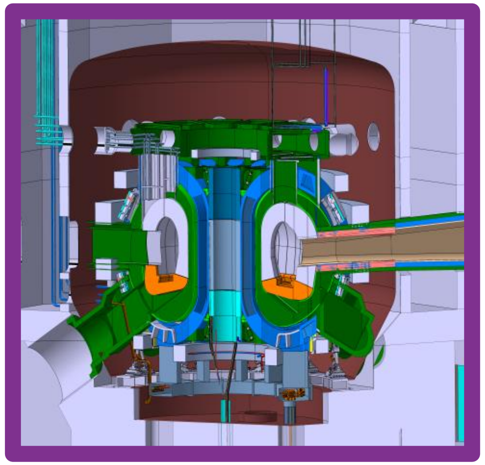
Design Activities today (2)

- **We are investigating the feasibility of a nuclear plasma device that serves as a 14 MeV n-source (VNS) to be run in parallel to ITER operation and DEMO design process**

Objectives:

✓ Decrease DEMO risks by qualifying essential FNTs in advance
✓ Demonstrate breeding, quantify failure modes
✓ Eliminate need for high-fluence qualification in DEMO
✓ Enable faster deployment of FPP.
✓ Provide additional experience in design, construction and licensing of a nuclear fusion device
✓ Keep industry, private Investors and governments' interest high in the near

P_{fus}<50 MW, P_{el}=0. GW
Steady state
R= 2.5 m, a =0.5 m
B_o=6 T, B_{leg}=14 T
I_p=1.5 MA
NWL= 0.5 MW/m^2,
Fluence = tbd > 20 dpa



- **Breeding blanket/ fuel cycle are the most novel and complex DEMO systems**
  - **Most critical technology gap that needs to be urgently addressed**

Physics basis and main challenges of a VNS

The device should be a plasma based 14 MeV n- source

- **Minimized T-consumption:** **< 50 MW.**
- **Peak NWL > = 0.5 MW/m²**
- **Testing surface: available equatorial ports and outboard wall > 10 m² of exposed first wall**

By "thermal", bulk plasma fusion one would need a large fusion power to get a sufficient NWL. **Not OK!**

$$P_{fus} \propto R^3 \qquad NWL \propto \frac{P_{fus}}{S} \propto R$$

Necessity of beam – target fusion

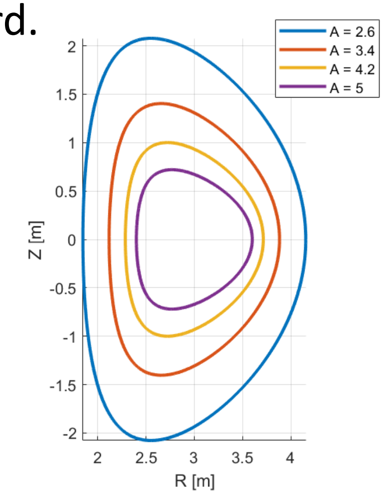
- Non-thermal (beam-target) n-production dominates over thermal production.
- JET record shot is actually an example for such a plasma (but NWL still too low (factor 5-10)).

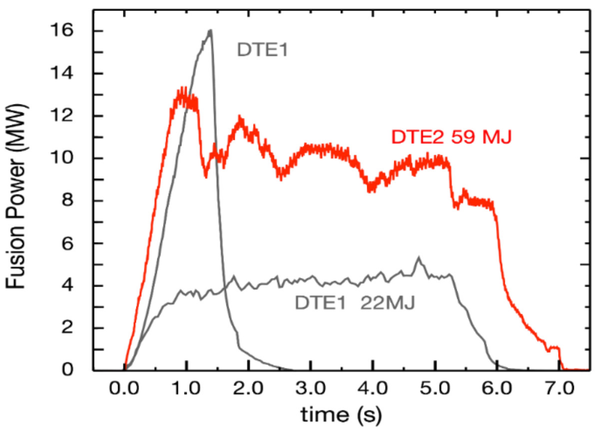
This depends *only* on beam power – no volume dependence. A compact device is then conceivable

$$NWL \propto \frac{A}{R^2}\frac{P_b}{E_b}\frac{T_e}{z_b^2} \qquad \beta_N^{fast} \propto \frac{P_b}{R^3} A^3 \frac{q}{B^2 n_e}\frac{T_e^{3/2}}{z_b^2}$$

Large A: minimize the surface - maximises NWL!

