Physics Project Board #08

Digital Solutions for Fusion Office (DSO)

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Digital Solutions for Fusion Office (DSO)

The DSO will **drive and coordinate EUROfusion digital innovation activities**, including the provision and management of computational and data storage resources. It will **support the development of research and engineering software**, with a focus on integrating computational tools into a common environment. The DSO will **provide digital solutions** tailored to the specific needs of other WPs and departments.

Digital Twin Environment

Predictive capabilities, real-time control, coupled physics-engineering simulations, and analysis tools for next-generation facilities.

Advanced Computing Hubs

Support for code developers:

- High-Performance Computing;
- Modelling Frameworks and Standardized Workflows.

Data Management Plan

Unified access to experimental data using FAIR principles. Support further development and maintenance of existing multi-machine databases.

Computing & Data Storage Systems

Management & distribution of dedicated computing resources (PITAGORA HPC system, collaboration with Japan, new Gateway, Long-Term Data Storage Facility).

Key goals and recent activities

Key goals

- Build a vibrant, collaborative **ecosystem that integrates physics, engineering, and digital technologies**
- Develop and employ **digital twins of fusion systems (helping to save cost and time)**
- Emphasize **development & dissemination of EUROfusion Standard Software (opportunity to build user bases)**
- Close **coordination with various departments and WPs**, particularly the newly established **WPTM**
- Collaborations with **colleagues in the UK and the USA**

Recent activities in preparation of 2026/27

- Selection of **ACHs** (down from 5 to 4 due to a ~30% budget reduction w.r.t. 2021-25 values)
- Selection of **TSVVs** (down from 15 to 11 due to a ~30% budget reduction w.r.t. 2021-25 values)
- Selection of **DTE projects** (replacing the 7 Proof of Concept projects, since April 2025)
- Selection of **Data projects**
- Selection of **ACH projects** for 2026

- **Jan 14 & 28, 2026**: EUROfusion Science Meeting - TSVV Final Reports (2021-2025)
- **Feb 9-13, 2026**: 2nd E-TASC General Meeting (organized by DSO & WPTM)

Determining software standards

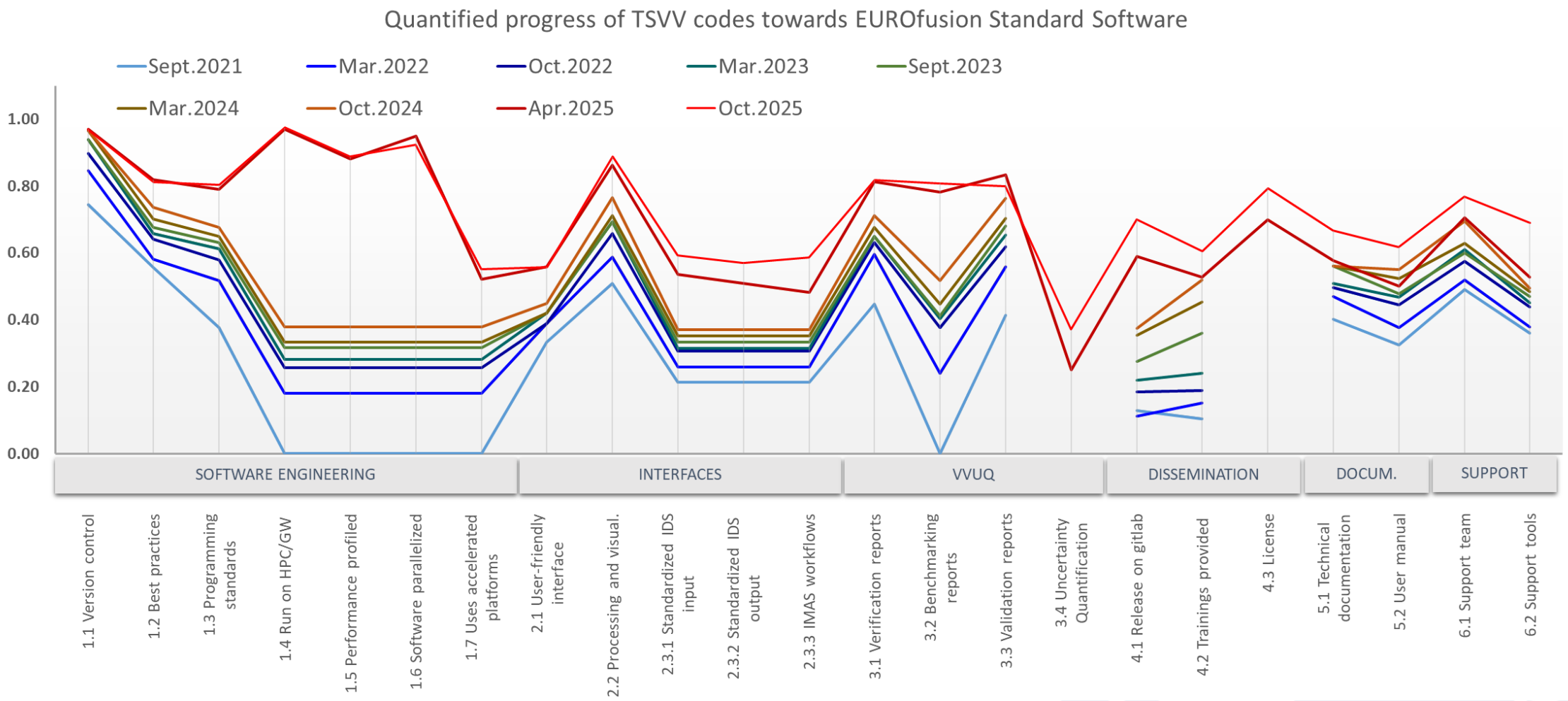
The quality assurance framework for EUROfusion Standard Software (ESS)

