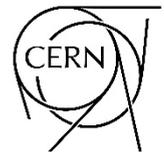


Technology Development Programme

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: <ol style="list-style-type: none">1. Introduction2. The mapping process3. Fuel cycle technology breakdown (draft) Other sections will be completed after the workshop.
1.0	17/11/2025	After the online workshop, incorporating the changes agreed to the technology map
2.0	27/02/2026	After the in-person workshop - Draft final report for comments by participants
2.1		Final report for publication

Foreword

Will be completed for the final version

Executive summary

Will be completed for the final version

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 they are 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 help 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, was distributed to participants and discussed during the [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 (this report v 1.0) 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:

- Quantification of the characteristics of the technology (see appendix 2 for a typical list of characteristics to be evaluated).
- Definition of several technology development actions to increase its maturity (eg analysis, prototype, testing, industrialization plan etc).
- Prioritization of the technology development actions leading to development roadmaps 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 will 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.

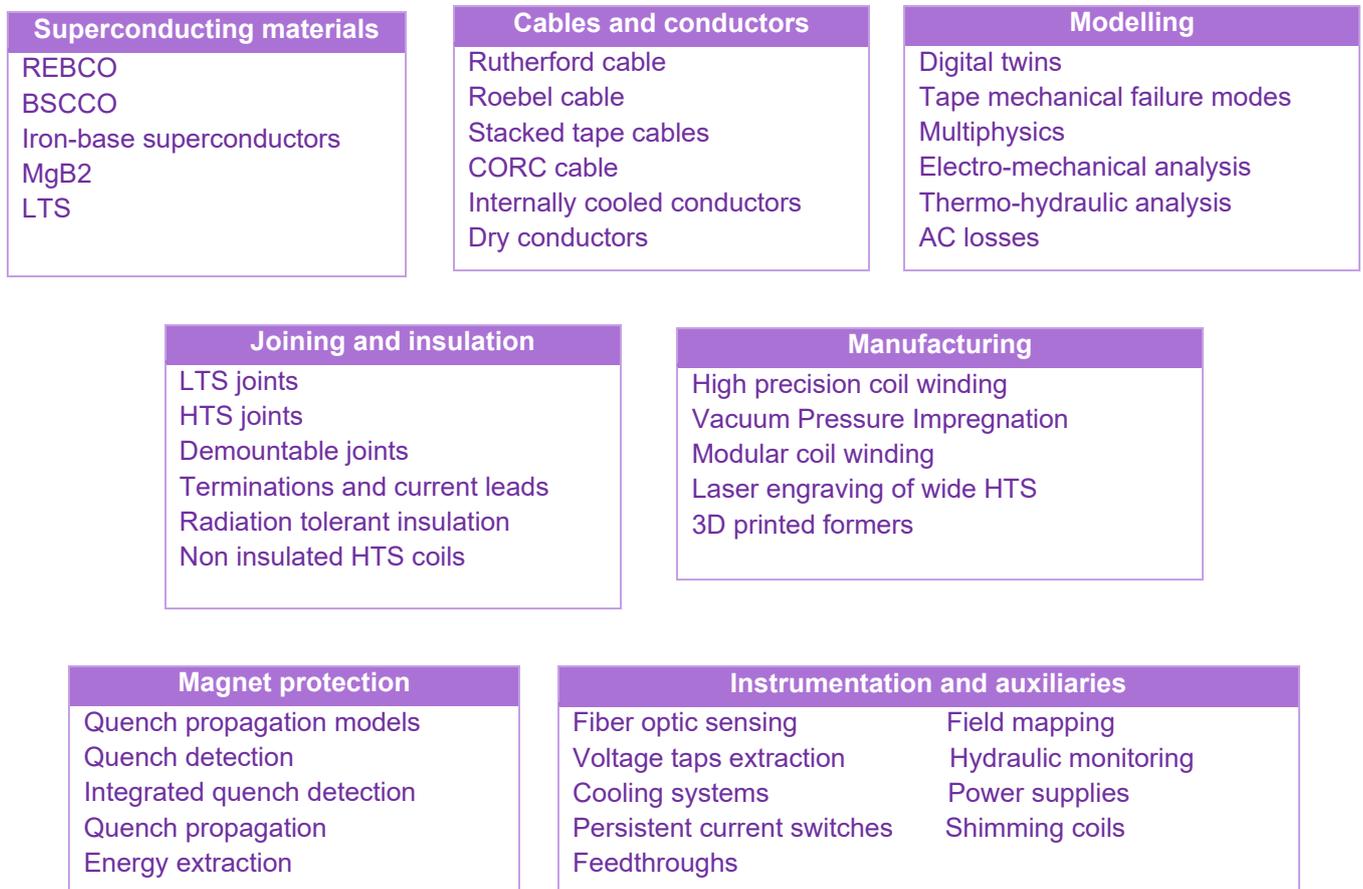
In magnetic confinement fusion devices like tokamaks and stellarators, superconducting magnets provide confinement and plasma shaping functions. Magnets for fusion applications are characterised by their large bore (multiple meters), high field (10 to 20 Tesla), transient operation (in the case of tokamaks) 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

Relevant technologies to superconducting magnets have been listed and broken down into 7 areas:



3.3 Description of individual technologies

3.3.1 Superconducting materials

REBCO

REBCO (Rare Earth Barium Copper Oxide) materials are high-temperature superconductors with chemical composition $ReBa_2Cu_3O_{7-x}$, 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

MgB₂ 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.

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.

3.3.2 Cabling and 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. A solution to this is to twist stacks 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.

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.

Dry conductors

Dry conductors are superconducting cables that operate without liquid cryogenes, using conduction cooling or cryocoolers to maintain low temperatures. The coolant is replaced by a solid thermal link—typically copper or aluminium—that connects the superconducting strands to a cryocooler or cooling structure. One common design is the Conduction-Cooled Conductor (CCC), where strands or tapes are embedded in or wrapped around a high-thermal-conductivity material, ensuring efficient heat transfer. This approach is more suited for compact magnets, medical devices, and high-field research where liquid cryogenes are impractical.

3.3.3 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.

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.

Electro-mechanical analysis

Electro-mechanical analysis simulates electromagnetic, thermal, and mechanical 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, and design verification, ensuring adequate cooling margin and thermal stability throughout magnet operation.

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.

3.3.4 Joining and insulation

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.

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.

3.3.5 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.

Vacuum Pressure Impregnation

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

Modular coil winding

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.

Laser engraving of wide HTS

Laser engraving of large HTS material relies on the production of wide sheets of HTS material where the different layers can be engraved with a laser to distribute the current in complex paths to fabricate complex, high-performance superconductors onto a support surface. This approach provides infinite possibilities for the shape of the HTS material and could provide major simplifications in the production of complex magnets.

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.

3.3.6 Magnet protection

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 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.

3.3.7 Instrumentation and auxiliaries

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.

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

In total, 185 people registered for participation in the 2025 Magnets Technology Mapping workshop. The online workshop registered a peak of 115 participants whilst 82 people attended the in-person workshop. 64 public and private entities were represented. CERN, Fusion for Energy and EUROfusion wish to thank all participants for their input during and after the workshop.



Logos of participating entities (excluding CERN, EUROfusion and Fusion for Energy)



Geographical repartition of the participants to the in-person workshop

Details of the meetings can be found on the [event web page](https://app.swapcard.com/event/magnets-mapping-workshop)¹. The agenda and outputs including presentations, documents and recordings are also available there.

¹ <https://app.swapcard.com/event/magnets-mapping-workshop>

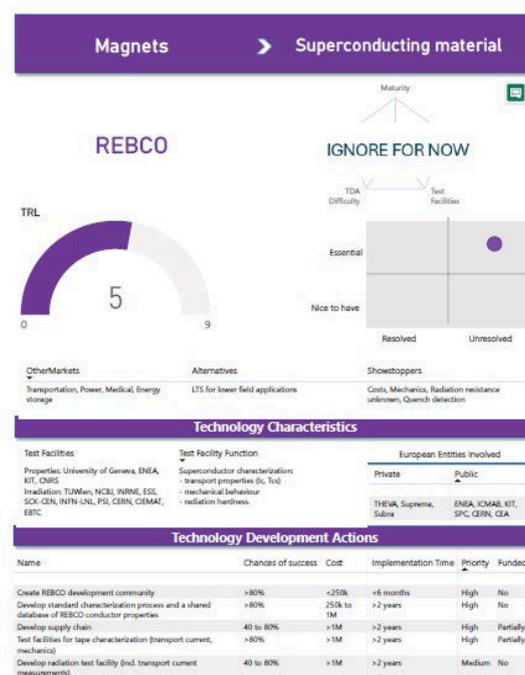
5 Outcome: technology road-mapping

5.1 Technology dashboards

During the in-person workshop and in the process of preparing this report, a lot of valuable data was collected into a database. For each technology, the following data is now available:

- TRL
- Criticality
- Other fields of application
- Alternative technologies
- Potential showstoppers
- Existing and needed test facilities
- European entities involved
- Technology development actions

This data has been arranged into a dashboard for each of the technologies:



Typical technology dashboard

Note that the spider diagram (scores out of 9) has been arranged in such a way that the more the colored area, the more development is needed.

All technology dashboards are available in Appendix 3: Technology dashboards.

The dashboards are a view of the database at the time of publishing this document. The database will be updated regularly, and Appendix 3 may be re-published as necessary. We encourage the community to communicate updates to their Fusion for Energy, EUROfusion or CERN contact. In the future, we may publish this data for interactive consultation on the CERN, EUROfusion or Fusion for Energy websites.

5.2 Overview of the EU landscape for superconducting magnets

5.2.1 SWOT analysis

<p>Strengths:</p> <ul style="list-style-type: none"> • Strong basis to build upon: infrastructure and know-how in R&D, modelling and manufacturing • Emerging start-up ecosystem (tape + HTS magnet technologies) • Solid LTS and MgB2 supply chain 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Fragile and underdeveloped HTS supply chain for both materials and cables • Bottleneck in cable test facilities • Lack of diverse HTS conductor experience (focus on stacked tapes) • Limited expertise on HTS magnets operation (including quench detection and protection)
<p>Opportunities</p> <ul style="list-style-type: none"> • Set up validation programmes for large scale HTS magnets using both established manufacturers and start-ups • Scale up the production capacity of HTS material and cables • Exploit synergies between High Energy Physics, Fusion and other relevant sectors • Expand test facility capacity • Boost R&D in emerging iron-based HTS technology 	<p>Threats</p> <ul style="list-style-type: none"> • Possible dependence for materials on other territories benefiting from more centralised and well-funded strategies. • Lack of continuity in public funding for large projects posing existential threat to established manufacturers

Strengths:

Europe has developed a **strong basis for further advancements in superconducting magnet technology**.

- At its core is a **network of leading public research institutions and centers**. Key organizations such as CERN, ENEA, CEA, the University of Geneva, SPC-EPFL, PSI, the University of Twente, ITER, KIT, INFN, and CIEMAT contribute extensive expertise in magnet research and development. This collective knowledge covers areas such as materials science, magnet design, and advanced manufacturing processes.
- In addition, Europe hosts a **well-established community focused on magnet modelling**. This community has created advanced simulation tools that improve the accuracy of magnet design and performance predictions, facilitating efficient development and reducing technical risks. It is based both in the public and private sector both involved in manufacturing some of the most advanced magnets in the world in the last 20 years.
- The EU's **magnet manufacturing supply chain** has indeed benefited from major projects like the LHC and ITER, which have provided demand and helped maintain a skilled industrial base. Europe can also count on an experienced supply chain for superconducting magnets for applications outside the high energy physics and fusion fields such as MRI, NMR, power etc. Companies like **ASG, Bruker, Noel, ELYTT or SigmaPhi** form a strong basis for the European ecosystem.

- Europe also offers several **specialized test facilities**, including the Sultan test bench hosted by SPC-EPFL in Lausanne, Switzerland. They play a crucial role in supporting R&D activities. These facilities enable thorough testing and validation of cables and magnet prototypes under realistic operational conditions, supporting fast development cycles.

Europe is rapidly developing a **start-up ecosystem** focused on superconducting tape and high-temperature superconducting (HTS) magnet technologies.

- In the **materials sector**, start-ups such as **TE Magnetics** (UK), **Suprema** (Italy), and **Subra** (Denmark) are aiming at producing high performance and cost-effective tape and conductor solutions for magnet manufacturers. They add their capabilities to more established players in the tape or cable fields such as Theva, Bruker, ICAS, Columbus and Nexans.
- On the **magnet technology front**, fusion start-ups like **Tokamak Energy** (UK), **Gauss Fusion** (Germany), **Renaissance Fusion** (France), and **Proxima Fusion** (Germany) are entering this area directly or in partnership with other established private and public magnet manufacturers and growing rapidly.
- The total capitalization of these start-ups is increasing rapidly and is worth over **€600 million** as of the end of March 2026.

The presence of **established European manufacturers for LTS and MgB2 materials** represents a significant strength for the European superconducting magnet ecosystem. Companies like **Bruker**, **Luvata** and **ASG-Columbus Superconductors** provide a local supply chain for both Low Temperature Superconductors (LTS) such as NbTi and Nb3Sn, and MgB2, which is critical for advanced applications in fusion energy, medical imaging, and high-energy physics. Their long-standing collaborations with research institutions and industrial partners ensure reliable access to high-performance superconducting materials and reduce dependency on non-European suppliers.

