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AMICI

Accelerator and Magnet Infrastructure for Cooperation and Innovation

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DELIVERABLE REPORT

REPORT ON SUPERCONDUCTING MAGNET MARKET STUDY

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Authored by	P. Védrine, A. Yildirim	CEA	30/08/2019
Reviewed by	A. Gleeson [WP4 Leader]	STFC	04/10/2019
Approved by	O. Napoly [AMICI Coordinator]	CEA	07/10/2019

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1. INTRODUCTION

1.1 BACKGROUND

The AMICI H2020 project is charged by the European Commission with engaging the Technological Infrastructures (TIs), currently dedicated to European science-based accelerators and large magnets, with new, efficient and sustainable collaboration models by means of Cooperation and Innovation with industrial companies. The project has the challenging task of building the conditions for consolidating and exploiting collaborations to strengthen the capabilities of European companies, enabling them to compete on the global market, not only as qualified suppliers of components for accelerators and big superconductor magnets, but also in the development of innovative applications in advanced sectors such as healthcare, security and space.

To achieve this, AMICI Innovation-related activities aim to transfer the knowledge and know-how of the technological infrastructures to industry and create new products and new applications of direct benefit to society. It is anticipated that Industry will access a pool of technical platforms made available by European Technological Infrastructures. This will be by means of collaboration initiatives and opportunities between Industry and the TIs that include: research and development of key technology prototypes, test and verification of industrial products, professional training and apprenticeship, certification studies and training (e.g. vacuum, cleanliness, welding, etc.), harmonization and standardization studies (e.g. cryogenics, material, etc.).

1.2 OBJECTIVES

The overall objective of the Work Package 4 on Innovation is to promote the potential applications of mature Accelerator and Magnet technologies to European businesses, with a particular focus on innovative SMEs, which have the potential to apply their expertise to applications for societal needs through successful engagement with Technological Infrastructures. By drawing up an industry survey on magnet technologies, the present report will:

- Identify a European network of commercial organisations, consisting of both large companies and SMEs, that has the potential to innovate in the field of mature Magnet technologies.
- Identify domains of societal applications and potential markets beyond Research Infrastructures that can be developed by these innovative commercial organisations.
- Identify ways to optimise the effective engagement between Industry and the Technological Infrastructures to support the development of societal applications by industry.

This will allow industrials and TIs to enhance their visibility and competitiveness in new markets, and overcome the technology development barriers and further develop commercial opportunities within the Research Infrastructures and wider societal markets.

We will not deal in the rest of the document with "permanent magnet" or resistive type magnet applications because we will focus on the most promising potential applications, namely magnets using superconductors. Nowadays, the use of superconductivity is essential for the construction of magnets for physics. By using superconducting magnets, the Joule effect can be eliminated because the electrical resistance below a critical temperature is zero. The magnetic field generated in very large volumes can also be increased compared to conventional magnets. The operating cost of the machines can be reduced, despite the additional equipment necessary to maintain the magnet at low temperature and the size of the magnets is decreased due to the high current density in the superconducting materials.

1.3 METHODOLOGY

This investigation collects data from various primary and secondary sources including not only surveys and interviews with industrial companies performed in the framewok of WP4.2 but also white papers and other reports from magnet-related projects such as FuSuMaTech, and TIARA. For example we will use the work done in the FuSuMatech[1] to examine the synergies between industrial areas of MRI, NMR as well as other relevant applications and HL-LHC and FCC (Future Circular Collider) investments in the superconducting magnets technologies will be used.

Identification of European commercial organizations in the field of superconducting magnets

The European commercial organizations in the field of magnet have been identified thanks to AMICI partner personal contacts, Industry Liaison Offices, and public information. At the time of starting the investigation, a total of 86 companies have been identified and surveyed. The companies using superconducting magnet technologies represent 51 companies, being 59% of the identified global accelerator companies (See figure 1 below). These magnet-related companies are located in 13 countries (Austria, Czech Republic, Denmark, France, Germany, Greece, Italy, Poland, Spain, Sweden, Switzerland and the United Kingdom) (See figure 2 below).

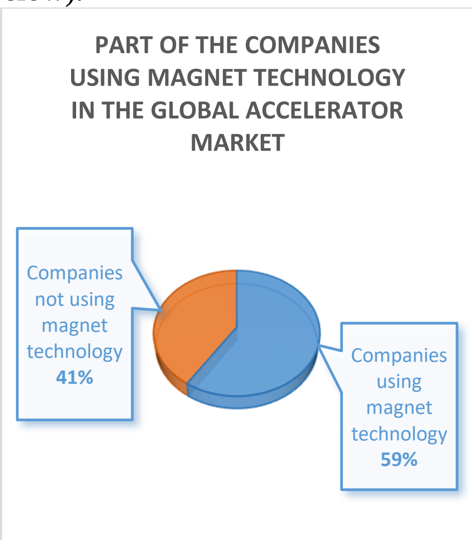

Figure 1: Part of the companies using magnet technologies in the global accelerator and magnet market

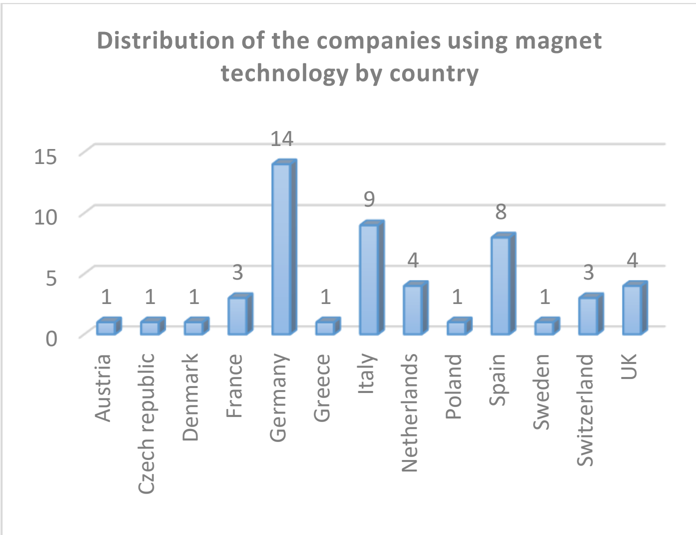

Figure 2: Distribution of the companies using magnet technologies by country

[1] This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 766974

The implementation of the web survey

The survey has been sent to industrial companies with questions focused on the market segments that could benefit companies; the magnet products or technological developments they expect; and the barriers and constraints they experienced from collaboration with the Technology Infrastructures.

The survey specific to the Magnet Market has been added as a 6th section to the survey prepared by theWP4.3. This section is composed by 8 questions structured into 3 main themes:

- Theme 1 – The existing magnet market segments (Q1,Q2)
- Theme 2 – The potential magnet market development (Q3 to Q7)
- Theme 3 – The constraints for cooperation (Q8, Q9)

Among the 51 contacted companies, 6 have answered specifically to the questionnaire i.e. the response rate is 12%.

The whole survey is shown in the Appendix A.

The implementation of the interviews

Carried out after, the telephone or face-to-face interviews take into account the experience gained from the web surveys as well as the output of the FuSuMaTech report published in April 2019. The interviews are prepared to complement the findings of the web survey, building a broader and deep picture of the companies/TIs relation strengths, weaknesses and needs within the magnet market. The companies interviewed have been selected among the ones that answered the questionnaire and the ones considered as key stakeholders in the European magnet market.

2. EUROPEAN SC MAGNET TECHNOLOGY AREAS

Superconductivity is a "macroscopic quantum phenomenon" which some materials exhibit at low temperatures. The superconducting state shows a number of extraordinary features: it allows, for example, an electrical DC current to flow with no loss. Today large and powerful superconducting magnets, exploiting this zero resistance, are routinely used in science, research and technological development (RTD) and in medical diagnosis, using Magnetic Resonance Imaging (MRI), the latter representing the biggest current market for superconductivity. In addition, the ultralow AC losses of superconductors may also result in potentially large energy savings in power applications, and demonstrations of power cables, transformers, motors or current limiters have already been made.

The fast development of these technologies and their dissemination in the European market and society could lead to a new paradigm for an energy-efficient, ecological, healthier and connected society.

2.1 STATE OF THE ART

Up to the 1980s, superconductivity could only be utilized when the materials were held at very low temperatures (Low Temperature Superconductors, LTS, with transition temperature typically below 15 K). Then, in 1986, a new class of materials (cuprates) was discovered which shows the transition to superconductivity already at higher temperatures (High Temperature

Superconductors, HTS, with transition temperature below 90 K). The perspective of operating temperatures which need much less expensive and less complex cooling systems, including the cryogen-free ones, raised hopes for a broad breakthrough of superconductor technology. The initial high-flying expectations ignored the complex nature of these new materials and so it took time to surmount the grain boundary problem of these ceramics which is now fully solved through mature manufacturing technologies leading to superior devices. Since then the discovery of novel superconductors continues and an unrested progress in understanding the unique intriguing properties of HTS materials has been registered. A superconductor which in several respects is somewhere between LTS and HTS is the Magnesium Diboride MgB2 which was discovered in 2001. Another class, the Iron Picnitides, which have slightly higher transition temperatures than MgB2, came up in 2008, and very recently the barrier of 200K as transition temperature was crossed in H2S under high pressure. A better understanding of the superconducting behaviour and the research of novel materials at higher critical temperature, field and current must be strongly pursued to enable new breakthroughs that could expand superconductor technology. For example, new progress in understanding the vortex matter physics is necessary to approach the fundamental limits in critical current performance.