https://idm.euro-fusion.org/?uid=2Q72WQ&version=v2.2

(endorsed by the E-TASC SB on March 12, 2025)

- Progress toward ESS establishment has been regularly monitored, showing clear advances since 2021; remaining gaps are expected to be addressed during 2026-27.
- Increasing numbers of codes are being released as open source, aligned with IO/EU policies and enabling collaboration with start-ups under appropriate licensing.
- Strategic focus is shifting from software development to software use, with targeted training for users within mission budget constraints.

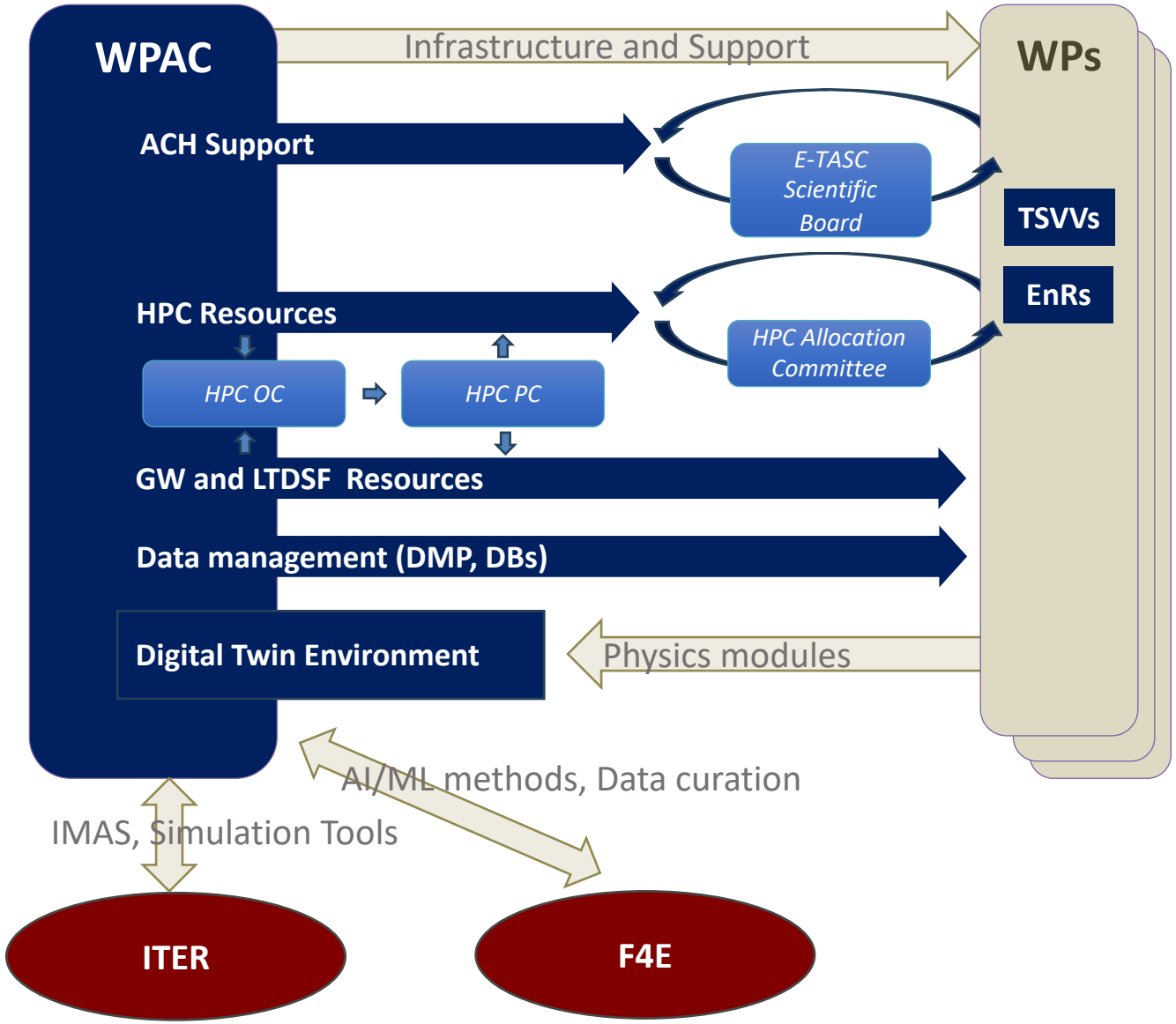
Progress towards EUROfusion Standard Software



An updated list of E-TASC codes (with coordinators) will be compiled and shared, to include new activities as DTE.

Work Package *Advanced Computing*

Processes and collaborations



Infrastructure and Support

Facilitate the development and deployment of advanced computational tools across all WPs.

Standardized Data Access (using FAIR principles)

Available for all MST devices as well as JET, ensuring transparency, reproducibility, and interoperability across systems.

Development of a Digital Twin Environment

Leverage the latest advancements from relevant TSVVs and WPs, integrating state-of-the-art computing and AI/ML to enhance predictive modeling capabilities.

Liaison to ITER and F4E

Ensure their effective engagement in the planning, implementation, and exploitation of software development activities.

WPAC structure: Advanced Computing Hubs

4 ACHs recommended for 2026/27, aiming at broad competence coverage within available resources:

- Cat1 (HPC): **CIEMAT**, **EPFL**, **MPG**
- Cat2 (MFSW): **IPPLM**

VTT (AI/ML focus): not funded as standalone activity due to budget constraints, but competences to be integrated under **ACH-MPG**

Category 1: High Performance Computing (HPC)	Category 2: Modeling Frameworks and Standardized Workflows (MFSW)