Weaknesses

Europe's HTS supply chain remains fragile and under-developed, a key weakness in the broader superconducting magnet ecosystem. The number of suppliers capable of producing advanced HTS materials (e.g. REBCO) and cables is limited, and most are either in **early-stage development** or **lack the capacity** to meet large-scale production demands. The scarcity of established suppliers creates bottlenecks in the procurement of high-quality European HTS tapes and cables. The established European HTS cable supply chain also still faces difficulties in pursuing long length production due to process maturity and quality issues. All this tends to generate a dependency to other more advanced territories and puts Europe at a competitive disadvantage.

Europe also faces a significant **bottleneck in cable testing infrastructure**, which hampers the development and validation of superconducting magnet technologies. Only a handful of facilities can perform high-field, high-current evaluations. **Sultan (EPFL-SPC)**, the primary test station for superconducting cables is a world class facility. Nevertheless, it can become oversubscribed and subject to downtimes for maintenance and upgrades. These constraints result in delays for critical qualification campaigns, slowing down innovation cycles and time-to-market for new magnet designs.

Europe's **experience with HTS conductors is heavily concentrated on stacked tape configurations**, limiting its ability to explore and optimize alternative designs. Other conductor architectures—CORC or equivalent, Roebel— are not being pursued in Europe. This narrow focus contrasts with other territories, where a broader range of HTS conductor technologies are being actively developed and commercialized. The lack of diversity in conductor experience restricts innovation in magnet design and poses a risk of possible technological lock-in, reducing the ability to adapt to new requirements.

Europe currently faces a **shortage in expertise for the operation of HTS magnets**, particularly in critical areas such as **quench detection and protection systems**. This limited experience slows the reliable deployment of HTS magnets in demanding applications, where robust performance are essential. The shortage of knowledge in these areas generates risks during scaling and commercialization, potentially delaying progress in critical projects for fusion and high energy physics.

Opportunities:

To address the gaps identified in Europe's HTS magnet ecosystem in the HTS field, it is crucial to **support private and public validation programmes for large HTS magnets**. Targeted investment in the development of relevant model coils would ensure that Europe can compete with regions that have already advanced their HTS technologies. There are several **existing initiatives** already ongoing in start-ups (Tokamak Energy, Renaissance Fusion, Proxima Fusion, Gauss Fusion), in the public sector (e.g. Suprafusion with CEA, EUROfusion, CIEMAT) or in Public-Private partnerships (20T@20K with CERN, F4E, EUROfusion and ENI). They **need to be supported financially and accelerated**. Collaboration between research institutions, start-ups, and established manufacturers also needs to be fostered to create a cohesive ecosystem that drives innovation and commercialization. **Europe should actively pursue parallel development paths by engaging both established manufacturers and emerging start-ups** in the validation effort for large HTS magnets. This dual approach leverages the strengths of each group: traditional manufacturers bring proven industrial capacity, quality assurance, and scalability, while start-ups contribute agility, novel ideas, and disruptive technologies.

Europe must urgently **scale up its domestic production capacity for HTS tapes and cables**. This will reduce dependence on external suppliers and secure its place in the superconducting technologies global market. This requires a dual strategy: strengthening existing manufacturers while fostering the growth of innovative start-ups.

Firstly, Europe must provide targeted funding and incentives for companies like **THEVA** and **ASG Superconductors** to expand production lines, modernize equipment, and diversify the range of high-performance HTS tapes and cables offered. Secondly, Europe must provide more direct investment for emerging players such as **TE Magnetics**, **Suprema**, and **Subra** to accelerate their transition from R&D to large-scale manufacturing. Public-private partnerships can help bridge the gap between prototype development and commercial production. In general Europe must **facilitate collaboration** between material suppliers, cable producers, and end-users to create a robust, end-to-end HTS ecosystem. It must launch **EU-wide initiatives to support breakthroughs in tape and cable development**, such as higher current density, improved mechanical strength, and cost-effective manufacturing processes. By expanding production capacity, Europe can ensure a reliable supply of critical components for fusion, energy, and medical applications, while reducing vulnerabilities in the global supply chain. This will position the EU as a self-sufficient leader in HTS technology, driving both economic growth and technological sovereignty.

Europe can maximize its impact in superconducting magnet technology by fostering **cross-sector collaboration between high energy physics, fusion research, and industries such as medical imaging, energy production and transportation**. These sectors share common technical challenges and needs: optimize and validate HTS conductor configuration, develop knowledge in magnet protection and operation, secure a robust supply chain. They can be addressed through **knowledge transfer, joint and complementary R&D programs and shared infrastructure**. This workshop, bringing together the fusion and high energy sectors, sets the tone and brings down barriers between those communities. More needs to be done to identify synergies and target funding at initiatives that bridge multiple sectors to maximize funding efficiency.

To overcome Europe's testing bottlenecks and support the full development cycle of superconducting magnets, a tiered expansion of test infrastructure is essential. This requires investment in three distinct types of facilities, each addressing critical stages of R&D and industrial validation:

- **Full Magnet Test Facilities (eg CERN, JORDI at EPFL-SPC, ITER, CEA Saclay):** Large-scale infrastructure capable of testing complete magnet systems under operational conditions, including high-field and cryogenic environments.
- **Advanced Conductor Test Facilities (e.g., Sultan at EPFL-SPC):** Specialized stations for evaluating high-temperature superconducting (HTS) cables and advanced conductor architectures under realistic operational conditions. These facilities enable validation of conductor performance, mechanical stability, and quench behaviour. No facility is currently available for high-field (15-20 T), high current (>100 kA) and high temperature (20-77K) testing.
- **Simple Conductor Characterization Facilities:** Accessible, smaller-scale labs for routine testing of conductor properties, such as critical current, thermal stability, thermos-hydraulic characteristics and mechanical integrity in relevant conditions of field and temperature that are beyond present capability, or available with limited access. These facilities support rapid iteration during early-stage development and quality control in manufacturing.

Existing facilities must be upgraded to adapt to emerging requirements (higher field and current for example) and opened to third parties access when this is not the case. Whenever required, new facilities must be built, possibly using public/private partnerships to ensure adequate capacity.

Additionally, for some of the applications such as fusion, **a neutron irradiation facility** should be identified and possibly adapted to test the impact of neutron bombardment on the performance of tapes, conductors and coils. Extension to other particles and high energy spectra would draw much interest from other applications in nuclear and high-energy physics.

Europe could also **invest in Iron-based HTS research and development**. These materials typically exhibit critical temperatures up to about 55 K, which is intermediate compared to other HTS compounds like cuprates (which can exceed 130 K). This intermediate range, combined with their high upper critical fields and lower anisotropy, makes iron-based superconductors suitable for high-field applications. Their metallic parent compounds and excellent grain boundary properties may also **contribute to more stable operational performance**.

As an emerging technology, iron-based HTS could offer **significant competitive advantages**. Europe must accelerate material characterization, optimization, manufacturing scalability, and system integration. Currently, research in the field is mostly fundamental research and university based. This knowledge could be leveraged into large R&D programmes led by national laboratories or universities with the experience of translating fundamental research into small scale production. Investing in iron-based HTS could **reduce dependency on rare-earth materials, enhance supply chain resilience, and position Europe alongside China as a leader** in this evolving field.

Threats

Europe's superconducting magnet sector faces a significant threat due to its **reliance on external territories not only for raw materials but also for transformed products such as superconducting tapes**. Regions like Asia and North America benefit from well-funded programmes that dominate both material extraction and the production of advanced superconducting components. Those programmes required major advances in technology and therefore place those territories at the frontier of technological development in the field. This dual dependence—on raw materials and finished products—poses a critical risk, as the EU's own production capacity remains limited and fragile. The lack of robust domestic manufacturing for superconducting tapes and other key components heightens vulnerability to supply chain disruptions, geopolitical tensions, or trade restrictions. Such dependencies could lead to delays, increased costs, and reduced competitiveness in the global market. Without strategic investments to strengthen domestic production and secure alternative supply chains, Europe's ability to innovate and deploy next-generation superconducting magnets may be compromised.

Europe's superconducting magnet sector faces an existential threat from **the lack of continuity in public funding for large-scale projects**. Institutions such as CERN and ITER have invested 100s of millions of Euros into the sector over the last 20 years. These initiatives have historically driven demand,

sustained industrial expertise, and maintained a skilled workforce within the EU. Those projects have now come to an end with no other major project on the horizon. This is destabilizing established manufacturers, who rely on such projects for long-term contracts and revenue stability.

Without reliable, sustained investment, manufacturers may struggle to retain their experienced workforce as well as critical manufacturing capabilities and may not be in a position to innovate, or compete globally. This uncertainty could lead to the erosion of Europe's industrial base, loss of specialized jobs, and weakened leadership in superconducting technologies.

5.2.2 Main test facilities

Name	Operator	Functionality and main characteristics
	University of Geneva	Superconducting material characterisation
	ENEA	Superconducting material characterisation
	CNRS	Superconducting material characterisation
	CNR-SPIN	Superconducting material characterisation
Jordi	EPFL-SPC	Superconducting material characterization 4.5K, 10kA
FRESCA 2	CERN	Superconducting material characterization 1.9-4.3K 13T 12.4 kA
Twente press	University of Twente	Superconducting material characterisation
	CIEMAT	Superconducting material characterisation
Cryogen free test stand	PSI	Superconducting material characterization 1.5 W @ 4.2 K and 35 W @ 50 K, 2kA
	INFN-LASA	Superconducting material characterisation
Josefa	CEA	Superconducting material characterization 5-15K, 7.5T, 10 kA
CryoMak / FBI	KIT	Cable and conductor performance 4.2K-77K, 100kN, 12T
Sultan	EPFL-SPC	Cable and conductor performance 100 kA, 10.9T, 4.2 K
Saclay Test Facility	CEA	Test of full coils xxxkA, YYYYK
Magnet Test Stand – SM18	CERN	Test of full coils xxxkA, YYYYK
Magnet Test Stand	EPFL-SPC	Test of full coils xxxkA, YYYYK
Magnet Cold Test Facility	ITER	Test of full coils 65 kA, 4.2K
Frascati Coil Cold Test Facility	ENEA / DTT	Test of full coils 42.5 kA, 4 K
	TU Wien	Radiation resistance testing

5.2.3 Gaps in the ecosystem

This section describes the areas where new actors (R&D or Suppliers) would need to be mobilized to successfully develop the associated technology. This covers all actors based in the EU, UK and Switzerland.

More critical items are highlighted in **bold**.

Research and development		
Handful of actors	One actor	No identified actor
<ul style="list-style-type: none"> • CORC • Dry conductors • HTS Roebel cables • HTS Rutherford cables • Feedthroughs • Voltage taps extraction • Quench models • 3D Printed formers • High precision coil winding 	<ul style="list-style-type: none"> • Persistent current switches • MgB2 • Laser engraving of wide HTS 	<ul style="list-style-type: none"> • Acoustic emission monitoring • Resin Vacuum Pressure Impregnation • Digital twins • BSSCO •

Supply chain		
Handful of actors	One actor	No active supplier
<ul style="list-style-type: none"> • Dry conductors • HTS Rutherford cables • Internally cooled conductors • Stacked tape cables • Cryogenic cooling systems • Feedthroughs • Power supplies • Demountable joints • HTS joints • Non-insulated HTS coils • REBCO 	<ul style="list-style-type: none"> • MgB2 • Laser engraving of wide HTS 	<ul style="list-style-type: none"> • CORC • HTS Roebel cables • Acoustic emission monitoring • Persistent current switches • Voltage taps extraction • Multiphysics modelling • BSCCO • Iron-based superconductors

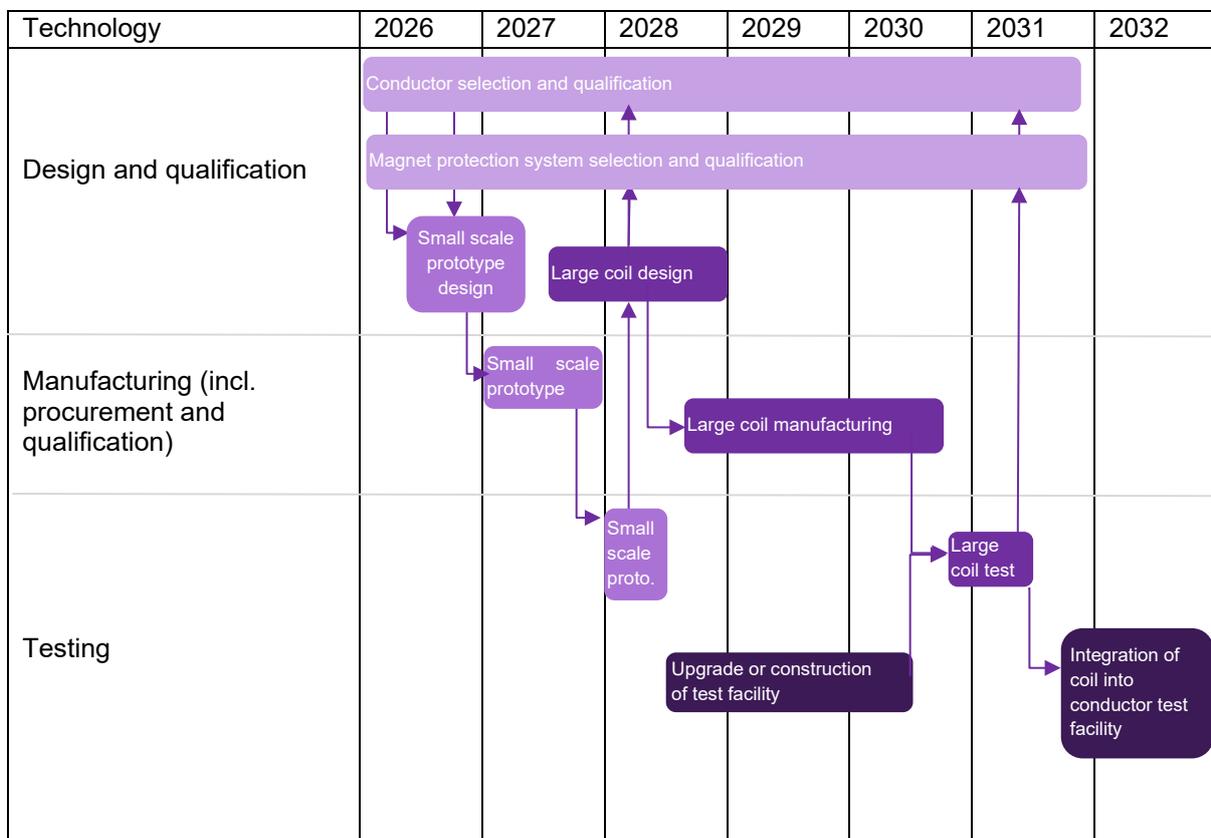
5.3 Roadmaps

This section presents some of the Technology Development Actions (TDAs) in the form of roadmaps for relevant technologies. The timings are indicative and may evolve significantly depending on funding available from various sources and associated priorities.