Superconductor technology combining proper electrical, mechanical and thermal management of nano-engineered materials, allows solutions ranging from power components operating at current densities 100 times higher than copper to quantum-based electronic circuits. Key features are higher efficiencies, higher currents, fields and forces, higher power densities, smaller weight and size, higher resolutions, quantum-precision sensitivities or ultra-high speed. Thus in several respects superconductors offer ultimate technical performance and unique functionalities which make them a first choice for overcoming technological barriers thereby enabling sustainable solutions and saving rare raw materials.

The activities in Superconducting magnets can be classified into 3 macro-areas: Science, Energy & Transportation, and Medical applications.

Science

Nearly all LTS applications utilize wires and cables based on NbTi, Nb3Sn or other A15 compounds, and by far the majority of them are magnet applications offering performances otherwise technically unachievable. Different applications require a variety of different types of conductors. In general, LTS wires represent a mature viable technology today providing a solid basis for magnet applications in science, RTD incl. Nuclear Magnetic Resonance Spectroscopy (NMR), in MRI and in new emerging, mostly industrial applications. Due to the sometimes very tough requirements as regards the conductor technology, these high-current high-field applications will essentially remain LTS-based for the next several years.

Controlled thermonuclear fusion is also a very interesting large-scale application and requires magnetic confinement of the plasma with fields maintained in large volumes (several hundreds m^3) and can result in very high driver fields (10 to 20 T) for a field in the plasma volume of the order of 6-7 T. Several machines have been built in the past and are in use. The superconducting magnets of the International Thermonuclear Experimental Reactor (ITER) project in Cadarache, France, is under construction.

On the other hand, the combination of LTS and HTS conductors has opened a completely new field with potential for many new applications: the ultrahigh magnetic field magnets, i.e. magnets in the 30 -50 T range can now be envisaged. This new frontier has been made possible with the recent development of nanostructured HTS conductors where there's room for transformative applications. Here one should mention High Energy Physics (HEP), particularly with the Future Circular Collider (FCC) which expects to build a 80 km ring delivering 100 TeV protons using 16 to 20 T LTS/HTS hybrid magnets.

NMR requires the currently highest magnetic fields with ultimate spatial homogeneity and temporal stability. NMR then allows us to monitor e.g. organic macro molecules with highest spectral resolution thereby providing an increasingly important analytical tool for the pharmaceutical industry and other life sciences. This has resulted in very significant growth rates for very high-field superconducting magnets.

Energy and transportation

In addition to these existing LTS applications, a number of electric power components such as transmission cables, current limiters, transformers, generators, motors and Superconducting Magnetic Energy Storage (SMES) systems e.g. for the stabilization of the electric grid, have been demonstrated. These devices and machines were originally fabricated with LTS wires and, from the technical point of view, successfully tested quite a while ago. However, these mostly low-to-medium-field high-current components are in strong economic competition with established normal-conducting solutions which have been continuously improved over decades. Furthermore the very low operating temperature of LHe prevented a practical implementation of these LTS devices. For this reason it is anticipated that most of these addressable new businesses will be based on new superconducting HTS materials which allow higher operating temperatures, but which also have to be developed to techno-economic maturity.

Different materials are currently pursued for long-length conductors needed for cables and different types of windings. Initially the worldwide focus was on Bi-HTS, the so-called first generation HTS (1G-HTS) which use a rolling-induced texturing step together with conventional powder-in-tube technology. The prospect of operating at elevated temperatures, also under higher field conditions, has stimulated intense developments towards the so-called second generation HTS or Coated Conductors (2G-HTS) which are based on well-textured YBa2Cu3O7 (YBCO)-HTS films deposited on metal substrates. For moderate field applications another material finds increasing interest, MgB2, which in terms of operating temperature and manufacturing complexity lies somewhere between LTS and HTS. Meanwhile all three conductor types are commercially available in lengths of several hundred metres or kilometres and with different specifications for different purposes, but the conductor cost especially for 1G- and 2G-HTS is still a significant barrier for several applications and so many different approaches to use low cost manufacturing approaches are being investigated. In summary, these new materials hold great economic potential, but sustained and strong efforts are still required in order to bring down further process complexity and costs.

Superconducting transformers mainly offer reduced ac losses, size and weight. All of these aspects are especially relevant in transport applications e.g. in trains. Because of the relatively low magnetic field in transformers, these devices can be realized with HTS operated at LN2 temperatures but the need of cost reduction is still preventing commercial implementation.

An application area for HTS that is seen as increasingly promising is the whole area of rotating machines. Superconducting motors and generators primarily aim at higher efficiencies, coupled with weight and size reductions and these attributes make them attractive e.g. for wind power generators. In addition, superconducting machines also offer a stiffer operational mode i.e. a reduced dependence on fluctuations of the supply grid, in the case of motors or on load fluctuations in the case of generators. The promising performances of novel nanostructured HTS conductors is raising very high expectances in this field and so renewable energy generation could deeply benefit from this development.

Superconducting cables offer not only reduced losses, size and weight, but also oil-free operation, as for transformers. These aspects are of relevance e.g. in densely populated cities when the electric grid has to be upgraded or simply replaced because of age. The field tests carried out so far used Bi-HTS operated at LN2 temperatures. New developments utilizing 2G-HTS also for DC transmission are on the way.

One device that has been pursued with several different materials, fabrication technologies and operating principles, is the fault current limiter (FCL). Whether inductive or resistive, as a self-switching and self-recovering device it offers a new functionality of network operation i.e. for controlling short-circuits in electric grids, compared with existing solutions. The combination of the current-limiting capability with cables or transformers may further enhance the benefit of such superconducting components for utility customers. These devices will secure and allow a strong penetration of renewable energy into the European Grid.

Concerning transportation, there are two areas which have been recently deeply attracted by the potential of superconductivity: avionics, where the electrical plane of the future is being explored through international collaborations involving the main players (Airbus, NASA, NEDO) and ship propulsion with electrical motors and generators. Another option may be superconducting levitated systems like the Maglev in Japan but in smaller size for urban transport or even clean-room facilities.

For quite a while, efforts have been made to open up new markets for superconducting magnets. Meanwhile new applications are found in the field of industrial processing, other than the well-known magnetic separation of kaolin clay needed in the paper industry or the controlled growth of large Silicon single crystals for the electronics industry.

Medical

By far the biggest market for superconductivity today is Magnetic Resonance Imaging (MRI) which started off at the beginning of the eighties. It has become a standard diagnostic tool routinely used in hospitals and surgeries. In addition to the use of whole-body systems using quite big solenoid coils, also smaller open systems based on split coils have attracted growing interest over the last few years, because they allow, for example, interventional surgery. In MRI most systems operate at magnetic fields up to 1.5 Tesla, but the number of 3 Tesla systems is increasing, and experimental systems for 7 Tesla and even beyond 11 Tesla are tested. At the same time low-field open MRI systems which allow monitoring the patient's status during a surgery, have come up. For this field new superconductors with reduced cooling requirements are seen as particularly attractive. Developments are ongoing towards applying HTS in this medical field with significantly simpler cooling technology.

2.2 SC MAGNET KEY TECHNOLOGY AREAS

AMICI partners have a long history in design and manufacturing of superconducting magnets:

- for high-energy physics with accelerators (HERA, LHC, etc.)
- for particle detectors (Aleph, ATLAS, CMS, etc.)

- for thermonuclear fusion (Tore Supra, JT-60SA, ITER)
- for power applications

In parallel, the considerable expertise acquired on these large projects have enabled AMICI partners to move to other applications:

- Health applications (MRI, gantries for proton therapy, etc..)
- intense high magnetic fields (EMFL, ..)

AMICI partners are working on the next generation of magnets, by using new superconducting materials and by developing innovative technologies.

The latest developments in magnet key technologies are pursued in two domains: firstly by pushing the high field limits using the Low Temperature Superconductors Nb-Ti and Nb3Sn and secondly by using very innovative developments with High Temperature Superconductors. With these LTS conductors new accelerator magnets, NMR and MRI magnets have recently been realised. The materials used today in the design of superconducting magnets are metal alloys such as NbTi, inter-metal compounds such as Nb3Sn or ceramics (ReBCO, BISCO). They can withstand current densities of up to 3000 A / mm2 at 12 T and 4.2 K. Especially for the NMR and MRI magnets these have led and will lead on the short to medium term to new products in the medical and research magnet domain.

Challenges on key technological areas to build bigger and stronger magnets are the:

- Development and use of ultimate performance Nb3Sn conductors is the most mature option for magnets on future accelerators (i.e. FCC) and high field magnets;
- Development and use of HTS conductors still need high tech R&D (from material science to electromagnetic/electromechanical engineering) to be implemented in high field magnets at affordable costs
- Increase of the operating temperature and the simplification of the cryogenics
- Reinforcement of the conductor mechanical strength and the protection of the coils against quenches.

Development and use of ultimate performance Nb3Sn conductors

Nb3Sn is the most mature option for magnets on future accelerators and high field magnets. Research and development is currently focused on developing magnets and high-field magnets for the luminosity and energy upgrade projects of the LHC, HL-LHC, HE-LHC and FCC. Recent advances on the Nb3Sn Fresca2 (Facility for the REception of Superconducting CAbles) magnet with a record field of 14.6 T in a 100 mm aperture and the test of an HTS insert generating an additional field provide a glimpse of a possible horizon for the 20 T. These magnets are incorporated into the R&D programme for future circular colliders (FCC) including a 16 T short model dipole.