Tasks under the category include:	
• Enabling effective GPU usage of a selected set of codes on EUROfusion's HPC platforms with expanded GPU partitions • Selecting and implementing scalable algorithms • Assisting with code parallelization and performance optimization • Optimizing communication patterns and memory usage • Supporting code refactoring efforts • Providing targeted support and training for code developers • Promoting best practices in software engineering and efficient HPC resource utilization • Providing support for the development of AI/ML surrogates for physics models • Supporting large-scale model training and inference on EUROfusion infrastructure • Supporting the development and application of advanced visualization tools	• Supporting the development and maintenance of the Integrated Modelling and Analysis Suite (IMAS) framework to ensure extensibility, maintainability, and usability • Offering technical support to code developers in adapting their codes to the IMAS data model to enable integration and validation • Assisting with code integration and workflow optimization • Contributing to the development of a unified, scalable, and interoperable modelling ecosystem aligned with EUROfusion's long-term objectives • Advancing database infrastructure and evaluating/implementing software solutions for data storage, management, and analysis, as well as authenticated/authorized access control

WPAC structure: Data

Data Management Plan (DMP)

- Ensure FAIR access to EUROfusion experimental and simulation data.
- Implement Scenario C: traceable data access via Persistent Identifiers (PIDs).
- Develop software solutions for: *1) Data storage and management; 2) Analysis and access control; 3) Account provisioning and resource allocation (supported by ACHs)*
- Promote AI/ML technologies for data validation, analysis, and optimization.

