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EUROPEAN Roadmap

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EUROfusion Programme Management Unit

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

EUROFUSION MEMBERS

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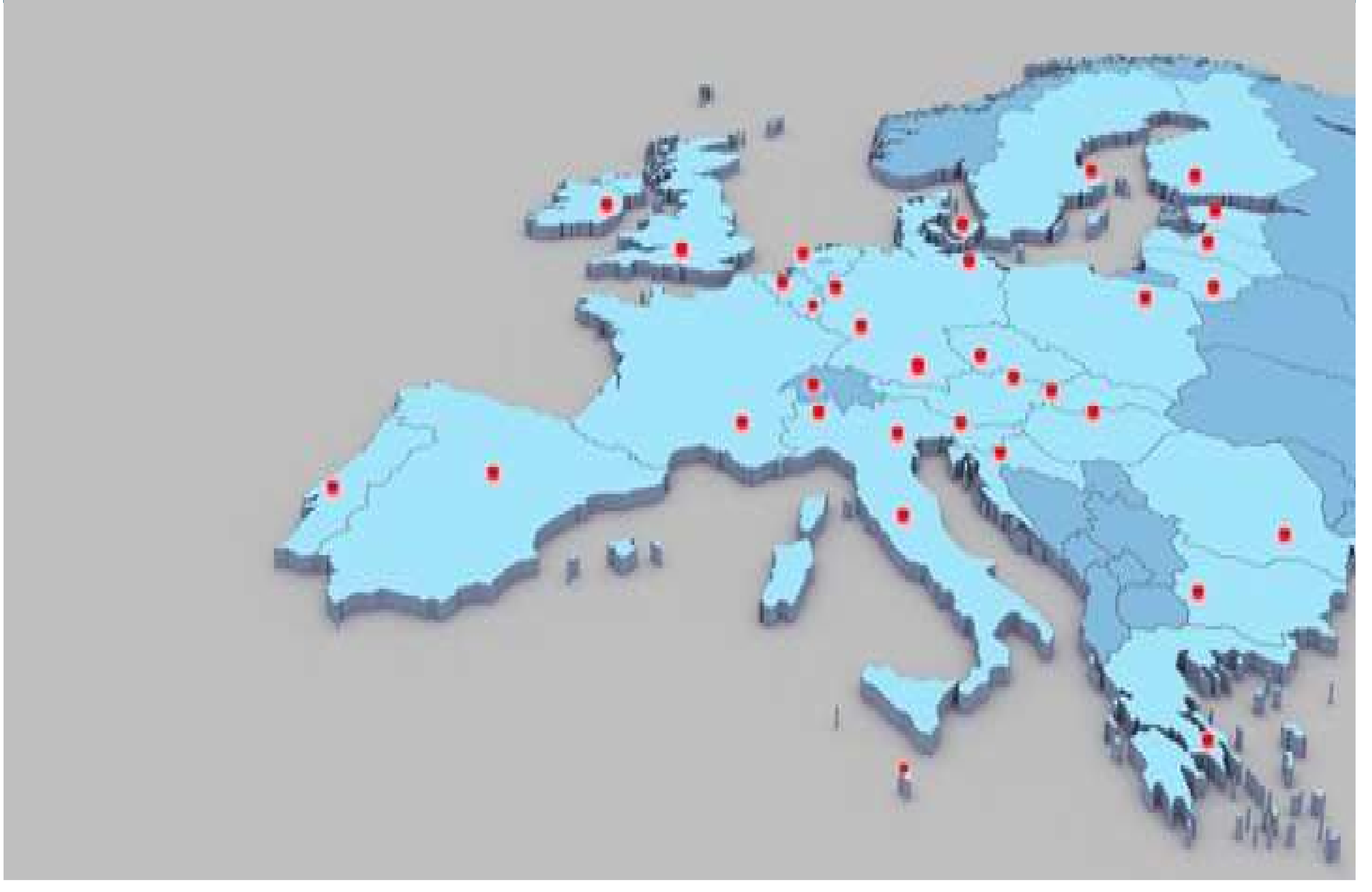

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION HORIZON 2020

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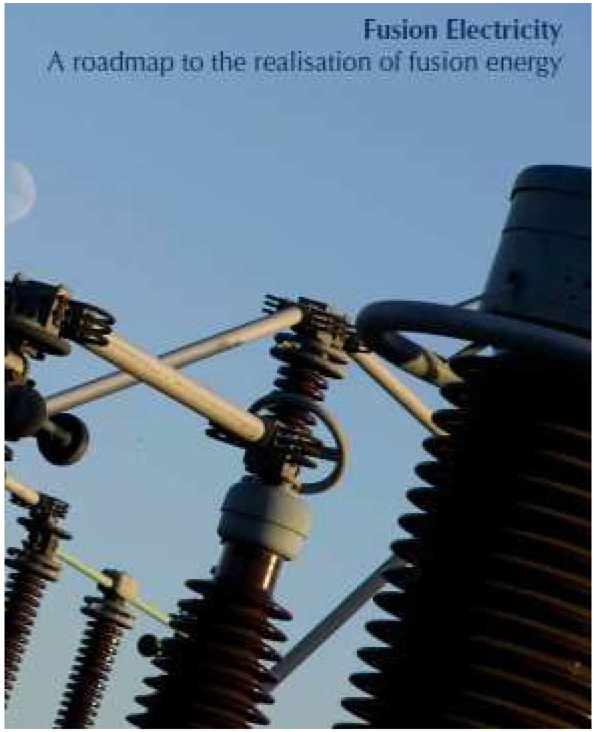
EUROPEAN ROADMAP TO THE REALISATION OF FUSION ENERGY

http://www.efda.org/efda/activities/the-road-to-fusion-electricity/



- A Roadmap to the realization of fusion energy adopted end of 2012.
- The roadmap aims at achieving the know-how to start the construction of a demonstration power plant (DEMO) by 2030, to reach the goal of fusion electricity in the grid by 2050.
- **ITER, the key facility in the roadmap & critical path**
- **Roadmap conceived as a living document**
- EU strategy to DEMO: only step between ITER and a commercial fusion power plant. To minimize the risk of the DEMO R&D a **pragmatic approach** → simple and robust technical solutions + established/reliable regimes of operation from ITER
- **A goal oriented approach**: eight different Missions

