Technology Development Programme

Technology Mapping

2025 Series

Magnets

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Version history

VERSION	DATE	CHANGES
0.0	10/09/2025	First issue: input data for online workshop. Covers: 1. Introduction 2. The mapping process 3. Fuel cycle technology breakdown (draft) Other sections will be completed after the workshop.
1.1		After the online workshop, incorporating the changes agreed to the technology map
2.0		After the in-person workshop - Draft final report for comments by participants
2.1		Final report for publication

Foreword

Will be completed after the workshop taking place in November 2025

Executive summary

Will be completed after the workshop taking place in November 2025.

1 Introduction

1.1 Context

In 2024, Fusion for Energy launched a Technology Development Programme (TDP) as part of the implementation actions of its Industrial Policy. This TDP is dedicated to building and reinforcing European Fusion Supply chain capabilities for those technologies that are deemed to be critical for the future of commercial fusion. The programme requires the identification of key technologies to direct R&D contracts to European contractors.

Since 2014, EUROfusion has been paving the way for fusion power reactors by funding research based on the "European Roadmap to the Realisation of Fusion Energy" as a joint programme within Euratom Horizon Europe. EUROfusion currently manages a research programme evolved from short-, mid- and long-term roadmaps.

Prioritizing and allocating funding opportunities across both organizations requires a comprehensive review of the technologies involved in each major fusion technical domain. Doing this exercise in a collaborative way will enable stakeholders to identify which technologies are fundamentally needed (technology mapping) and when are they needed (technology road mapping). A roadmap built through consensus of key stakeholders in the field can also serve as a powerful argument when seeking additional funding from national and international public and private investors.

CERN is a major actor in the field of superconductive magnets, boasting a long tradition of developing and mass producing large high field superconducting magnets for high energy physics accelerators and detectors.

There are strong synergies in research and development activities linked to superconducting magnets for fusion and high energy physics applications, it was therefore natural for CERN, EUROfusion and F4E to coordinate their efforts, and launch a technology mapping initiative uniting academia, research laboratories, industry, start-ups and the ITER Organization to develop a comprehensive technology development roadmap for superconducting magnets technologies.

The outcome of this exercise will serve all stakeholders to guide their action in their respective domains, allowing an effective investment of resources. Given the fast evolution of technology, a periodical follow-up of the workshop outcome shall be assured in subsequent technology mapping exercises.

1.2 Magnets technology mapping

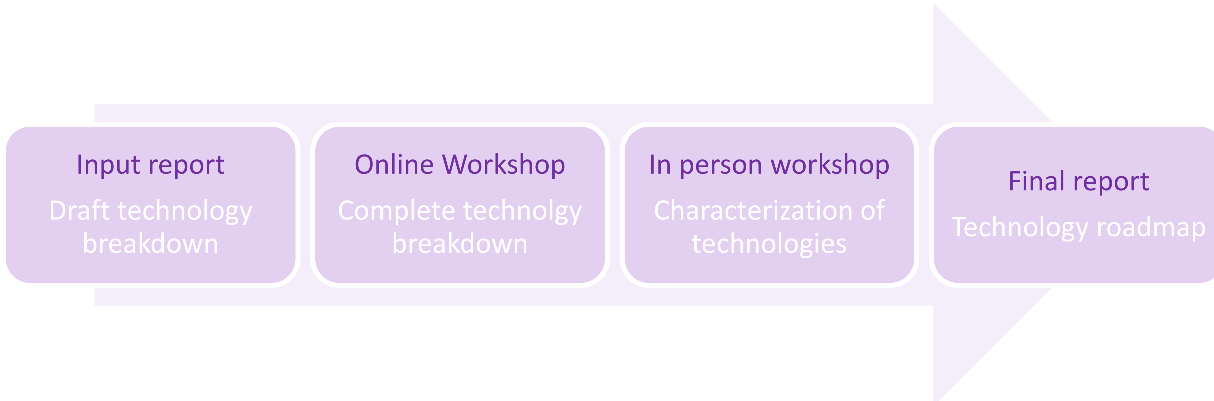
The scope of the of the Magnets Technology Mapping Workshop covers relevant technologies for superconducting magnets including materials, conductors, coil design and manufacturing, quench management as well as instrumentation and auxiliary systems required for coil integration and operation. The workshop will hold a specific focus on High temperature Superconductivity given the maturity of the Low Temperature Superconductivity technologies and the relevance of HTS for high energy physics and fusion applications.