EUROfusion Multi-Machine Databases

- Maintain and extend databases: *pedestal, disruption, transport, L-H transition*
- Updates and developments: *TCV pedestal database with WPTE data; Develop L-H transition database; Coordinate transport database; Standardize Infrared Imaging Systems database; Update CICLOP long pulse database*

AMNS Database

- Continued support and maintenance: *Align with latest IMAS Data Dictionary (DD) releases; Extend datasets included*

WPAC structure: Digital Twin Environment

- The notion of a Digital Twin first emerged around 2002 in the context of Product Lifecycle Management. It was later adopted as a conceptual basis in aerospace engineering and many other discipines.
- Excellent source: “Foundational Research Gaps and Future Directions for Digital Twins“ (National Academies of Sciences, Engineering, and Medicine, 2024): http://nap.nationalacademies.org/26894
- **A Digital Twin (DT) is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system, is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value.**
  - The key elements that comprise a DT include (1) a virtual representation of a physical counterpart, and (2) a bidirectional interaction between the virtual and the physical. This bidirectional interaction forms a feedback loop that comprises **dynamic data-driven model updating** (e.g., sensor fusion, inversion, data assimilation) and **optimal decision-making** (e.g., control, sensor steering).
  - A DT should be defined at a **level of fidelity and resolution that makes it fit for purpose**. Important considerations are the required level of fidelity for prediction of the quantities of interest, the available computational resources, and the acceptable cost. This may lead to the DT including high-fidelity, simplified, or surrogate models, as well as a mixture thereof.
- **A Digital Twin Environment (DTE) is an integrated, multi-domain physics application space for operating on DTs for a variety of purposes** (according to Michael Grieves & John Vickers: https://rdcu.be/d1wRu)

WPAC structure: Digital Twin Environment (2)

Pulse Design Tool (PDT) Extension Towards Digital Twin Functionality

- Simulator-agnostic DTE integration – towards a consolidated framework with an ITER relevance
  - Sven Wiesen, DIFFER
- Development of generic coupling between transport and free-boundary eq. codes with breakdown modules for PDTs
  - Stefano Marchioni, IPP.CR

Data Driven Predictive Modeling for Real-Time Feedback

- A machine-agnostic DT framework towards fast simulation and real-time plasma prediction and control
  - Alessandro Pau, EPFL
- A novel ML-based DT architecture for real-time monitoring, integration, and control of the breeding blanket
  - Antonio Cammi, ENEA

Advanced Visualization

- Verification-oriented interactive visualisation and decision support for the DTE
  - Leon Kos, JSI

WPAC structure: Digital Twin Environment (3)

