Technology Development Programme

Magnets

2025

Technology dashboards for review

Introductory notes

What is this document?

This is an intermediate document in the mapping process aiming at providing the technology dashboards to the participants for review.
The document contains the post processed data following the workshop for each technology covered.

What is expected from participants?

If you have the time and interest, please review the technologies of interest to you. Let us know if you feel the data needs to be modified (missing or incorrect information).

We are particularly interested in your feedback on:

- TRL
- Test facilities
- Entities involved (public and private)
- Technology Development Actions

This is also the final chance to comment on the list of technologies in case you feel modifications are required.

The current list of technologies is provided on page 3 to facilitate your navigation in the file. The description of the TRL scale is provided in Appendix for reference.

How to provide feedback?

Send an email to marc.simon@f4e.europa.eu.

You may either annotate this file directly or list your comments in the body of the email.

What do I need to know about the dashboards?

The test facilities and actors listed must be based in the EU, UK or Switzerland. For test facilities, we have accepted to list those which are operated by companies based in the EU, UK and Switzerland even if they are outside those territories.

List of technologies

Superconducting materials
BSCCO
Iron-base superconductors
LTS
MgB2
REBCO

Cables and conductors
CORC cable
Dry conductors
HTS Rutherford cable
HTS Roebel cable
Internally cooled conductors
Stacked tape cables

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

Manufacturing
3D printed formers
High precision coil winding
3D printed HTS
Modular coil winding
Resin VPI

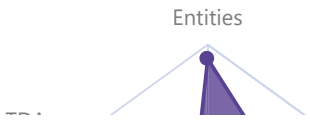
Joining and insulation
Demountable joints
HTS joints
LTS joints
Non insulated HTS coils
Radiation tolerant insulation
Terminations and current leads

Magnet protection
Energy extraction systems
Quench acceleration
Quench detection techniques
Quench models

Instrumentation and auxiliaries
Cryogenic cooling systems
Feedthroughs
Fiber optic sensing
Hydraulic monitoring
Magnetic field mapping
Persistent current switches
Power supplies
Shimming coils
Voltage taps extraction

Magnets › Superconducting material

BSCCO



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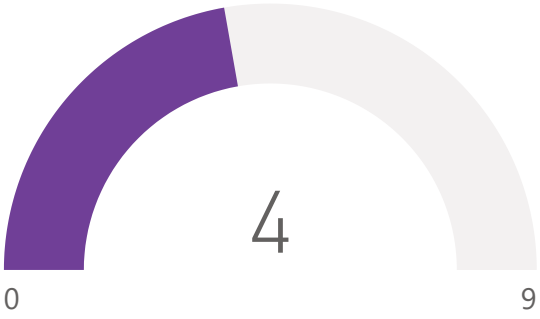

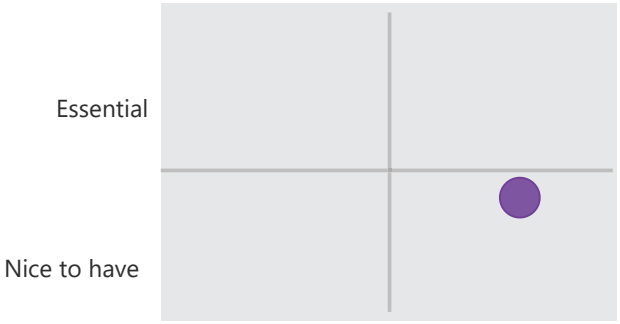

OtherMarkets	Alternatives	Showstoppers
Medical, Current leads, Energy storage, Mobility	REBCO LTS for other applications	Commercial availability, Cost

Technology Characteristics

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

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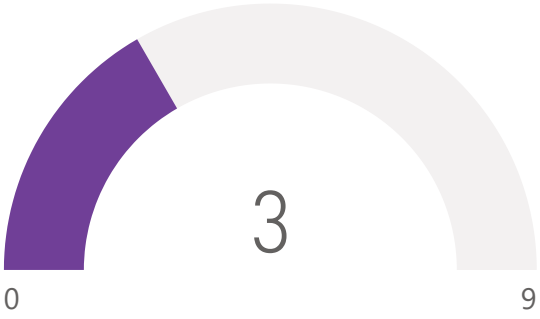

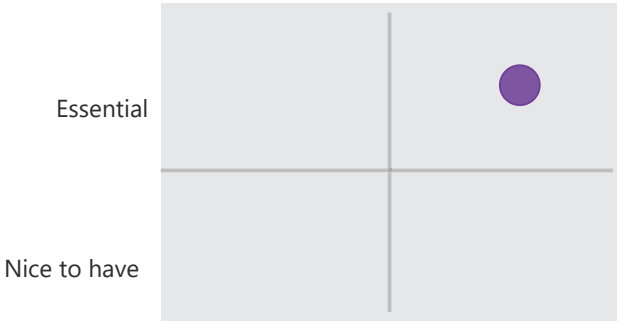

OtherMarkets	Alternatives	Showstoppers
Medical, Energy storage, Mobility, Power	REBCO LTS for some applications	Toxicity, Low critical current

Technology Characteristics

Test Facilities	Test Facility Function
CNR-SPIN, ENEA	Material characterization at lab scale Test synthesis process.

European Entities Involved	
Private	Public
	CNR-SPIN, ENEA

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

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TDA Difficulty — Relevance

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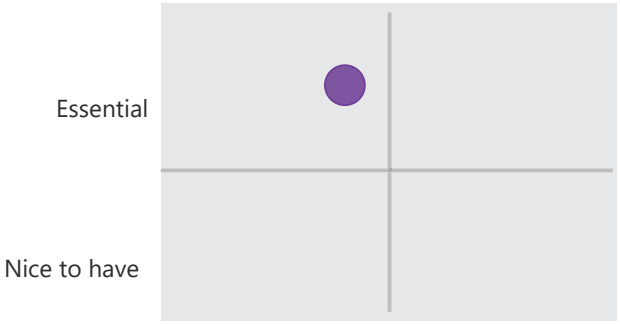


OtherMarkets	Alternatives	Showstoppers
Medical, Energy Mobility	REBCO	Use of Helium as cooling system, Medium field applications only

Technology Characteristics

Test Facilities	Test Facility Function
ENEA, EPFL-SPC, CERN, University of Twente, Durham, Oxford, CIEMAT, INFN-LASA, UniGE, CEA	Superconductor characterization: - transport properties (Ic, Tcs) - mechanical behaviour - radiation hardness

European Entities Involved

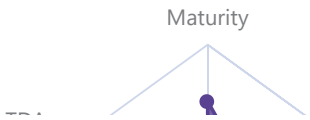
Private	Public
Bruker	University of Geneva

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



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Relevance

Test Facilities

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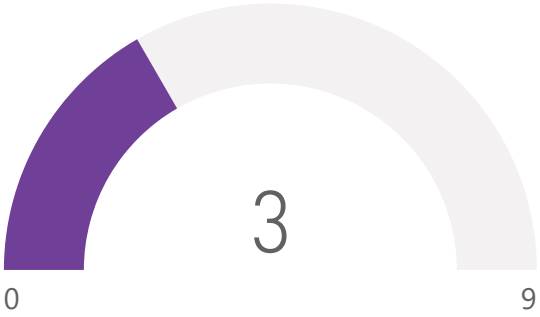

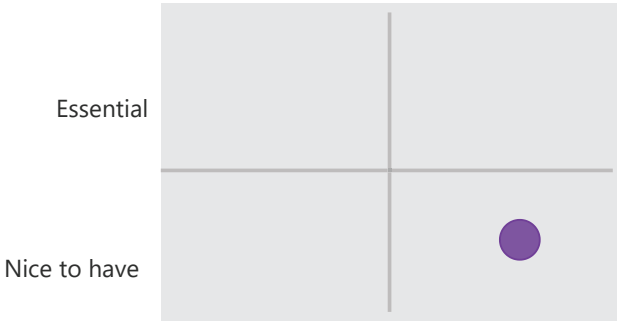

OtherMarkets	Alternatives	Showstoppers
Current leads, busbars, Energy transport, Medical	REBCO LTS for some applications	Low field applications only

Technology Characteristics

Test Facilities	Test Facility Function
Properties: University of Geneva, ENEA, KIT, CNRS Irradiation: TUWien, NCBJ, INRNE, ESS, SCK-CEN, INFN-LNL, PSI, CERN, CIEMAT, EBTC	Superconductor characterization: - transport properties (Ic, Tcs) - mechanical behaviour - radiation hardness.