The main associated event is a workshop held in September and November 2025 to generate most of the relevant data and provide an opportunity for participants to network and exchange knowledge.

This document provides a complete overview of the exercise, detailing the process and scope through a comprehensive technology breakdown, summarizing the meetings held and providing the resulting proposed technology development roadmap.

2 Technology mapping process

The technology mapping process consists of 4 stages.



2.1 Input report

In preparation of the exercise, staff from CERN, Fusion for Energy and EUROfusion prepared a draft technology breakdown, listing technologies of interest and grouping them functionally.
This breakdown, together with a brief description of each selected technology, is included in a draft input report (see section 3) for consultation by participants ahead of the first meeting (an online workshop on September 17th 2025).

2.2 Online workshop

The online workshop is the opportunity for all participants to the technology mapping exercise to come together with the following agenda:

- Welcome and introductory remarks
- The technology mapping process
- Overview of the European landscape
- Networking opportunity between participants
- Brief overview of technology breakdown
- Joint review of the technology breakdown
- Explanation of the next step (in person workshop)
- Survey feedback and wrap-up

The main output of the online workshop is an exhaustive list of relevant technologies agreed between participants in the workshop. This breakdown forms the basis of the technology mapping to take place during the in-person workshop. An updated version of the input report with an updated technology breakdown is made available to participants before the in-person workshop.

2.3 In-person workshop

The in-person workshop aims at providing a detailed characterization of the technologies part of the breakdown agreed during the online workshop including their prioritization(timeline).
The characterization of technologies takes place in three steps applicable to each technology:

- Agreement on current Technology Readiness Level (see Appendix 1 for definitions)
- Definition of the next step (eg analysis, prototype, testing, industrialization plan etc) and time permitting of the one after that.
- Quantification of the characteristics of the technology (see appendix 2 for a typical list of characteristics to be evaluated).
- A timeline with a classification of what is needed when, for the technologies considered in the technology mapping. Typical timelines can cover short, medium and long term activities.

The workshop is highly collaborative, with sessions designed for participants to exchange, build consensus and provide feedback on specific interests and the mapping process itself.
The workshop also provides ample opportunities for participants to share knowledge and form partnerships over a typical duration of one and a half day which includes specific times for formal and informal networking.

2.4 Final report

After the in-person workshop, staff from CERN, Fusion for Energy and Eurofusion compile the outcome in a final report (an evolution of the input report). The report shall include an overview of European capabilities in the field as well as the proposed technology roadmap detailing and prioritizing possible actions for the period until the next review (typically 2 to 3 years).
Participants are given an opportunity to comment before the final version of the report is published.

3 Magnet technology Breakdown

3.1 Technology overview

Superconducting magnets are fundamental to both magnetic confinement fusion and high-energy physics as they generate strong and stable magnetic fields with minimal energy loss.
In magnetic confinement fusion devices like tokamaks and stellarators, superconducting magnets provide confinement and plasma shaping functions. Magnets for fusion applications are charaterised by their large bore (multiple meters), high field (10 to 20 Tesla), transient operation (in the case of tokamaks) and high neutron radiation load.
In particle accelerators, superconducting magnets are used to accelerate, bend and focus charged particle beams. The Large Hadron Collider, for example, uses over 1,200 superconducting dipole magnets generating 8.3 Tesla fields to guide proton beams around its 27-kilometer circumference. For particle detectors, superconducting solenoid magnets curve charged particle trajectories, allowing precise momentum measurements. The magnetic field strength directly correlates with measurement precision—stronger fields produce greater curvature, enabling better discrimination between particles with similar properties.
Without superconducting magnets, neither controlled fusion energy nor modern high-energy physics experiments would be feasible at their current scale and precision.