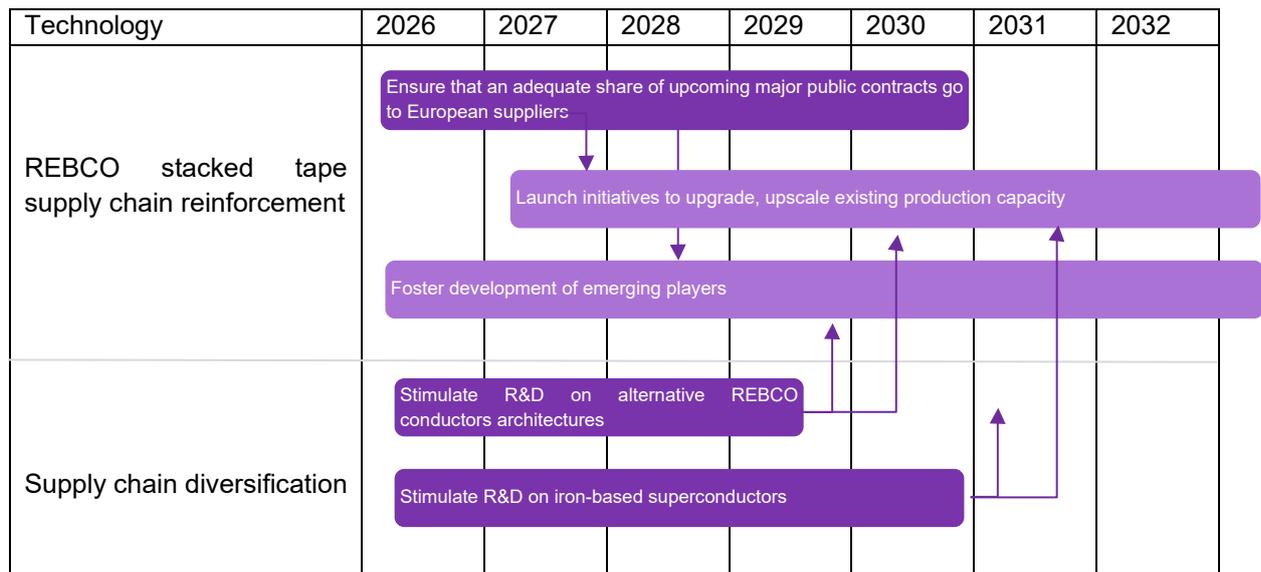
TDAs which are not fundamentally linked to other activities and can be executed independently are not included on roadmaps. This is true, for example, for the pumping area.

5.3.1 HTS coils validation programme

This roadmap provides an example of HTS coil validation programme. It includes the option of integrating the coil manufactured into a conductor test facility. It is also suitable for implementation through a Public-Private Partnership if adequate.



5.3.2 HTS supply chain development



6 Conclusion

Will be completed for the final version.

Appendix 1: Technology Readiness Levels

For this workshop, a TRL scale from 1 to 9 will be used, in line with the IAEA definitions². 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 itself¹.

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

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

Appendix 3: Technology Dashboards

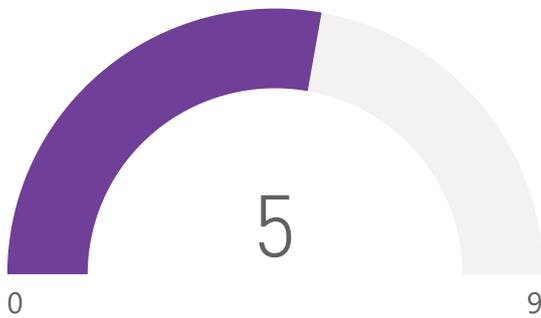
Magnets



Superconducting material

BSCCO

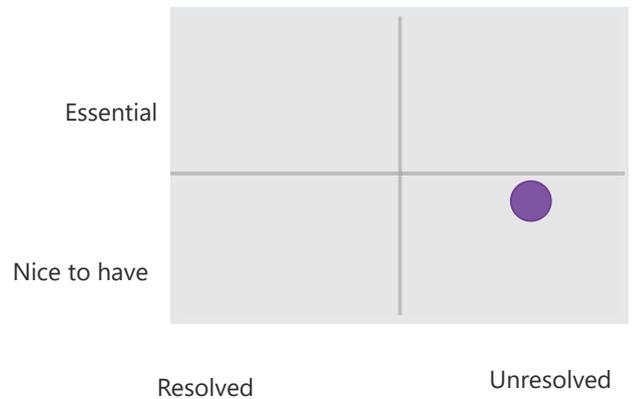
TRL



Entities



IGNORE FOR NOW



Other Markets

Medical, Current leads, Energy storage, Mobility

Alternatives

REBCO
LTS for other applications

Showstoppers

Commercial availability, Cost, Complex heat treatment process for Bi2212

Technology Characteristics

Test Facilities

Properties: University of Geneva, ENEA, KIT, CNRS
Irradiation: TUWien, NCBJ, INRNE, ESS, SCK-CEN, INFN-LNL, PSI, CERN, CIEMAT, EBTC

Test Facility Function

Superconductor characterization:
- transport properties (Ic, Tcs)
- mechanical behaviour
- radiation hardness.

European Entities Involved

Private

Public

Technology Development Actions

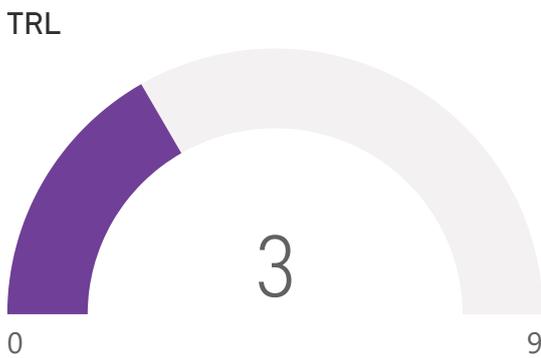
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Supply chain development	40 to 80%	>1M	>2 years	Low	No

Magnets

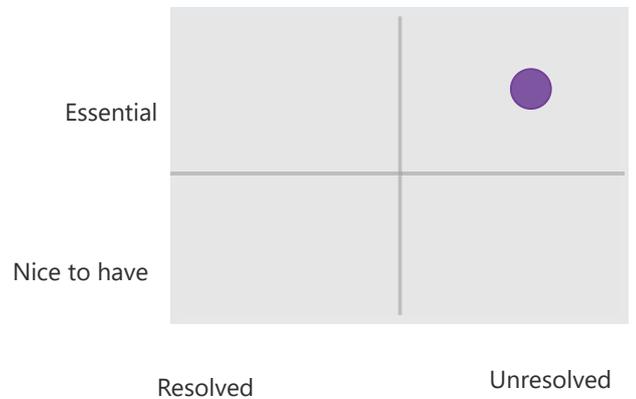


Superconducting material

Iron-base superconductors



IGNORE FOR NOW



OtherMarkets

Medical, Energy storage, Mobility, Power

Alternatives

REBCO
LTS for some applications

Showstoppers

Toxicity, Low critical current

Technology Characteristics

Test Facilities

CNR-SPIN, ENEA

Test Facility Function

Material characterization at lab scale
Test synthesis process.

European Entities Involved

Private

Public

CNR-SPIN, ENEA, EPFL, Max Plank Institute, ICMM-CSIC, IFW Dresden, TU Wien, LMU

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Foster R&D on Iron Based Superconductors in Europe	>80%	250k to 1M	>2 years	High	Partially

Magnets

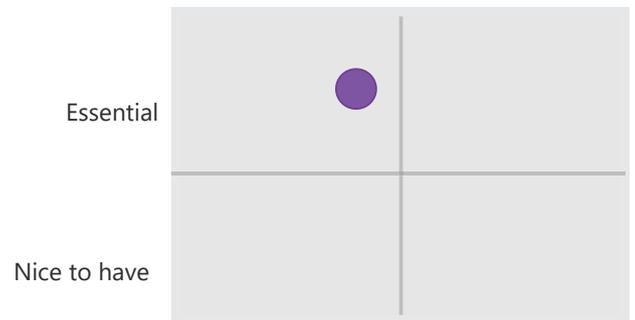
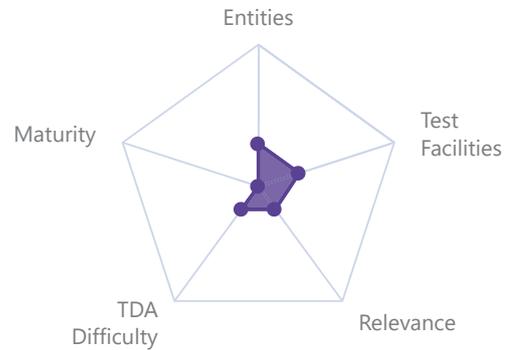


Superconducting material



LTS

TRL



OtherMarkets

Medical, Energy Mobility

Alternatives

REBCO

Resolved

Unresolved

Showstoppers

Use of Helium as cooling system,
Medium field applications only

Technology Characteristics

Test Facilities

ENEA, EPFL-SPC, CERN,
University of Twente,
Durham, Oxford, CIEMAT,
INFN-LASA, UniGE, CEA

Test Facility Function

Superconductor
characterization:
- transport properties (Ic, Tcs)
- mechanical behaviour
- radiation hardness

European Entities Involved

Private

Bruker, Luvata

Public

University of Geneva

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop EU supply chain on LTS to anticipate large projects (FCC, EU-DEMO)	>80%	>1M	>2 years	High	No
Improve Europe sovereignty for raw materials (Nb)	40 to 80%	>1M	6 months to 2 years	Low	No
Share the knowledge and expertise on LTS radiation damage	>80%	<250k	<6 months	Medium	Yes

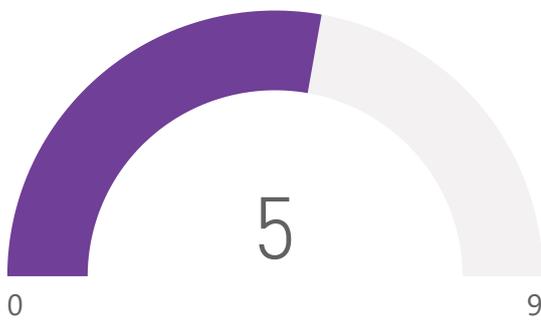
Magnets



Superconducting material

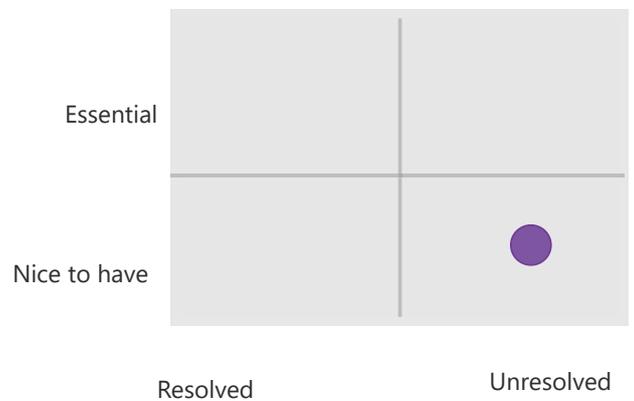
MgB2

TRL



IGNORE FOR NOW

Relevance ↔ Test Facilities



Other Markets

Current leads, busbars, Energy transport, Medical

Alternatives

REBCO
LTS for some applications

Resolved

Unresolved

Showstoppers

Low field applications only

Technology Characteristics

Test Facilities

Properties: University of Geneva, ENEA, KIT, CNRS
Irradiation: TUWien, NCBJ, INRNE, ESS, SCK-CEN, INFN-LNL, PSI, CERN, CIEMAT, EBTC

Test Facility Function

Superconductor characterization:
- transport properties (Ic, Tcs)
- mechanical behaviour
- radiation hardness.

