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EUROPEAN FUSION DEVELOPMENT AGREEMENT

A roadmap to the realization of fusion energy

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European Fusion Development Agreement

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Why a roadmap

- The need for a long-term strategy on energy technologies for security of supply, sustainability and economic competitiveness **requires long term programming and substantial re-direction of the programme**
  - EU Strategic Energy Technology plan, Energy Roadmap 2050
- In this context, Fusion must become a credible energy source
- European Commission proposal for Horizon 2020 (2014-2020), following the advice of an Independent Panel on *Strategic Orientation of the Fusion Programme* (Wagner Panel), states the need of ***an ambitious yet realistic roadmap to fusion electricity by 2050***.
- Hence, the request by the EC to EFDA for a fusion roadmap.

ITER is the key facility in the roadmap

- ITER is expected to achieve most of the important milestones needed for a decision on a demonstration fusion power plant (DEMO).
- ITER construction has triggered major advances in enabling technologies.
- ITER licensing has confirmed the intrinsic safety features of fusion and incorporated them in the design.
- Vast majority of proposed Roadmap resources on ITER construction and preparation.
- The assumption made here is that ITER will be built according to specification and within cost and schedule.

Background to the present work

- Fusion Fast Track (D. King, 2001)
- SET Plan (2007)
- Facility Review (2008)
- AHG group on JET and accompanying programme (2010)
- DEMO Working Group (2010)
- Strategic orientation of the fusion programme (2011)
- Common to these aspects
  - Central role of ITER
  - 14 MeV neutron sources (IFMIF) for material qualification
  - DEMO as a single step to the commercial power plant

The present roadmap attempts to put in a logical sequence and within a realistic plan the elements of the Reviews of the last few years taking into account the recommendations by the Review Panels.