European Entities Involved

Private	Public
Columbus (ASG)	ENEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets › Superconducting material

REBCO

Maturity

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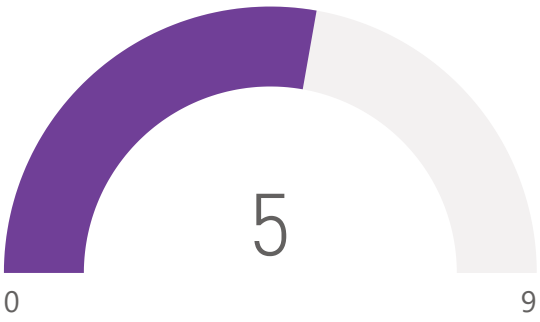

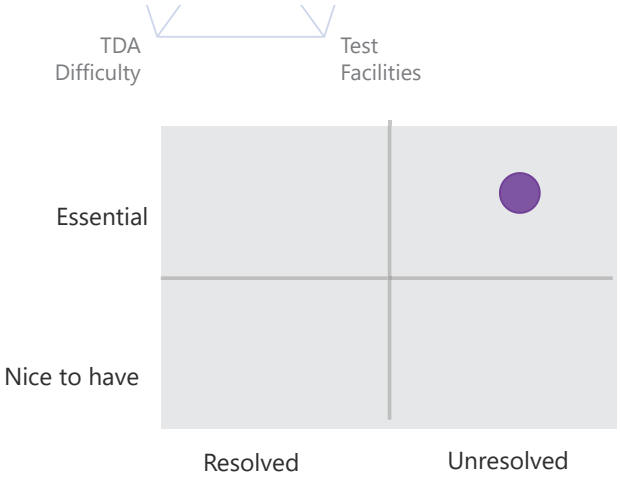

OtherMarkets	Alternatives	Showstoppers
Transportation, Power, Medical, Energy storage	LTS for lower field applications	Costs, Mechanics, Radiation resistance unknown, Quench detection

Technology Characteristics

Test Facilities	Test Facility Function
Properties: University of Geneva, ENEA, KIT, CNRS Irradiation: TUWien, NCBJ, INRNE, ESS, SCK-CEN, INFN-LNL, PSI, CERN, CIEMAT, EBTC	Superconductor characterization: - transport properties (Ic, Tcs) - mechanical behaviour - radiation hardness.

European Entities Involved

Private	Public
THEVA, Suprema, Subra	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

CORC cable

Entities

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Relevance — Test Facilities

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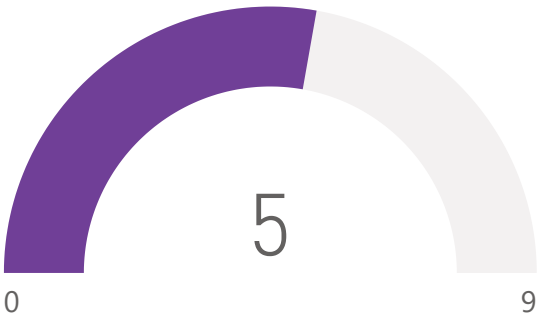

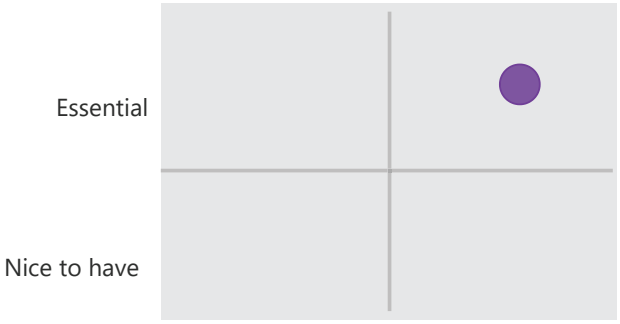

OtherMarkets	Alternatives	Showstoppers
AC cables, Power, Medical, Transport		Strain sensitivity, Cost, AC losses, Manufacturing, Low current density, Field quality.

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN (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

European Entities Involved	
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

Dry conductors

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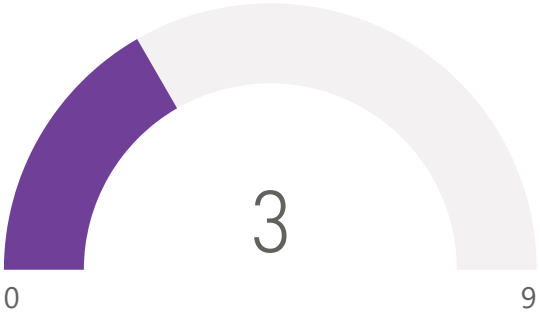

Maturity

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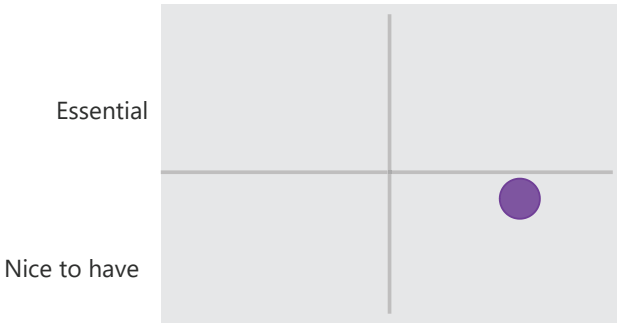
Relevance

Test Facilities



OtherMarkets	Alternatives	Showstoppers
		Resolved / Unresolved
Medical, Motors, Energy storage, Gyrotrons	CICC Stacked tapes	Heat load extraction, Quench protection

Technology Characteristics

Test Facilities	Test Facility Function
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

European Entities Involved

Private	Public
ICAS NEXANS NKT	SPC CERN

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

HTS Rutherford cables

Maturity

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Relevance

Test Facilities

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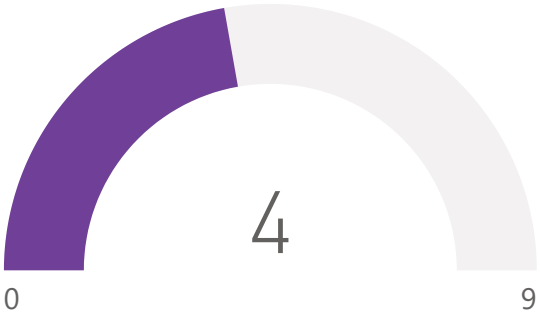

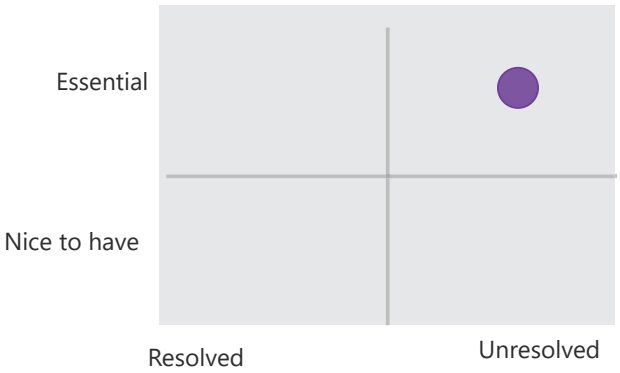

OtherMarkets	Alternatives	Showstoppers
Medical, NMR, MRI	CORC Stacked tapes	Maximum transverse stress, Heat load extraction, Manufacturing, Mechanical robustness

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN (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
FRESCA 2 (CERN)	High voltage tests

European Entities Involved

Private	Public
ICAS, Nexans, NKT	CERN, 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