Development and use of HTS conductors

HTS conductors still need high tech R&D (from material science to electromagnetic/electromechanical engineering) to be implemented in high field magnets at affordable cost. AMICI partners are working on the implementation of several materials and manufacturing technologies including the characterization of physical properties (critical current, mechanical and thermal properties, etc.) and the manufacturing processes (winding, impregnation, assembly, etc.). AMICI partners are involved in high-field magnets projects (> 30 T) using both hybrid and fully superconducting magnets. For this, the use of Nb3Sn and

HTS superconductors are essential and the associated technologies must be developed in partnership with high-field user laboratories in Europe.

The first objective is the development of second-generation high temperature superconducting (HTS) magnets to be installed as inserts in high-field hybrid magnets at 40 T in 5 to 10 cm apertures to increase performance and reduce energy consumption. The second and ultimate goal is to manufacture a superconducting “user magnet” of more than 40 T integrating a low temperature superconducting (LTS) part and an HTS part allowing Europe to become the leader of the international community of high field magnets. This more particularly concerns the development of HTS inserts embedded in hybrid magnets to reach fields of more than 60 T. In parallel, HTS R&D is aiming to study the problems inherent in HTS conductors and magnets; examples of areas of research currently being studied are: NI (No Insulation), MI (Metal as Insulation) and PI (Partial Insulation) windings, screening currents and the mechanics of non-impregnated coils.

Increase the operating temperature margin and simplify the cryogenics

In order to increase the operating margin, the internal cooling of superconducting magnet for accelerator needs experimental investigation of steady state and transient heat transfer within the superconducting coil for the optimization of the coil with respect to heat transfer . This subject deals with heat transfer in confined geometry (micro-channel and porous media) and serves to understand the thermodynamics of magnet quench. In parallel, numerical simulation is being developed for helium heat transfer in steady state and transient regimes including phase change from superfluid helium to vapor state.

After the success of thermosiphon cooling loops for large superconducting magnets (ALEPH, CMS at CERN, R3B-GLAD at GSI), optimization is still required for cryogenic autonomous gravity assisted circulation loops used by devices requiring remote cooling sources, such as magnets in sensitive environment (high field or radiation) . Small loops have been studied and installed (WAVE at ORPHEE). Cryogenic gravity assisted circulation loops for large HTS cryomagnetic systems are also concerned, essentially for two-phase flow nitrogen.

In order to install a remote cooling source in any layout, development of thermal links is required. Autonomous non-gravity assisted thermal links for the cooling of cryogenic systems has been initiated by using the so-called Pulsating Heat Pipes (PHP) which can work without gravity at different temperature (He, Ne, N2). These are the perfect candidate for space applications, rotating device and cryogen-free magnetic systems, especially for new generation of HTS superconducting devices. Numerical modelling of PHP for the understanding of the thermodynamics of such thermal links and their design is led. Additionally, involvement in medical applications, such as for superconducting RF antennas for Micro Magnetic Resonance Imaging analysis on small regions such as skins, articulations or small animals , requires constant development of cryogen free autonomous cooling systems and associated high conductive and flexible thermal links.

Reinforcement of the conductor mechanical strength and protection of the coils against quenches

AMICI partners are involved in several upstream R&D programmes to develop new design tools, in particular numerical tools, which could be used for future projects in the field of superconducting magnets to understand and be able to accurately predict the mechanical and electrical quench behaviour of the conductors and the magnets. AMICI partners have begun a mechanical simulation programme for the superconducting cable manufacturing and utilisation process. The final aim of this research programme is to achieve a mechanical model integrating the various scales of the cable in operation. 3D mechanical models of the conductor will gradually be coupled with the higher scale (homogenised 3D models of complete magnets) and with the lower scale (2D models of composite strands showing superconductor filaments). This will help the development of mechanically reinforced conductors together with new material development working at cryogenic temperatures, necessary to withstand the increasing level of mechanical stresses and forces.

Research is also being carried out on the system approach, with the implementation of multiphysics platforms for developing and coupling software in different fields (mechanical, thermal, fluidic, magnetism, quench behaviour etc.).

AMICI partners have also an expertise in the field of safety system for detecting quench in superconducting magnets (Magnet Safety System, MSS). The increasing complexity of the magnets requires the use of numerical techniques in order to process the more complex detection equations or a greater number of measurement channels, requiring a greater density of electronic equipment. Integration of FPGA (Field Programmable Gate Array) type components into a MSS requires specific developments for isolated measurements of the high voltage, the digitization of the data and the MSS software of the FPGA. It also includes R&D on the acquisition systems associated with the MSS, the function of which is to memorise the measurements when quench occurs.

2.3 POTENTIAL MARKETS IN SUPERCONDUCTING MAGNET TECHNOLOGY

Market landscape

Traditionally the first significant market for superconducting magnets were for science, research and technological development (RTD) which covers a broad range of different types of coils: from rather small laboratory magnets up to huge and sometimes quite complex structures for big science projects in high-energy physics like high-energy particle colliders or fusion experiments. Based on the mature LTS conductor technology, a great variety of different shapes and sizes of high-field coils are available today.

The situation for accelerator magnets, as analyzed in the Fusumatech final report, is significantly different from those of MRI and NMR magnets that form the bulk of the market. Accelerator magnets are a special market as they are very much customized products and one-off small production series, with a cyclic activity. The clients specify the magnets tailored to their accelerator requirements and very often provide detailed construction drawings made by their own design teams. The size of the orders are between a few units for specific replacements and upgrades to small series of up to a few hundred units for new machines. Only a few small size (up to several tens of magnets) accelerators are built per decade in the world, while on average one large machine for High Energy Physics with many hundreds of magnets is constructed every 2 to 3 decades. In this market the orders often take an element of technical collaboration instead of pure commercial contracts between the client and the firm in order to produce magnets that are at the edge of the technology. In many cases these orders de-facto constitute a transfer of technology from the academic world to the commercial world.

The biggest current market today is for magnets used in medical diagnosis, Magnetic Resonance Imaging (MRI). In contrast to such well-established fields, there are some emerging new businesses, which will mostly be based on new superconducting materials, but also on new system developments. Lower losses, higher fields, stronger forces, higher power density, smaller weight and size are motivations for current developments in the following areas: electric power, industrial processing, transportation, (new) medical applications. Also ultra-high magnetic field functional MRI scanners (B> 7T) offer neuroscientists exciting new possibilities to image the structure, function and biochemistry of the human brain and so huge advances in biomedical and clinical developments are expected.

The UHF MRI and NMR market is characterised by relatively low volume sales and high unit cost. The UHF NMR market, in particular, is very small and given the high barrier to entry this is likely to stay a monopoly for Bruker.

The UHF MRI market is significantly larger and also benefits from the “pull through” of other, lower field, system sales. This results in the MRI UHF market having a number of companies competing for the business (Siemens, Philips and GE), with Siemens being the clear market leader at this time.

China has a number of well-established MRI companies and at least a few of these are looking at obtaining or developing UHF MRI technology. A program to develop a domestic 9.4T whole-body magnet is yet to yield a working system but it is expected that Chinese built UHF MRI system will emerge (possibly with European technology at its heart) within the next five years.

In RTD a trend towards higher magnetic fields is observed e.g. 1 GHz Nuclear Magnetic Resonance (NMR) systems operating with fields beyond 23.5 Tesla and offering extended resolution for chemical analysis, are now commercially available. Future systems with even higher fields and analytical power will necessarily have to utilize HTS insert coils. Larger magnet systems today already use HTS current leads to reduce the heat load on the cryogenic part. Almost all large accelerators today use superconducting radio frequency cavities to achieve highest power levels.

Globally the UHF NMR market is dominated by Bruker. JOEL, in Japan is a well-established NMR system supplier with its commercial partner Jastec manufacturing the magnets. JOEL has a limited portfolio of UHF NMR magnets and has a strong NMR market position in Japan.

There is also an emerging NMR company in China (Q One Instruments of Wuhan) which is working to acquire and develop NMR magnet technology. At time of writing, this company is not offering a complete NMR system.

In contrast to these established fields, there are some exciting new businesses which will mostly be based on new superconducting materials, but also on new system designs. The highly cost-competitive commercial markets of energy, information and communication, industrial processing and transportation are addressed in addition to new medical applications. Currently the energy market is seen as the most promising one for new superconducting components. Further improvement of price-performances is needed to promote the commercial deployment of superconductor technologies in these fields. Moreover, references are needed from pilot customers, production facilities have to be ramped up, the market has to be actively developed and the related costs present another level of capital investment. We expect that during the next years, system developments and cost reductions for components will prepare the economical basis for these new fields.

The two established fields, RTD and MRI, together account for most of today's overall market for components, systems and services which almost reached 5.4 B€ in 2016. Although contributions from HTS are anticipated to grow (in the long term they may well exceed the size of the established businesses), the expectances to build up a new frontier of ultra-high field magnets has been opened, eventually through combination of HTS with LTS magnets.

Market share

The $ 5.5 billion superconductivity market is dominated by the magnet market. In 2016, these are used in science, research, technological development (73%, or $ 4.1 billion) and medical applications (for 26% or $ 1.5 billion).

The market for superconductivity is expected to increase to $ 8.7 billion by 2022, an average annual growth rate of 7.5% over the next five years. The segment of superconducting electrical equipment (for example, transformers, generators, motors, fault current limiters (FCL), energy storage, power lines and cables), to $ 66 million in 2016, should represent $ 1.5 billion in 2022, or 17% of the total $ 8.7 billion market for superconducting market

BCC Research report forecasts that science, research, and technology development's share will decline to about 58% of the market in 2022, while healthcare's share is expected to slip to about 24%. Most of the difference is expected to be made up by electric utilities (nearly 13% of the market in 2022) and transport (2%).