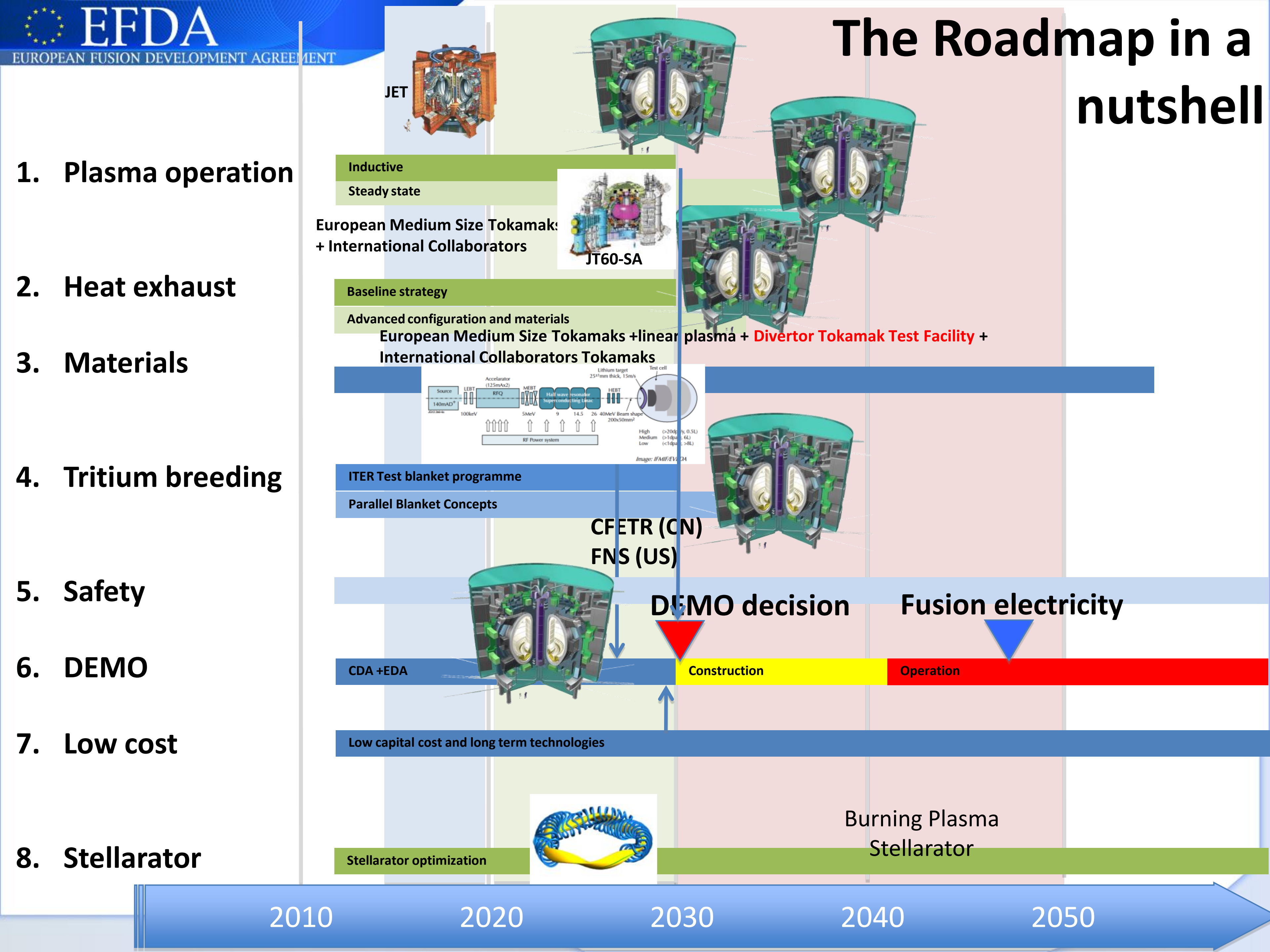
The present roadmap

- **Pragmatic approach to fusion energy**.
  - Define realistic DEMO goals (together with industry)
  - Avoid multiple critical paths by minimizing construction of new large and complex facilities.
    - Roadmap constructed to have a single critical path – ITER
- **Focus the effort of European laboratories**
  - Goal oriented approach articulated around 8 Missions
  - Priority to the items in the roadmap
- **Ensure innovation through early industrial involvement**
  - Industry must be able to take full responsibility for the commercial fusion power plant after successful DEMO operation.
  - Materials development: strong emphasis on the industrialisation
  - Reduction of plant capital costs
- **Exploit the opportunities arising from international collaborations**
  - Not every facility in Europe (but Europe should have all the necessary know-how by 2030 for the construction of DEMO).

The present roadmap

- Increase support to education and training (300PhD/y & 140Post-Doc/y).
- Maintain a sizeable amount of fund to basic (i.e. not Mission oriented) and "curiosity driven" research.