HTS Roebel cables

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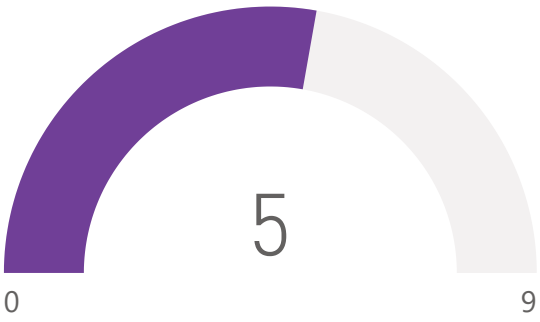

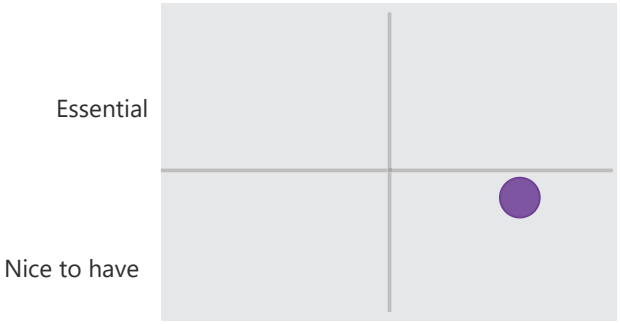

OtherMarkets	Alternatives	Showstoppers
Power (motors, generators, convertors)	All other types	Cost, Manufacturing, Mechanical strength, Material waste

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN (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

European Entities Involved

Private	Public
	CERN
	KIT

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets › Conductors and cables

Internally cooled conductors

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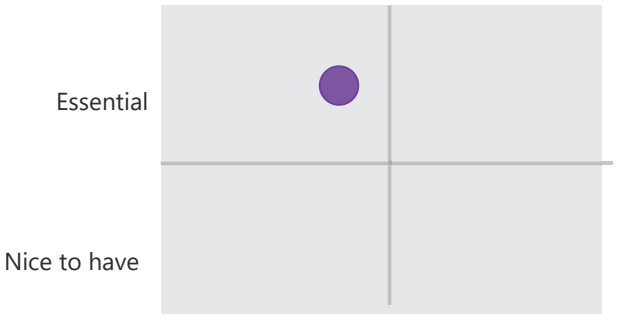


OtherMarkets	Alternatives	Showstoppers
Power, Busbar, current leads	Dry conductor	Low current density, Field quality

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN (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

European Entities Involved

Private	Public
ICAS	CERN
Gauss	SPC
Proxima Fusion	CEA
TE Magnetics	ITER
	ENEA

Technology Development Actions

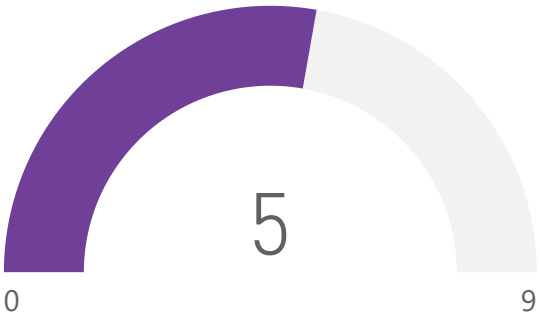
Name	Chances of success	Cost	Implementation Time	Priority	Funded

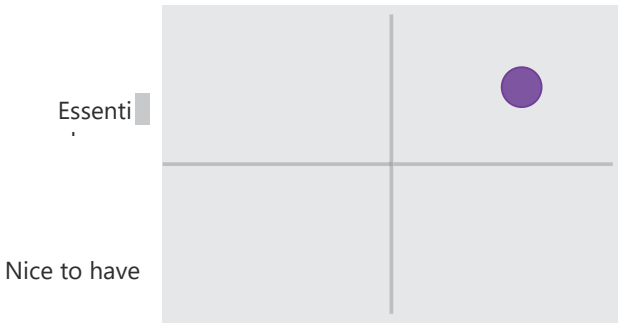
Magnets › Conductors and cables

IGNORE FOR NOW

Stacked tape cables

TRL





OtherMarkets	Alternatives	Showstoppers
Current leads and busbars, DC cables, Medical, Power	All other types	AC losses, Quench protection, Potential damage to tape, Field quality

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN (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

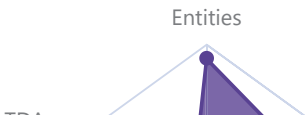
European Entities Involved

Private	Public
ICAS, TE magnetics, Proxima Fusion, Gauss	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

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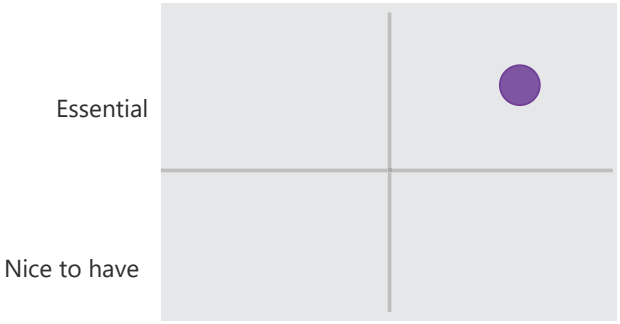

OtherMarkets	Alternatives	Showstoppers
MRI Energy management Mobility Electrical machines	Increased thermal margin Empirical models	Computational complexity (many length scales) Experimental validation

Technology Characteristics

Test Facilities	Test Facility Function
Josefa (CEA), SULTAN, ITER MCTF, SM18	With dedicated power supply

European Entities Involved	
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

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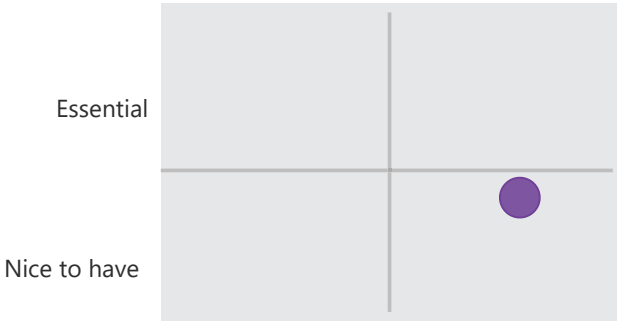

OtherMarkets	Alternatives	Showstoppers
Automation industry, robotics, mobility, civil engineering, power plants, aviation	Only for individual goals of digital twin - verification data, data-driven simulators, but not for all	Lack of test facilities Real-life application disturbances High system complexity

Technology Characteristics

Test Facilities	Test Facility Function
No Test facility oriented to digital twins	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

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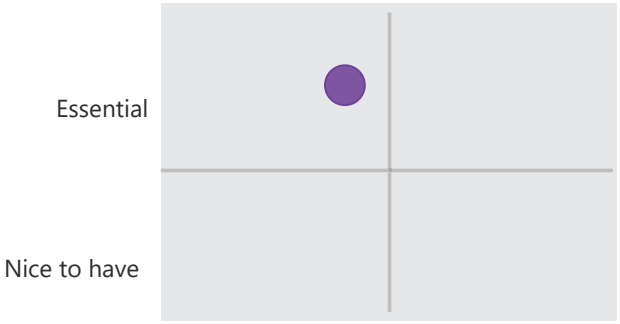


OtherMarkets	Alternatives	Showstoppers
Abundant examples		Input material properties, Computational resources, Knowledge of failure mechanisms

Technology Characteristics

Test Facilities	Test Facility Function
CERN	Material properties Validation of failure models

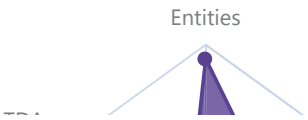
European Entities Involved	
Private	Public
	F4E, CERN, ITER

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



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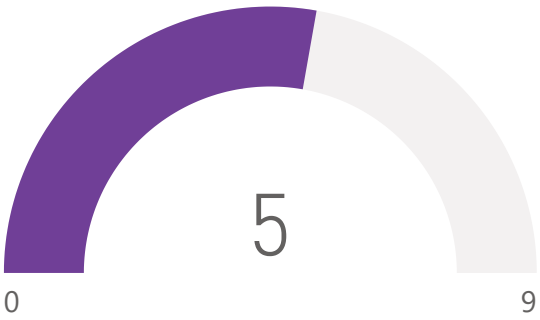
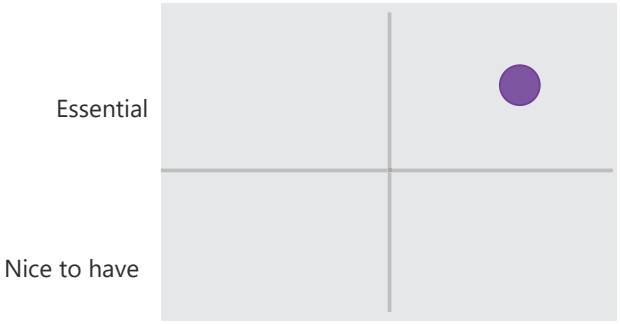