Integrated Physics/Engineering Simulation Framework for Fusion Devices

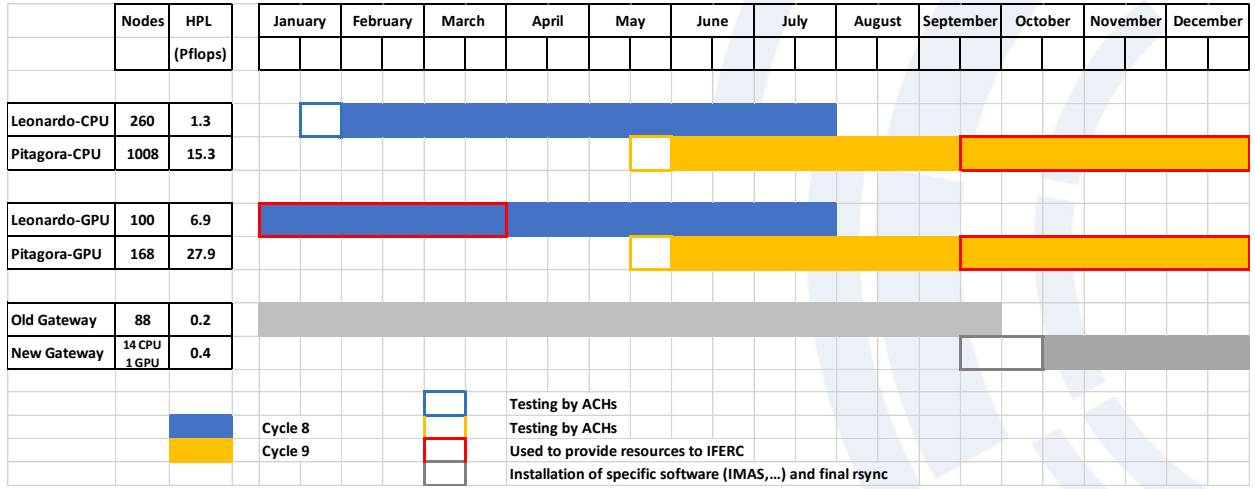
- A highly scalable and flexible DT of FPPs and photorealistic renderer based on physically accurate models
  - Cristian Sommariva, EPFL
- DT platform for integrated design of tokamak components – case studies on EU-DEMO divertor and ITER divertor
  - Domenico Marzullo, ENEA
- Integrated DT framework for breeding blanket systems: Coupling plasma, fuel cycle, and thermal-hydraulics dynamics
  - Carlos Moreno, CIEMAT
- A comprehensive numerical platform for advanced thermal protection of tokamaks
  - Marie-Helene Aumeunier, CEA
- An integrated validation and benchmarking framework for the EUROfusion DTE
  - Anna Glasser, CEA
- Development of a DT framework for fusion
  - Andrew Davis, UKAEA

WPAC structure: Computational systems

HPC PITAGORA (by CINECA)

- Computational resources for large-scale, time-consuming simulations
- CPU part.: 17 Pflops, GPU part.: 28.2 Pflops, storage: 16.2 PB (raw disk capacity) and 200 TB for home (backed-up)
- 10th cycle - **Mar.2026-Feb.2027**

	Nodes	HPL (Pflops)
Leonardo-CPU	260	1.3
Pitagora-CPU	1008	15.3
Leonardo-GPU	100	6.9
Pitagora-GPU	168	27.9
Old Gateway	88	0.2
New Gateway	14 CPU 1 GPU	0.4



EUROfusion Gateway (by CINECA)

- Central host for code development and releases, computing resources for codes not requiring HPC
- 14 CPU + 1 GPU, storage: 3.5 PB (raw disk capacity) and 100 TB for home (backed-up)

Long-Term Data Storage Facility (by PSNC)

- Long-term (~10 yrs) storage of simulation data
- Storage at PSNC (8 PB disks+8 PB tapes) + Fast (SSD) buffer at CINECA to provide fast connection to PITAGORA

Grant deliverables and milestones (2026)

Grant Deliverables

Deliverables Title	Date	Comments
Consolidated report including uptime KPIs, usage statistics, GPU/CPU utilisation, user feedback, and incident logs for HPC, EFGW, and LTDSF	12.2026	Produce consolidated report including uptime KPIs, usage statistics, queue times, GPU/CPU utilisation, user feedback, and incident logs for HPC, Gateway, and LTDSF by Dec 2026 [CHW]
Advanced Visualisation Toolkit	12.2026	Release version 1.0 of an interactive visualisation toolkit supporting IMAS data and DTE validation, including documentation and 2 demonstrator use cases. [DTE]

Grant Milestones

Milestones Title	Date	Comments
IMAS platform enabled for the use on Pitagora HPC	12.2026	Provide a containerised IMAS execution environment enabling the latest two IMAS releases on EUROfusion HPC systems, validated via at least three reference workflows (transport, equilibrium, turbulence). [CHW]
Allocation of HPC resources for Cycle 10 of production runs	03.2026	Completed project selection and resource allocation for the use of the EUROfusion HPC during Cycle 10 [CHW]
Achievement of KPIs on availability to users of EUROfusion computational resources	12.2026	Availability of HPC, Gateway and LTDSF in support of simulation programme as set by the Key Performance Indicators [CHW]

Urgent change request

CR1: Increase *mission funds* for 2026

- **Justification:**
  Mission funds available to WPAC activities in 2026/27 are *extremely* limited. Once the costs of the 2nd E-TASC General Meeting and the ACH coordination meeting are taken into account, **no funds remain to support further WPAC activities**.