3.2 Superconducting magnets technology map

This section and section 3.3 will be reviewed and completed during the online workshop on 17/09/2025.

Relevant technologies to superconducting magnets have been listed and broken down into 4 areas:

Materials and conductors

Materials
- LTS
- REBCO
- BSCCO
- Iron-base superconductors
- MgB2

Conductors
- Rutherford cable
- Roebel cable
- Stacked tapes
- Twisted stacked tape cables
- CORC cable
- Internally cooled conductors

Quench management

- Quench propagation models
- Quench detection techniques
- Integrated quench detection systems
- Quench propagation acceleration systems
- Energy extraction systems

Instrumentation and auxiliaries

Instrumentation
- Fiber optic sensing
- Voltage taps extraction
- Magnetic field mapping
- Hydraulic monitoring

Auxiliaries
- Cooling systems
- Power supplies
- Persistent current switches
- Shimming coils
- Feedthroughs

Coil design and manufacture

Modelling
- Digital twins
- AC losses
- Tape mechanical failure modes
- Multiphysics
- FEA
- Thermo-hydraulic

Joining
- LTS joints
- HTS joints
- Demountable coils
- Terminations and current leads

Insulation
- Radiation tolerant insulation systems
- Non insulated HTS coils – resistance control

Manufacturing
- High precision coil winding
- VPI
- Modular coil winding
- HTS production by additive manufacturing
- 3D printed formers

3.3 Description of individual technologies

3.3.1 Materials and conductors

Materials

LTS

LTS (Low Temperature Superconductors) refers to materials such as Nb-Ti and Nb3Sn that exhibit superconductivity at low temperatures, typically below 20 K. These materials have been the backbone of superconducting magnet technology, operating primarily with liquid helium cooling. LTS wires and tapes are widely used in accelerator magnets, MRI, and fusion devices due to excellent mechanical properties, manufacturing maturity, and cost-effectiveness.

REBCO
REBCO (Rare Earth Barium Copper Oxide) materials are high-temperature superconductors with chemical composition ReBa2Cu3O7-x, where Re is a rare earth element as yttrium or gadolinium. These are typically fabricated as coated conductors, using thin superconducting layers on flexible metal substrates. REBCO's superior performance in high magnetic fields, combined with its mechanical strength and thermal stability, makes it particularly suitable for high-field magnet applications.

BSCCO
BSCCO (Bismuth Strontium Calcium Copper Oxide) is a family of high-temperature superconductors, notably Bi-2212 and Bi-2223, with critical temperatures above 77 K. BSCCO conductors are produced as tapes or wires, often incorporating silver matrices for mechanical stability and current transfer. Bi-2212 conductors are manufactured as round wires using powder-in-tube techniques, making them compatible with existing LTS winding technologies and particularly suitable for high-field insert magnets. Bi-2223 tapes provide good current-carrying capability in moderate magnetic fields but exhibit significant performance degradation in high transverse fields. Both Bi-2212 and Bi-2223 are “niche” productions.

Iron-based superconductors
Iron-based superconductors (IBS) are a class of materials featuring iron-arsenide or iron-selenide compounds exhibiting superconductivity at intermediate temperatures (20–60 K). They feature high upper critical fields and low anisotropy. Their granular structure and sensitivity to strain pose challenges for conductor fabrication, but their potential for high-field performance and lower material costs offer potential for future magnet applications.

MgB2
MgB_2 is a metallic superconductor with a critical temperature of 39 K, bridging the gap between conventional LTS and high-temperature cuprate superconductors. The material shows particular promise for applications requiring modest magnetic fields (a few T) with reduced cooling complexity compared to LTS systems.

Conductors

Rutherford cable
Rutherford cable is a flat, multi-strand cable design where round superconducting wires are transposed and compacted. This form minimizes AC losses and optimizes current sharing among filaments. It is widely used for accelerator and fusion magnets based on LTS materials, enabling efficient winding, good geometry control, high engineering current density and robust performance under high stress.