THE ROADMAP* ADDRESSES THREE SEPARATE PERIODS WITH DISTINCT MAIN OBJECTIVES

Horizon 2020 (2014-2020) with five overarching **objectives**

- 1 Construct ITER within scope, schedule and cost;
- 2 Secure the success of future ITER operation;
- 3 Prepare the ITER generation of scientists, engineers and operators;
- 4 Lay the foundation of the fusion power plant;
- 5 Promote innovation and EU industry competitiveness

Second period (2021-2030):

- Exploit ITER up to its maximum performance
- Prepare DEMO construction

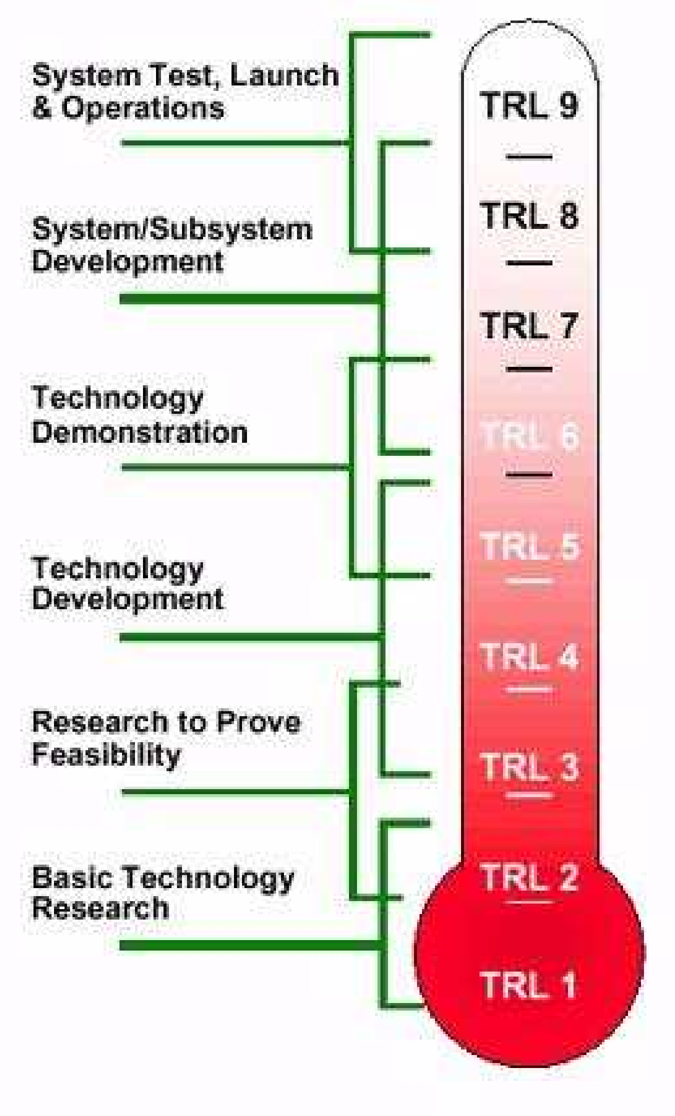
Third period (2031-2050):