European Entities Involved

Private

Columbus (ASG)

Public

ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

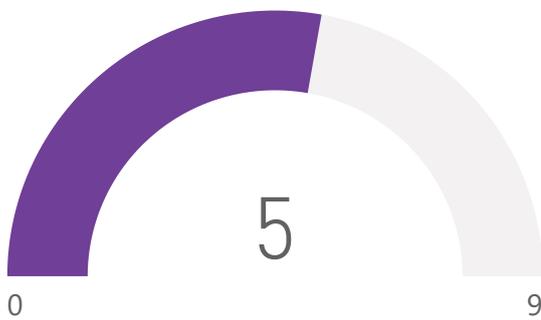
Magnets



Superconducting material

REBCO

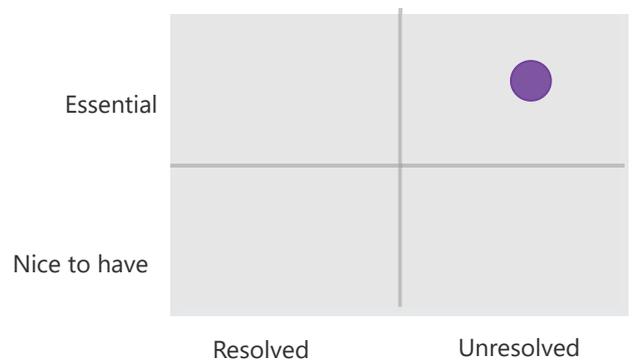
TRL



Maturity



IGNORE FOR NOW



Other Markets

Transportation, Power, Medical, Energy storage

Alternatives

LTS for lower field applications

Showstoppers

Costs, Mechanics, Radiation resistance unknown, Quench detection

Technology Characteristics

Test Facilities

Properties: University of Geneva, ENEA, KIT, CNRS, EPFL-SPC
Irradiation: TUWien, NCBJ, INRNE, ESS, SCK-CEN, INFN-LNL, PSI, CERN, CIEMAT, EBTC

Test Facility Function

Superconductor characterization:
- transport properties (I_c , T_c s)
- mechanical behaviour
- radiation hardness.

European Entities Involved

Private

THEVA, Suprema, Subra

Public

ENEA, ICMAB, KIT, SPC, CERN, CEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Create REBCO development community	>80%	<250k	<6 months	High	No
Develop standard characterization process and a shared database of REBCO conductor properties	>80%	250k to 1M	>2 years	High	No
Develop supply chain	40 to 80%	>1M	>2 years	High	Partially
Test facilities for tape characterization (transport current, mechanics)	>80%	>1M	>2 years	High	Partially
Develop radiation test facility (incl. transport current measurements)	40 to 80%	>1M	>2 years	Medium	No

Magnets



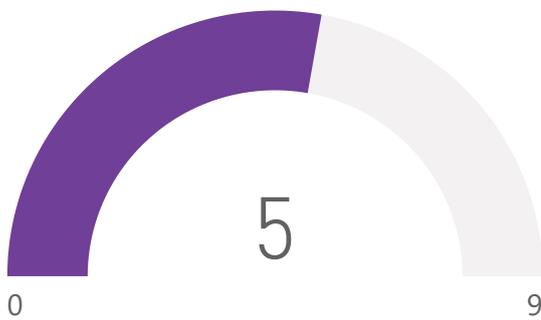
Conductors and cables

Entities

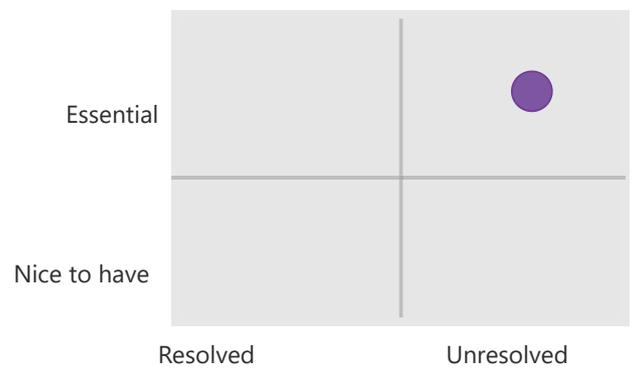


CORC cable

TRL



IGNORE FOR NOW



OtherMarkets

AC cables, Power, Medical, Transport

Alternatives

Showstoppers

Strain sensitivity, Cost, AC losses, Manufacturing, Low current density, Field quality.

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
SULTAN (EPFL-SPC), FBI (KIT), CryoMaK (KIT), Twente press (UniTwente), Magnet Test Stand (PSI), Saclay test facility (CEA)	AC and DC characterization Mechanical assessment Thermal and electromagnetic cycling tests Quench behaviour Thermo-Hydraulic characterization Neutron irradiation High voltage tests	Private	Public University of Twente, CEA

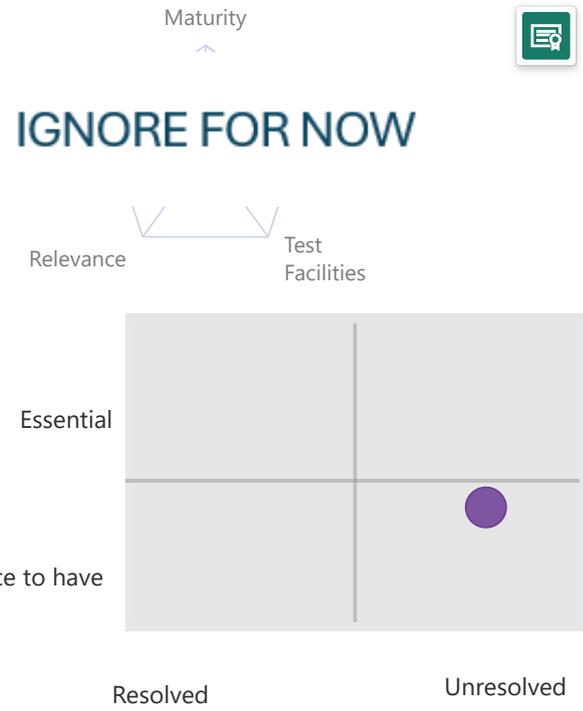
Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Design, build and test model coil	40 to 80%	>1M	>2 years	High	No
Development of a new high field, high current facility for full scale, long length conductors	>80%	>1M	>2 years	High	No
Identification of optimal HTS cable layout depending on the application	>80%	>1M	6 months to 2 years	High	No
Industrial scale up of long length production	>80%	>1M	>2 years	High	No
Development of neutron source to test coils and conductors	<40%	>1M	>2 years	Low	No
Development of a Sultan-like facility with higher performances	>80%	>1M	>2 years	Medium	No

Magnets



Conductors and cables



OtherMarkets

Medical, Motors, Energy storage, Gyrotrons

Alternatives

CICC
Stacked tapes

Showstoppers

Heat load extraction, Quench protection

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
CryoMaK (KIT)	AC and DC characterization	Private	Public
Twente press (UniTwente)	Mechanical assessment	ICAS	SPC
Magnet Test Stand (PSI)	Thermal and electromagnetic cycling tests	NEXANS	CERN
Saclay test facility (CEA)	Quench behaviour	NKT	
FRESCA 2 (CERN)	Thermo-Hydraulic characterization		
	Neutron irradiation		
	High voltage tests		

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of dedicated test facility for Dry conductors	>80%	>1M	>2 years	Low	Partially
Design, build and test model coil	40 to 80%	>1M	>2 years	High	No
Development of a new high field, high current test facility for full scale long length conductors	>80%	>1M	>2 years	High	No
Identification of optimal HTS dry cable layout depending on the application	>80%	>1M	6 months to 2 years	High	Partially
Industrial scale up of long length production	>80%	>1M	>2 years	High	No

Magnets



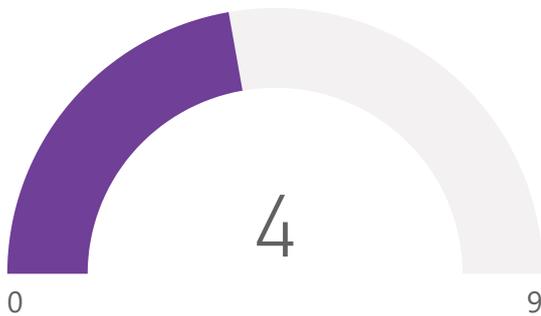
Conductors and cables

Maturity

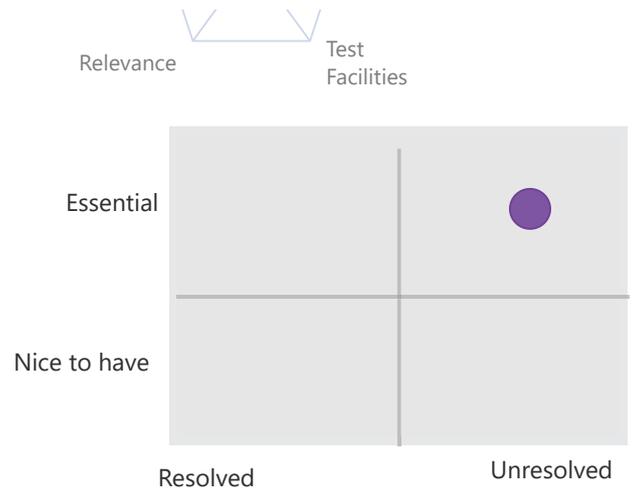


HTS Rutherford cables

TRL



IGNORE FOR NOW



Other Markets

Medical, NMR, MRI

Alternatives

CORC
Stacked tapes

Showstoppers

Maximum transverse stress, Heat load extraction, Manufacturing, Mechanical robustness, Complex heat treatment process

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public
SULTAN (EPFL-SPC) FBI (KIT) CryoMaK (KIT) Twente press (UniTwente) Magnet Test Stand (PSI) Saclay test facility (CEA) FRESCA 2 (CERN)	AC and DC characterization Mechanical assessment Thermal and electromagnetic cycling tests Quench behaviour Thermo-Hydraulic characterization Neutron irradiation High voltage tests	ICAS, Nexans, NKT	CERN, EPFL-SPC, INFN

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Design, build and test model coil	40 to 80%	>1M	>2 years	High	Partially
Development of a "Sultan like" facility with higher performances	>80%	>1M	>2 years	Medium	No
Development of a new high field, high current test facility for full scale long length conductors	>80%	>1M	>2 years	High	No
Identification of optimal HTS cable layout depending on the application	>80%	>1M	6 months to 2 years	High	Partially
Identification or development of neutron source to test coils and conductors	<40%	>1M	>2 years	Low	Partially
Industrial scale up of long length production	>80%	>1M	>2 years	High	No

Magnets



Conductors and cables

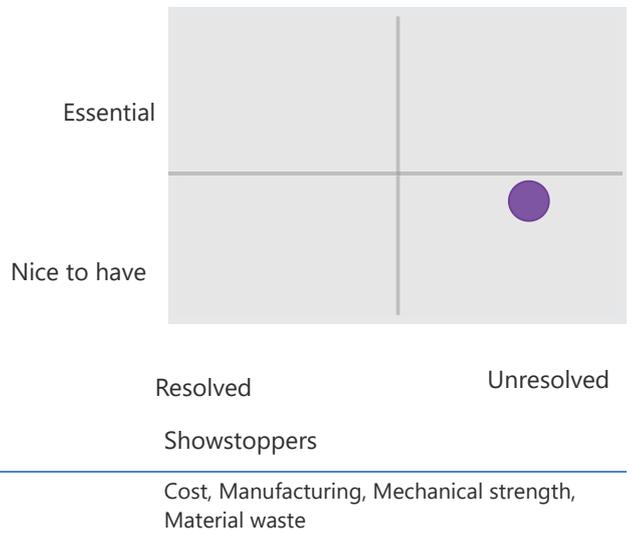
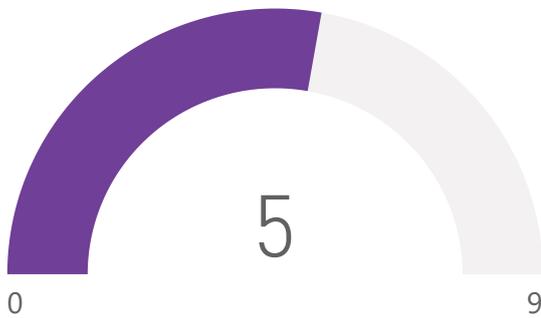
Entities



HTS Roebel cables

IGNORE FOR NOW

TRL



OtherMarkets

Power (motors, generators, convertors)

Alternatives

All other types

Resolved

Unresolved

Showstoppers

Cost, Manufacturing, Mechanical strength, Material waste

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public
SULTAN (EPFL-SPC)	AC and DC characterization		
FBI (KIT)	Mechanical assessment		
CryoMaK (KIT)	Thermal and electromagnetic cycling tests		
Twente press (UniTwente)	Quench behaviour		
Magnet Test Stand (PSI)	Thermo-Hydraulic characterization		
Saclay test facility (CEA)	Neutron irradiation		
	High voltage tests		
			CERN KIT