Consumption of superconducting materials used to fabricate these applications should grow from around $626 million in 2016 to $651 million in 2017 and to nearly $1.5 billion in 2022. Low-temperature superconducting (LTS) materials, such as the niobium alloys, made up the bulk of the market in the 2016 to 2017 time period, but high-temperature superconductors (HTSs) (e.g., MgB2, BSSC, YBCO) should represent more than 52% of the market by 2022.

The global market for superconducting magnets was worth almost $3.2 billion in 2016, a figure that is expected to climb to nearly $3.3 billion in 2017 and to over $3.4 billion by 2022, with a CAGR of 0.9% over the next five years.

Healthcare applications, specifically MRI, accounted for about 45% of the superconducting magnet market in 2016, a percentage that is expected to rise to 55% by 2022. These figures actually understate the importance of the healthcare market because they do not include magnets used in therapeutic particle accelerators. The latter are included with other particle accelerators used in basic research.

Science, research, and technology development accounts for most of the remainder (over 55% in 2016 and 45% in 2022) of the superconducting magnet market. A market for superconducting magnets in transportation applications (e.g., maglev trains) is not expected to develop until after 2022. Although additional maglev lines may become operational in the 2017 to 2022 time frame, these lines do not use superconducting magnet technology. Japan Railway's planned Linear Chuo Shinkansen, which will be the first commercial maglev line to use superconducting magnet technology, is not expected to reach the vehicle acquisition stage of its development before 2021.

Other industrial applications account for a small share of the superconducting magnet market. Their market share is projected to hold steady at about 0.1% through 2022.

3. EUROPEAN MAGNET TECHNOLOGY ECOSYSTEM

Basic research, traditionally the driving force for the development of essential technological domains, led to conducting innovative R&D and establishing large-scale facilities for production, assembly and qualification in the field of accelerator and SC magnets, for example test stands for superconducting magnets. A good understanding and outlook of the ecosystem and the actors involved future needs in Key Technological Areas, is needed to plan their development

3.1 EUROPEAN COMPANIES USING SC MAGNET TECHNOLOGIES

There are numerous suppliers of superconducting magnets and/or their components, as summarized in the following table.

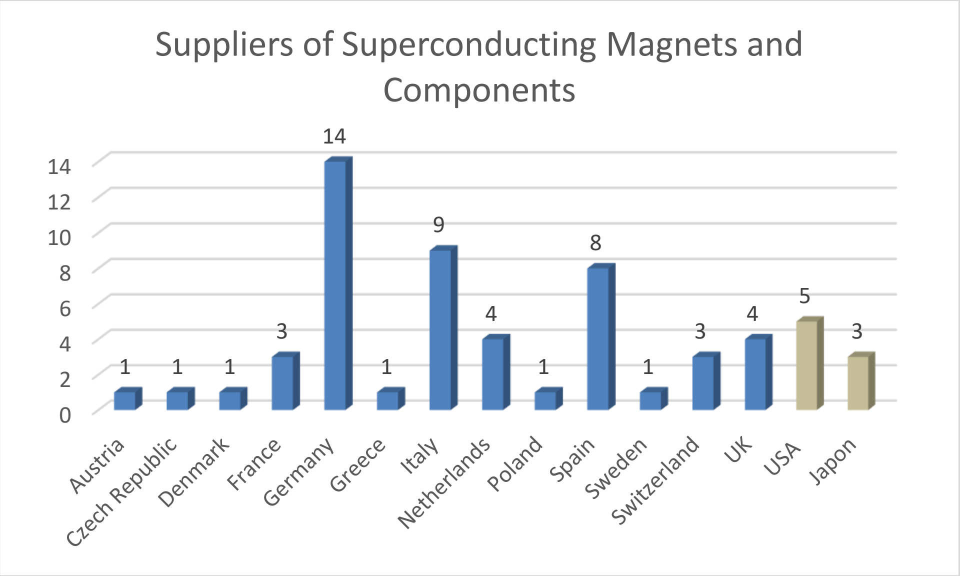

Figure 4: Suppliers of Superconducting Magnets and Components

3.2 EUROPEAN TEVHNOLOGY INFRASTRUCTURES OWING SC MAGNET TECHNOLOGY PLATFORMS

- CERN (Geneva)
- CEA (Paris Saclay)
- **CIEMAT (Madrid Spain)** → *not an AMICI partner*
- CNRS (Grenoble, France)
- **GSI (Darmstadt)** → *not an AMICI partner*
- DESY (Hamburg)
- IFJ (Krakow)
- INFN (Milano, Salerno)

- KIT (Karlsruhe)
- PSI (Villigen)
- STFC (Daresbury)
- Uppsala Universitet (Uppsala)
- **University of Twente (Netherlands)** → *not an AMICI partner*

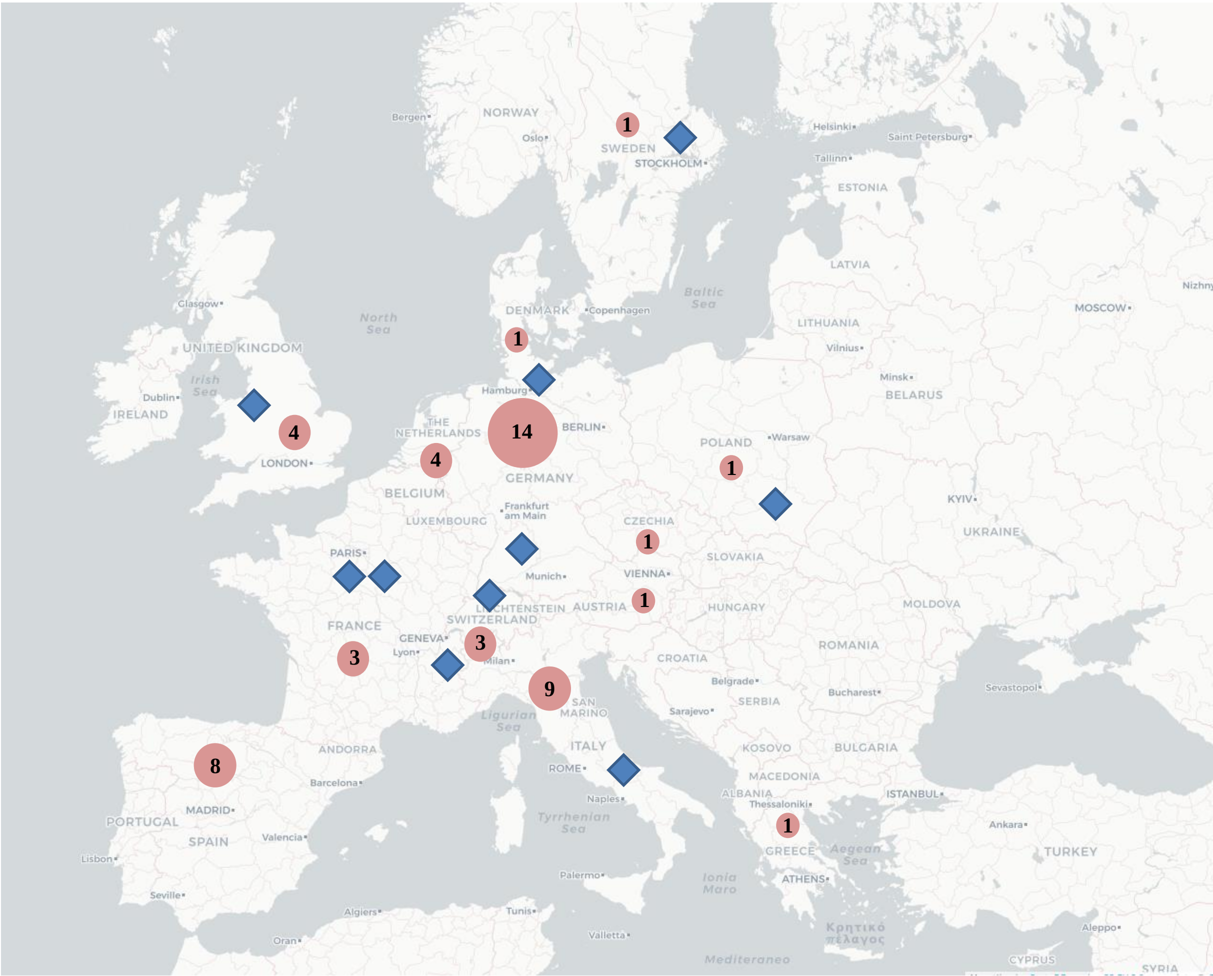

Figure 3: European SC Magnet Technology Ecosystem, showing AMICI beneficiaries (blue diamonds) and the number of magnet-related companies (red circles)

3.3 POSITION OF EUROPE AND EXISTING LINKED INITIATIVES

Position of Europe

The European research and industry related to superconductor technology has developed a strong position due to a continuous and sustained research and development policy from the 1970s to the 2000s. This strong position and that of European manufacturers is reflected in the EU market share which in the well established businesses is nearly half of the total world market today. Several initiatives were set-up in the past by the European Commission with SCENET – the European Network for Superconductivity, SCENET POWER, the European Network for

Power Applications of Superconductivity, aimed at setting-up coherent strategies of research and development and encourage links between academia and industries in the field of applications of superconductivity. In the EU Framework Programmes for Research and Innovation FP7 andH2020, as well as COST actions, several projects linked to superconducting science and technology were launched, , EUROTAPES for conductors, SUPRAPOWER or ECOSWING for wind turbines, BEST PATHS for cables, SUNJET for the electrical plane, FUSMATECH for superconducting magnets, and ARIES for applications to accelerators.