Also, more space on the inboard.





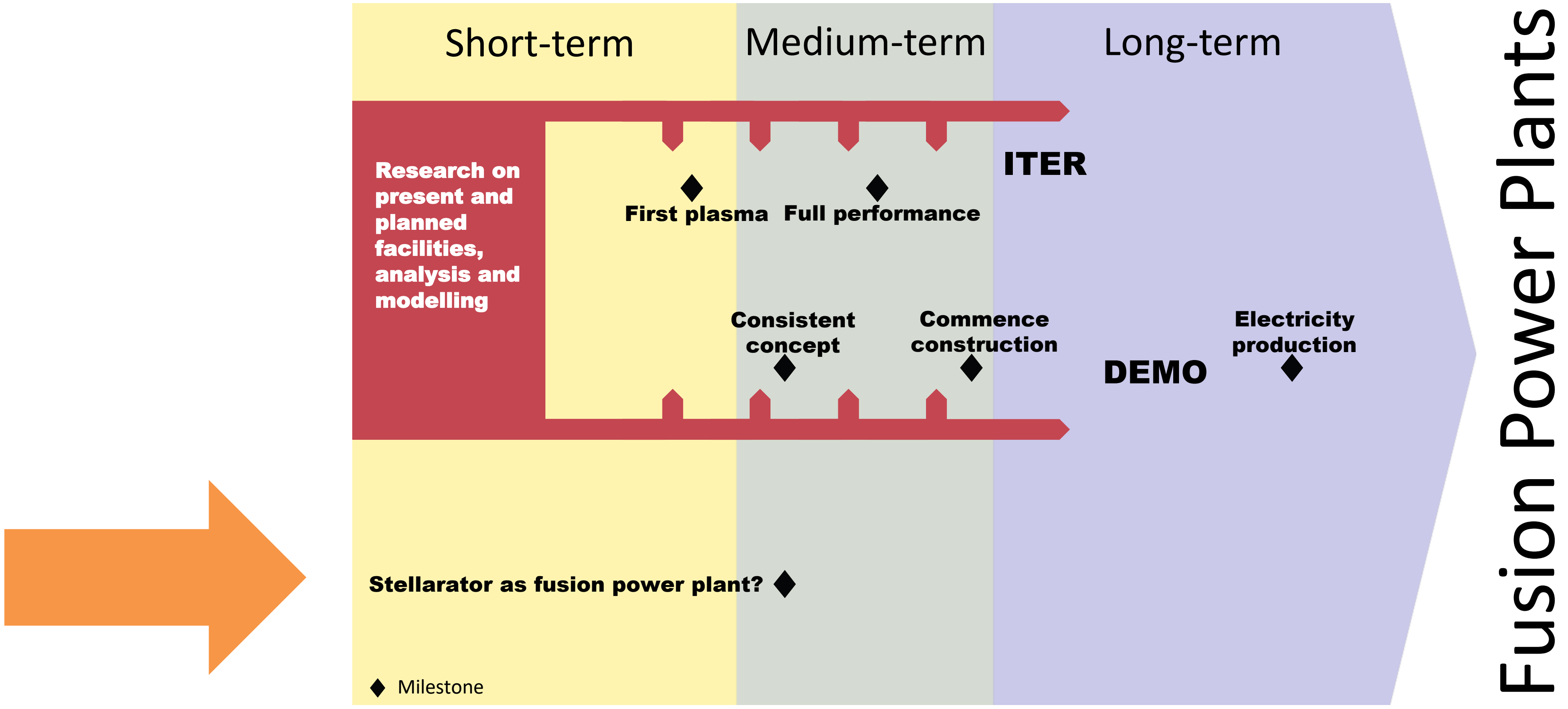
Physics Challenges:

