EFDA

Fusion Electricity

A roadmap to the realisation of fusion energy

28 European countries signed an agreement to work on an energy source for the future:

EFDA provides the framework, JET, the Joint European Torus, is the shared experiment, fusion energy is the goal.

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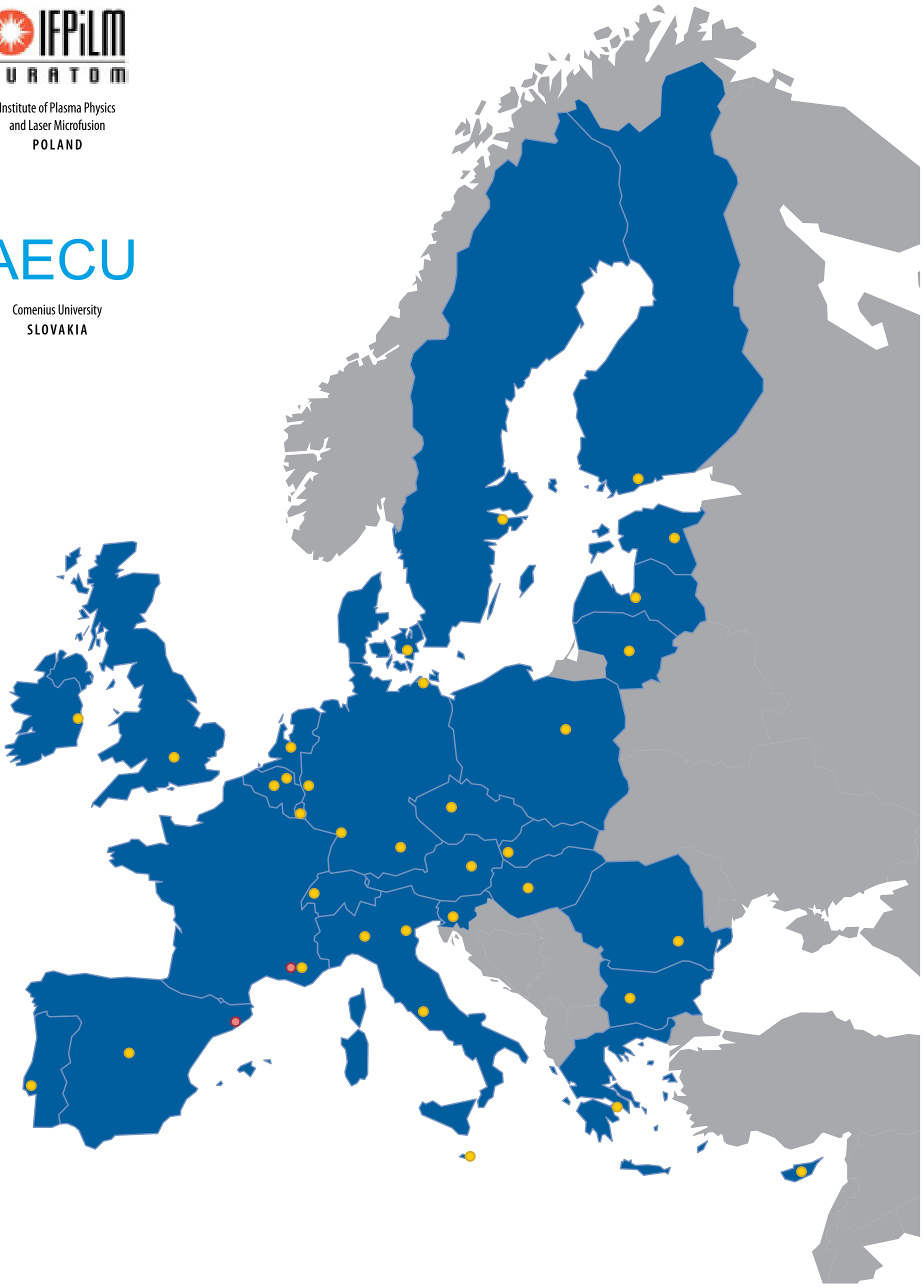


Preface

A long-term perspective on fusion is mandatory since Europe has a leading position in this field and major expectations have grown in other ITER parties on fusion as a sustainable and secure energy source. China, for example, is launching an aggressive programme aimed at fusion electricity production well before 2050. Europe can keep the pace only if it focuses its effort and pursues a pragmatic approach to fusion energy. With this objective EFDA has elaborated the present roadmap.