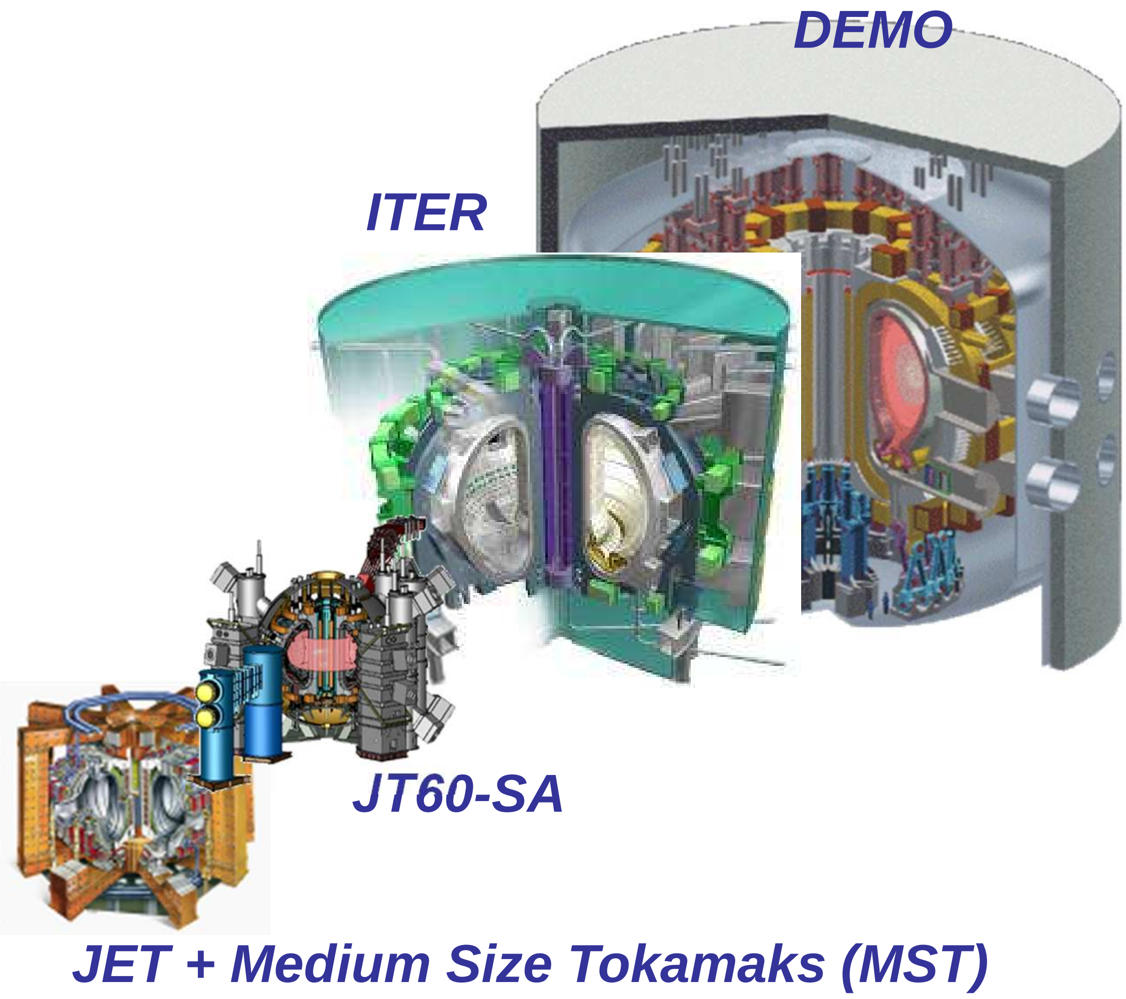
- Complete the ITER exploitation
- Construct and operate DEMO

The assumption made is that ITER is built according to specification and within cost and schedule.

*Authors : Francesco Romanelli, Pietro Barabaschi, Duarte Borba, Gianfranco Federici, Lorne Horton, Rudolf Neu, Derek Stork, Hartmut Zohm

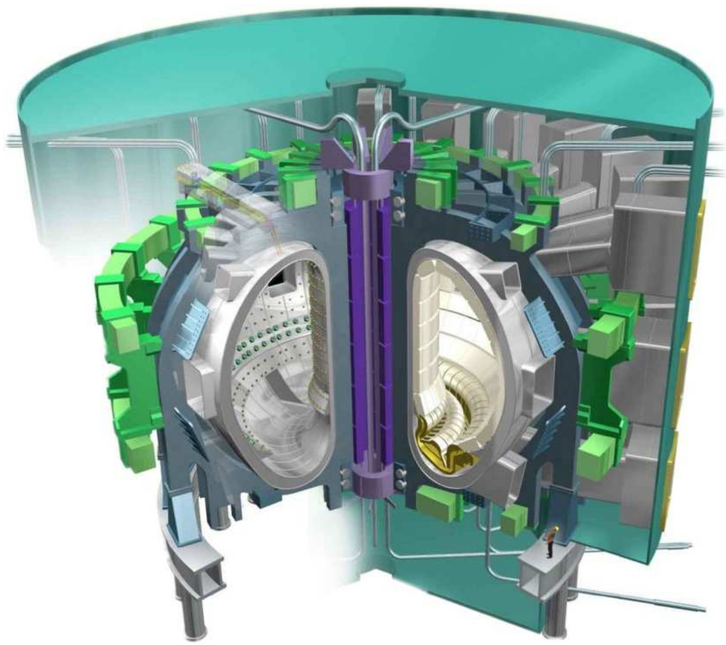
FUSION ROADMAP & TECHNOLOGY READINESS LEVEL





ITER & EUROPEAN FUSION ROADMAP

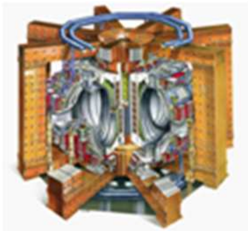
- **ITER the key facility of the roadmap**
- **ITER to achieve most of the important milestones to DEMO**
- **ITER construction triggered major advances in enabling technologies**
- **ITER licensing confirmed intrinsic safety feature of fusion and incorporated in design**



ITER

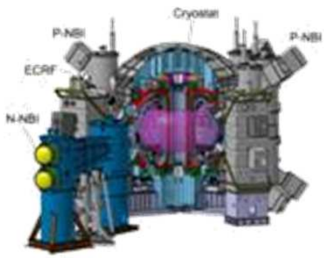
European Fusion Accompanying Programme in the coming years will focus on the preparation of ITER operation