- Three periods considered
  – H2020 (2014-2020) detailed work packages and budget
  – 2021-2030 indicative programme and budget
  – Beyond 2030 – only outline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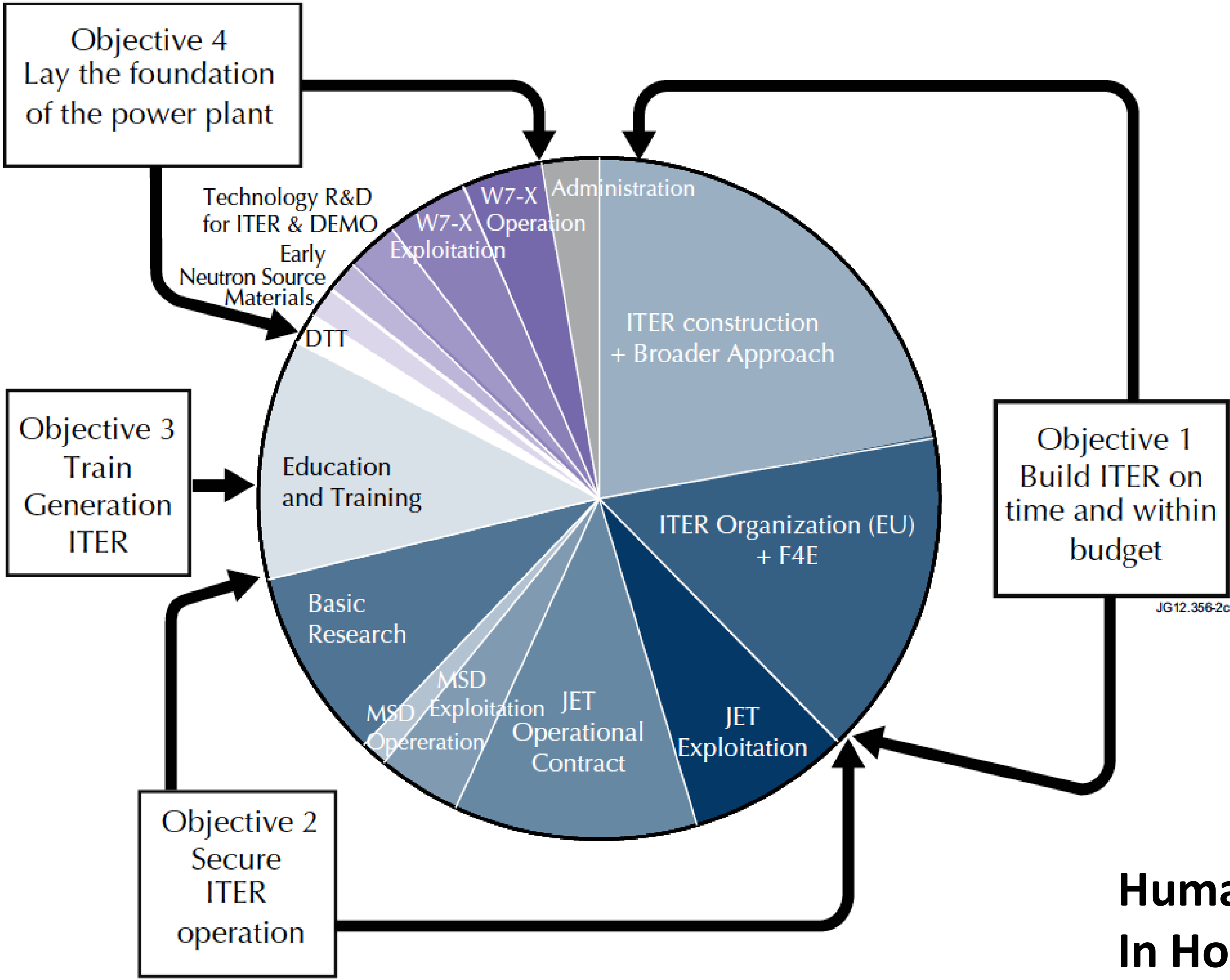
The Roadmap in a nutshell
1. Plasma operation
2. Heat exhaust
3. Materials
4. Tritium breeding
5. Safety
6. DEMO
7. Low cost
8. Stellarator
JET
Inductive
Steady state
European Medium Size Tokamaks + International Collaborators
JT60-SA
Baseline strategy
Advanced configuration and materials
European Medium Size Tokamaks +linear plasma + Divertor Tokamak Test Facility + International Collaborators Tokamaks
ITER Test blanket programme
Parallel Blanket Concepts
CFETR (CN)
FNS (US)
DEMO decision
Fusion electricity
CDA +EDA
Construction
Operation
Low capital cost and long term technologies
Burning Plasma Stellarator
Stellarator optimization
2010
2020
2030
2040
2050

Resources



Human resources
In Horizon 2020

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Resources

	2014-2018 average	2019-2020 average	2021-2030 average
	M€	M€	M€
Mission 1 w/o JET & ITER	20	33	33
Mission 2 w/o JET & ITER	36	70	44
Mission 3	39	67	33
Mission 4 w/o JET & ITER	19	14	In Mission 6
Mission 5	3	2	In Mission 6
Mission 6	13	9	200
Mission 7	5	5	5
Mission 8	45	50	50
Basic research	35	35	35
Computing resources	8	2	8
Education	9	9	9
Training	15	15	15
Administration & Mobility	10	10	10
JET operation	56	68	0
JET exploration	32	30	0
TOTAL w/o ITER	**344**	**418**	**441**
ITER construction	511	115	0
ITER operation	0	0	99
ITER exploration	0	0	42
ITER & JT60SA enhancement	0	0	9