ITER is the key facility in the roadmap: ITER construction is fostering industrial innovation on a number of enabling technologies. Its licensing, completion of construction and successful operation will be fundamental milestones towards the fusion power plant. Thus ITER success is the most important overarching objective of the programme.

Still, the realisation of fusion energy has to face a number of technical challenges. For all of them candidate solutions have been developed and the goal of the programme is now to demonstrate that they will also work at the scale of a reactor. Eight different roadmap missions have been defined and assessed. They will be addressed by universities, research laboratories and industries through a goal-oriented programme detailed here for the Horizon 2020 period. This effort cannot be pursued only at European level – all the opportunities from international collaborations need to be exploited.

According to the present roadmap, a demonstration fusion power plant (DEMO), producing net electricity for the grid at the level of a few hundred Megawatts is foreseen to start operation in the early 2040s. Following ITER, it will be the single step to a commercial fusion power plant.

Defining, designing, building and operating DEMO requires the direct involvement of industry in the fusion programme that in the coming decades will move from being science-driven, laboratory-based towards an industry-driven and technology-driven venture. This transition requires strengthening the available engineering resources, and has to be facilitated already during Horizon 2020 by specific measures in support of training and education.

The success of the roadmap relies on the assumption that adequate resources will be made available by the European Commission and the EURATOM Member States. Coherently with the pragmatic approach advocated here, resources will be focussed on few well-defined objectives. As a consequence, the amount of resources for the roadmap will not exceed the amount originally recommended by the Council for FP7 outside the ITER construction, with the vast majority of resources being devoted to the ITER preparation. This will ensure that Europe will fully benefit from the large investment in the ITER construction.

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

Francesco Romanelli
EFDA Leader

Executive Summary

- **ITER is the key facility in the roadmap.**
  ITER will break new ground in fusion science and the European laboratories should focus their effort on its exploitation. To ensure its success, the preparation of operation on JET and JT-60SA should be undertaken as main risk mitigation measures. Small and medium sized tokamaks, both in Europe and beyond, with proper capabilities, will play a role in specific work packages. No major gaps exist in the foreseen world programme concerning the possibilities to develop operation scenarios for ITER and DEMO. However, adequate enhancements of ITER and JT-60SA will have to be carried out in the period 2021-2030.

- **A solution for the heat exhaust in the fusion power plant is needed.**
  A reliable solution to the problem of heat exhaust is probably the main challenge towards the realisation of magnetic confinement fusion. The risk exists that the baseline strategy pursued in ITER cannot be extrapolated to a fusion power plant. Hence, in parallel to the programme in support of the baseline strategy, an aggressive programme on alternative solutions for the divertor is necessary. Some concepts are already being tested at proof-of-principle level and their technical feasibility in a fusion power plant is being assessed. Since the extrapolation from proof-of-principle devices to ITER/DEMO based on modelling alone is considered too large, a dedicated test on specifically upgraded existing facilities or on a dedicated Divertor Tokamak Test (DTT) facility will be necessary.

- **A dedicated neutron source is needed for material development.**
  Irradiation studies up to ~30 dpa with a fusion neutron spectrum are needed before the DEMO design can be finalised. While a full performance IFMIF would provide the ideal fusion neutron source, the schedule for demonstration of fusion electricity by 2050 requires the accelaration of material testing. 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. A selection should be made early in Horizon 2020 of risk-mitigation materials for structural, plasma-facing and high-heat flux zones of the breeding blanket and divertor areas of DEMO, also seeking synergy with other advanced material programmes outside fusion.