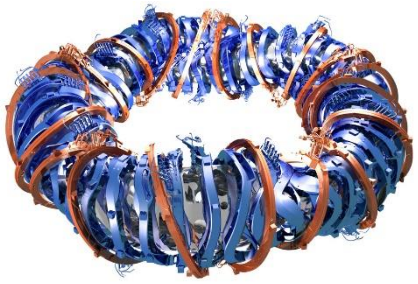
- ✓ **Equilibrium and VS:** very challenging (Tiny plasma, distant coils)
- ✓ **β-limit becomes an issue** (high plasma pressure, large energy in low volume)
- ✓ **Fast particle confinement** difficult - may lead to hot spots
- ✓ **Divertor/ power exhaust** optimise divertor geometry and impurity mix

Engineering Challenges:

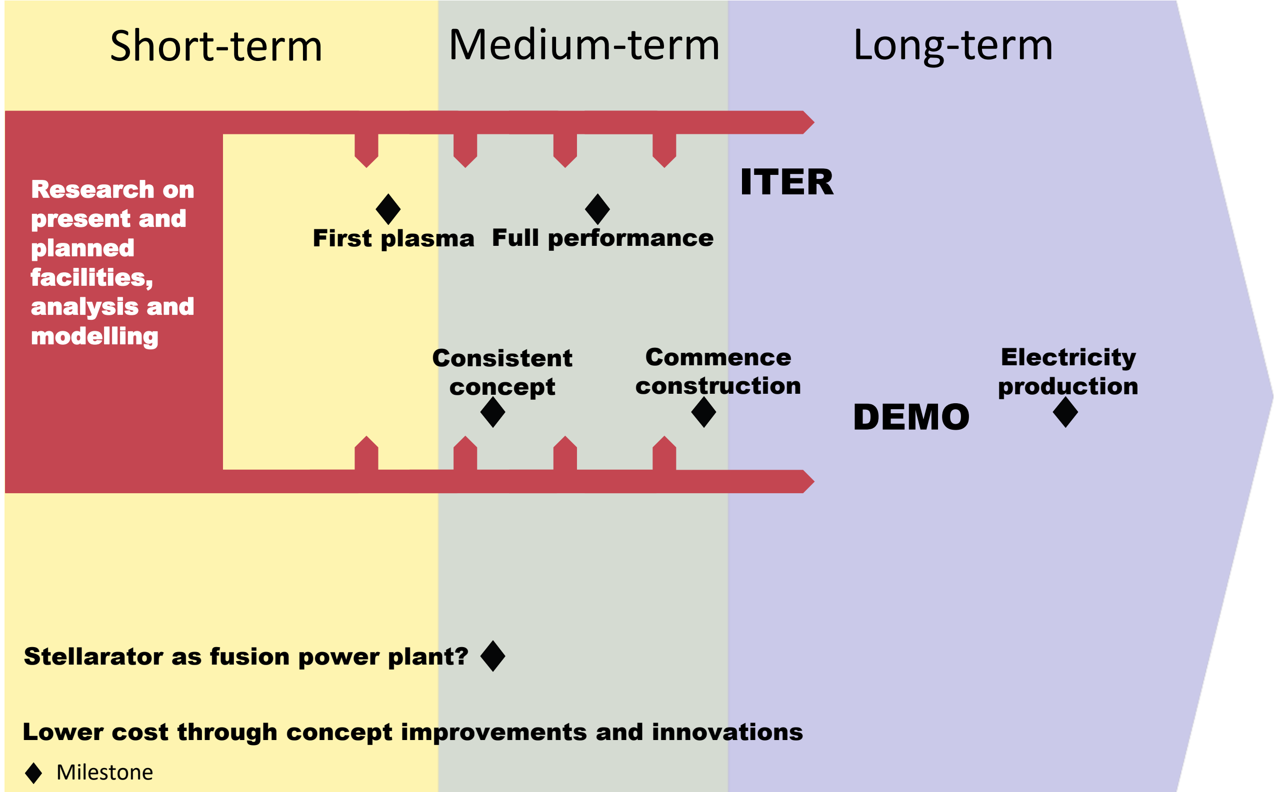
- ✓ **n- shielding inboard TF coils and NBI ports** advanced shields (WC, W2B5. etc)
- ✓ **Magnets / Equilibrium:** stabilizing plates, inner coils, PF coil nearer vessel/ plasma
- ✓ **Neutral beam: pumping/ regeneration and availability/maintainability** improve regeneration of NBI pumps, NBI pumping advanced concepts
- ✓ **Integration/ maintenance IVCs** develop robust solutions for mechanical/ hydraulic connections
- ✓ **Consolidate testing strategy,** consolidate breeding blanket testing strategy in port out/ of ports