In the applied superconductivity fields, Europe has a strong historical heritage – discovery of superconductivity, development of innovative superconducting magnets, whole range of cooling solutions – and holds considerable expertise with several laboratories being leading R&D performer in cryotechnologies, as well as leading industries (Oxford Instruments, Siemens, Air Liquide, Linde, to name a few). The European Society for Applied Superconductivity was founded on September 4, 1998. ESAS brings together scientists and engineers working in applied superconductivity across both industry and academia in Europe. The society most notably organises the biennial European Conference on Applied Superconductivity (EUCAS) but is also involved in a growing range of other activities aimed at promoting the field of applied superconductivity. Its goals are to strengthen the position of Applied Superconductivity, especially in Europe, to represent Applied Superconductivity in social, scientific, educational, industrial and political forums, and to promote communication in the area of Applied Superconductivity.

Several initiatives on the industrial side were established at the national and European level, like for example PIGES[2] or Conectus3. Piges is an association created in 2010 gathering French companies involved in Large Scale Research Infrastructures to promote their activities, to enhance links with research labs (training…), to initiate common R&D programs with Research Institutes and to liaise with French administration. Conectus is a consortium of European companies with the shared vision that commercialization of superconductivity will translate into significant benefits to Europe's economy and society. Conectus objectives are to strengthen the basis for commercial applications of superconductivity in Europe and provides a platform for industry to exchange information and to provide a united voice on public policy issues of common interest to superconductivity stakeholders.

Comparison with existing international research initiatives linked to magnets

Several initiatives are developed worldwide. Recently the US Energy Department announced up to $25 million in available funding aimed at advancing technologies for energy-efficient electric motors through applied R&D. This effort will fund innovative technologies that will significantly increase the efficiency of electric motors, which use approximately 70% of the electricity consumed by U.S. manufacturers and nearly a quarter of all electricity consumed nationally. Four key technology areas have been identified to drive cost-effective efficiency enhancements and weight reductions while addressing the limitations of traditionally used conductive metals and electrical steels. Two of them are linked to superconductors with High temperature superconducting wire manufacturing and the manufacturing of other enabling technologies to increase performance.

[2] http://www.piges.eu/en#Nos-objectifs

[3] https://conectus.org/

In 2013, the Japanese Ministry of Economy, Trade and Industry (METI) launched two new national projects on applications of high temperature superconductivity (HTS). . One program focused on HTS magnets for diverse applications (medical magnets for MRI and accelerators, magnets for train and large electric automotive vehicle motors, wind turbine electric power generators, etc..). The second is on HTS dc power cables, which is supposed to provide an experimental proof of the HTS dc power transmission system. Korea and China have also intensive R&D superconductivity programs with similar technological goals.

3.4 RELATIONS BETWEEN INDUSTRY AND TECHNOLOGICAL INFRASTRUCTURES FOR INNOVATION

Several initiatives are or were existing at the National and European level to foster the cooperation and co-innovation between the research laboratories hosting the technological infrastructures and the industries. At the European level, CARE program in FP6, EUCARD and EUCARD2 in FP7 and ARIES and Fusumatech programs in H2020 have developed several work packages to enhance the innovation and the cooperation on different key technical areas with some of them on superconducting magnet technologies. Understanding the needs of industrial partners is an effective way to foster collaborative R&D projects between European program partners and industry. "Market Pull" approach will thus be favoured to a "Technology Push".

At the national levels a variety of collaboration actions and financing programs exist: national project-based funding agencies, investment funds, local/regional public funding, tax credit, ccompany funding, etc. For SMEs the amount of funding could represent several M€.

The developments in the industries could benefit from the pre-existing technical facilities in the research laboratories hosting Technical Infrastructures. Access to equipment with fair access costs for manufacturers could reduce their investment costs.

The support of the Technological infrastructures is essential in the technology of Superconducting Magnets, as far as the TIs are used to develop a lot of frontier edge high field magnet systems. The Research Laboratories hosting the Technological Infrastructures are perfectly adapted to build a bridge between low TRL and high TRL and to overcome the so called “Death Valley” between these two areas.

For example, the majority of the AMICI partners are supporting the Fusumatech initiative. The aims of Fusumatech are to foster research and innovation in the field of superconducting magnet for scientific instruments, medical instrumentation, electric power generation, transmission and storage, and to support the European cluster of superconducting magnet technology to keep the leading position of Europe in the domain by developing a co-innovation eco-system between academics and industry. Several R&D&I projects have been shared by the partners and are understood as very promising for growth of the European Cluster of both academics and Industrial partners.

4. RESULTS OF THE SURVEY

4.1 RESULTS FROM THE WEB SURVEY

The received answers have been collected and for some of them summarized in plots when appropriated in order to provide an easier and clearer interpretation. In each plot the reference question and the total number of received answers for that particular question have been reported.

The number of answering companies (6) is small compared to the number of contacted companies (51). Two are designing and manufacturing superconducting magnets and four are providing components or materials for the magnets. All the companies are SMEs.

- **Theme 1 – The existing magnet market segments (Q1,Q2)**

About the question 1 on which segment could benefit from the technology infrastructure 3 companies have answered, saying that the whole range of their market or components for superconducting magnets for particle physics.

Figure 1 reports the expected percentage growth in the segments of the companies market, which could benefit from the Technology Infrastructure in 5 years (Q2). It shows that the impact of possible collaborations with TIs is moderate on the expected growth of the superconducting magnet market segment, around 10 %.

- **Theme 2 – The potential magnet market development (Q3 to Q7)**

Figure 2 describes the repartition of the possible magnet product or technological developments expected by the companies using the Technology Infrastructure in the next 5 years (Q3). The results are well balanced with an interesting high percentage score in the transportation applications. This market seems to be considered by the industries as a potential future market, which is today an unexploited market for superconducting applications, especially if we compare this result to the low score of the energy applications.

Apart these markets the contacted companies do not consider new other markets expect one, in water filtration using SC magnets (question 4).

No company gave a positive answer to the question 5 about the potential breakthrough innovation that could be translated into their market following a prior development in the Technology Infrastructure.

Figure 3 and 4 reports on the type of Technical Platforms of the Research Laboratories and at which steps of the development companies which could use in their future magnet market development. The companies are mainly interested by the test capacities of the TIs during all the development steps from R&D to prototyping at the clear exception of the series manufacturing.

- **Theme 3 – The constraints for cooperation (Q8, Q9)**

Figure 5 shows the potential barriers to use the technical infrastructures. Access cost, availability of the technical facilities and IP issues are equally cited as potential barriers. No other issues arise from the web survey.

About the question 9 on the reasons which would make companies preferably choose to use the Technical Platforms located at Research Laboratories or their own Technical Platforms, one company prefers to use their own facilities, whereas the other company emphasizes on the customer proximity, and the ease of creating new opportunities and ideas.

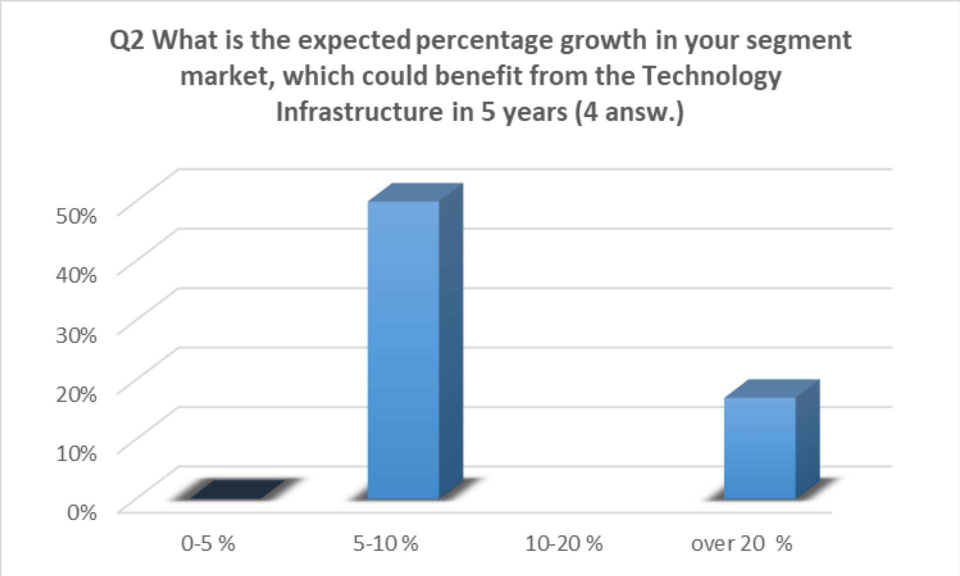

Figure 1: Expected percentage growth in segment market, expressed as percentage of positive responses against the total number of 6 companies.