Financial resources
EC + Member States
(FP7 350-400M€)

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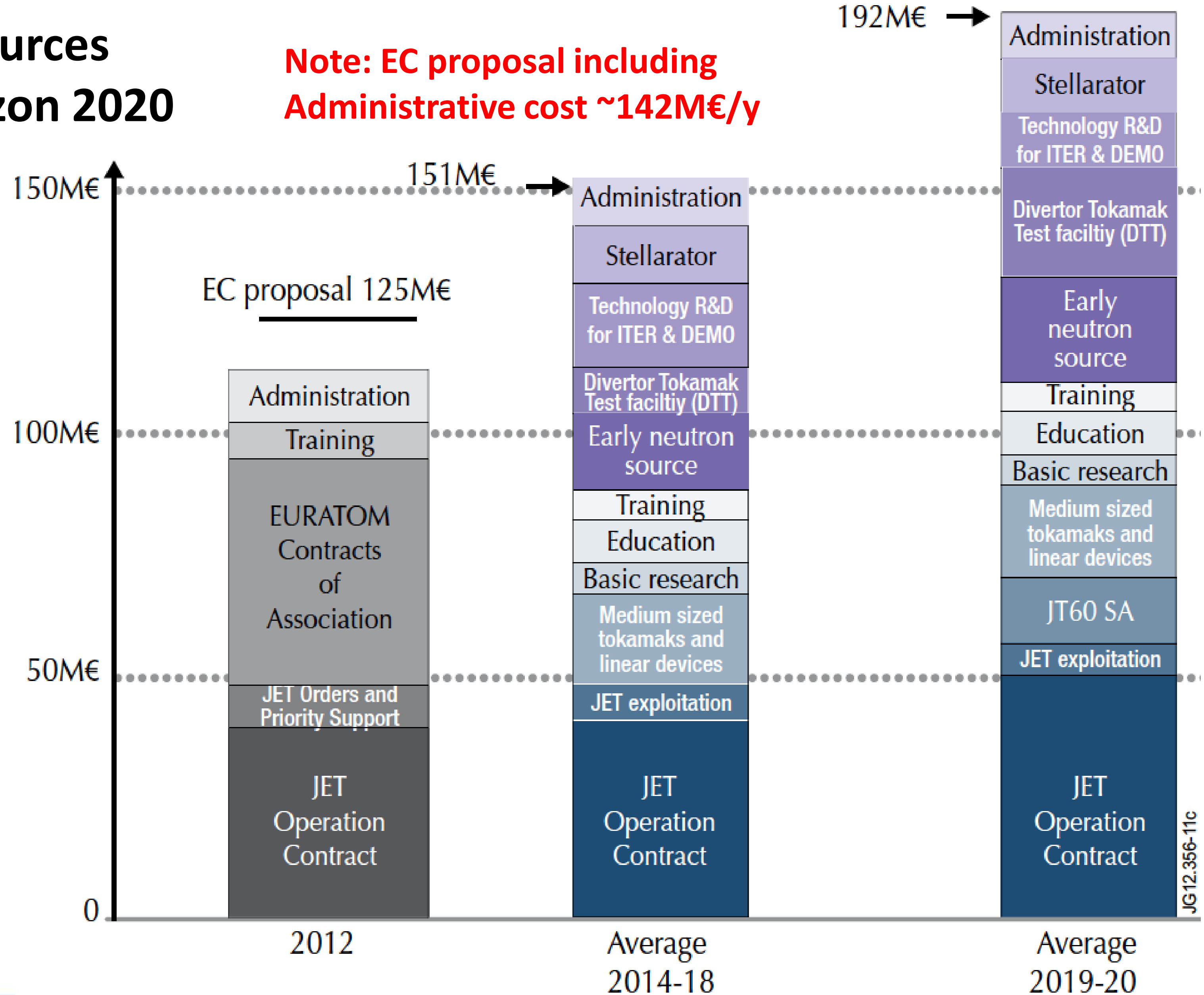
Resources