Inductive operation

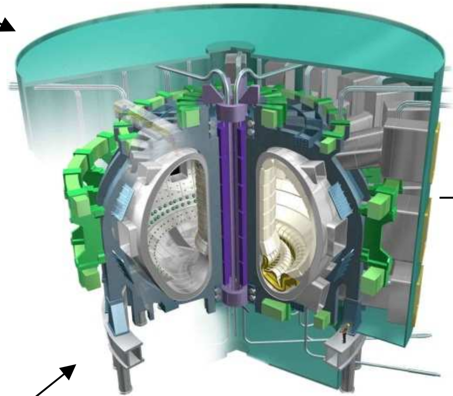


JET

Steady-state operation



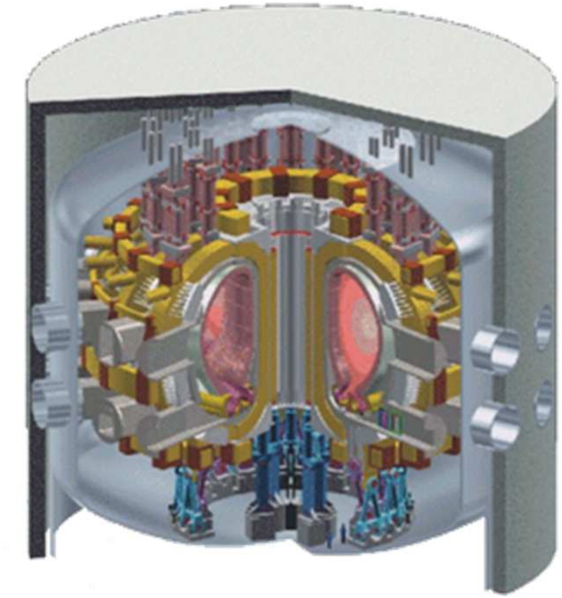
JT60-SA



ITER

800 m^3

~ 500 MW$_{th}$



DEMO

~ 1000 - 3500 m^3

~ 2000 - 4000 MW$_{th}$

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

HORIZON 2020

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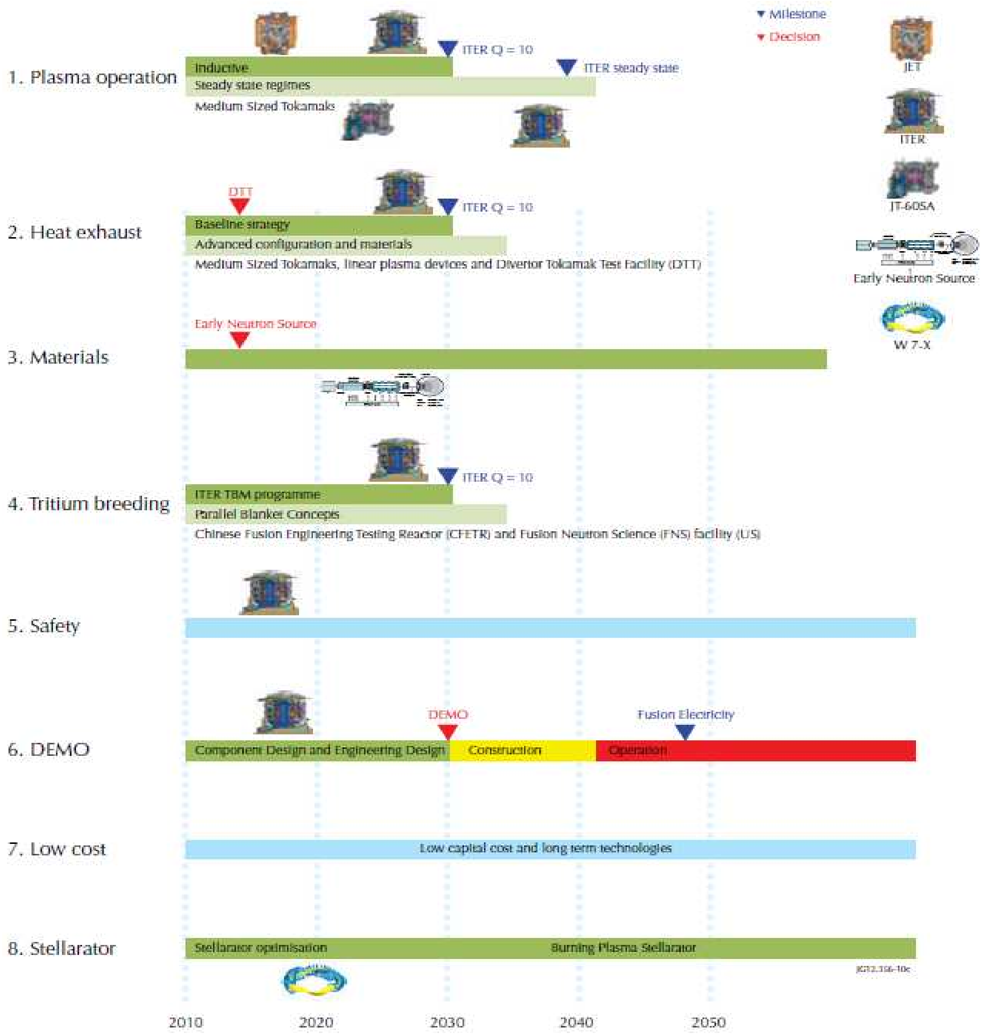
A GOAL ORIENTED APPROACH : IN EIGHT DIFFERENT MISSIONS