Roebel cable
Roebel cables, derived from electrical machines, are fabricated assembling single wires or tapes with a meander structure. This has been applied lately to HTS tapes, punching REBCO tapes to form the meander shape. The Roebel design is transposed with respect to external field change, thus reducing AC losses and improving the distribution of current and magnetic fields within the cable, making it advantageous for applications requiring low-loss, high-current, high engineering current density HTS conductors.

Stacked tapes
When using HTS REBCO tapes, one option to obtain a high current conductor is to assemble the tapes directly as stacks of two or more tapes. These tape stacks can reach high current, and high engineering current density, though winding may be an issue because the conductor is not transposed.

Twisted stacked-tape cables

Twisted stacked-tape cables are assemblies of high-temperature superconducting tapes, such as REBCO, stacked and twisted together in helical configurations. This allows high current and flexibility for winding into coils, while maintaining mechanical integrity and minimizing coupling losses in high-field magnet designs. The twisting of stacks reduces the effective engineering current density of the conductor

CORC cable

CORC (Conductor on Round Core) HTS cables are made by winding REBCO tapes helically around a round former. This geometry results in high current capacity, isotropic properties, mechanical flexibility, and compatibility with standard coil winding techniques, characteristics of interest for compact, high-field superconducting magnets. The engineering current density tends to be reduced due to the round filling factor.

Internally cooled conductors

Internally cooled conductors (ICC) are cables where the coolant (customarily helium) flows in the cable space or in pipes in intimate thermal contact with the cable. Several variants are possible for ICC's, one of which is a Cable-in-conduit conductor (CICC). A CICC consists of superconducting strands roped inside a metallic conduit, with forced-flow coolant circulating around the filaments. This design provides integrated mechanical support, cooling, and electrical insulation in a single component, making it ideal for large-scale applications like fusion magnets. Alternative ICC configurations are cables around a cooling tube, either LTS or HTS.

3.3.2 Coil design and manufacture

Modelling

Digital twins

Digital twins integrate real-time sensor data with multiphysics models to simulate magnet performance, predict degradation, and optimize operation. They enable proactive maintenance and design validation by mirroring physical assets in a virtual environment.

AC losses

AC loss modelling quantifies the energy dissipated as heat in superconducting conductors due to alternating current and changing magnetic fields. Accurate modeling of hysteresis, coupling, and eddy current losses is essential for cryogenic load estimation, stability analysis, and efficient magnet operation.

Tape mechanical failure modes

Models predict delamination, cracking, or buckling in HTS tapes under Lorentz forces, thermal cycling, and bending. Finite element analysis (FEA) identifies stress concentrations and guides reinforcement strategies to ensure mechanical integrity.

Multiphysics

Multiphysics modelling involves simultaneous simulation of electromagnetic, thermal, mechanical, and fluid dynamic phenomena in superconducting magnets. This approach provides comprehensive understanding of coupled effects, guiding optimized design, quench protection, and operational strategies for complex magnet systems.

FEA

FEA simulates electromagnetic, thermal, and structural behaviour in magnets, resolving field distributions, stress, and temperature gradients. It is essential for validating designs, optimizing coil geometries, and predicting failure modes.

Thermo-hydraulic modelling

Thermo-hydraulic modelling simulates the combined behaviour of heat transfer and fluid flow in cryogenic systems associated with superconducting magnets. Computational techniques range from one-dimensional network models to three-dimensional CFD analysis depending on system complexity and required resolution. Thermo-hydraulic analysis enables cooling system optimization, operational limit determination, and design verification while ensuring adequate cooling margin and thermal stability throughout magnet operation.

Joining

LTS joints

LTS joints are electrical connections between low temperature superconductor segments, typically Nb-Ti or Nb3Sn wires. These joints must minimize resistance and maintain superconductivity under high current and magnetic field conditions. Techniques include mechanical lap joints, soldered connections, or diffusion bonding.