- **Objective:**
  The Digital Twin Environment (DTE) projects are new within the E-TASC framework and, due to the timing of the 2026 planning cycle, were not included in the ACH support allocation. To address this, it is proposed to organize a **one-week in-person hands-on meeting (DTE + ACH)** to foster early integration and accelerate progress toward the development of Digital Twins.

Outlook to FP10

Strategic key objectives for 2026/27 and beyond

Based on discussions at the E-TASC General Meeting #2:

- Meeting the **needs and opportunities** with regard to the interpretation of data from W7-X and TE devices, including JET, and to addressing physics gaps relevant to ITER, JT-60SA, FOAK, and tokamak/stellarator-based fusion pilot plant concepts
- **Development and dissemination of EUROfusion Standard Software**
- **Facilitating Stellarator Collaborations**
- **Towards Systematic and Reproducible VVUQ**
- **Enabling Data-Driven Fusion Science**
- **From Open Source to Open Data**
- **Promoting the Reproducibility of Published Scientific Results**
- **Taking Advantage of the AI Revolution**
- **For Reference: New Approach of the U.S. Fusion Program**

Supporting VVUQ, Open Data & AI in fusion

- Enable federated, FAIR, and AI-supported fusion data ecosystems
- Accelerate IMASification of experimental and simulation data
- Promote open data publication alongside scientific results
- Strengthen transparency and reproducibility via citable repositories
- Combine AI with physics-based models toward Digital Twins

Above mentioned policies will be encouraged during FP9 and should become mandatory in FP10.

The big picture

EUROfusion's role may evolve significantly, with implications for DSO strategies:

- Support the **development of future FOAK/FPP devices**
- **Support of ITER operations** remains a central objective
- Leverage digital solutions to **mitigate risks** and **reduce costs & timelines**
- Digital solutions provide **moderate-cost, high-impact contributions** to Europe's fusion program

DSO key objectives:

- Maintain **fundamental theory and simulation** as core program components
- **Integrate plasma physics with fusion engineering and materials science** to support FOAK/FPP readiness
- Strengthen **communication and collaboration between scientific and engineering communities**
- Prioritize key methodologies – **VVUQ, AI, and Digital Twins** – as central elements of FP10 objectives
- Provide state-of-the-art **computational resources** dedicated for fusion
- Enable **ACHs** to fully leverage EUROfusion's HPC investments

Private sector & funding engagement:

- Promote **coordinated, win–win collaborations** with the private sector
- Maximize the impact of EC funding by **supporting public institutions** in ways that also benefit private stakeholders (cmp. INFUSE voucher program in the US)

Links to important materials

- **2nd E-TASC General Meeting (Feb 9-13, 2026, Garching)**

  Summary: https://idm.euro-fusion.org/?uid=2TBH6G&action=get_document

  Materials: https://indico.euro-fusion.org/event/3723/
- **1st E-TASC General Meeting (Nov 11-15, 2024, Garching)**

  Summary: https://idm.euro-fusion.org/?uid=2S53YT&action=get_document

  Materials: https://indico.euro-fusion.org/event/3034/
- **EUROfusion Standard Software**

  https://idm.euro-fusion.org/?uid=2Q72WQ&version=v2.2
- **Review of Advanced Computing Hubs (2024)**

  https://idm.euro-fusion.org/Portal/Pages/ContentView.aspx?uid=2RHUC2
- **WPAC reporting**

  https://idm.euro-fusion.org/default.aspx?uid=2PMTS8
- **DSO/WPAC Wiki**

  https://wiki.euro-fusion.org/wiki/DSO_wiki_pages