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

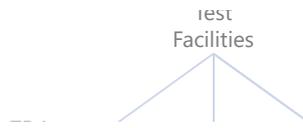
Magnets



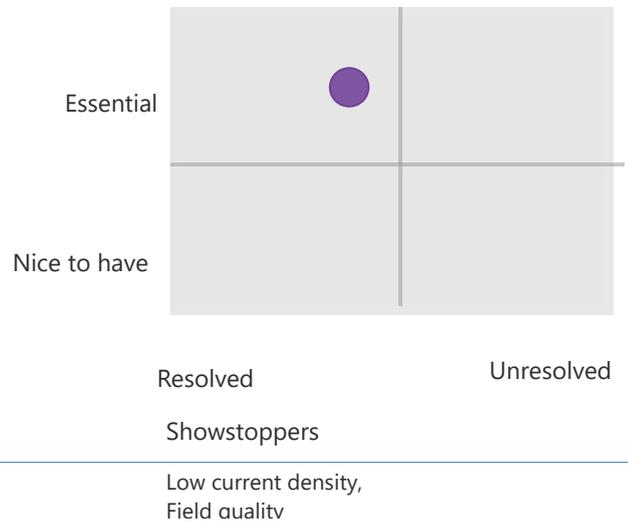
Conductors and cables

Internally cooled conductors

TRL



IGNORE FOR NOW



OtherMarkets

Power, Busbar, current leads

Alternatives

Dry conductor

Showstoppers

Low current density,
Field quality

Technology Characteristics

Test Facilities

SULTAN (EPFL-SPC)
FBI (KIT)
CryoMaK (KIT)
Twente press (UniTwente)
Magnet Test Stand (PSI)
Saclay test facility (CEA)

Test Facility Function

AC and DC characterization
Mechanical assessment
Thermal and electromagnetic cycling tests
Quench behaviour
Thermo-Hydraulic characterization
Neutron irradiation
High voltage tests

European Entities Involved

Private

ICAS, Gauss, Proxima Fusion,
TE Magnetics, ELYTT Energy

Public

CERN
EPFL-SPC
CEA
ITER
ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets



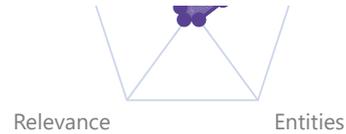
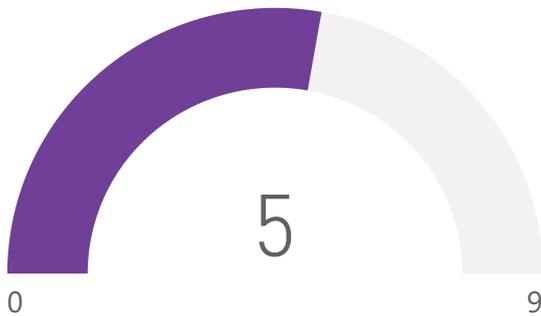
Conductors and cables



IGNORE FOR NOW

Stacked tape cables

TRL



Other Markets

Current leads and busbars, DC cables, Medical, Power

Alternatives

All other types

Showstoppers

AC losses, Quench protection, Potential damage to tape, Field quality

Technology Characteristics

Test Facilities

SULTAN (EPFL-SPC)
FBI (KIT)
CryoMaK (KIT)
Twente press (UniTwente)
Magnet Test Stand (PSI)
Saclay test facility (CEA)

Test Facility Function

AC and DC characterization
Mechanical assessment
Thermal and electromagnetic cycling tests
Quench behaviour
Thermo-Hydraulic characterization
Neutron irradiation
High voltage tests

European Entities Involved

Private

ICAS, TE magnetics, Proxima Fusion, Gauss, ELYTT Energy

Public

CERN, SPC, ENEA, CEA, PSI

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of a "Sultan like" facility with higher performances	>80%	>1M	>2 years	Medium	No
Identification or development of neutron source to test coils and conductors	<40%	>1M	>2 years	Low	No
Design, build and test model coil	40 to 80%	>1M	>2 years	High	Partially
Development of a new high field, high current facility for full scale, long length cable performance validation	>80%	>1M	>2 years	High	No
Identification of optimal HTS cable layout depending on the application	>80%	>1M	6 months to 2 years	High	Partially
Industrial scale up of long length production	>80%	>1M	>2 years	High	Partially

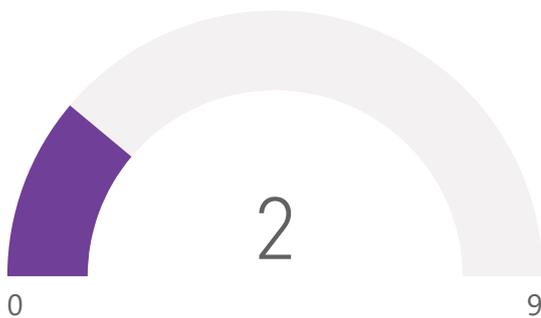
Magnets



Modelling

AC losses

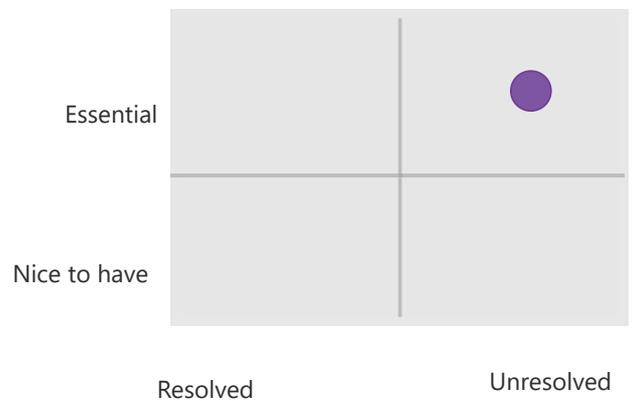
TRL



Entities



IGNORE FOR NOW



OtherMarkets

- MRI
- Energy management
- Mobility
- Electrical machines

Alternatives

- Increased thermal margin
- Empirical models

Showstoppers

- Computational complexity (many length scales)
- Experimental validation

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
Josefa (CEA), SULTAN (EPFL-SPC), ITER MCTF, SM18	With dedicated power supply	Private	Public
			CEA, PSI, ITER, CERN, ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of analytical formulae for real HTS cabling	40 to 80%	250k to 1M	>2 years	High	Partially
Eddy current calculations in large/detailed models	>80%	250k to 1M	>2 years	Medium	

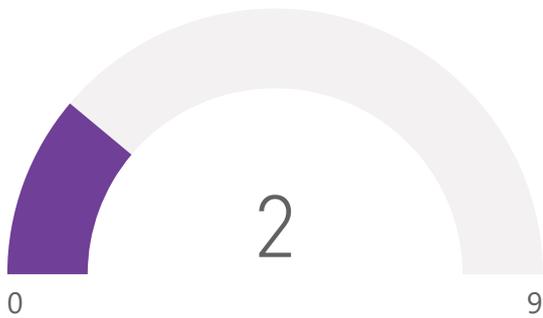
Magnets



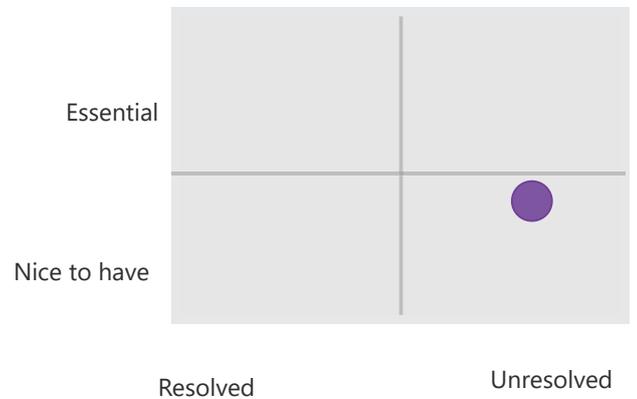
Modelling

Digital twins

TRL



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OtherMarkets

Automation industry, robotics, mobility, civil engineering, power plants, aviation

Alternatives

Only for individual goals of digital twin - verification data, data-driven simulators, but not for all

Showstoppers

Lack of test facilities
Real-life application disturbances
High system complexity

Technology Characteristics

Test Facilities

No Test facility oriented to digital twins

Test Facility Function

Definition, Validation, Training and Education, fine-tuning of the digital twin

European Entities Involved

Private

Public

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Identification and development of capabilities to start building digital twins	>80%	250k to 1M	>2 years	Medium	

Magnets



Modelling

Electro-mechanical analysis

TRL



OtherMarkets

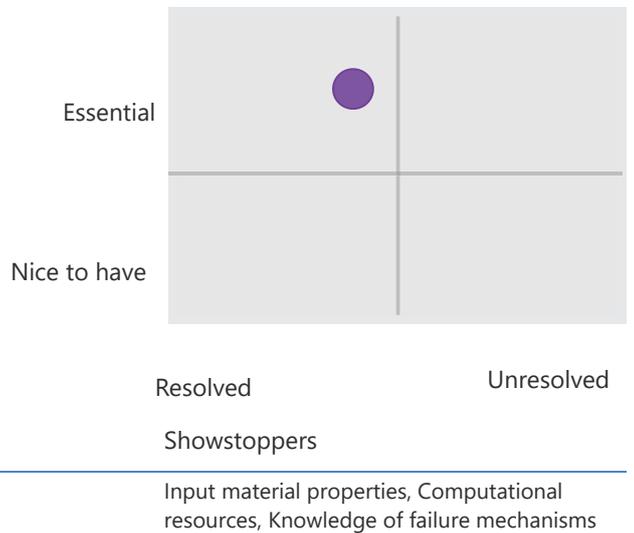
Abundant examples

Alternatives

Entities



IGNORE FOR NOW



Technology Characteristics

Test Facilities

CERN

Test Facility Function

Material properties
Validation of failure models

European Entities Involved

Private

Public

F4E, CERN, ITER

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Understanding of acceptable stress levels in copper former for HTS conductors	>80%	<250k	<6 months	Medium	No

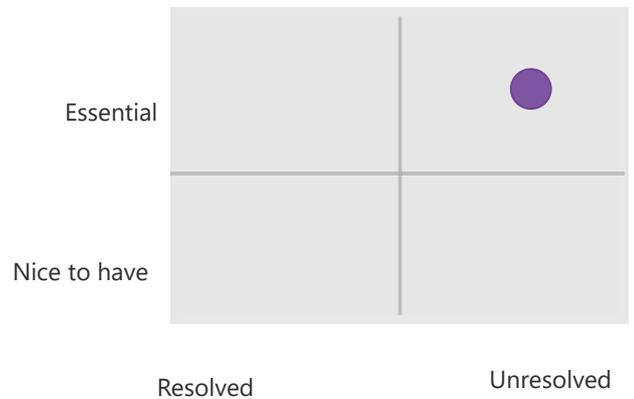
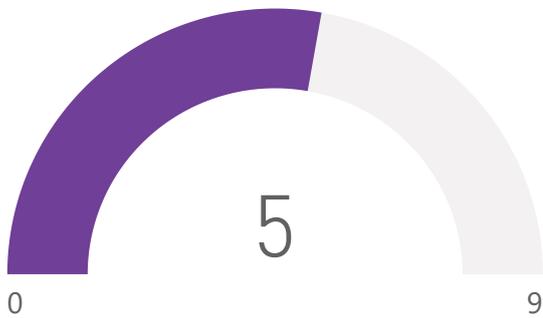
Magnets



Modelling

Multiphysics

TRL



OtherMarkets

Abundant examples

Alternatives

Safety factors accounting for other physical effects, experimental data

Showstoppers

Computational resources, need of HPC
Validation of models
Deep knowledge-base needed to develop these models

Technology Characteristics

Test Facilities

ITER MCTF, ASDEX, WEST, W7-X, SM18 at CERN, DTT Cold Test Facility, SULTAN (EPFL-SPC), TCV, Jordi

Test Facility Function

Validate models used to design fusion magnets and HTS devices
Validation of assumptions, input parameters, interaction between sub-components

European Entities Involved

Private

Public

ITER, CERN, ENEA, CEA, PSI, KIT, SPC

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Validation of numerical models for HTS/cables/magnets	>80%	>1M	>2 years	High	No
Development of techniques to speed up of models	40 to 80%	250k to 1M	>2 years	Medium	

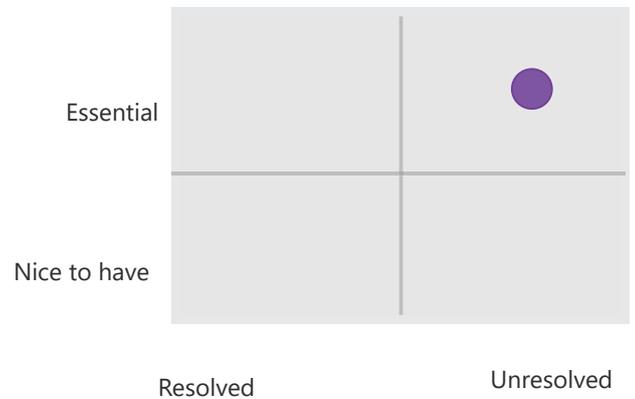
Magnets



Modelling

Tape mechanical failure modes

TRL



OtherMarkets

Alternatives

HTS powerlines, composite materials, MRI

Showstoppers

Connection between the strain (and degradation) and superconductivity state in HTS, Basic principles of HTS materials, Homogeneous characteristics in samples

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

SULTAN (EPFL-SPC), Twente Press University, KIT, ENEA, CERN

Characterization of failure modes for tapes/cables/conductors
Qualification of failure modes for tapes/cables/conductors

Private

RINA, ASG

Public

PSI, Twente University, KIT, ENEA, CERN, University of Bristol, ICMAB, CEA, University of Tuscia

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Experimental Campaigns to Characterize mechanical properties and strength	>80%	>1M	>2 years	High	Partially
Modelling of mechanical failure in tapes	>80%	>1M	>2 years	High	
Understanding of irradiation damage mechanism	>80%	>1M	>2 years	High	

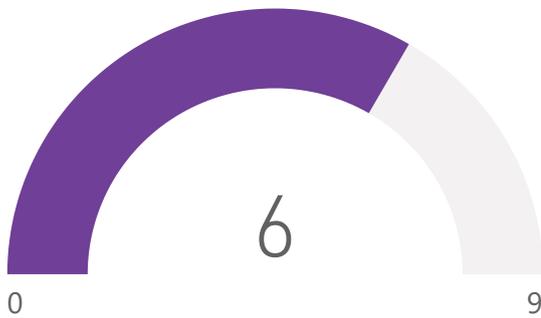
Magnets



Modelling

Thermo-hydraulic analysis

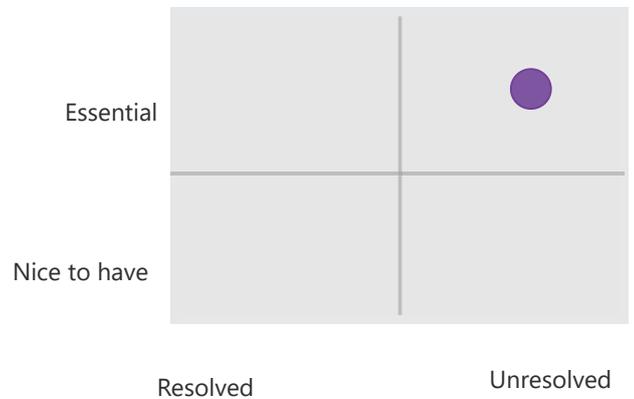
TRL



Entities



IGNORE FOR NOW



OtherMarkets

Cryogenics, Heat exchangers

Alternatives

Experimental data

Showstoppers

Understanding two-phase flow behavior in narrow environments, Complex models or difficult validation (liquid metal). Limited validation data.