HTS joints

High-temperature superconductor joints face unique challenges due to the tape geometry and material properties of REBCO and BSCCO conductors, requiring specialized techniques for achieving low-resistance connections. Methods include resistive soldering, diffusion welding, and mechanical compression joints using intermediate superconducting materials or optimized metal interfaces. Joint design considerations include minimizing current redistribution, preventing delamination, and ensuring long-term stability under electromagnetic and thermal stresses typical of HTS magnet operation.

Demountable coils

Demountable coils are magnet coils designed for mechanical separation, enabling replacement, maintenance, or upgrade without full system disassembly. Demountable designs are particularly important for large-scale applications like fusion magnets where remote maintenance and component replacement are essential. The joint technology must maintain electrical, mechanical, and thermal performance equivalent to permanent connections while providing reliable operation through multiple assembly cycles and exposure to operating stresses.

Termination and current leads

Terminations and current leads form interfaces between superconducting magnets and room-temperature power supplies. They must conduct large currents while minimizing heat influx to the cryogenic environment. Hybrid designs, often combining copper and HTS segments, are used to optimize thermal and electrical performance. Termination design includes stress relief, electrical insulation, and thermal anchoring to intermediate temperature stages. Current leads must handle fault conditions including quenches and overcurrent situations while maintaining structural integrity and preventing damage to the superconducting system.

Insulation

Radiation tolerant insulation systems

Radiation-tolerant insulation materials and systems are designed to maintain electrical and mechanical properties under intense neutron and gamma radiation environments typical of fusion reactors and high-energy physics applications. These systems utilize inorganic materials such as ceramic-fiber tapes, mica-based compounds, and mineral-filled epoxies that resist radiation-induced degradation of dielectric strength and mechanical properties. Design considerations include radiation dose limits, outgassing characteristics, and long-term stability under combined radiation, thermal, and mechanical stresses.

Non Insulated HTS coils - transverse resistance control

Non-insulated HTS coils are wound without inter-turn insulation, allowing current sharing across turns and self-protecting against hot spots. Transverse resistance control introduces engineered resistive paths to manage current diffusion, protect the coil from quench, and optimize field penetration dynamics in HTS magnet applications.

Manufacturing

High precision coil winding

Precision winding ensures accurate placement of superconducting cables or tapes, minimizing field errors and mechanical stress. CNC-controlled winding machines, real-time tension monitoring, and laser metrology achieve tight tolerances for field quality and structural integrity.

VPI

VPI (Vacuum Pressure Impregnation) is a coil insulation process where windings are impregnated with resin under vacuum and pressure. The resin fills voids, bonds conductors, and enhances mechanical strength, electrical insulation, and quench stability in superconducting magnet coils.

Modular coil winding and other cost containment solutions

Modular coil winding divides large or complex superconducting magnets into multiple independently wound and assembled modules. This technique simplifies manufacturing, transport, and maintenance, and supports scalable, flexible magnet architectures for fusion devices and accelerators.

HTS tape production by additive manufacturing techniques

HTS tape production by additive manufacturing uses layer-by-layer deposition and patterning to fabricate complex, high-performance superconducting tapes or conductors. This approach enables fine control of microstructure, material composition, and conductor architecture for next-generation magnet applications.

3D printed formers

3D printed formers are coil supports or mandrels fabricated using additive manufacturing, allowing rapid prototyping and complex geometries matched to coil requirements. These formers facilitate precise coil placement, reduce waste, and can be customized for specialized magnet designs.

3.3.3 Quench management

Quench propagation models

Quench propagation models simulate the spread of normal (resistive) zones in superconducting magnets during resistive transitions. Advanced models include multi-dimensional effects, current redistribution, and coupling between electromagnetic and thermal phenomena. Quench propagation models predict temperature, current, and voltage evolution, supporting the design of protection systems and helping to prevent damage. Modelling should include conventional insulated coils with active detection/protection systems, as well as non-insulated (NI) coils involving both passive and active protection approaches.

Quench detection techniques

Quench detection techniques applicable for HTS magnets operating at 4.5 K and above. Enumerate and map techniques for the detection of quench initiation ranging from standard electrical means (i.e., voltage taps) to novel approaches based on non-electrical detection of quench (e.g., fibre optics, thermocouple, etc.). In HTS coils operating at temperatures well above 4.5 K, when coil pack heat capacity is much higher, extremely sensitive detection techniques will be needed in order to achieve the quench detection times needed to safely protect the magnet.