1. Demonstrate plasma regimes of operation
2. Demonstrate heat exhaust system
3. Development of neutron resistant materials
4. Ensure tritium self sufficiency
5. Implementation of the intrinsic safety features of fusion
6. Produce an integrated DEMO design supported by targeted R&D activities
7. Competitive cost of electricity
8. Bring the stellarator line to maturity

http://www.efda.org/efda/activities/the-road-to-fusion-electricity/

HORIZON 2020 — THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

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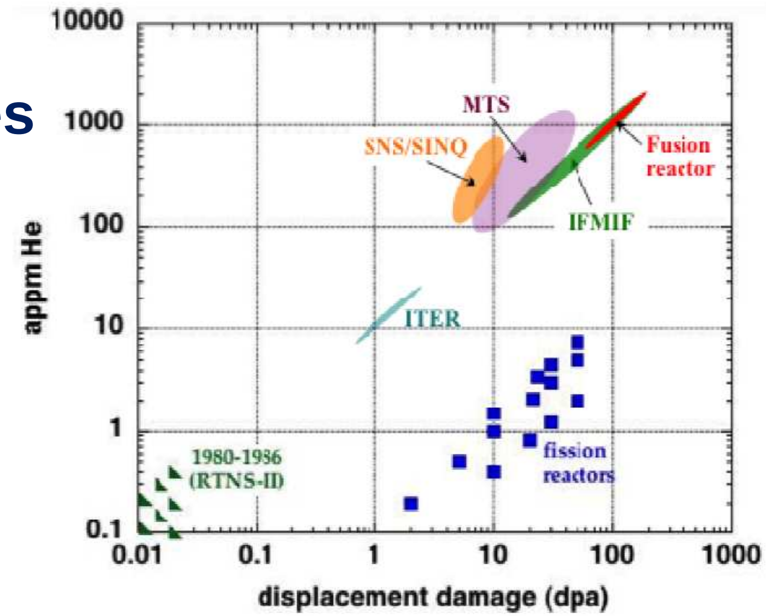
EU ROADMAP TO ADRESS KEY CRITICAL SCIENCE+TECHNOLOGY ISSUES

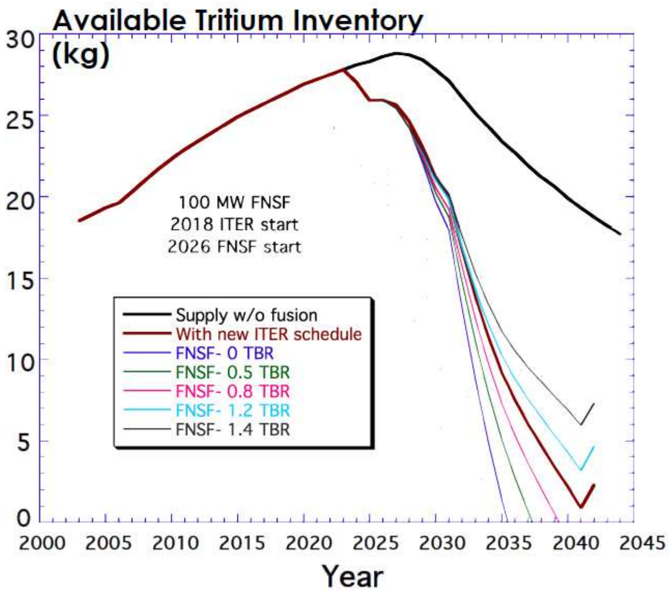
1) Sustain high gain burning plasma

- $P_{alpha} > P_{ext}$, fast particle, long duration, PWI
- Missions 1, 2 , 5, 8

2) Materials resisting to high heat fluxes and neutron fluence

- Damage + He production
- Low activation
- Missions 3, 2, 6-8





3) Tritium self-sufficiency & fuel cycle

- ~12kg T/month for 1000MWe DEMO
- Efficient breeding & extraction
- Missions 4, 5-8

INCREASE COORDINATION BETWEEN EUROPEAN DEVICE

To ensure ITER success: preparation of operation on JET, MST and JT-60SA as main risk mitigation measures

Address issues where EU coordination bring added values:

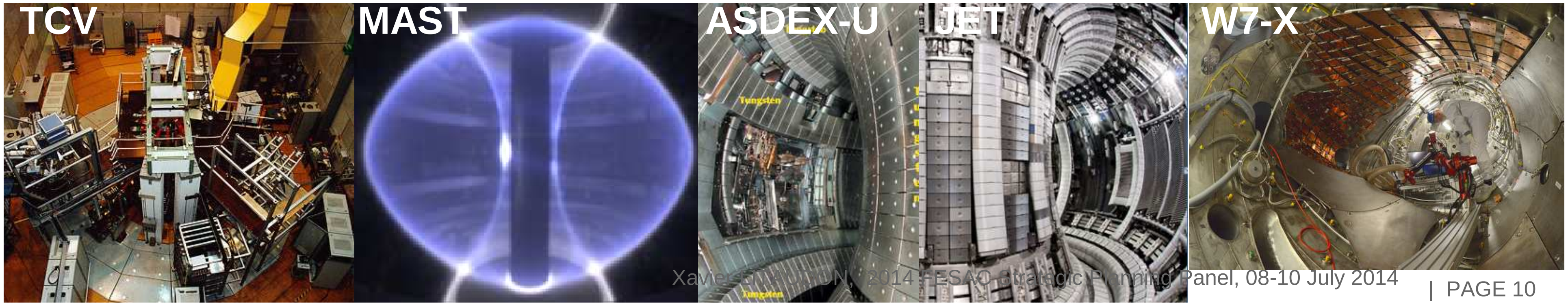
- Scaling to JT-60SA, ITER and reactors conditions
- Plasma scenario with core & edge integration, High power steady-state
- Divertor & PWI issues, ELMs mitigation, Disruptions
- Diagnostics, Shaped configurations, Tight aspect ratios physics, …