EUROfusion research is prioritised along the Fusion Roadmap

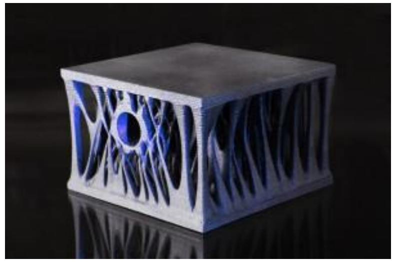


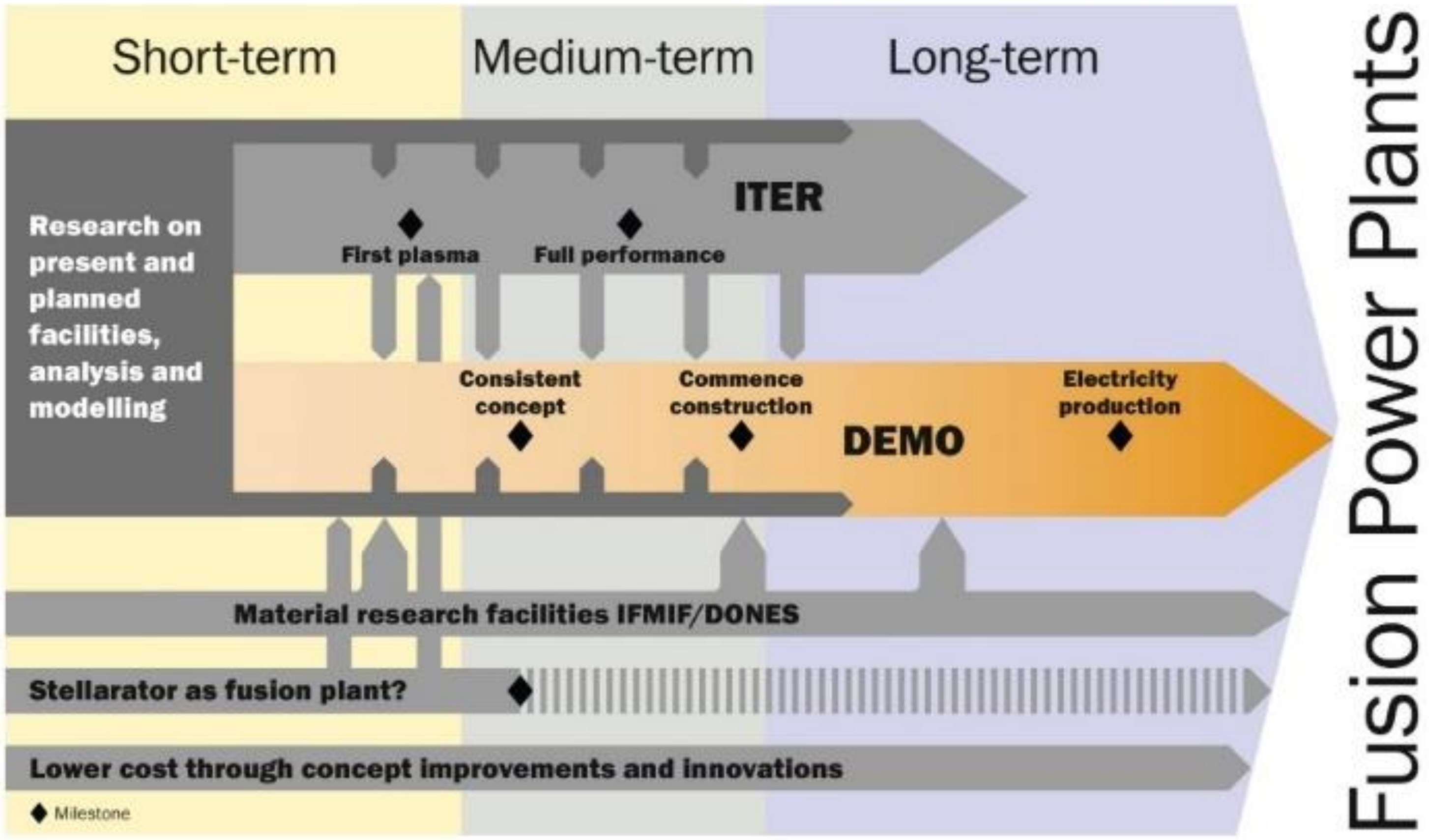


EUROfusion research is prioritised along the Fusion Roadmap

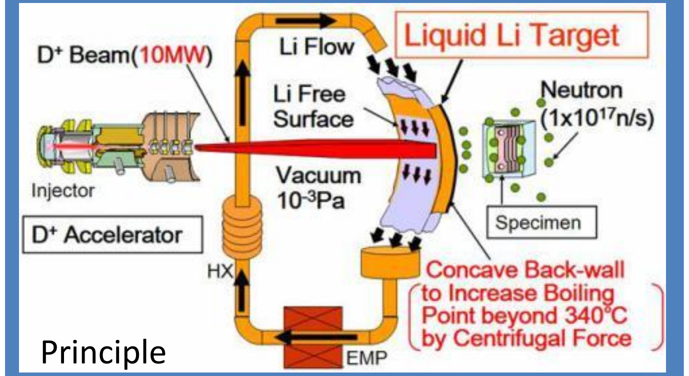


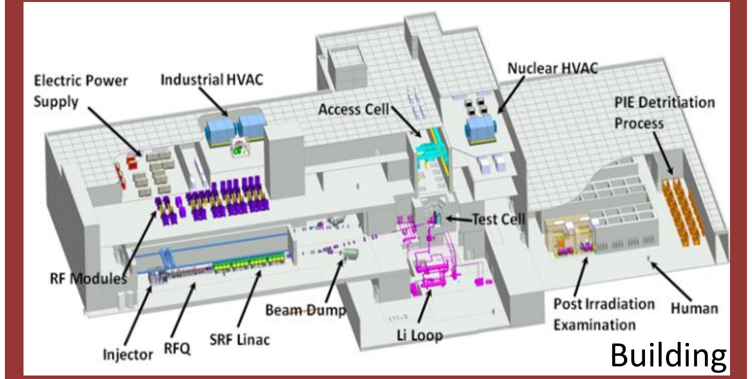
Fusion Power Plants

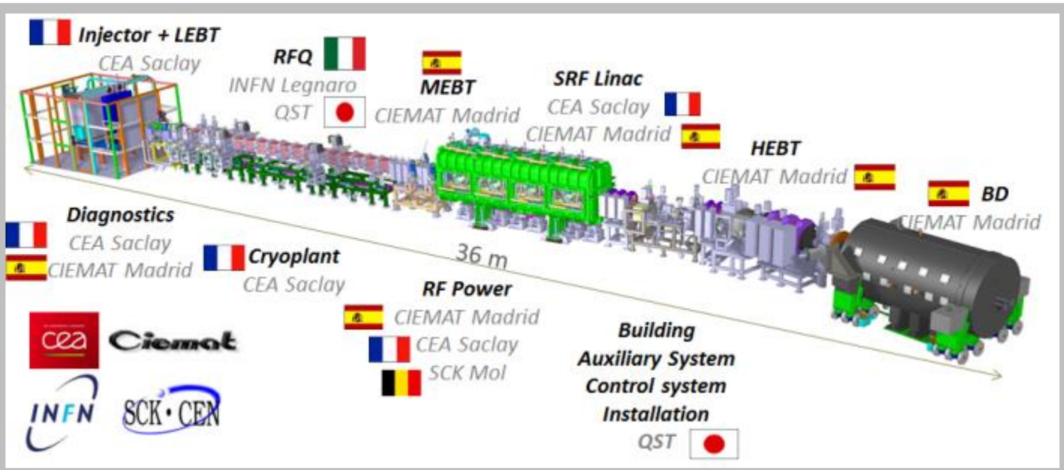



Short-term
Medium-term
Long-term
Research on present and planned facilities, analysis and modelling
ITER
First plasma
Full performance
Consistent concept
Commence construction
DEMO
Electricity production
Material research facilities IFMIF/DONES
Stellarator as fusion plant?
Lower cost through concept improvements and innovations
Milestone
Fusion Power Plants