EC resources In Horizon 2020

Note: EC proposal including Administrative cost ~142M€/y



International collaborations

- In addition to the ITER exploitation and the BA projects, the following opportunities are underlined:
  - The exploitation of JT-60SA in collaboration with Japan for the preparation of ITER Phase 2;
  - The construction of a pilot IFMIF plant (Early Neutron Source) in collaboration with Japan within a post EVEDA phase;
  - The collaboration on a joint Divertor Tokamak Test facility;
  - The collaboration on other smaller scale DEMO R&D (for example making use of the infrastructure developed with Japan during the BA for that purpose);
  - The use of the Chinese Fusion Experimental Tokamak Reactor (CFETR) facility with China and of the Fusion Neutron Science (FNS) facility in US;
  - The share of know-how on the TBM programme with other ITER parties whenever a win-win situation is expected;
  - The use of non-EU research fission reactors;
  - The collaboration on stellarator lines other than the HELIAS (i.e. Heliotron and compact stellarator).
- Europe can offer to the other parties the participation in its facilities, and specifically to JET as training facility for ITER. Specific funds also foreseen for participation to machines abroad.

Next steps

- The roadmap will be a living document, reviewed regularly in response to the physics, technology and budgetary developments

Main findings

- **The demonstration of the plasma regimes of operation for reactor application will be completed by ITER**:
  - Main risk mitigation from preparation of operation on **JET** and **JT60-SA**.
  - **Small and medium size tokamaks** (MST), with proper capabilities, will play a role on specific work packages.
  - **No major gaps** exist in the foreseen world programme concerning the possibilities to develop regimes of operation for ITER and DEMO.
- **A reliable solution to the problem of heat exhaust is probably the main challenge towards the realization of magnetic confinement fusion**:
  - Programme in **support of the baseline ITER strategy** on JET/JT60-SA, MST and linear plasma-wall interaction facilities.
  - Aggressive programme on **alternative solutions** for the divertor.
  - Since the extrapolation from proof-of-principle devices to ITER/DEMO based on modelling alone is considered too large, a dedicated test on on specifically upgraded existing facilities or on a dedicated **Divertor Tokamak Test** (DTT) facility will be necessary
- **A dedicated 14MeV neutron source is needed for material development**.
  - By the end of FP7 the possibility of an **early start to an IFMIF-like device** with a reduced specification (e.g. an upgrade of the IFMIF EVEDA hardware) or a **staged IFMIF programme** should be assessed.
  - Although it is in principle possible to rely on the existing portfolio of structural and high heat flux materials for DEMO, a number of high-impact risks can be identified. The development of ‘risk-mitigation’ materials with more ‘advanced’ characteristics is essential.

Main findings

- **The R&D to ensure tritium self-sufficiency should be strengthened**.
  - The leading role will be played by **the ITER Test Blanket Module (TBM) programme**.
  - As a risk mitigation strategy it is seen as necessary to consider the evaluation and, potentially, the development, of parallel lines such as a water-cooled lithium lead design, in addition to the two TBM designs based on the use of He as coolant
- **DEMO design will benefit largely from the experience that is being gained with the ITER construction**.
  - **Modest targeted investments in integrated design and system development** (magnets, heating and current drive, vacuum pumping system and remote handling), safety and analysis of cost minimization strategies are expected in Horizon 2020.
  - **Substantial investments** for the construction of medium and large prototypes are expected during the **engineering design activity** (2020-2030).
  - **Safety** against 'Design Basis Accidents' must be assured by 'passive safety' and 'defence in depth' – **follow ITER experience**
  - Set as a target the perspective of economic electricity production from fusion, e.g. **minimizing the DEMO capital costs**.
- **The EU Stellarator programme should focus on the optimized HELIAS line**.
  - For Horizon 2020, the **main priority should be the completion and start of scientific exploitation of W7-X** with full exploitation under steady-state conditions achieved beyond 2020.
  - If W7-X confirms the good properties of optimised stellarators, a next step HELIAS burning plasma experimental device will be required to address the specific dynamics of a stellarator burning plasma. The exact goal of such a device can be decided only after a proper assessment of the W7-X results.