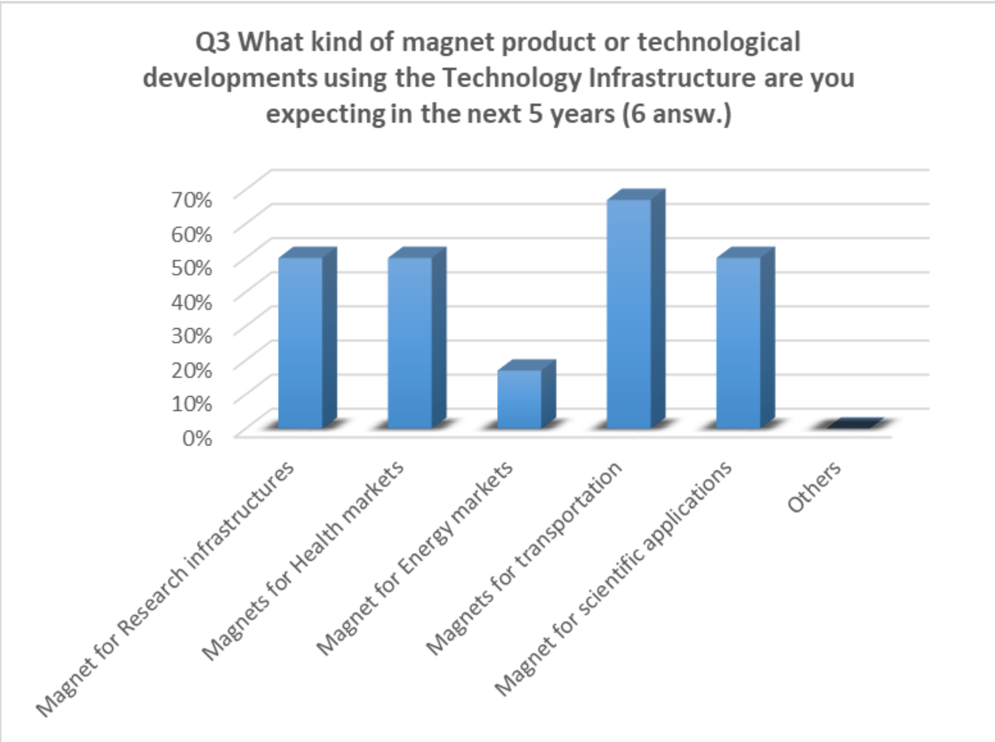

Figure 2: Possible magnet product or technological development markets, expressed as percentage of positive responses against the total number of 6 companies.

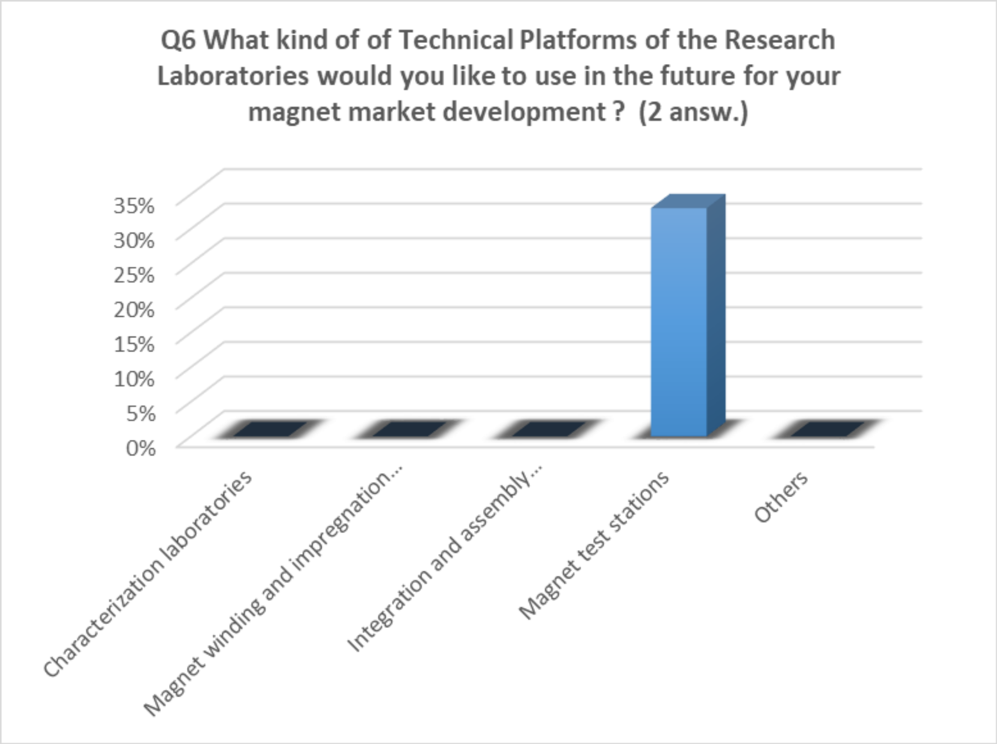

Figure 3: Potential use of Technical platforms by companies.

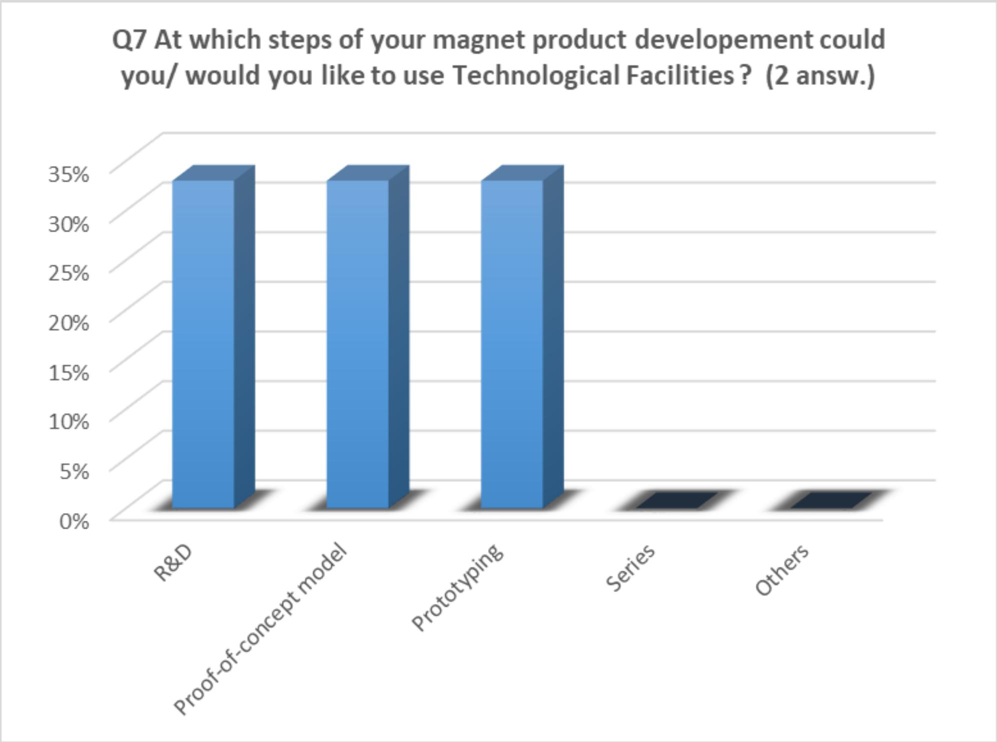

Figure 4: Preferred steps of development to use Technical facilities.

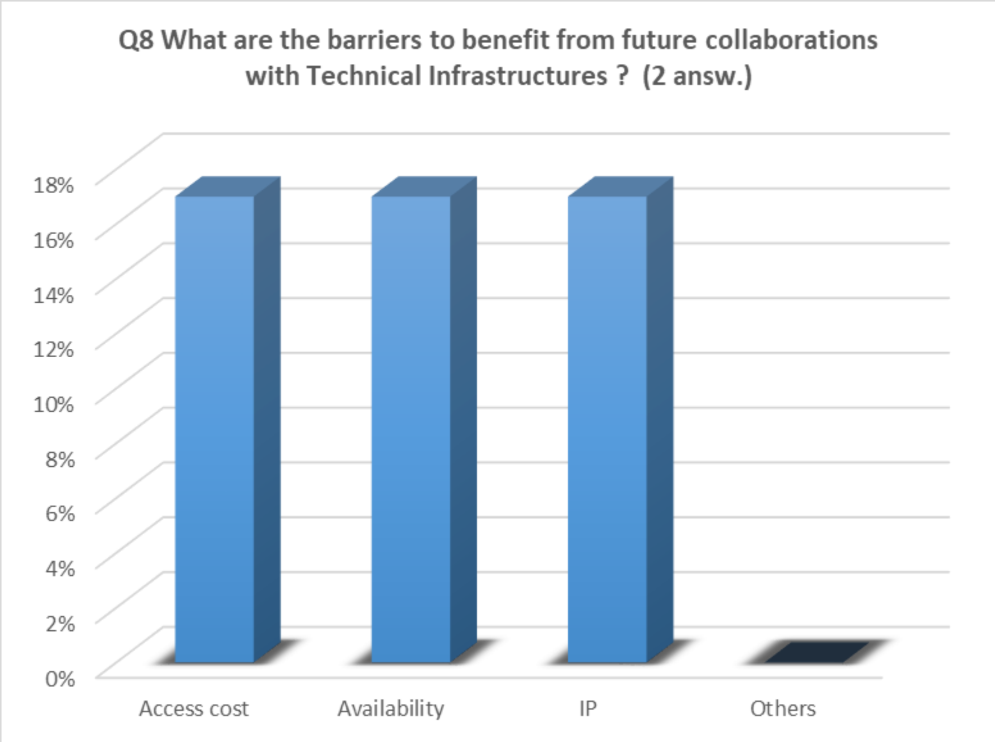

Figure 5: Potential Barriers to use Technical infrastructures.

4.2 FEEDBACK FROM THE INTERVIEWS

This section provides an overview of the main points discussed during the interviews with companies.

Companies are interested to use resources in the National Labs hosting the TIs for consultancy works during the call for tender/design phases and for the cryogenic testing of models and prototypes.

Companies are very interested to share with the research laboratories the agenda of the future projects and to have easy access to the potential business opportunities.

The confidence between the partners and a good repartition of the work is important. More and more companies want to be involved and to develop their know-how in the design phase. Common publication like posters helps industry to quickly spread out its new know how.