Technology Characteristics

Test Facilities

Test Facility Function

Model validation, measurement of material properties

European Entities Involved

Private

Public

CEA (Grenoble)

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Different coolants: experimental campaigns to feed models, establish basic correlations	>80%	>1M	>2 years	Medium	
Tailoring existing tools for HTS tapes/cables and magnets	>80%	250k to 1M	6 months to 2 years	High	Yes
Thermal management based on different cooling schemes	>80%	250k to 1M	>2 years	Medium	

Magnets



Manufacturing

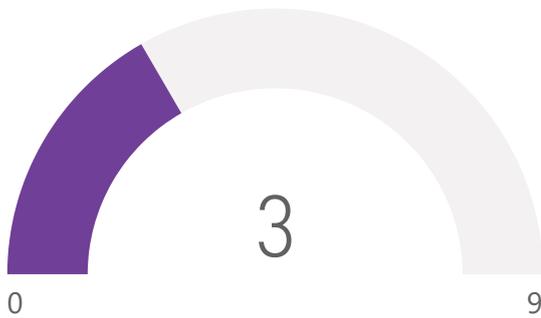
Maturity



3D printed formers

IGNORE FOR NOW

TRL



OtherMarkets

Alternatives

Resolved

Unresolved

Showstoppers

Anywhere where structural parts are used

Machined
Cast

Mechanical and physical properties

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

HP, Rosswag, Probeam,
AMCM GmbH, ASG, Bruker,
SeaAlp

CERN, PSI

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
3D Former Proof of Concept	>80%	>1M	6 months to 2 years	Medium	Partially

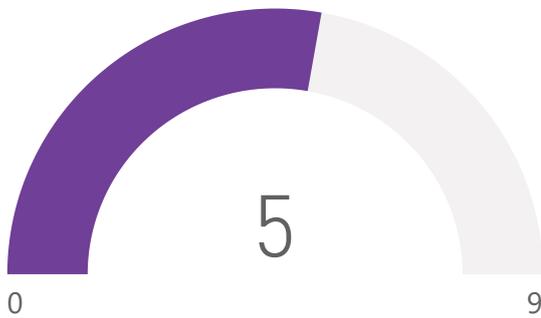
Magnets



Manufacturing

High precision coil winding

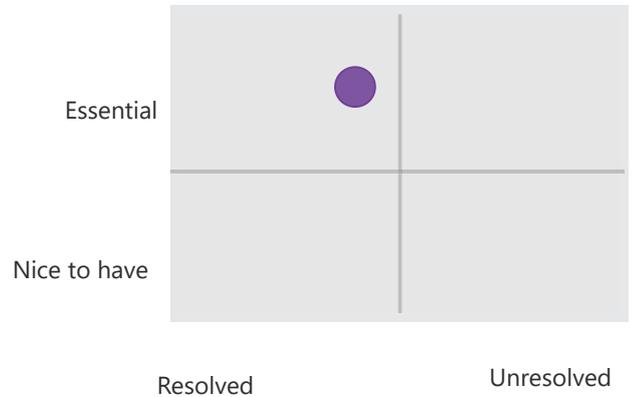
TRL



Maturity



IGNORE FOR NOW



Other Markets

Alternatives

Showstoppers

NMR
Medical
Energy storage
Mobility

3D printing/etching
Modular coils

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

CERN
PSI (SW)

Test winding accuracy

Private

Public

ASG, Ridgway (UK), Tesla Engineering (UK), ICE Oxford, SigmaPhi, Elytt, Bilfinger, TE Magnetics

CERN, ITER, PSI

Technology Development Actions

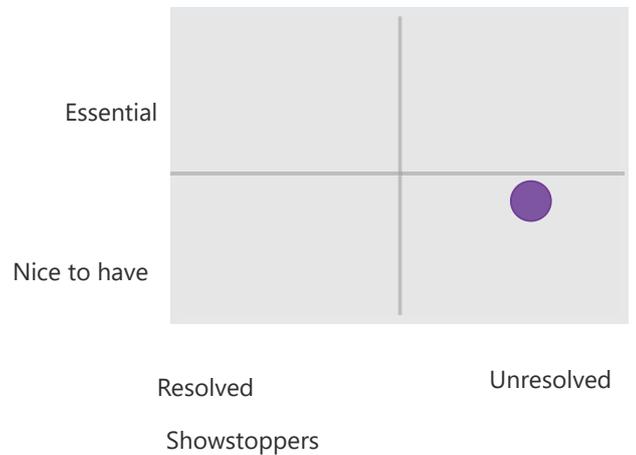
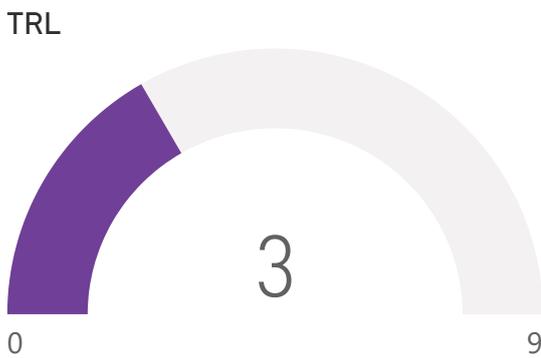
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Winding Automation	40 to 80%	>1M	6 months to 2 years	Medium	Partially
Winding of Large Section HTS Conductors	40 to 80%	>1M	6 months to 2 years	Medium	Partially

Magnets



Manufacturing

Laser engraving of wide HTS



OtherMarkets

Alternatives

Medical
Energy storage
Mobility

Narrow tapes
Complex windings

Reliability of HTS production processes over large surfaces

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

Renaissance Fusion

KIT

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Qualify laser engraving technique for HTS materials	40 to 80%	>1M	>2 years	Low	Partially
Proof of concept using Cu sheets	>80%	250k to 1M	6 months to 2 years	Low	Yes
Improve deposition process to guarantee quality over width and length of the wide sheets	<40%	>1M	>2 years	High	Partially

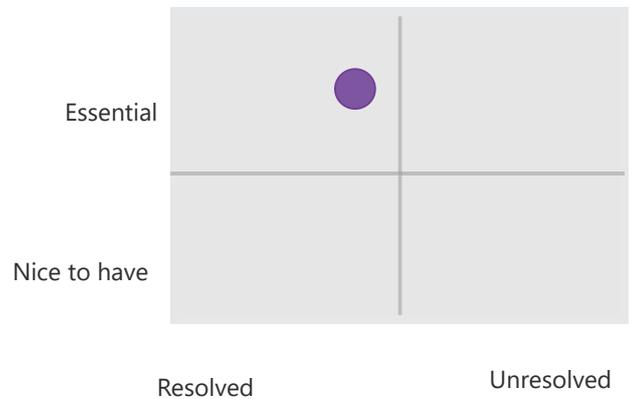
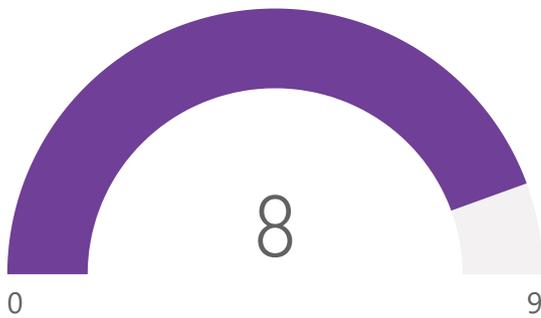
Magnets



Manufacturing

Modular coil winding

TRL



OtherMarkets

Alternatives

Showstoppers

Medical
Energy storage
Mobility
Medical

Layer wound coils

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

ASG, Bruker, Tokamak Energy, Ridgway,
ELYTT Energy

ENEA, CEA, PSI, CERN

Technology Development Actions

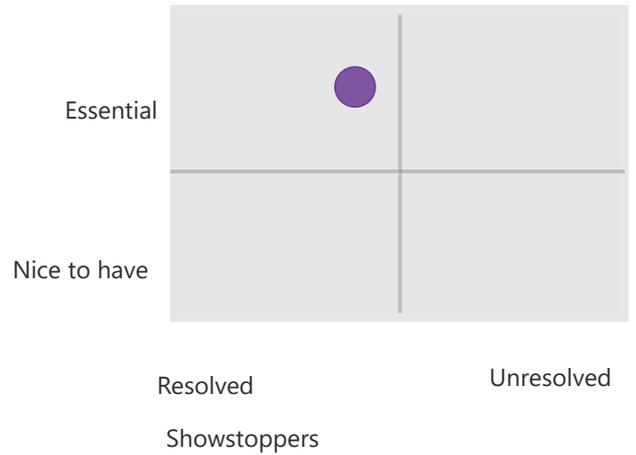
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop Coil Architecture for High Performance HTS Coils	40 to 80%	>1M	>2 years	High	Partially
Inter-module Joints for HTS Coils	40 to 80%	>1M	>2 years	High	Yes

Magnets



Manufacturing

Resin Vacuum Pressure Impregnation



OtherMarkets

- Automotive
- Electrical machines
- NMR
- Medical
- Composite structures

Alternatives

- Wet and wind
- Pre-impregnated
- Non insulated coils
- Dry insulation

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

- DEMAK
- ASG
- Bruker
- Elytt Energy

Public

ITER

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of Solder Impregnation Process	40 to 80%	>1M	6 months to 2 years	High	Partially

Magnets



Insulation and joining

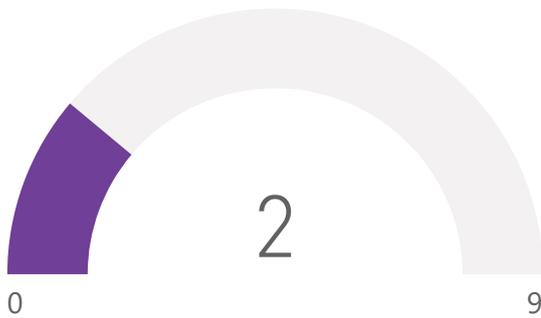
Maturity



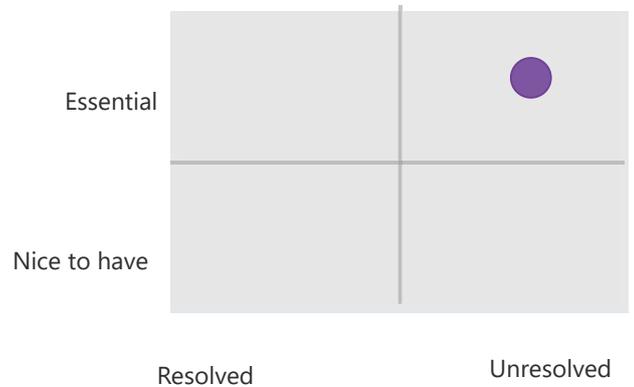
Demountable joints

IGNORE FOR NOW

TRL



Test Facilities Entities



Other Markets

Alternatives

Complexity and low asset integrity

Showstoppers

Repeatability
Ability to use remote handling
Reliable performance (resistance and leak tightness)

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Sultan (EPFL-SPC)

Ability to test batches of demountable joints

Private

Public

Gauss Fusion
ENI
ASG
ELYTT Energy

ENEA
F4E
CEA
KIT

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of specialized tooling for mounting / dismounting Joints					
Define resistance requirements for demountable HTS joints	>80%	<250k	<6 months	High	Partially
Improve reliability in a variety of conditions (mounting/demounting cycles, stresses, radiation, etc.)	40 to 80%	>1M	>2 years	Medium	Partially
Prototyping and Testing of HTS Joints against EM forces	40 to 80%	>1M	6 months to 2 years	Medium	Partially