OtherMarkets	Alternatives	Showstoppers
Abundant examples	Safety factors accounting for other physical effects, experimental data	Computational resources, need of HPC Validation of models Deep knowledge-base needed to develop these models

Technology Characteristics

Test Facilities	Test Facility Function
ITER MCTF, ASDEX, WEST, W7-X, SM18 at CERN, DTT Cold Test Facility, SULTAN, TCV, Jordi	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

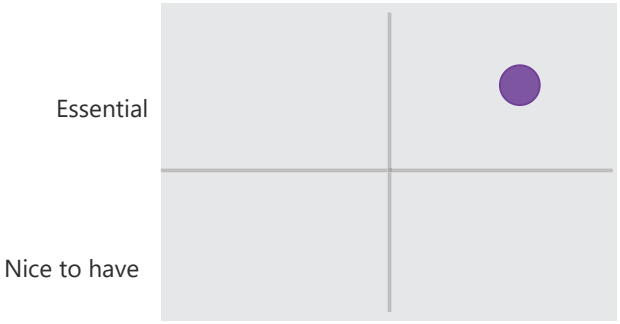
Technology Development Actions

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	Showstoppers
HTS powerlines, composite materials, MRI		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
SULTAN, Twente Press University, KIT, ENEA, CERN	Characterization of failure modes for tapes/cables/conductors Qualification of failure modes for tapes/cables/conductors

European Entities Involved

Private	Public
RINA, ASG	PSI, Twente University, KIT, ENEA, CERN, University of Bristol, ICMAB, CEA, University of Tuscia

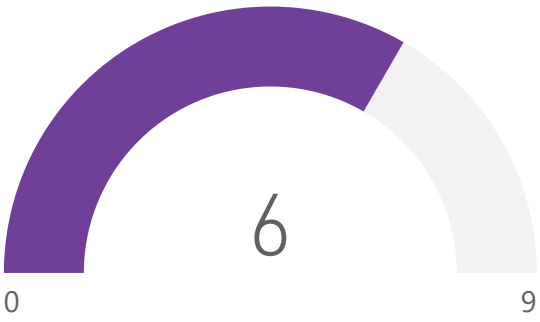
Technology Development Actions

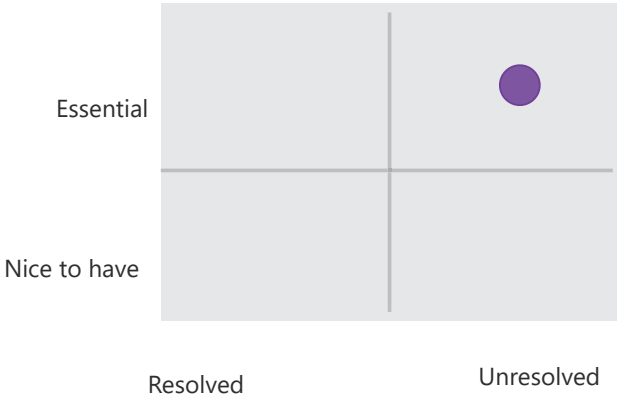
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Experimental Campaigns to Characterize mechanical properties and strength	>80%	>1M	>2 years	High	Partially
Modelling of mechanical failure in tapes	>80%	>1M	>2 years	High	
Understanding of irradiation damage mechanism	>80%	>1M	>2 years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

Magnets › Modelling

Thermo-hydraulic analysis

TRL





OtherMarkets	Alternatives	Showstoppers
Cryogenics, Heat exchangers	Experimental data	Understanding two-phase flow behavior in narrow environments, Complex models or difficult validation (liquid metal). Limited validation data.

Technology Characteristics

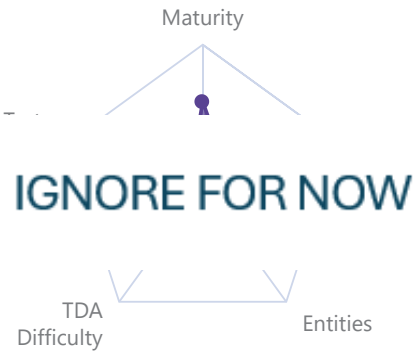
Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public
	Model validation, measurement of material properties		

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

3D printed formers



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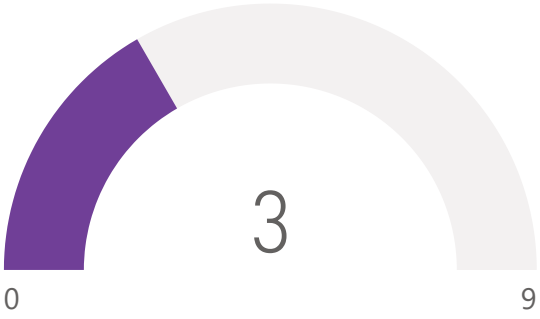
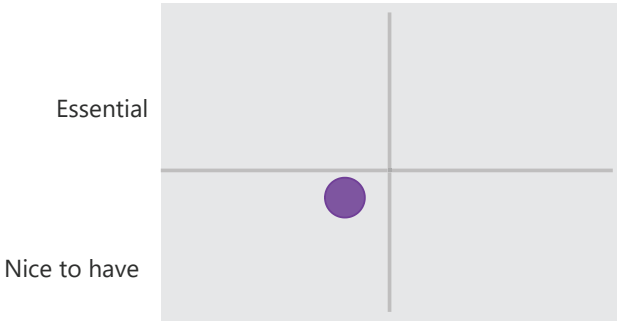




OtherMarkets	Alternatives	Showstoppers
Anywhere where structural parts are used	Machined Cast	Mechanical and physical properties

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public
HP, Rosswag, Probeam, AMCM GmBH, ASG, Bruker, SeaAlp	CERN, PSI

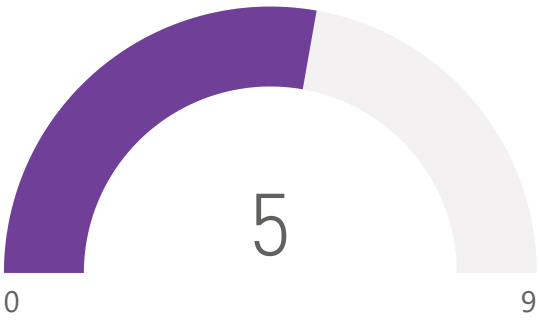
Technology Development Actions

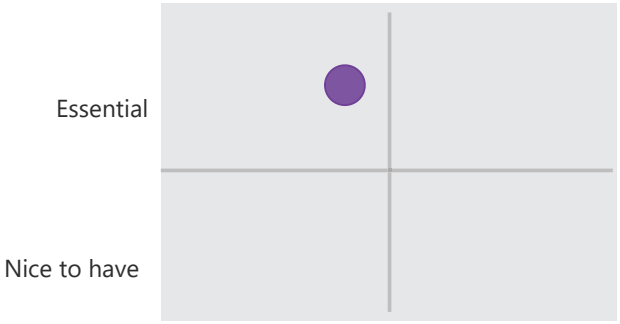
Name	Chances of success	Cost	Implementation Time	Priority	Funded
3D Former Proof of Concept	>80%	>1M	6 months to 2 years	Medium	Partially

Magnets › Manufacturing

High precision coil winding

TRL





OtherMarkets	Alternatives	Showstoppers
NMR Medical Energy storage	3D printing/etching Modular coils	

Technology Characteristics

Test Facilities	Test Facility Function
CERN PSI (SW)	Test winding accuracy

European Entities Involved

Private	Public
ASG, Ridgway (UK)	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