Integration of knowledge through modelling

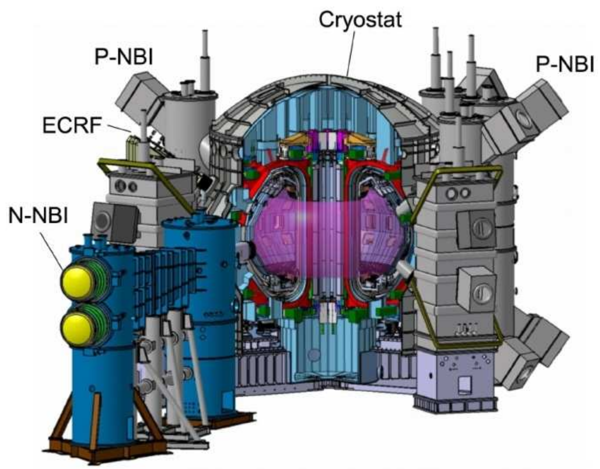
Systematic extrapolation for JT-60SA, ITER and DEMO

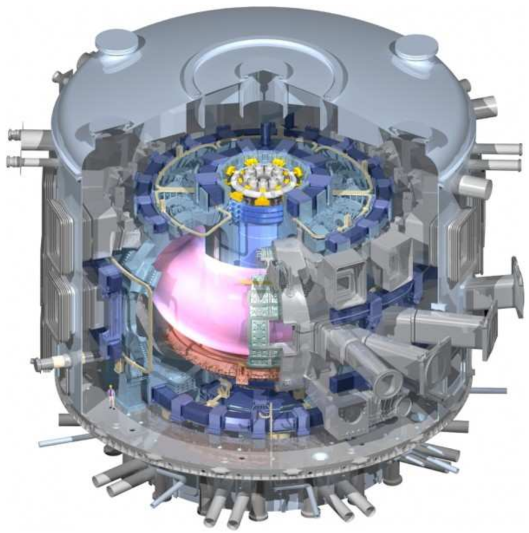
Prepare EU to JT-60SA operation

Internationalization of JET to prepare ITER operation



MISSION 1: PLASMA REGIMES OF OPERATION





Preparation on existing devices: JET, MST + international collaborations

Demonstrate and qualify regimes that meet the needs of ITER and DEMO

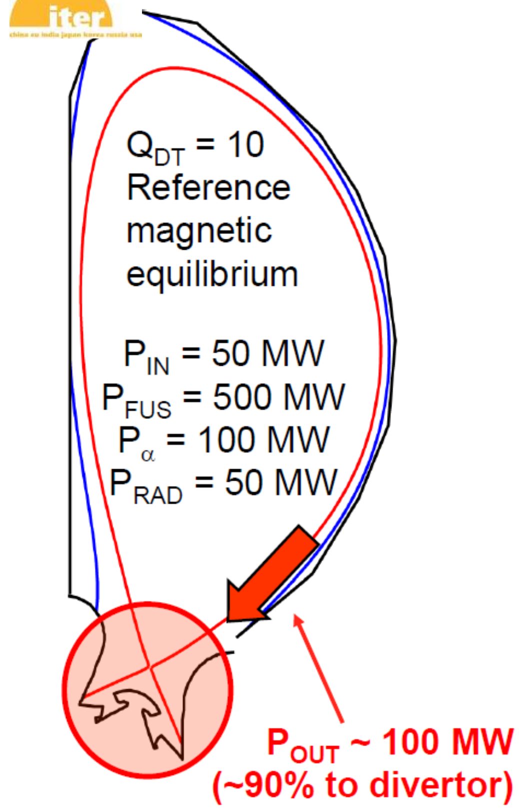
High fusion performance with metallic PFC by improving transport and by controlling MHD instabilities.

Acceptable power depositions in the W divertor, radiate as much as possible power while keeping the performance

Develop integrated scenarios with controllers (MHD, detached, Divertor, dilution…)

Try to achieve steady state conditions

MISSION 2: HEAT EXHAUST SYSTEMS

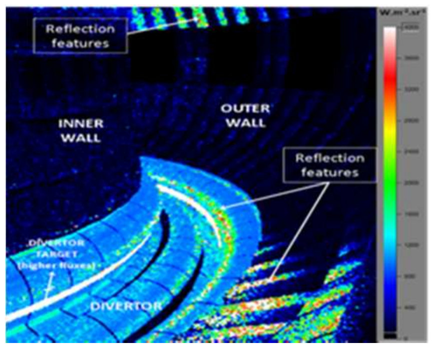


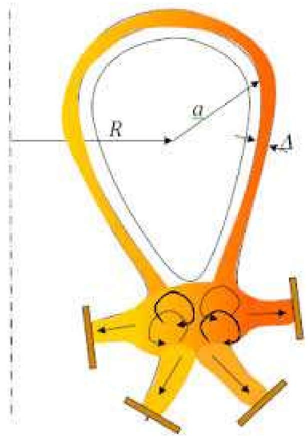
[courtesy D. J Campbell, ITER research plan]

The baseline strategy 'detached' divertor together with research in alternative divertor solutions: Super-X, snowflake, liquid metal divertors