The cyclical nature of funding research infrastructure projects and national co-innovation tools is also a major challenge for companies in defining their strategic innovation agenda.

Intellectual property management is another important issue that needs to be well defined before the start of the collaboration / co-innovation process

If the market, developed under the co-innovation program, has long-term viability, companies will invest in the technical infrastructure needed for their business. These new infrastructures will then be used for their own research and development and the need to use TIs is reduced.

Paperwork and administration of the proposed co-innovation tools may become cumbersome, especially when the anticipated success rate is low. Some projects might even not be started because of this.

In these type of collaboration companies are sometimes restricted to detailed design and manufacturing phases, which is the most difficult to finance. They express the need to balance design work and manufacturing work; the more design will be done in their premises; the more company is willing to contribute to the funding.

Co-innovation is easier in cases where the technologies or the manufacturing techniques required by the co-innovation required by the laboratories hosting TIs, overlap with those to be directly integrated in existing product line directly (cyclotrons/synchrotrons, UHF MRI etc.).

If a long-term R & D plan can be defined, it is possible to create joint laboratories between research organizations and SMEs. In this case, partners are encouraged to establish common governance for the laboratory, as well as a road map for research and innovation activities and to define allocated resources. A strategy to ensure value creation from research results is an important point for this type of laboratory.

Another tool available to companies to develop their know-how is the scheme called Pre-Commercial Procurement (PCP) funded by the European Union Horizon 2020 initiative. The spirit of the scheme is to fund companies to perform R&D in a competitive environment. The business case is to engage small/medium industries to work on edge technologies, even if no large market volumes are expected. The PCP instrument can serve the purpose of enlarging the market basis (by reducing financial barrier for SMEs), to attract SMEs (by sharing the technological risk of committing into difficult R&D), to mitigate risk of over or under specifications, by engaging industries at the early stage. The financial risks are reduced for companies by gradually committing into the scope. The technical risks are mitigated by splitting the scope in phases and operating technology transfer by the laboratories. For the buyers the advantages are to pool resources to implement the project, to shorten the time to R&D completion and to reduce the cost. Companies can acquire potentially transferable know-how in markets other than research infrastructures. They can also increase their industrial capabilities by deploying usable tools for similar manufacturing, thus expand the market, and encourage innovation and novelty.

One successful example is the PCP called QUACO[4]. The project run in collaborative effort among four partners of AMICI around the development of the Q4-MQYY full scale quadrupole magnet prototypes for HL LHC project. QUACO is organized in three competitive phases: conceptual design (4 months), engineering design and mock-ups (13 months), prototype manufacturing phase (18 months). Four firms started the project. From one phase to the next, one firm is eliminated based on technical, quality assurance and project management evaluations. At the end of Phase 3 scheduled in June 2020, two firms will remain and deliver a MQYY prototype ready for test.

5. STRATEGIES & RECOMMENDATIONS

- We have identified several European business organizations that have the capacity and potential to innovate and develop solutions in the fields of magnet technologies. These are mainly a small number of highly specialized SMEs that are part of the research infrastructure supply chain. They are highly dependent on market fluctuations due to the cyclical nature of major research infrastructure projects.

[4] H2020 under Grant Agreement 689359, https://quaco.web.cern.ch/

- We have also identified key technology areas for superconducting magnets and some domains of societal applications and potential markets. Beyond the existing markets, research infrastructures, scientific equipment and health, they interest potential markets for energy and transport. A business case would certainly be needed to evaluate their potential.

- We need to develop or upgrade existing facilities to be ready to deal with these new developments (high-current and high-field critical current measurement systems, equipment for measuring material properties at different temperatures, new R&D, prototyping and manufacturing facilities for Nb3Sn and HTS conductors and coils, etc.). A roadmap for these new facilities should be developed. Investment costs could be borne by new projects and national or European incentive funds.

- The co-innovation strategy in the field of SC magnets is not different from the one used for accelerators. Conclusions from WP4.1 are also applicable to the magnet market. A common approach should be developed.

- As part of the co-innovation between Reseach Laboratories and companies, we need to explore the possibility of sharing certain R&D and prototyping activities in a subsidized way for better use of funds. We could use new tools like the PCP, the innovation partnership, or other efficient schemes of collaboration (like the common laboratories, European of national project-based funding, etc.). However, we must keep in mind the maintenance of a technical capability in the TIs independent of market uncertainties and short-term business strategy. In this sense, duplicating TFs in different locations will help maintain the robustness of the ecosystem

- We need to strengthen co-innovation initiatives between AMICI partners and the industry benefiting from public funding tools at national and European level. These tools will need to be strengthened and expanded with adequate funding. Fusumatech is an example.

6. CONCLUSION

Based on a survey addressed to industry, this report formulates the potential of European businesses to apply their expertise for societal needs, through successful engagement with Technological Infrastructures**.**

The identified European commercial organizations working in the field of superconducting magnet technologies, including both large companies and SMEs, represent an important market worldwide. These companies, established in numerous European countries but unequally shared, represent an innovation potential for Europe.

The superconducting magnet technologies are surely used for the Research and Technological Development (RTD) but it goes even beyond. Indeed the medical applications cover almost the half of the market for magnets and will become more and more important in the next few years. The growth of the medical field is mainly based on the expansion of the superconducting technologies and particularly on the development of the MRI.

In addition, the segment of superconducting electrical equipment is growing and is expected to account for 17% of the superconductors market in 2022. This brings the energy and transport market to a potential market position for magnets, although no major developments is not expected until 2022. Among other applications, the magnets for transport appear, for the majority of companies surveyed, as the most anticipated market in the next 5 years.

Through this report, AMICI addresses strategy and recommendations to optimize the effective engagement between Industry and the Technological Infrastructures but also challenges on key technological areas to build more and more sophisticated magnets for societal application. Numerous initiatives have been undertaken by either academia or industry. The liaising role of the initiatives like AMICI remains essential to allow industrials and TIs to enhance their visibility and competitiveness in new markets, overcome the technology development barriers, and further develop commercial opportunities within the Research Infrastructures and wider societal markets.

APPENDIX A: DATA SOURCE

FuSuMaTech, Future Superconducting Magnet Technology, Periodic Technical Report, Part B from 23/10/2017 to 22/04/2019.

Gourlay, Stephen A, Prestemon, Soren O, Zlobin, Alexander V, Cooley, Lance, and Larbalestier, David. The U.S. Magnet Development Program Plan. United States: N. p., 2016. Web.

Brian G. Marchionini ; Yutaka Yamada ; Luciano Martini ; Hiroyuki Ohsaki, High Temperature Superconductivity, A Road Map for the Electrical Power Sector 2015-2030, IEEE Transactions on Applied Superconductivity (Volume: 27 , Issue: 4 , June 2017), DOI: 10.1109/TASC.2017.2671680

A.M. Wolsky, HTS from precommercial to commercial, A roadmap for Future Use of higher-temperature superconductors by the power sector, IEA Energy Technology Network, Superconductivity, (10 September 2013)

Superconductors: Global Markets to 2022, BCC research, Published - Dec 2017, Code - AVM066F|, Analyst - Andrew McWilliams.

EUCARD2 Applications for Particle Accelerators in Europe – June 2015 https://edms.cern.ch/document/1325147/2

APPENDIX B: INDUSTRIAL SURVEY

This report studies only the answer collected from the part 6 *'The magnet technology market I wish!'*

Part 1 – Industry General Information

1) **First, Last Name and function (of the person answering the survey)**
2) **Name of the Company**: *free answer*
3) **Company Commercial Operating Field**: *multiple choice answer*
   - Accelerating Structures-Normal Conducting
   - Accelerating Structures-Super Conducting
   - Waveguides and waveguides Components
   - High Power Systems (Klystrons, Modulators, Inductive Output Tubes,…)
   - Vacuum Chambers
   - Pumping Systems (Ion Pumps, Turbo-molecular,…)
   - Diagnostics
   - Normal Conducting Magnets
   - Super Conducting Magnets
   - Magnets Power Supplies
   - Cryogenic systems
   - Other specialized mechanical components for accelerators
   - Other specialized mechanical components for magnets
   - Electronics and instrumentation for accelerators
   - Electronics and instrumentation for magnets
   - Other

4) **Other details on Company Operating Fields**: *free answer*
5) **What is the annual company % of turnover relative to the field of accelerator technology?** *multiple choice answer*
   - 0-10%
   - 10-40%
   - 40-70%
   - Over 70%
6) **What is the annual company % of turnover relative to the field of magnet technology?**
   - 0-10%
   - 10-40%
   - 40-70%
   - Over 70%
7) **Number of Employees**: *free answer*
8) **Number of Employees (FTE) devoted to R&D**: *free answer*
9) **Do/did you have collaborations/business/supply of components with these Institutes?** *multiple choice answer*
   - Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
   - European Organization for Nuclear Research (CERN)
   - Stiftung Deutches Elektronen-Synchrotron Desy (DESY)
   - Istituto Nazionale Fisica Nucleare (INFN)
   - The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences (IFJ)
   - Centre National De La Recherche Scientifique (CNRS)
   - Science and Technology Facilities Council (STFC)
   - Uppsala Universitet (UU)
   - Paul Scherrer Institut (PSI)
   - Kalsruher Institut Fuer Technologie (KIT)
   - Other: specify
10) **What kind of business/collaboration do/did you have with the mentioned Institutes?** *multiple choice answer*
   - Supply of standard/catalogue components for Institute
   - Development of custom components for Institute including design
   - Supply of build to print component for Institute
   - Purchase of special components from Institute
   - Use of Technical Platforms in the Institute
   - Research Collaboration
   - Licensing
   - Other