3D printed HTS

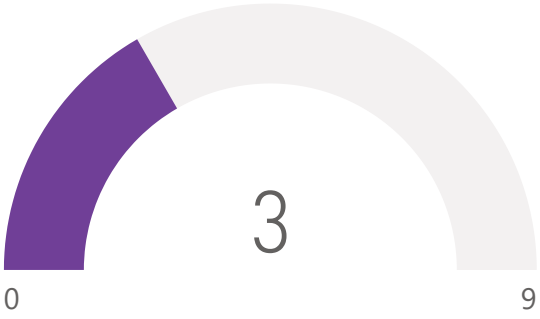
Maturity

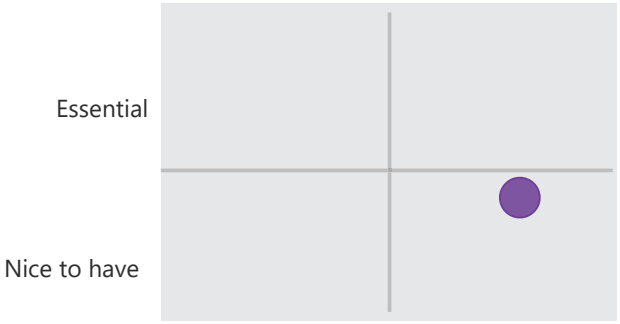
IGNORE FOR NOW

TDA Difficulty

Relevance

TRL





OtherMarkets	Alternatives	Showstoppers
Medical Energy storage Mobility	Vapour and chemical deposition Round wire production	Scalability Reliability Powder availability Cost

Technology Characteristics

Test Facilities	Test Facility Function

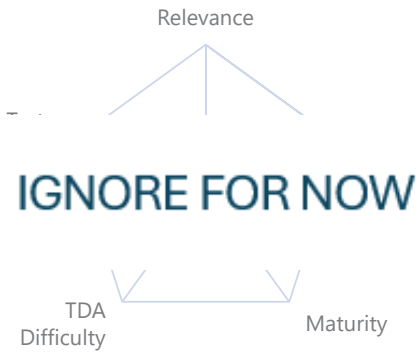
European Entities Involved	
Private	Public
SUBRA, Suprema, Theva, Renaissance Fusion	ENEA, CERN, KIT, CEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded
Proof of concept that profiled HTS can be successfully manufactured	<40%	>1M	>2 years	Medium	Partially

Magnets > Manufacturing

Modular coil winding



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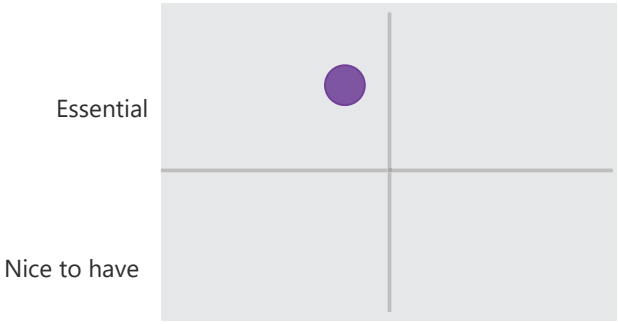


OtherMarkets	Alternatives	Showstoppers
Medical Energy storage Mobility	Layer wound coils	

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public
ASG, Bruker, Tokamak Energy, Ridgway	ENEA, CEA, PSI, CERN

Technology Development Actions

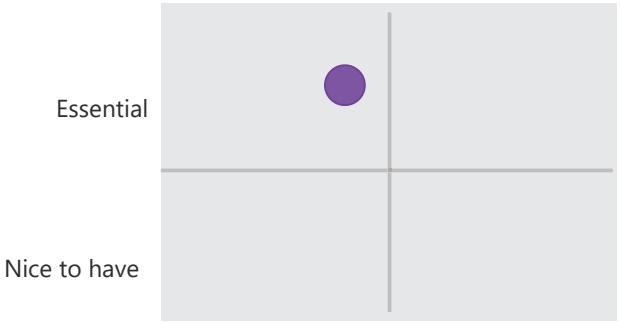
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop Coil Architecture for High Performance HTS Coils	40 to 80%	>1M	>2 years	High	Partially
Inter-module Joints for HTS Coils	40 to 80%	>1M	>2 years	High	Yes

Magnets > Manufacturing

Resin Vacuum Pressure Impregnation

IGNORE FOR NOW

TRL



OtherMarkets	Alternatives	Showstoppers
Automotive	Wet and wind	
Electrical machines	Pre-impregnated	
NMR	Non insulated coils	
Medical	Dry insulation	
Composite structures		

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public
DEMAK	ITER
ASG	
Bruker	
Elytt Energy	

Technology Development Actions

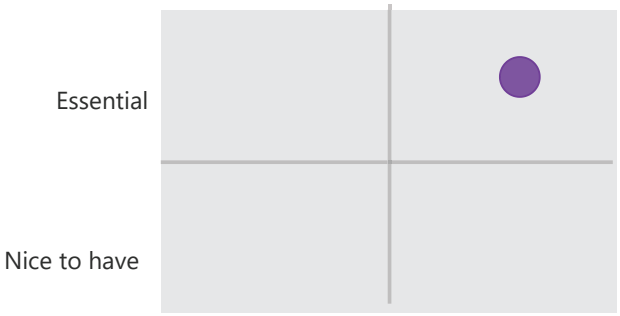
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of Solder Impregnation Process	40 to 80%	>1M	6 months to 2 years	High	Partially

Magnets › Insulation and joining

Demountable joints

IGNORE FOR NOW

TRL



		Resolved	Unresolved
OtherMarkets	Alternatives	Showstoppers	
	Complexity and low asset integrity	Repeatability Ability to use remote handling Reliable performance (resistance and leak tightness)	

Technology Characteristics

Test Facilities	Test Facility Function
Sultan (SPC)	Ability to test batches of demountable joints

European Entities Involved

Private	Public
Gauss Fusion	ENEA
ENI	F4E
ASG	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

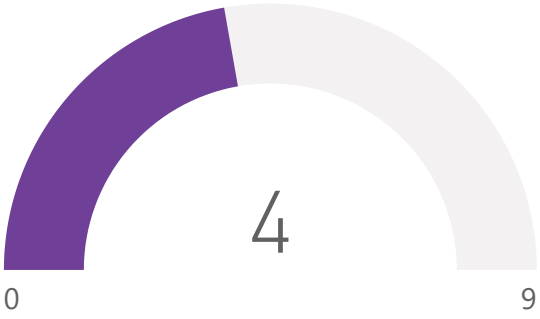
Maturity

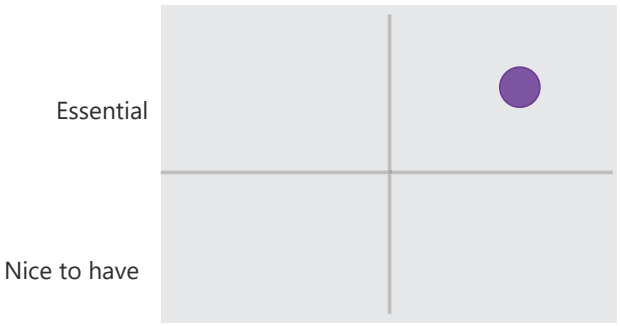
IGNORE FOR NOW

TDA Difficulty

Test Facilities

TRL





OtherMarkets	Alternatives	Showstoppers
MRI, Defense, Rotary Machines, Mobility, Medical	LTS	

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN	Qualification of the junction, exposure to different environmental conditions, radiation exposure, reliability