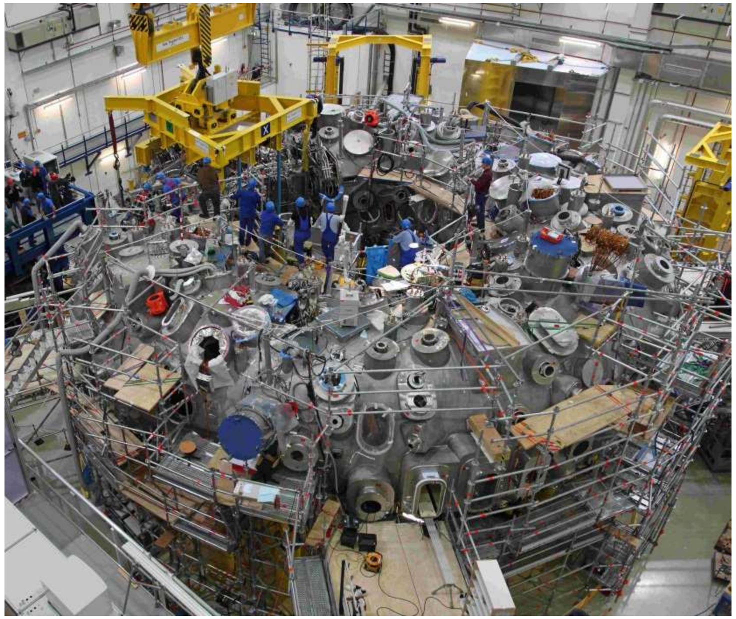
- Detachment control for ITER and DEMO
- Efficient PFC operation for ITER and DEMO
- Predictive models for ITER and DEMO divertor/SOL
- Investigate alternative power exhaust solutions
- Research to find more robust materials

Main existing : JET, MST + Linear devices
+ international collaborations
Potentially a Divertor Test Tokamak?





MISSION 8: BRING THE STELLARATOR LINE TO MATURITY



Bring stellarator to maturity as a possible long-term alternative to tokamaks, EU programme focuses on the HELIcal Advanced Stellarator, HELIAS, line

For 2014-2020 : main priority scientific exploitation of the W7-X including theory development & modelling

Wendelstein 7-X

Impact on the progress of the basic understanding of plasma physics in support of Mission 1 and 2 and in support of the ITER preparation

IMPLEMENTING WORK PACKAGES FOR ITER PHYSICS DEPARTMENT

ITER Physics Department : Missions 1 , 2 & 8

Mission 1

- JET Campaigns & JET enhancements
- Technological Exploit of DT Operation for ITER preparation
- Medium-Size Tokamak Campaigns (MST) & enhancement
- Preparation of exploitation of JT-60SA

Mission 2

- Investigation of Plasma-Facing Components for ITER, Preparation of efficient PFC operation
- Assessment of alternative divertor & liquid metals PFCs
- Definition and design of the Divertor Tokamak Test facility

Mission 8

- W-7X Campaigns, Stellarator optimisation

- **Support to missions: code development for Integrated modelling, Infrastructure support activities**

ITER Physics Department : Missions 3-7

- Materials
- Early neutron source & design

Mission 3

- Breeding blankets
- Safety & environment

Mission 4,5

- Design Integration and Physics Integration
- Magnet system
- Divertor
- Tritium and fuelling
- Heating and current drive
- Diagnostics and control
- Remote maintenance systems
- Containment structures
- Heat transfer, balance-of-plant

Mission 6,7

STATUS OF ONGOING COLLABORATIONS

Support for international collaborations under EUROfusion consortium

- EU scientists participate to experiments in all ITER parties
- In 2014, EU participation to US is the largest: 47 % of mission support over the total budget representing 38% of ppy in terms of human resources

Status of recent US collaborations with JET (c.f. L Horton's talk)

- Explore advanced inductive scenarios (GA)
- Modelling on JET plasmas (Transport, MHD …) (PPPL)
- ICRH Physics and Spectroscopy (ORNL)
- ILW experiments (high Z impurity sources) and control and Active Alfven Eigenmodes studies (MIT)
- Lost alpha particle diagnostics (CSM)

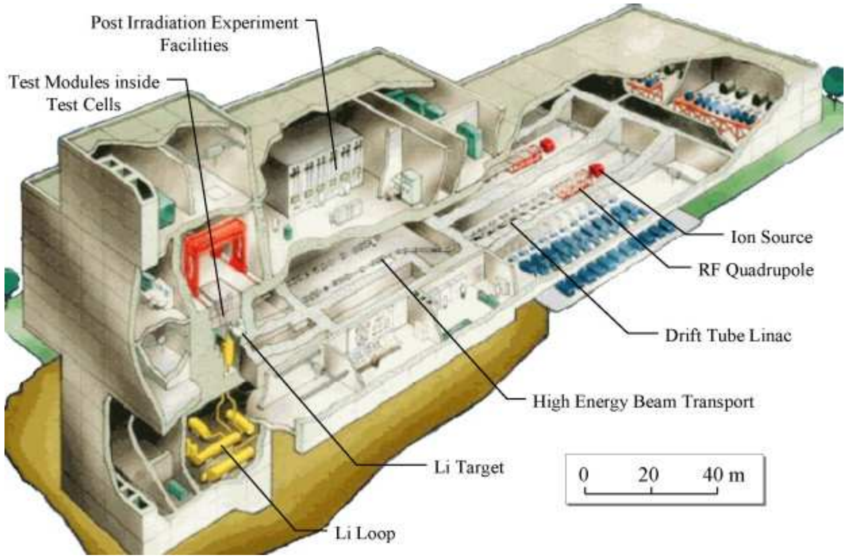
CONCLUSIONS ON OPPORTUNITIES FOR INTERNATIONAL COLLABORATION

- Develop strong International collaboration with objectives aligned with the EU roadmap, e.g. collaboration on a joint DTT facility ?, Fusion Neutron Science facility ? stellarator lines ? early neutron source ?
- Coordination and support to the participation to ITPA, Address high priority ITPA tasks, Joint experiments
- Develop international collaboration for specific issues that could complement the EU program and by opening EU experimental facilities (JET, MST, W7-X) to international participation where international collaborators could contribute with in-kind components
- The exploitation of JT-60SA in collaboration with Japan
- Internationalization of JET to prepare ITER operation with ITER task Forces