Integrated quench detection systems

Integrated quench detection systems employ multiple sensor technologies including voltage measurements, temperature monitoring, acoustic emission detection, and magnetic field sensing to identify the onset and location of quench events in real-time (a machine-learning approach to fuse the input from sensors as described in the previous section). Rapid detection is essential for activating protection circuits and initiating energy extraction to limit thermal and mechanical stress. Predictive analytical or FEA models can be used to shorten the reaction time of active protection systems.

Quench propagation systems

To minimize concentrated heating in the quench initiation zone, quench propagation systems are engineered features, such as resistive elements or heaters, that promote rapid and uniform distribution of a quench throughout the coil to dissipate the stored energy rapidly and efficiently within the cold mass. Such quench acceleration could be achieved by resistive or inductive means (and sometimes both).

Energy extraction systems

Energy extraction systems safely transfer stored magnetic energy from a superconducting magnet during a quench. These systems typically use fast switches and dump resistors to divert current away from the magnet, limiting voltage buildup and protecting magnet integrity.

3.3.4 Instrumentation and auxiliaries

Instrumentation

Fiber optic sensing

Fiber optic sensing employs optical fibers embedded within or around superconducting coils to measure strain, temperature, or magnetic field with a high spatial resolution. These sensors are radiation resistant and offer immunity to electromagnetic interference. They can integrate flexibly into complex magnet assemblies.

Voltage taps extraction

Voltage taps extraction involves attaching electrical contacts at defined points along the conductor to monitor voltage differences. This technique is critical for quench detection, diagnostic measurements, and ensuring the electrical integrity of superconducting coils.

Magnetic field mapping

Magnetic field mapping uses arrays of sensors, such as Hall probes or fluxgate magnetometers, to characterize the spatial distribution of magnetic fields around a superconducting magnet. Accurate mapping ensures field uniformity, alignment, and compliance with design specifications.

Hydraulic monitoring

Hydraulic monitoring tracks the flow, pressure, and temperature of cryogenic fluids in superconducting magnet cooling circuits. Monitoring ensures adequate cooling, early detection of leaks or blockages, and supports the safe, reliable operation of large-scale magnet systems.

Auxiliaries

Cooling Systems

Cooling systems for superconducting magnets include cryostats, helium liquefiers, closed-loop coolers, and thermal links. They maintain required operating temperatures, remove heat from joints and current leads, and ensure stable superconducting operation across a range of magnet technologies.

Power supplies

Power supplies for superconducting magnets deliver stable, precisely controlled direct currents, often in the kiloampere range. These supplies are engineered for low ripple, high stability, and include features for ramping, protection, and remote operation in large-scale magnet installations.

Persistent current switches

Persistent current switches are superconducting or hybrid devices that enable the transition of a magnet between powered and persistent current operation. Once closed, they allow the magnet to carry current indefinitely with negligible loss, maintaining stable fields for extended periods.

Shimming coils

Shimming coils correct field errors using active or passive conductors. Superconducting or room-temperature coils, often with optimized geometries, compensate for harmonics and enhance field uniformity.

Feedthroughs

Feedthroughs provide critical interfaces that allow electrical, optical, or fluid connections to pass through cryogenic boundaries while maintaining vacuum integrity, thermal isolation, and electrical performance in superconducting magnet systems. These components must minimize heat conduction from room temperature to cryogenic regions while carrying electrical current, signals, or coolant flow without compromising system performance. They must operate reliably under thermal cycling and electromagnetic forces typical of magnet operation.

4 Summary of meetings

Will be completed after the workshop taking place in November 2025.

5 Outcome: technology road-mapping

Will be completed after the workshop taking place in November 2025.

6 Conclusion

Will be completed after the workshop taking place in November 2025.