European Entities Involved

Private	Public
ASG, Renaissance, Gauss, Tokamak Energy,	KIT, ENEA, CEA, CIEMAT

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

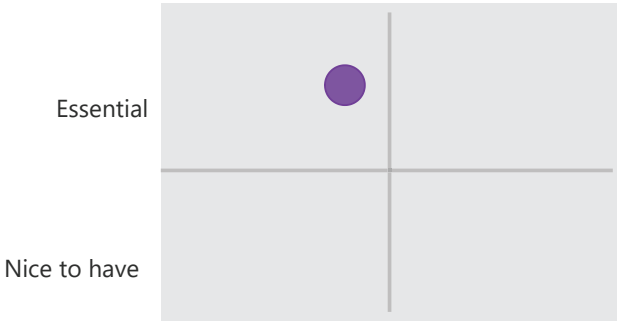
Relevance

IGNORE FOR NOW

Maturity

Test Facilities

TRL



OtherMarkets	Alternatives	Showstoppers
MRI, Militar, HEP, NMR, Accelerators		

Technology Characteristics

Test Facilities	Test Facility Function
SULTAN	Additional capability for testing for a scalable market

European Entities Involved	
Private	Public
ASG	ENEA, CIEMAT, CEA, CERN, PSI, KIT, VTT

Technology Development Actions

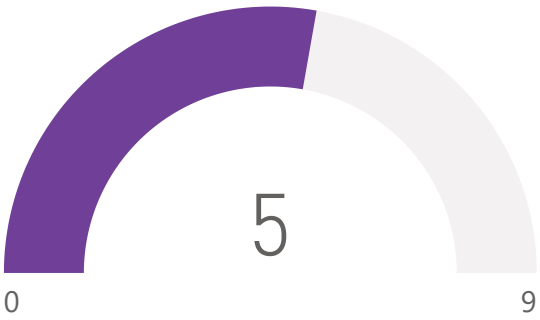
Name	Chances of success	Cost	Implementation Time	Priority	Funded

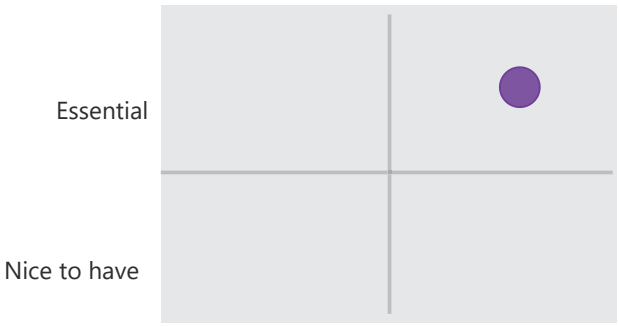
Magnets › Insulation and joining

Non insulated HTS coils - resistance control

IGNORE FOR NOW

TRL





OtherMarkets	Alternatives	Showstoppers
	Insulated coils	Mechanical stability Detection of fast signals

Technology Characteristics

Test Facilities	Test Facility Function

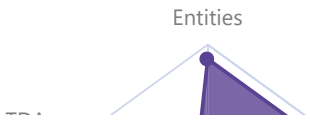
European Entities Involved	
Private	Public
ASG, Gauss, Renaissance Fusion, Tokamak Energy	ENEA, UKAEA

Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets › Insulation and joining

Radiation tolerant insulation systems



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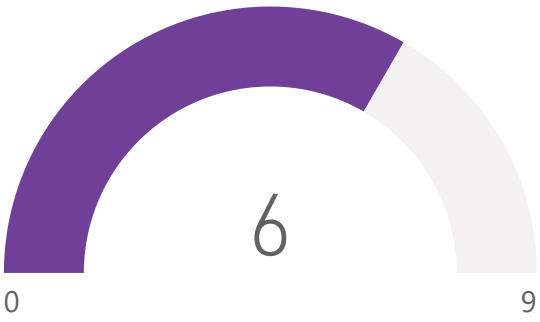
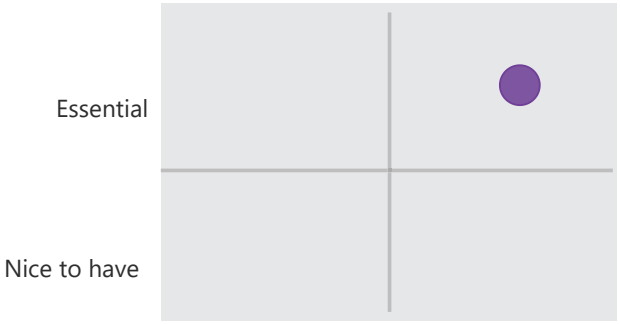




OtherMarkets	Alternatives	Showstoppers

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public
CERN (mechanical, uncoupled), KIT, Vienna University, Experimental Fission reactors	Radiation test		

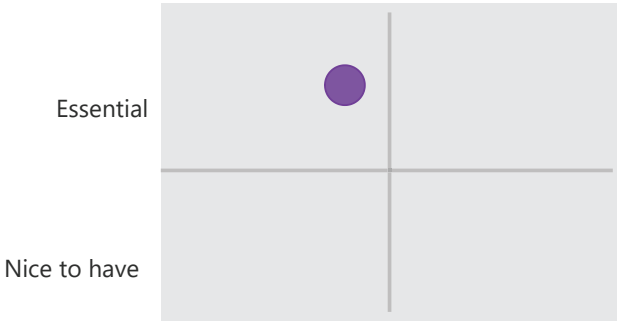
Technology Development Actions

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 optmization of radiation tolerant insulation	>80%	250k to 1M	6 months to 2 years	Medium	No

Magnets › Insulation and joining

Terminations and current leads

TRL



OtherMarkets	Alternatives	Showstoppers
Power transmission Data centers		

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public
ASG, Bruker	CERN, KIT, CIEMAT, CEA, ENEA

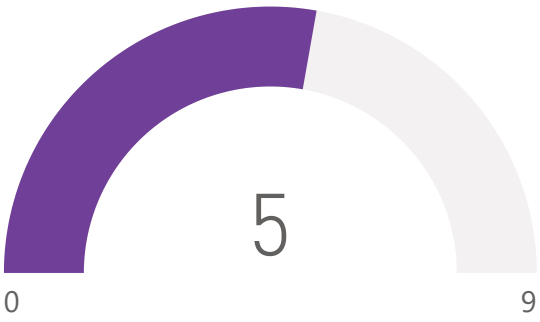
Technology Development Actions

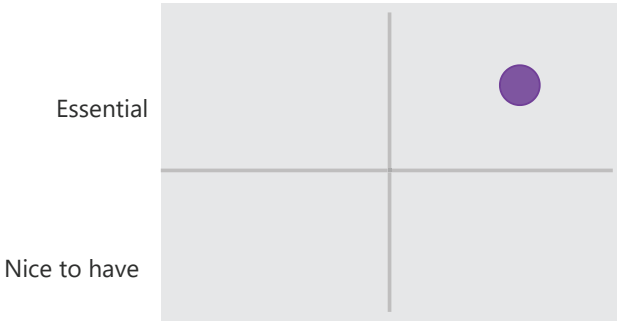
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Assessing degradation and obtaining qualified HTS current leads	>80%	250k to 1M	6 months to 2 years	Low	No

Magnets › Magnet protection

Energy extraction systems

TRL





OtherMarkets	Alternatives	Showstoppers
NMR, MRI, SMES LTS magnets	internal energy dump	Voltage management

Technology Characteristics

Test Facilities	Test Facility Function
ITER, CEA, CERN, DTT, ENEA	no need for a specific facility, we could use any other existing facility with minor adaptation

European Entities Involved

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

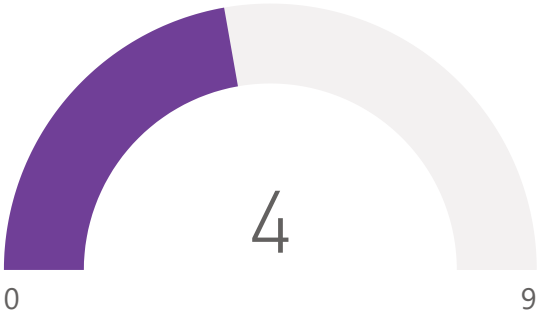
Maturity

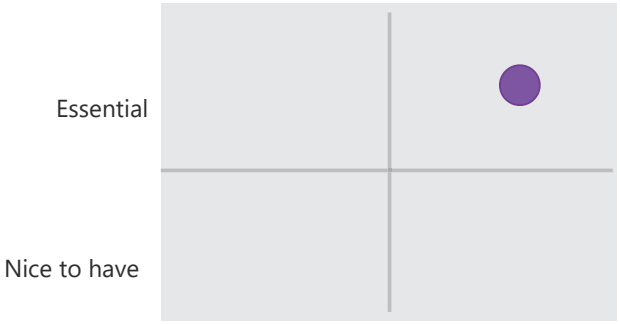
IGNORE FOR NOW

Test Facilities

TDA Difficulty

TRL





OtherMarkets	Alternatives	Showstoppers
MRI, LTS magnet systems, medicine, motor/generator, aerospace	external energy extraction (when applicable)	Suitable facility, Validation, Difficult to implement.