QUESTIONS

3: NEUTRON RESISTANT MATERIALS

- Full characterization of the baseline materials for DEMO:
  EUROFER as structural material
  Tungsten as Plasma Facing Component
  Copper-alloys for cooling

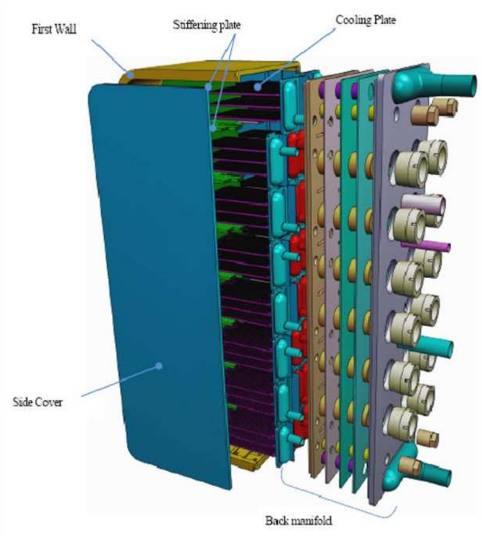


- Expand the operational range of these materials (e.g. EUROFER has an operational range of 350 – 550 °C

Main devices: IFMIF, Early Neutron Source, Irradiation facilities, HFETR, CEFR?

4: TRITIUM SELF-SUFFICIENCY

- Main question is whether a fusion reactor can produce enough tritium for its own fuel supply



- Research concentrated on two test blanket modules in ITER
- Research in extraction of tritium from the blankets
- Main devices (on ITER):
  - TBM based on eutectic Pb-16Li and TBM on ceramic material; both using He as coolant
  - Possibly also research in water-cooled Pb-16Li
  - Synergy with CFETR?

5: INTRINSIC SAFETY FEATURES

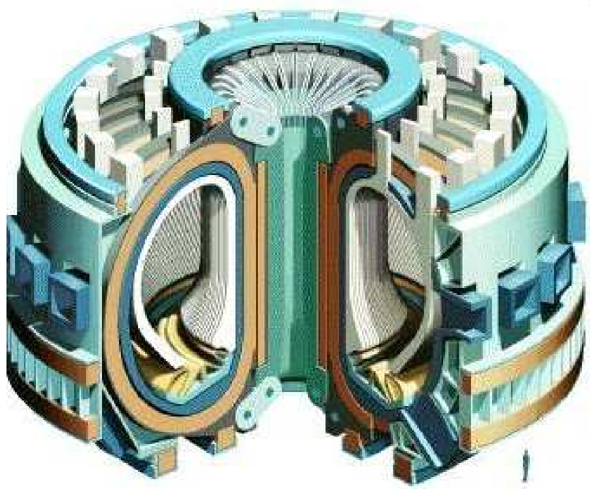
- A relatively small mission to study the specific nuclear licensing procedures for DEMO and to study how the amount of radioactive waste can be reduced as much as possible.

- Differences between ITER and DEMO in this respect are the much higher neutron and tritium fluences

- Main device: ITER

6: INTEGRATED DEMO DESIGN AND SYSTEM DEVELOPMENT

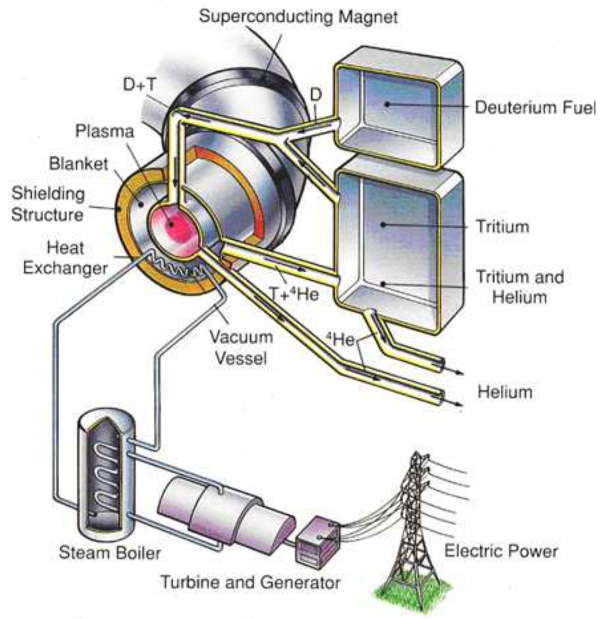
- Find ways to reduce degradation of superconducting cables under continuously changing loads



- Study application of high T_c superconductors
- Increase gyrotron frequencies for ECRH and ECCD to ~230 GHz
- Optimize remote handling and remote maintenance strategies
- Develop control strategies for underdiagnosed plasmas

7: COMPETITIVE COST OF ELECTRICITY

- Which impact do design choices for DEMO have on the ultimate price of electricity:



- Cheap and straightforward design solutions
- Components with long life-expectancy
- High machine availability
- High temperature superconductors?

BUDGET DISTRIBUTION

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