IFMIF-DONES: Material testing & qualification

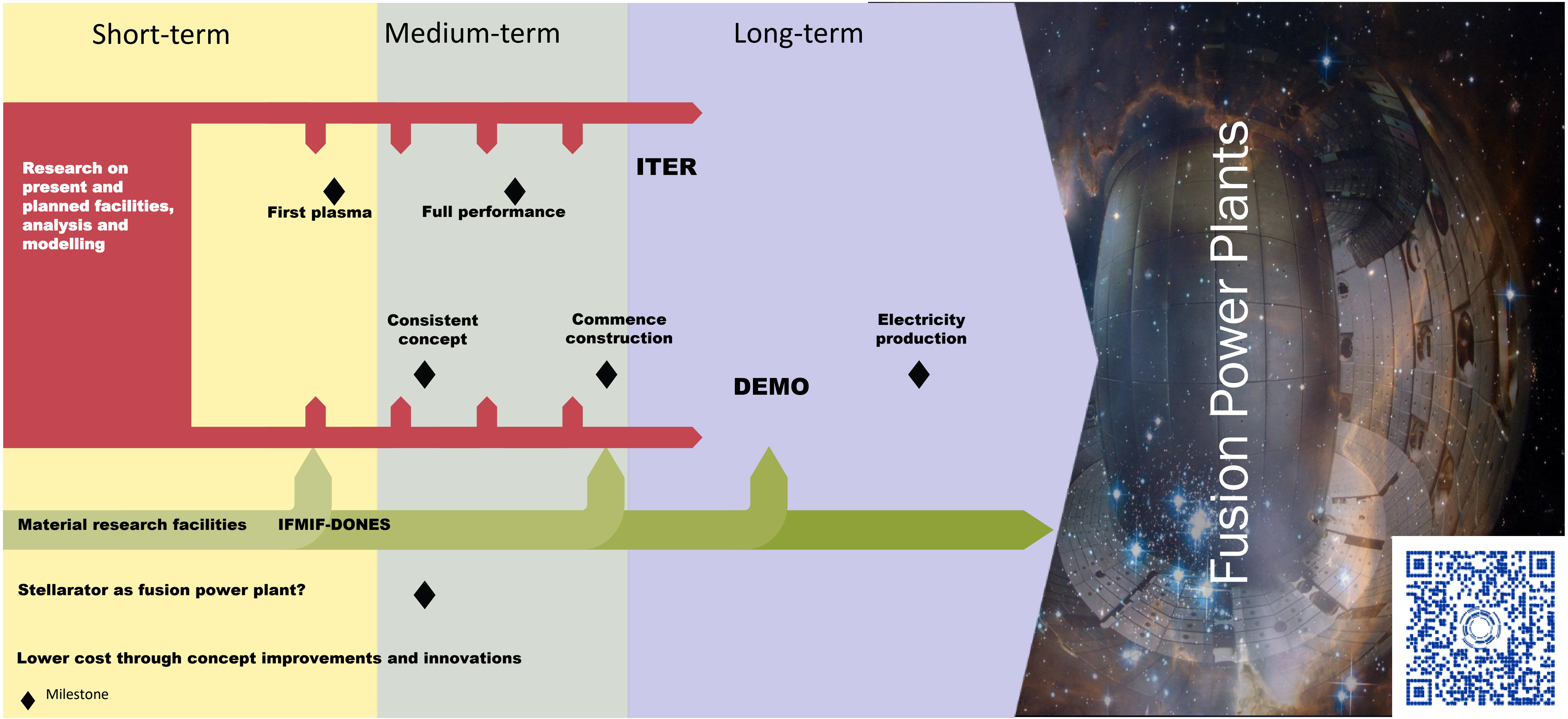




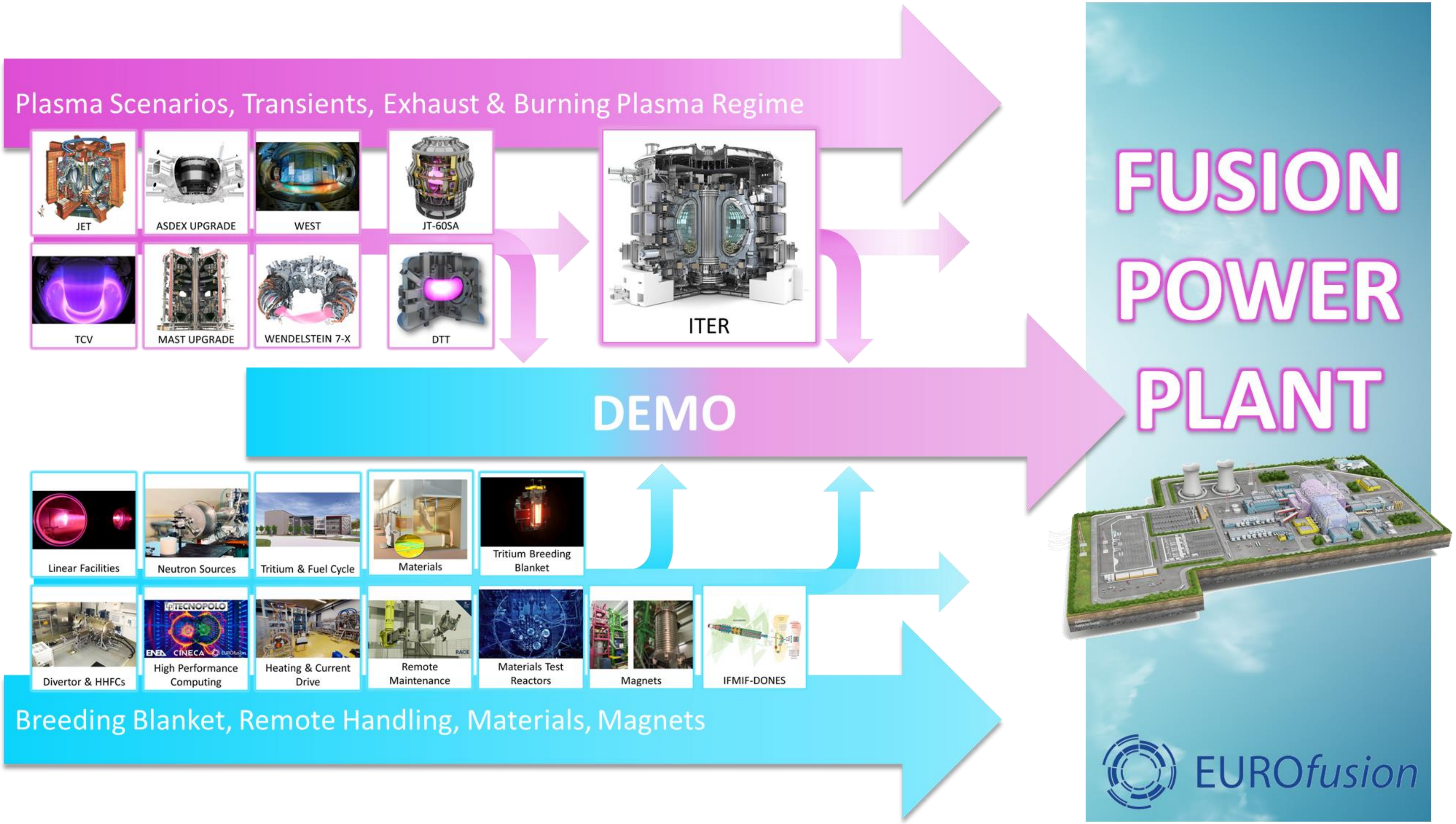


EUROfusion involved in commissioning of LIPAc (Japan) and responsible for Engineering Design of IFMIF-DONES

EU Roadmap currently under revision



Parallelization of ITER and DEMO



Strategy for Industry Involvement

During conceptual design phase, industry is involved as a partner for

- some technology R&D in selected areas (e.g. closure plate, complex mechanical structures, etc.);
- as advisor for some engineering tasks (e.g. layout, building design, etc.);
- as consultant to take into account in the conceptual design the constraints coming from the other phases (in particular manufacturing and assembly constraints)

During the basic engineering phase, the role of industry should cover