Technology Characteristics

Test Facilities	Test Facility Function

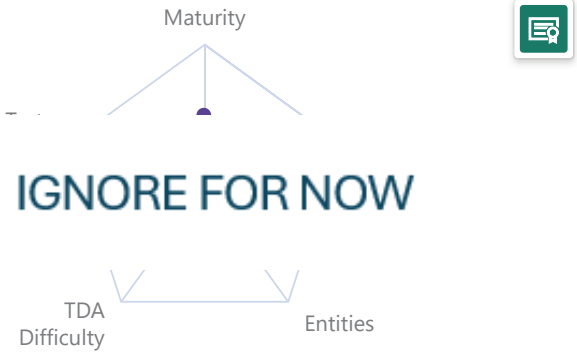
European Entities Involved	
Private	Public
Proxima	INFN, EPFL

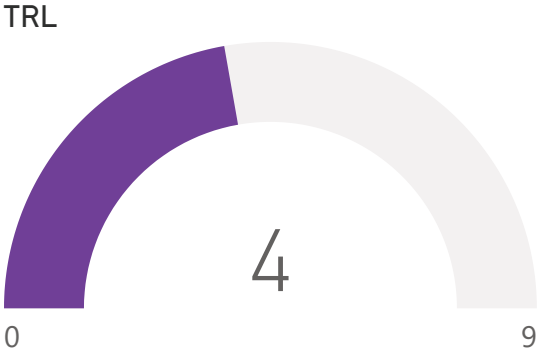
Technology Development Actions

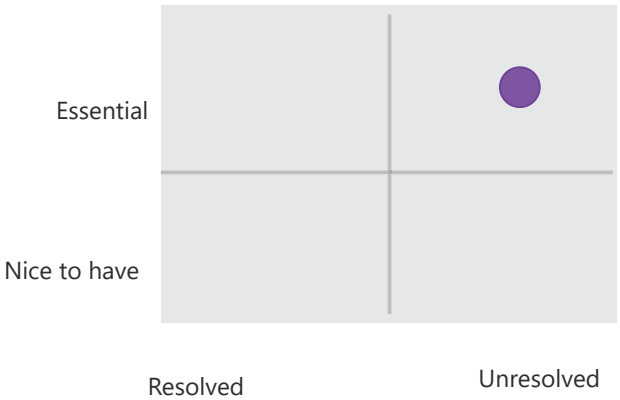
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Create benchmark models for HTS to investigate all quench propagation methods (distributed heaters - internal or external, EM, uniformous conductors or conductor with current flow divertor)	40 to 80%	250k to 1M	6 months to 2 years	High	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	Alternatives	Showstoppers
MRI, LTS magnet systems, medicine, motor/generator, aerospace	Passive quench protection	Sensitivity of the instruments Lack of test facilities.

Technology Characteristics

Test Facilities	Test Facility Function
CEA, FBI (KIT), DTT, Sultan (EPFL)	Validate quench detection techniques for different magnet configurations

European Entities Involved

Private	Public
Renaissance, Proxima, Tokamak Energy, ASG superconductors, Bilfinger, SIGMAphi, Oxford instrument, Tesla	CEA, KIT, DTT , EPFL, 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

IGNORE FOR NOW

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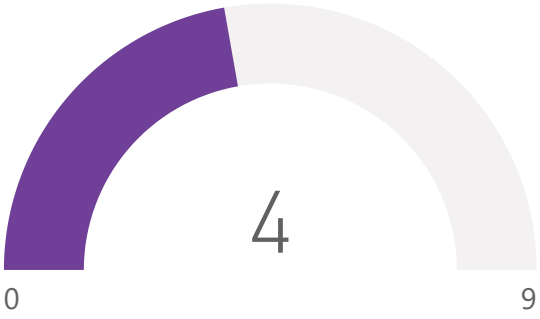
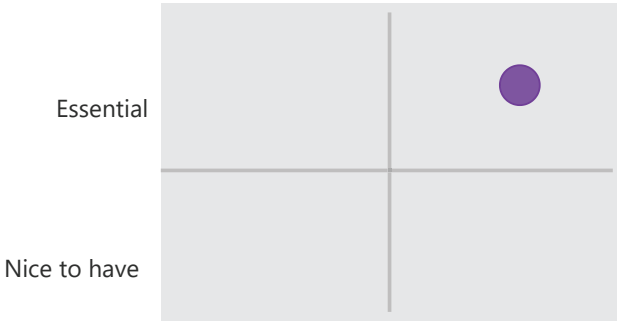




OtherMarkets	Alternatives	Showstoppers
MRI, NMR market, accelerator magnets, oncology, military, motor/generator, energy transmission, space application		Complexity, Validation of the models.

Technology Characteristics

Test Facilities	Test Facility Function
The TEAM (Testing Electromagnetic Analysis Methods), we need something similar for quench propagation models TFMC is a good example	(benchmark pre-defined cases)

European Entities Involved	
Private	Public
Proxima, ASG, Renaissance, Bruker Tokamak, LBE	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

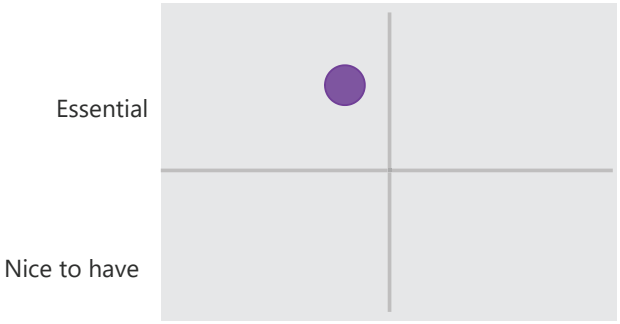
Cryogenic cooling systems

Relevance

IGNORE FOR NOW

Maturity Entities

TRL



OtherMarkets	Alternatives	Showstoppers
Hydrogen		
Mobility		
Medical		
Electronics		
Energy		
Quantum computing		

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved

Private	Public
Air Liquide	ESET, F4E, CERN, ITER, ENEA
Linde	
Absolut Systems	

Technology Development Actions

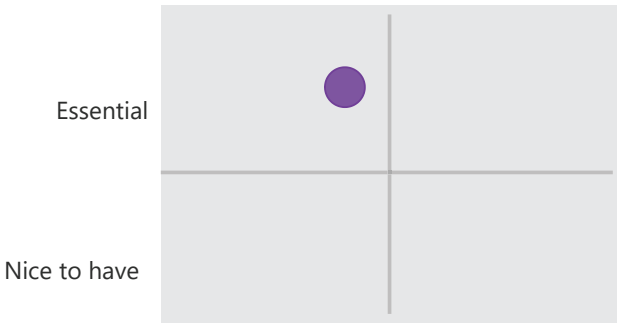
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Development of Turbo Brayton for HTS magnets	40 to 80%	<250k	<6 months	Medium	Partially

Magnets › Instrumentation and auxiliary systems

Feedthroughs

IGNORE FOR NOW

TRL



OtherMarkets	Alternatives	Showstoppers
Medical Mobility Energy		

Technology Characteristics

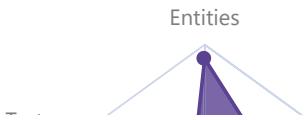
Test Facilities	Test Facility Function
	High current test facility for commercializing feedthroughs

European Entities Involved	
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