Part 2 – Collaboration: Description, Results, Agreement

1) **How was the collaboration with Institute established?**

- Public tender
- Supply of standard/catalogue components for Institute
- European project that foresaw a collaboration between Institute and the private Company
- National funding that foresaw a collaboration between Institute and the private Company
- Other: please specify

2) **Who is your contact in the Institute?** *grid answer*
   - Personal – The contact is based on one or more researcher/technician
   - Dedicated Offices (e.g. Technology Transfer Office)
   - No Contact
3) **Among the interactions you had with Institute, what percentage was problematic:** *multiple choice answer*
   - 0-10%
   - 10-40%
   - 40-70%
   - Over 70%
4) **In particular you had immediate interaction on:** *free answer*
5) **In particular you had problematic interaction on:** *free answer*
6) **During the past 10 years, did you collaborate with Institute in scientific publications, commercial products development, prototype development, patent requests?…** *tick boxes*

	0	1-2	3-5	6-10	>10
Publication					
Patent					
Prototype					
Commercial product					

7) **The commercial products you developed in collaboration with Institute were finalized to:**
   - Products of interest for the Institute only
   - Products for external market whose idea has been conceived by Institute
   - Products for external market whose idea has been conceived by the Company
8) **What type of commercial products have you developed in collaboration with Institute?**
   - Research Equipment
   - Medical products (e.g. diagnostics systems, etc…)
   - National security (e.g. X-ray scan systems)

- Material treatment (e.g. sterilization, …)
- Other: please specify

9) **Did the collaboration have the possibility to support qualified personnel like Ph. D students, temporary contract researcher, technician, interns? If so, please indicate who paid for them?** *Multiple Choice Answer*
   - The company
   - The RL
   - A co-financing programme

10) **Other comments on the social impact of Collaboration (e.g. after the collaboration the qualified personnel has been hired by the Industry, etc…)** *free answer*

11) **In the framework of the collaboration, were there some training/education from the Institute to Industry personnel?** *Multiple Choice Answer*
   - Yes
   - No

12) **Has the training/education from the Institute to Industry personnel been useful?** *linear scale answer*
   - Not useful (1) → Useful (5)

13) **In the framework of the collaboration, were there some training/education from the Industry to Institute personnel?** *Multiple Choice Answer*
   - Yes
   - No
   - Other

14) **What training your company will be interested in?** *Multiple Choice Answer*
   - Superconducting radiofrequency
   - Vacuum Technology
   - Cryogenics Technology
   - Superconducting Magnet Technology
   - Beam Diagnostic
   - Other: specify

15) **Would your company be interested in:** *Multiple Choice Answer*
   - E-learning (MOOC)
   - On-line training (professor somewhere trainees at another location) for the theoretical part
   - Hands-on training
   - Other: specify

16) **Within the collaboration, were there issues on Intellectual Property Rules and/or Patenting Rules?** *Multiple Choice Answer*
   - Yes
   - No
   - Other

17) **If yes, was there a standard agreement model on Property Rules and/or Patenting Rules proposed by the Institute?** *Multiple Choice Answer*

- Yes
- No

18) **Were you satisfied with the proposed "agreement" with the Insitute?** *Linear scale answer*
    - No (1) → Yes (5)
19) **Were there particular problems/limitations during this phase? Or do you have suggestions in order to facilitate/to improve the "agreement" stipulation/management?** *Free answer*

Part 3 – Access to Technological Facility of Research Institutes

1) **Have you ever had the possibility to use/have access to Technological Facility of Institute?** *Multiple Choice Answer*
    - Yes
    - No
2) **What type of Technical Platform did you use?** *Multiple Choice Answer*
    - Test beam facilities
    - Magnet manufacturing equipment
    - Magnet measurement equipment
    - Cryogenics plants
    - Radiofrequency cavity measurements
    - Chemistry, clean room and assembly halls
    - Characterization and measurement laboratories
    - Other
3) **How was the utility for the Industry?** *Linear scale Answer*
    - Not Useful (1) → Useful (5)
4) **How was the access to the equipment?** *Linear Scale Answer*
    - Difficult (1) → Easy (5)
5) **Do you have any suggestions in order to improve or facilitate the use of equipment of Institute?** *Free answer*
6) **In the collaboration, has Institute personnel been involved?** *Multiple Choice Answer*
    - Yes technician
    - Yes researcher
    - Yes but for the use of the Institute equipment only
    - No
    - Other: specify
7) **Referring to the involvement of Institute personnel, how was the utility for the Industry?** *Linear scale answer*
    - Difficult (1) → Easy (5)
8) **Referring to the Institute personnel, was it easy to involve them?** *Linear scale Answer*
    - No (1) →Yes (5)

9) **In case of not easy access to support from Institute personnel what were the main limitations?** *Free answer*

10) **What was the time lapse from the request to the effective access to Technological Facility equipment or support from Institute personnel?** *Multiple Choice answer*
- Weeks
- Month
- Up to six months
- Year
- Other: please specify

11) **Is it suitable for the project timescale of your company?** *Multiple Choice Answer*
- Yes
- No

Part 4 – Participation to Tenders and/or National/European funding Calls

1) **Did you participate to a tender published by Institute?** *multiple choice answer*
- Yes
- No

2) **Was the participation easy?** *linear scale answer*
- Difficult (1) → Easy (5)

3) **In case of difficult participation what were the issues?** *multiple choice answer*
- Bureaucracy complications
- Difficulties in submitting the documents
- Difficulties to have clarifications on the tender
- Other: please specify

4) **Did you ever participate to a National/Regional funded Call in collaboration with Institute?** *multiple choice answer*
- Yes
- No
- If yes please specify

5) **How can you describe this experience?** *linear scale answer*
- Not useful (1) → Useful (5)

6) **Are the National/Regional funded Calls sufficiently promoted from the Institutions?** *linear scale answer*
- No (1) → Yes(5)

7) **Are the National/Regional funded Calls sufficiently clear in their purpose and easy to submit?** *linear scale answer*
- Not (1) → Yes (5)

8) **Suggestions for enhancing the impact of National Call for Companies:** *free answer*

9) **Did you ever participate to a European Call in collaboration with some Institute?** *multiple choice answer*
   - Yes
   - No
   - If yes please specify

10) **How can you describe this experience?**
   - Not Useful (1) → Useful (5)

11) **Are the European funded Calls sufficiently promoted from the Institutions?** *linear scale answer*
   - No (1) → Yes (5)

12) **Are the European funded Calls sufficiently clear in their purpose and easy to submit?** *linear scale answer*
   - Not (1) → Yes (5)

13) **Suggestion for the improvement of the impact of European Call** *free answer*

14) **Do you think Institute are well prepared in "Project Writing"?** *Linear Scale Answer*
   - Absolutely not Prepared (1) → Expert (5)

Part 5 - The collaboration I wish!

1) **Do you know the research activities and the available Technological Facilities of the Institute whom you collaborate with?** (visit http://eu-amici.eu/technology_infrastructure) *Linear Scale Answer*
   - No (1) -> Yes(5)
2) **How did you know them?** *Multiple Choice Answer*
   - Seminars
   - Open day event
   - Personal relationship
   - Web Sites
   - Other: please specify
3) **Do you think the available information is satisfying?** Linear Scale Answer
   - No(1)->Yes(5)
4) **In any case, what kind of information would be useful for you?** *Multiple Choice Answer*
   - Available equipment
   - Available personnel profile
   - Details of Research projects
   - Other
5) **How would you like to have this information presented (website, dedicated meetings…)?**
6) **In particular, let us know if you would like to suggest improvement in the presentation on the AMICI website? http://eu-amici.eu/** *Free Answer*

Part 6 – The magnet technology market I wish!

1) **Which segment of your market could benefit from the Technology Infrastructure?** *Free Answer*
2) **What is the expected percentage growth in your segment of market, which could benefit from the Technology Infrastructure in 5 years?** *Multiple Choice Answer*
    - 0-5%
    - 5-10%
    - 10-20%
    - Over 20%
3) **What kind of magnet product or technological developments using the Technology Infrastructure are you expecting in the next 5 years?** *Multiple Choice Answer*
    - Magnets for Research infrastructures
    - Magnets for health markets (new imaging systems and therapy) Magnets for energy markets (production transportation and use),
    - Magnets for transportation (high speed trains, zero frictions conductor free cars, space crafts)
    - Other applications: please specify
    - Magnets for scientific applications (high field , NMR, etc..)
4) **Are you expecting new potential markets in magnet technologies applications, which could benefit from the Technology Infrastructure?** *Free Answer*
5) **What potential breakthrough innovation translated into your market could be developed in the Technology Infrastructure or could be an application of technologies developed in the Technology Infrastructure?** *Free Answer*
6) **What kind of Technical Platforms of the Research Laboratories would you like to use in the future for your magnet market development?** *Multiple Choice Answer*
    - Characterization laboratories
    - Magnet winding and impregnation laboratories
    - Integration and assembly laboratories
    - Magnet Test stations
    - Others: please specify
7) **At which steps of your magnet product development could you/would you like to use Technological Facilities?** *Multiple Choice Answer*
    - R&D
    - Proof-of-concept model
    - Prototyping
    - Series
    - Others

8) **What are the barriers to benefit from future collaborations with the Technology Infrastructure?** *Multiple Choice Answer*
    - Access Cost
    - Availability
    - IP
    - Others: specify

9) **What are the reasons which would make you preferably choose to use the Technical Platforms located at Research Laboratories or your own Technical Platforms?** *Free Answer*