- the realization of large prototypes to validate the design manufacturability
- the basic engineering design of plant system

During the detailed design

- industry performs all detailed and manufacturing design
- partnerships shall be established in order to ensure that the industry that has performed a given manufacturing design commits to manufacture the piece

Current Strategy Implementation w.r.t. Industry Involvement

	Project Phase			
Project activities	**Conceptual Design**	**Basic Eng. Design**	**Detail & manufacturing design**	**Construction**
Project Sponsor	Dedicated organisation with assistant project sponsor capabilities separated from project management			
Project Management	EUROfusion	DEMO Organization (or equivalent)	DEMO Organization or Industry (to be defined)	DEMO Organization or Industry (to be defined)
Architecting, integration, System Engineering, etc.	EUROfusion	DEMO Organization (or equivalent)	DEMO Organization (or equivalent)	DEMO Organization or Industry (to be defined)
Tech. R&D	EUROfusion	EUROfusion	n/a	n/a
Conceptual design	EUROfusion	DEMO Organization (or equivalent)	n/a	n/a
Basic Eng. Design of fusion systems	n/a	DEMO Organization (or equivalent) * with Industry as advisor	DEMO Organization (or equivalent) (diagnostics, etc.)	n/a
Basic Eng. Design of non fusion systems (utilities, etc.)	n/a	Industry	Industry (nota: the remaining part of basic eng. Design shall be limited as it may poses integration problems)	n/a
Detail and Manufacturing Design	n/a	n/a	Industry	Industry
Construction	n/a	n/a	n/a	Industry

Partnership to ensure that the industry performing the design is also in charge of the construction

Thank you very much for your attention !