Magnets

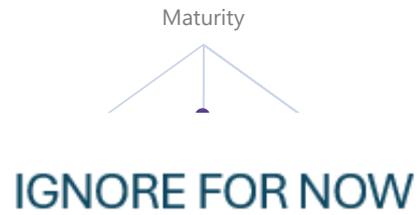
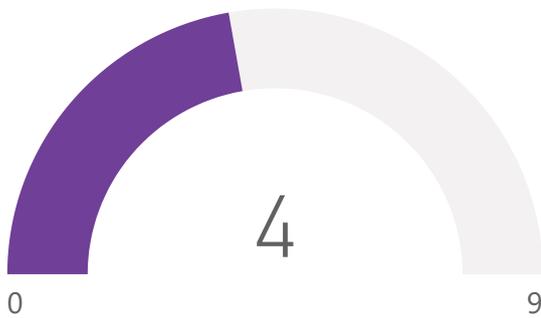


Insulation and joining



HTS joints

TRL



OtherMarkets

MRI, Defense, Rotary Machines, Mobility, Medical

Alternatives

LTS

Technology Characteristics

Test Facilities

SULTAN (EPFL-SPC)
SELFIE (CEA)

Test Facility Function

Qualification of the junction, exposure to different environmental conditions, radiation exposure, reliability

European Entities Involved

Private

ASG, Renaissance, Gauss, Tokamak Energy, ELYTT Energy

Public

KIT, ENEA, CEA, CIEMAT, EPFL-SPC

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop pressure-based concepts for HTS joints	<40%	250k to 1M	>2 years	High	Partially
Dedicated Testing Facilities for HTS Joints	>80%	>1M	>2 years	High	No
Standardization of joint design for most promising families of HTS tapes	>80%	>1M	>2 years	Medium	Partially
Develop repair strategy for existing concepts	40 to 80%	250k to 1M	>2 years	Medium	No

Magnets

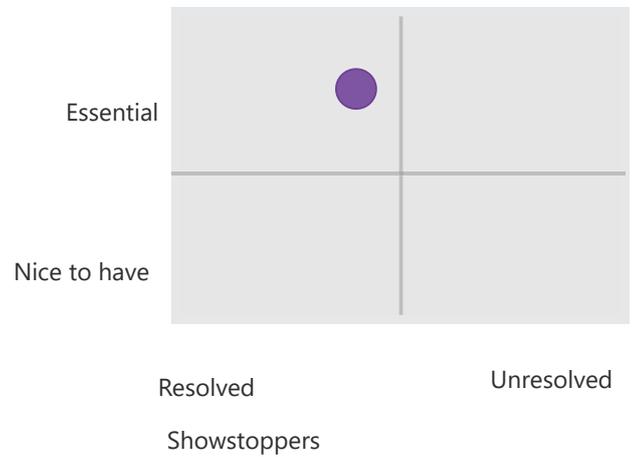


Insulation and joining



LTS joints

TRL



OtherMarkets

Alternatives

▲
MRI, Militar, HEP, NMR, Accelerators

Technology Characteristics

Test Facilities

SULTAN (EPFL-SPC), SELFIE (CEA)

Test Facility Function

▲
Additional capability for testing for a scalable market

European Entities Involved

Private

▲
ASG

Public

ENEA, CIEMAT, CEA, CERN, PSI, KIT, VTT

Technology Development Actions

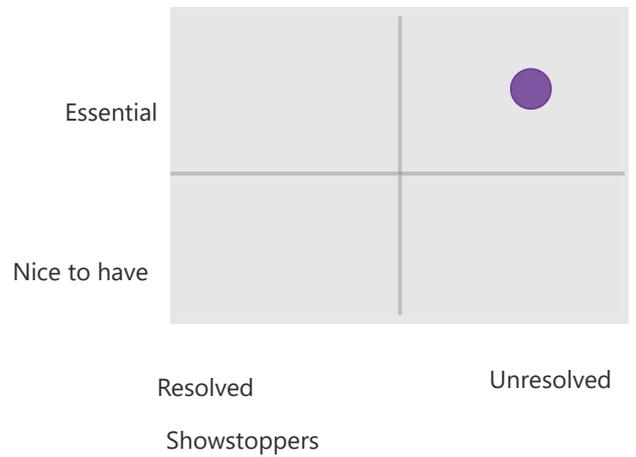
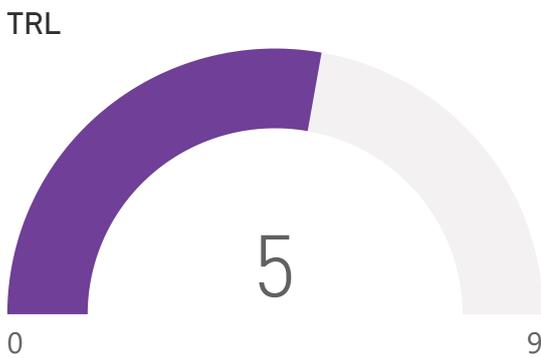
Name	Chances of success	Cost	Implementation Time	Priority	Funded
	▲				

Magnets



Insulation and joining

Non insulated HTS coils - resistance control



OtherMarkets

Alternatives

Resolved

Unresolved

Showstoppers

Insulated coils

Mechanical stability
Detection of fast signals

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

ASG, Tokamak Energy

ENEA, UKAEA, CERN, PSI, CEA, INFN

Technology Development Actions

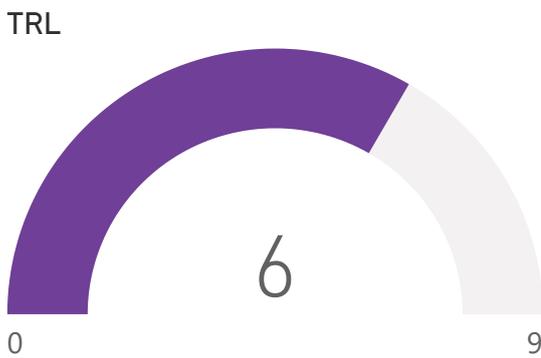
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Build and test a small prototype coil to evaluate solutions	>80%	>1M	6 months to 2 years	High	Partially
Define QA standards for the winding of non-insulated HTS coils to enhance reproducibility and reliability	>80%	250k to 1M	6 months to 2 years	Medium	No
Build and test a large coil to validate findings	40 to 80%	>1M	>2 years	High	Partially
Material development and characterisation	40 to 80%	>1M	6 months to 2 years	High	Partially

Magnets

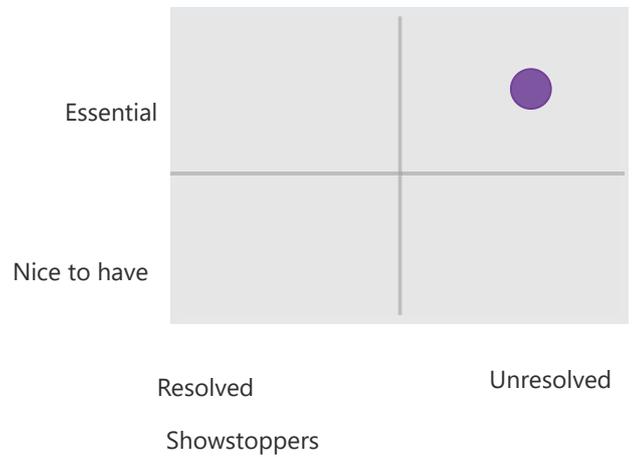


Insulation and joining

Radiation tolerant insulation systems



IGNORE FOR NOW



OtherMarkets

Alternatives

Technology Characteristics

Test Facilities

CERN (mechanical, uncoupled), KIT, Vienna University, Experimental Fission reactors

Test Facility Function

Radiation test

European Entities Involved

Private

Public

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Dedicated facility for testing coils insulation	>80%	250k to 1M	>2 years	Medium	No
Further exploration and optimization of radiation tolerant insulation	>80%	250k to 1M	6 months to 2 years	Medium	No

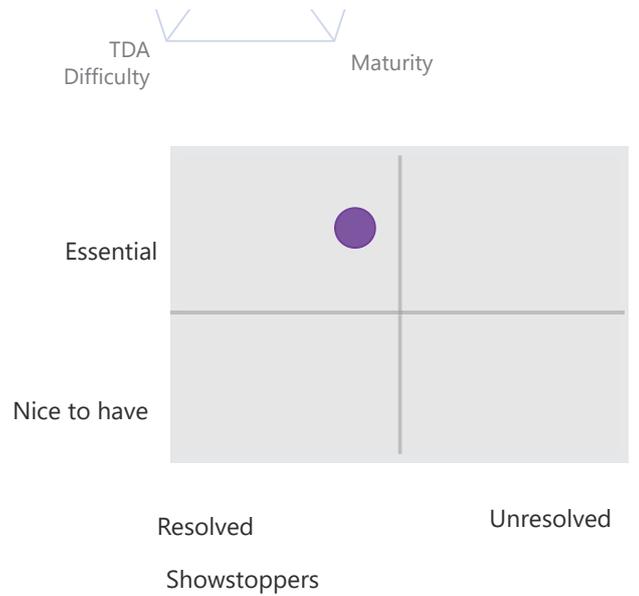
Magnets



Insulation and joining



Terminations and current leads



OtherMarkets

Alternatives

Power transmission
Data centers

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

ASG, Bruker

CERN, KIT, CIEMAT, CEA, ENEA

Technology Development Actions

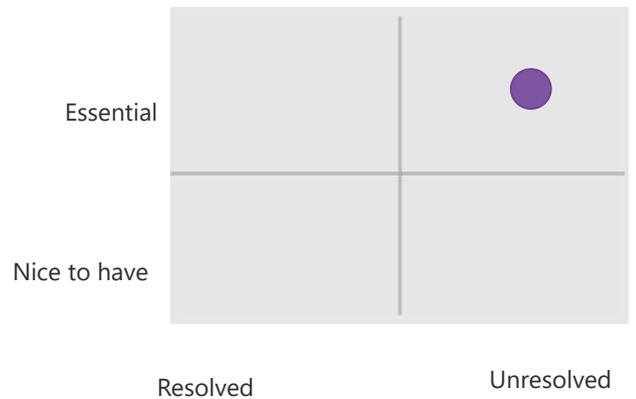
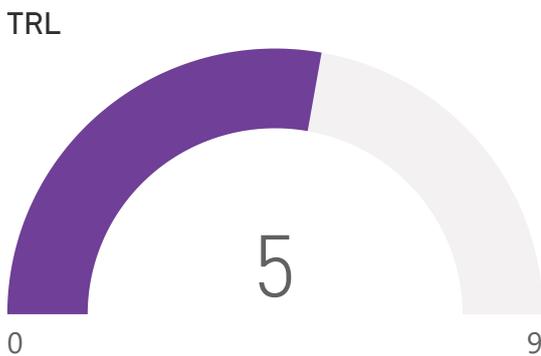
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Assessing degradation and obtaining qualified HTS current leads	>80%	250k to 1M	6 months to 2 years	Low	No

Magnets



Magnet protection

Energy extraction systems



OtherMarkets

NMR, MRI, SMES
LTS magnets

Alternatives

internal energy dump

Showstoppers

Voltage management

Technology Characteristics

Test Facilities

ITER, CEA, CERN, DTT, ENEA

Test Facility Function

no need for a specific facility, we could use any other existing facility with minor adaptation

European Entities Involved

Private

Varistors (Metrosil), Danfysik, Ocem, ABB, Secheron

Public

ITER, CEA, CERN, DTT, ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop high current DC (~60kA) switches	40 to 80%	>1M	>2 years	Medium	Partially

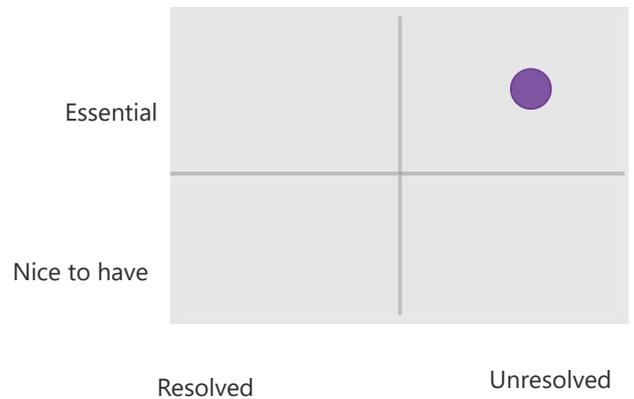
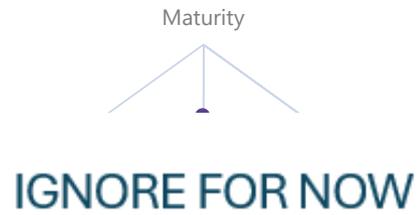
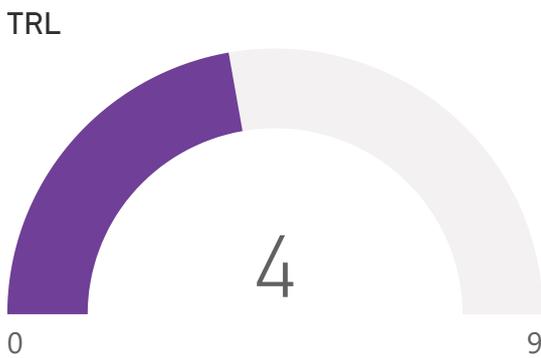
Magnets



Magnet protection



Quench acceleration



OtherMarkets

MRI, LTS magnet systems, medicine, motor/generator, aerospace

Alternatives

external energy extraction (when applicable)

Showstoppers

Suitable facility, Validation, Difficult to implement.