- **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. However, the DEMO blanket selection will be made taking into account the constraints on coolant and breeder arising from the choice of an efficient Balance of Plant. As a risk mitigation strategy it is seen as necessary to foresee the evaluation, and potentially, the development, in addition to the two TBM designs based on the use of helium as coolant, of parallel lines such as a water-cooled lithium lead design.

- **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 minimisation strategies are expected in Horizon 2020. Substantial investments for the construction of medium and large prototypes are expected during the engineering design activity (2021-2030).

2. ITER – The key facility of the roadmap

Image: Agence ITER France

ITER is the key facility of the roadmap. ITER is expected to achieve most of the important milestones needed on the path to a fusion power plant (FPP), notably robust burning plasma regimes, the test of the conventional physics solution for power exhaust and the validation of the breeding blanket concepts. ITER construction has triggered major advances in enabling technologies for the construction of the main components and of the auxiliary systems. The ITER licensing process has confirmed the intrinsic safety features of fusion and incorporated them in the design. Thus, ITER success remains the most important overarching objective of the programme and, in the present roadmap, the vast majority of resources in Horizon 2020 are devoted to ensure that ITER is built within scope, time and budget, that its operation is properly prepared and that a new generation of scientists and engineers is trained for its exploitation.

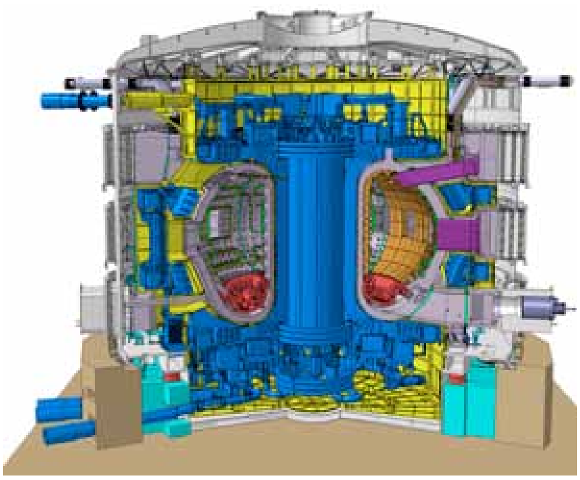
ITER will continue to play the key role over the other two periods of this roadmap. The ITER exploitation up to its maximum performance (demonstration of a fusion gain Q=10) will require focussed effort by scientists and engineers during the period 2020-2030. In the period 2030-2040 ITER will complete its objectives by qualifying advanced regimes of operations. In order to continue to make research at the cutting edge, ITER, like any other major facility, will require upgrades. The most likely upgrades have been considered in the present roadmap for the period 2020-2030.

The assumption made here is that ITER will be built according to specification and within cost and schedule. All contracts for the main components (toroidal field magnets, vessel and buildings with poloidal coils to follow shortly) have been launched and the R&D activities on heating and diagnostic systems, which are expected to mobilise significant resources in the European fusion laboratories, are being started. To ensure a proper management and integration of these activities is the responsibility of Europe's ITER Domestic Agency, Fusion for Energy (F4E). The related work is not described here, but the section on resources includes those foreseen for ITER.

Since ITER is expected to achieve the main scientific milestones on the path to the FPP, the risk mitigation strategy proposed in this roadmap has been to a large extent built on that proposed by the ITER Organization (IO) to prepare ITER operation. Most of the Work Packages proposed will at the same time secure ITER success and provide the basis for the decision on the demonstration FPP.

ITER

ITER, the world's largest and most advanced fusion experiment, will be the first magnetic confinement device to produce a net surplus of fusion energy. It is designed to generate 500 MW fusion power which is equivalent to the capacity of a medium size power plant. As the injected power will be 50MW, this corresponds to a fusion gain Q=10. ITER will also demonstrate the main technologies for a fusion power plant. .



Picture: ITER Organization

The realisation of fusion energy depends fully on ITER's success. Therefore, the vast majority of resources in Horizon 2020 are dedicated to the construction of ITER and the preparation of its exploitation. ITER is currently being built in southern France in the framework of a collaboration between China, Europe, India, Japan, Korea, Russia and the USA.