Fiber optic sensing

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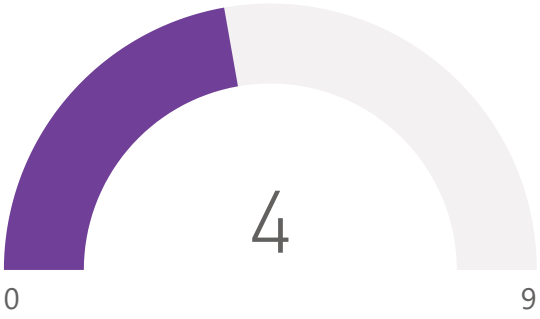
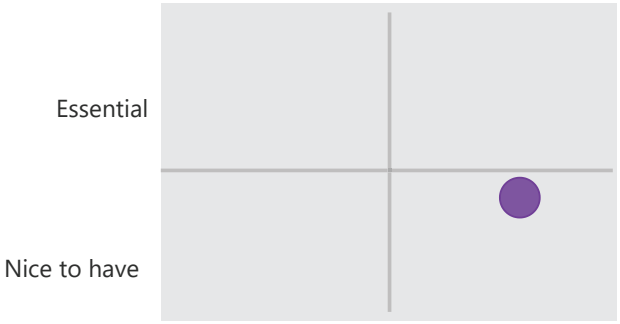
TRL





OtherMarkets	Alternatives	Showstoppers
Power plants Infrastructure Aerospace	Voltage taps	Fragility

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public

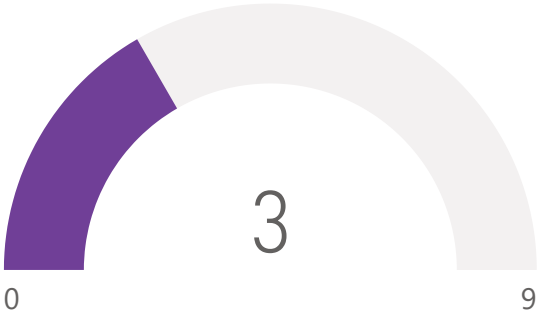
Technology Development Actions

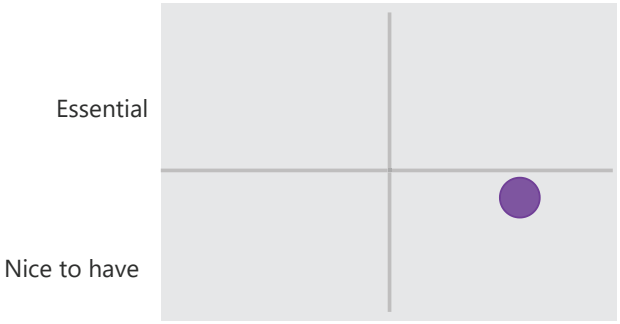
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Develop a robust way for fiber optics integration into a magnet for a reliable operation	40 to 80%	250k to 1M	6 months to 2 years	Medium	No

Magnets › Instrumentation and auxiliary systems

Hydraulic monitoring

TRL





OtherMarkets	Alternatives	Showstoppers
Pressure vessels		

Technology Characteristics

Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public

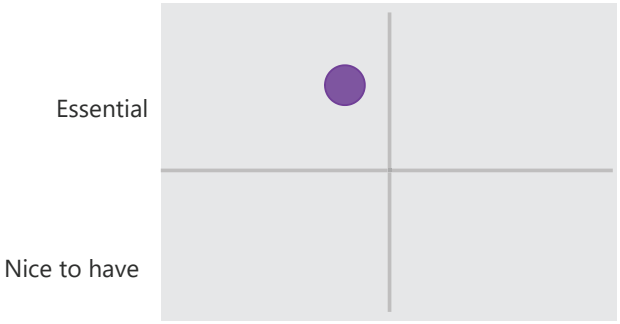
Technology Development Actions

Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets › Instrumentation and auxiliary systems

Magnetic field mapping

TRL



OtherMarkets	Alternatives	Showstoppers
Mass detection Medical Space Spectrometers		

Technology Characteristics

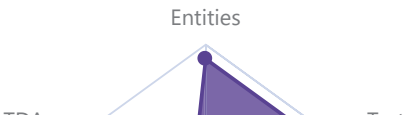
Test Facilities	Test Facility Function	European Entities Involved	
		Private	Public
	Calibration of Hall probes in high fields		PSI

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



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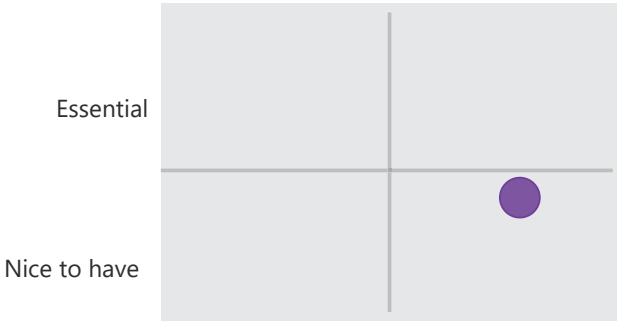


OtherMarkets	Alternatives	Showstoppers
Energy storage Mobility Medical NMR	Protection as per current state-of-the-art by room temperature circuit breakers	High demands to residual resistivity of the switch Strict demands for heat dissipation

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public

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

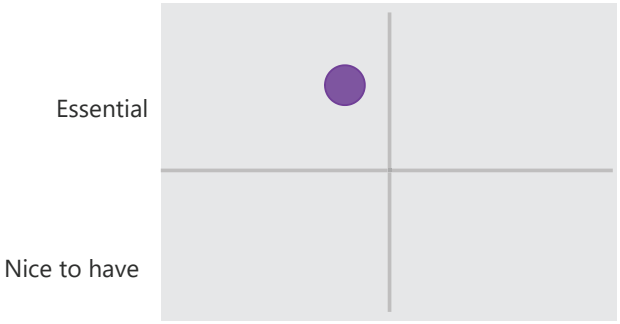
Test Facilities

IGNORE FOR NOW

TDA Difficulty

Entities

TRL



OtherMarkets	Alternatives	Showstoppers
Mobility		
Medical		
Space		
Data centres		
Metal production		
Defense		

Technology Characteristics

Test Facilities	Test Facility Function

European Entities Involved	
Private	Public
Ampegon, ABB	

Technology Development Actions

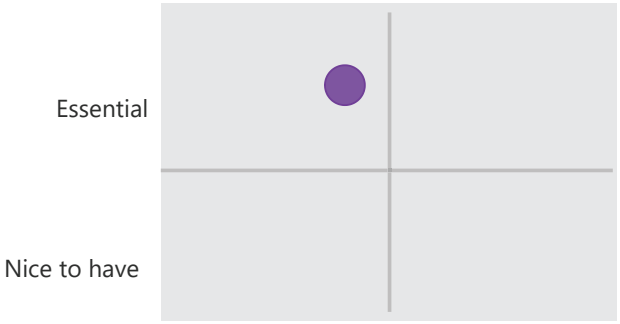
Name	Chances of success	Cost	Implementation Time	Priority	Funded
Formulate requirements which are applicable for future magnets	>80%	<250k	<6 months	Medium	No

Magnets › Instrumentation and auxiliary systems

Shimming coils

IGNORE FOR NOW

TRL



OtherMarkets	Alternatives	Showstoppers
Medical NMR		

Technology Characteristics

Test Facility Function	European Entities Involved	
	Private	Public

Technology Development Actions

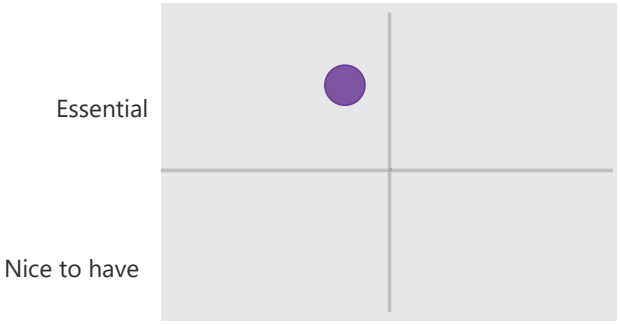
Name	Chances of success	Cost	Implementation Time	Priority	Funded

Magnets › Instrumentation and auxiliary systems

Voltage taps extraction

IGNORE FOR NOW

TRL



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

Appendix 1: Technology Readiness Levels

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

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

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