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Proxima

Public

INFN, EPFL-SPC

Technology Development Actions

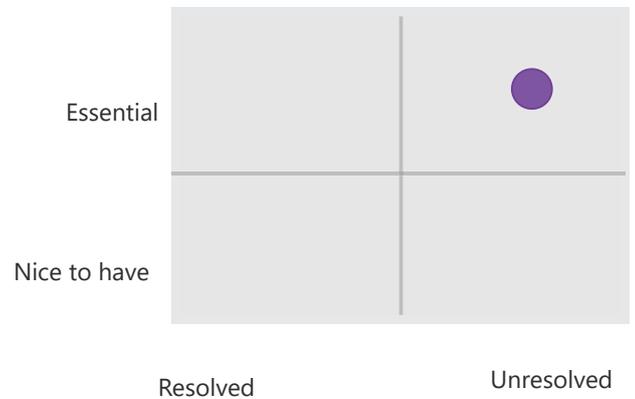
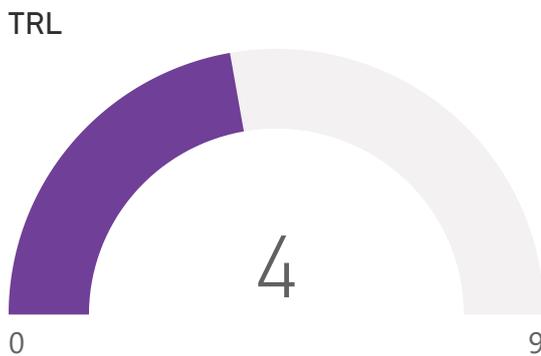
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Create benchmark models for HTS to investigate all quench propagation methods (distributed heaters - internal or external, EM, uniform conductors or conductor with current flow divertor)	40 to 80%	250k to 1M	6 months to 2 years	High	Partially
Develop models for EM quench propagation models	40 to 80%	<250k	6 months to 2 years	Medium	No

Magnets



Magnet protection

Quench detection techniques



OtherMarkets

MRI, LTS magnet systems, medicine, motor/generator, aerospace

Alternatives

Passive quench protection

Showstoppers

Sensitivity of the instruments
Lack of test facilities.

Technology Characteristics

Test Facilities

CEA, FBI (KIT), DTT, Sultan (EPFL-SPC)

Test Facility Function

Validate quench detection techniques for different magnet configurations

European Entities Involved

Private

Renaissance, Proxima, Tokamak Energy, ASG superconductors, Bilfinger, SIGMAphi, Oxford instrument, Tesla

Public

CEA, KIT, DTT, EPFL-SPC, ITER, CERN, ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
develop AI-assisted quench detection techniques	>80%	>1M	6 months to 2 years	Low	No
Develop facilities for quench detection validation	>80%	>1M	>2 years	Medium	No
Model coils to identify suitable quench detection techniques	40 to 80%	>1M	>2 years	High	No

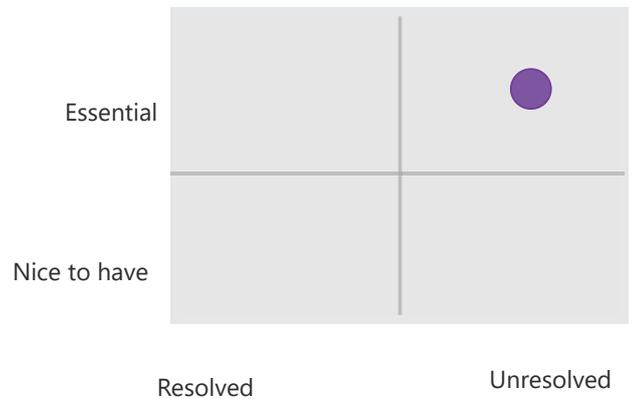
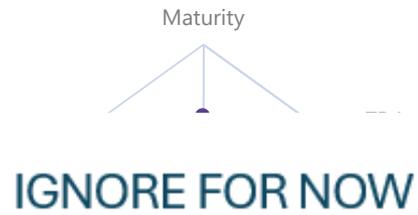
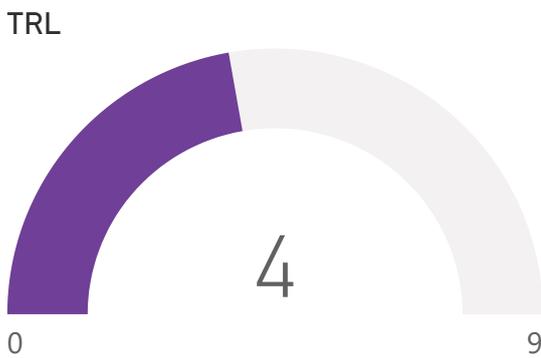
Magnets



Magnet protection



Quench models



OtherMarkets

MRI, NMR market, accelerator magnets, oncology, military, motor/generator, energy transmission, space application

Alternatives

Resolved

Unresolved

Showstoppers

Complexity, Validation of the models.

Technology Characteristics

Test Facilities

The TEAM (Testing Electromagnetic Analysis Methods), we need something similar for quench propagation models
TFMC is a good example

Test Facility Function

(benchmark pre-defined cases)

European Entities Involved

Private

Proxima, ASG, Renaissance, Bruker Tokamak, LBE

Public

University of Liège, KIT, Darmstadt

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Connect to the existing HTS quench propagation model community	>80%	<250k	<6 months		
Develop quench design criteria specific for HTS	40 to 80%	250k to 1M	>2 years	Medium	No
Develop/extend database for cryogenic properties	>80%	<250k	6 months to 2 years	Medium	No

Magnets

Instrumentation and auxiliary systems

Cryogenic cooling systems



OtherMarkets

- Hydrogen
- Mobility
- Medical
- Electronics
- Energy
- Quantum computing

Alternatives

Resolved

Unresolved

Showstoppers

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

- Air Liquide
- Linde
- Absolut Systems

Public

ESET, F4E, CERN, ITER, ENEA, CEA (Grenoble)

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of Turbo Brayton for HTS magnets	40 to 80%	<250k	<6 months	Medium	Partially

Magnets

Instrumentation and auxiliary systems

Entities



Feedthroughs

IGNORE FOR NOW

TRL



TDA Difficulty Relevance



OtherMarkets

Alternatives

Medical
Mobility
Energy

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

High current test facility for commercializing feedthroughs

Private

Public

ITER, CERN

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop a program for qualification of commercially available connectors for required environment conditions	40 to 80%	250k to 1M	6 months to 2 years	Low	Partially

Magnets

Instrumentation and auxiliary systems

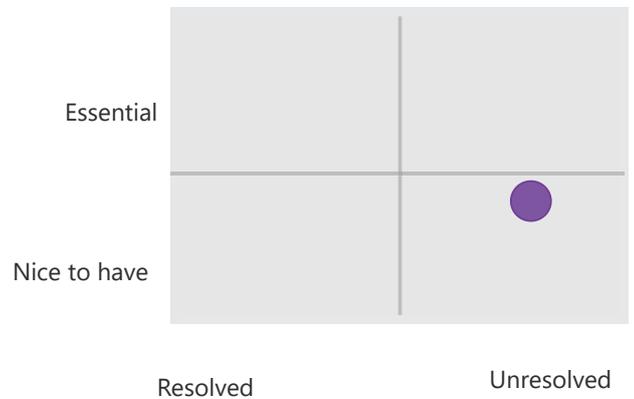
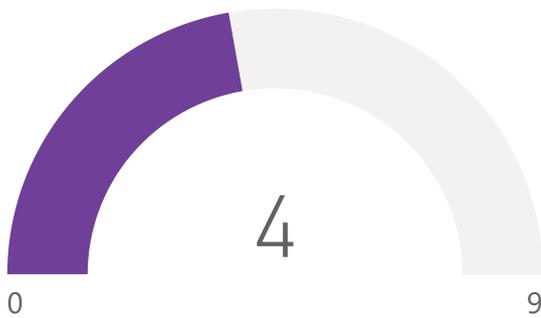
Entities



Fiber optic sensing

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TRL



OtherMarkets

- Power plants
- Infrastructure
- Aerospace

Alternatives

- Voltage taps

Resolved

Showstoppers

- Fragility

Unresolved

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

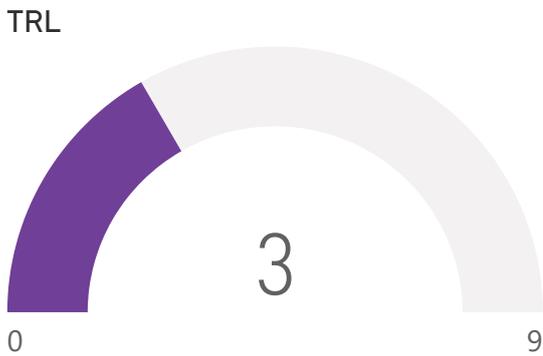
Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop a robust way for fiber optics integration into a magnet for a reliable operation	40 to 80%	250k to 1M	6 months to 2 years	Medium	No

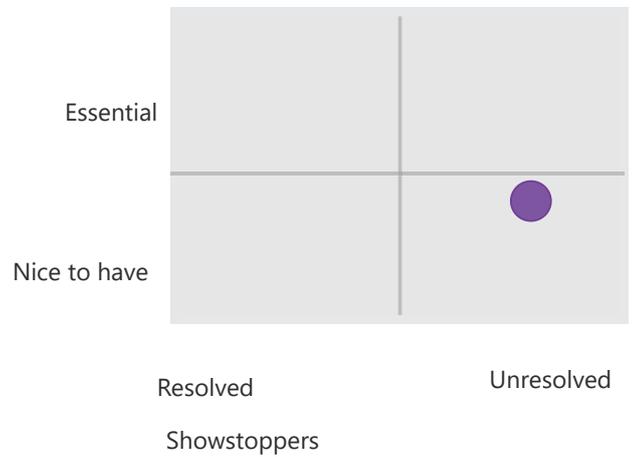
Magnets

Instrumentation and auxiliary systems

Acoustic emission monitoring



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OtherMarkets
▲
Pressure vessels

Alternatives

Technology Characteristics

Test Facilities

Test Facility Function
▲

European Entities Involved

Private
▲

Public

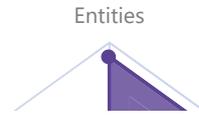
Technology Development Actions

Name	Chances of success ▲	Cost	Implementation Time	Priority	Funded
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Magnets

Instrumentation and auxiliary systems

Magnetic field mapping



IGNORE FOR NOW



OtherMarkets

Alternatives

Mass detection
Medical
Space
Spectrometers

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Calibration of Hall probes in high fields

Private

Public

PSI

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop practical method for measuring magnetic field in large volume coils	40 to 80%	250k to 1M	6 months to 2 years	Low	No
Develop supply chain for high field cryo calibrated Hall probes	40 to 80%	250k to 1M	6 months to 2 years	Low	No

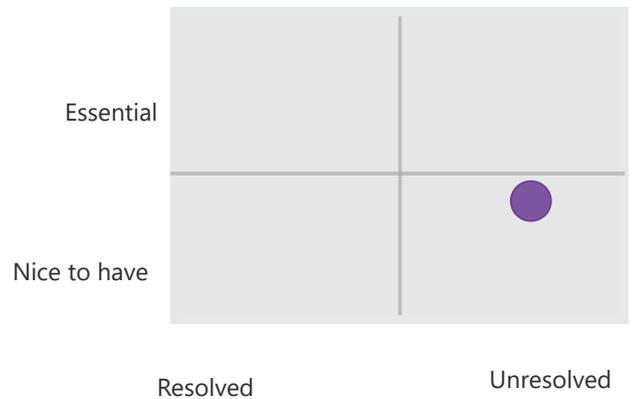
Magnets

Instrumentation and auxiliary systems

Persistent current switches



IGNORE FOR NOW



OtherMarkets

Energy storage
Mobility
Medical
NMR

Alternatives

Protection as per current state-of-the-art by room temperature circuit breakers

Showstoppers

High demands to residual resistivity of the switch
Strict demands for heat dissipation

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

EPFL-SPC

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop high current superconducting switches for magnets protection	40 to 80%	>1M	6 months to 2 years	Low	No

Magnets

Instrumentation and auxiliary systems



Power supplies

IGNORE FOR NOW

TRL



OtherMarkets

Alternatives

- Mobility
- Medical
- Space
- Data centres
- Metal production
- Defense

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

Ampegon, ABB, Tektronix

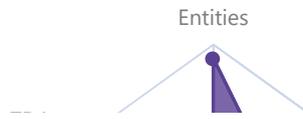
Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Formulate requirements which are applicable for future magnets	>80%	<250k	<6 months	Medium	No

Magnets

Instrumentation and auxiliary systems

Shimming coils



IGNORE FOR NOW



OtherMarkets

Alternatives

Medical
NMR

Technology Characteristics

Test Facility Function

European Entities Involved

Private

Public

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets

Instrumentation and auxiliary systems

Voltage taps extraction



OtherMarkets

Alternatives

Showstoppers

Electrical systems

Optical fibres
Thermocouple arrays

Technology Characteristics

Test Facilities

Test Facility Function

European Entities Involved

Private

Public

ITER

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop reliable insulation methods for magnet penetrations	>80%	250k to 1M	6 months to 2 years	Medium	No
Develop industrial standard for HV extraction	>80%	<250k	6 months to 2 years	Low	No
Developing cold electronics for remote sensing	40 to 80%	250k to 1M	6 months to 2 years	Low	No

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