Appendix 1: Technology Readiness Levels

For this workshop, a TRL scale from 1 to 9 will be used, in line with the IAEA definitions[1].
It considers the different criteria for different streams as illustrated in the table below extracted from the document in reference. By default, the "System" stream will be used. For more details, please refer to the TECDOC 2047 itself[1].

TRL	Systems	Materials	Software	Manufacturing	Instrumentation
1	Basic principles	Evidence from literature	Mathematical formulation	Process concept proposed	Understand the physics
2	Technology concept	Agreed property targets, cost & timescales	Algorithm implementation documented	Validity of concept described	Concept designed
3	Proof of concept	Materials' capability based on lab scale samples.	Prototype architectural design of important functions is documented	Experimental proof of concept completed	Lab test to prove the concept works.
4	Validation in a laboratory environment	Design curves produced.	ALPHA version with most functionalities implemented with User Manual and Design File available	Process validated in lab	Lab demonstration of highest risk components
5	Partial system validation in a relevant environment	Methods for material processing and component manufacture	BETA version with complete software functionalities, documentation, test reports and application examples available	Basic capability demonstrated using production equipment	Requiring specialist support
6	Prototype demo in a relevant environment	Validated via component and/or sub-element testing.	Product release ready for operational use	Process optimised for capability and rate using production equipment	Applied to realistic location/environment with low level of specialist support.
7	Prototype demo in an operational environment	Evaluated in development rig tests	Early adopter version qualified for a particular purpose	Economic run lengths on production parts	Successful demonstration in test.
8	Test and demonstration	Full operational test	General product ready to be applied in a real application	Significant run lengths	Demonstrated productionised system
9	Successful mission operation	Production ready material	Live product with full documentation and track record available	Demonstrated over an extended period	Service proven

[1] IAEA TECDOC 2047 Considerations of TRL for Fusion Technology Components available from: https://www-pub.iaea.org/MTCD/Publications/PDF/TE-2047web.pdf

Appendix 2: Technology assessment

1. Added-Value Towards Nuclear Fusion		
Criterion	*Scale*	*Explanation*
Need for and potential benefit	Major / Medium / Minor	*Does this technology address a critical and unresolved challenge in nuclear fusion?*
Availability of alternative solutions	Yes/No (EU) Yes/No (Outside EU)	*Are there competing solutions in Europe or globally?*
Differentiation / Competitive Advantage	Yes / No	*Does this technology offer a unique advantage over existing solutions?*
2. Maturity & Feasibility		
Criterion	*Scale*	*Explanation*
Technology Readiness Level (TRL)	1 to 9	*Standard TRL scale (see Appendix).*
Expected time to TRL 9 (full maturity)	<5 years / 5–15 years / >15 years	*How long until the technology is commercially viable?*
Availability of test facilities	Yes / No	*Are there existing facilities in Europe to validate the technology?*
3. Interest from the Innovation Ecosystem		
Criterion	*Scale*	*Explanation*
Interest from start-ups	None / 1–3 interested parties / >3 interested parties	*Level of engagement from early-stage companies.*
Interest from industry	None / 1–3 interested parties / >3 interested parties	*Level of interest from established industry players.*
Interest from research institutions	None / 1–3 interested parties / >3 interested parties	*Interest from universities, national labs, and research centers.*
4. Other Investment Decision-Making Factors		
Criterion	*Scale*	*Explanation*
Market potential	Nuclear fusion-specific / Wider market potential	*Is the technology limited to fusion, or does it have broader applications?*
Competences & skills development	Yes / No	*Will this technology enhance European expertise in fusion?*
Regulatory impact	Yes / No	*Does the technology pose significant regulatory challenges?*
5. Risk, Cost, and Implementation Timeline of Next Step on Roadmap		
Criterion	*Scale*	*Explanation*
Outcome predictability & risks	Low risk / Medium risk / High risk	*How uncertain are the results of the next development?*
Estimated development cost	0–500k EUR / 501k–2M EUR / >2M EUR	*Rough cost estimate for next development step.*
Time to first output (once funded)	<1 year / 1–2 years / >2 years	*Timeframe for delivering tangible results.*

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