Superconductors

For a Green and Efficient Society

Why the Superconductors Flagship ?

Superconductors and related technologies will translate into significant benefits to our life, our societies and economies across a broad range of endeavors. Superconductors offer the promise of important major advances in efficiency and performance in electric power generation, transmission and storage; medical instrumentation; wireless communications; computing; transportation and scientific instruments that will result in new paradigms and in societal advances that are cost effective and environmentally friendly.

1. ABOUT US

This initiative is presented by the European Society of Applied Superconductivity (**ESAS**), The Cryogenics Society of Europe (**CSE**) and the Consortium of European companies determined to use Superconductivity (**Conectus**) and supported by a large number of European institutes, laboratories and companies involved in the field. It covers the whole chain from fundamental research to practical applications of superconductivity and so it involves the coordination between many European scientific societies in the areas of Physics, Chemistry, Materials Science, Engineering and Biomedicine with industrial and final user's consortia.

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.

CSE objectives are to strengthen the European position of cryogenic technologies, to represent European activities in cryogenic technologies in social, scientific, industrial and political forums, to promote communication and information exchange in the area of cryogenic technologies, to foster the training of young researchers in the area of cryogenic technologies, to bring together those active in cryogenic technologies and potential user communities so as to stimulate applications of these technologies.

Conectus objective is to strengthen the basis for commercial applications of superconductivity in Europe: Conectus is a consortium of companies with the shared vision that commercialization of superconductivity will translate into significant benefits to Europe's economy and society. Conectus provides a platform for industry to exchange information and to provide a united voice on public policy issues of common interest to superconductivity stakeholders. Conectus members seek to ensure that the benefits of superconductivity are fully realized by decision-makers in industry, academia and governments. Conectus members unite to advocate for key priorities and adequate government support focused on superconductor-related research, development and demonstration projects.

2. CHALLENGE AND VISION

•2.1. GAME CHANGER

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. Still another application is in exceedingly sharp, low noise microwave filters for base stations of radio communication systems. Finally, "Superconducting Quantum Interference Devices" (SQUIDs) based on weakly coupled so-called Josephson Junctions, enable us to monitor magnetic fields, which are more than a billion times weaker than the earth magnetic field, and made it possible to successfully record functions of the heart and the brain. These quantum interference effects have also been utilized in a new class of ultrafast, ultralow-power superconductor electronics, which in the future are expected to play an important role in areas like communication and computing, where traditional semiconductor electronics have reached their performance limit.

The fast development of these technologies and their dissemination in the European market and society pushed by this strong Flagship initiative will lead to a new paradigm for an energy-efficient, ecological, healthier and connected society.

2.2. RESEARCH PRIORITIES AND TECHNOLOGICAL ADVANCEMENTS

Up to the eighties of last century 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 initially sometimes 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 MgB_2 which was discovered in 2001. Another class, the Iron Picnitides, which have slightly higher transition temperatures than MgB_2, came up in 2008, and very recently the barrier of 200K as transition temperature was crossed in H_2S under high pressure. A better understanding of the superconducting behavior 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 Superconductors can be classified into 5 macro-areas, Science, Energy and transportation, Electronics, Medical and Cryogenics applications.

Science

Nearly all LTS applications utilize wires and cables based on NbTi, Nb_3Sn 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. 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 up a 80 km ring delivering 100 TeV protons using 20 T LTS/HTS hybrid magnets.

NMR requires the currently highest magnetic fields with ultimate spatial homogeneity and temporal stability. NMR then allows 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.

An LTS large scale application which is based on Nb metal sheets or coatings, are high-frequency cavities and systems. The ultra-high quality factors and the excellent power-handling capability of these Nb resonators make them the first choice for transmitting high microwave power to electrons, protons and ion beams in a variety of accelerators used in huge particle colliders of high-energy physics, in synchrotron radiation sources or in Free Electron Lasers with a strong impact on the basic research

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 $YBa_2Cu_3O_7$ (YBCO)-HTS films deposited on metal substrates. For moderate field applications also another material finds increasing interest, the MgB_2, 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 meters or kilometers 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 LN_2 temperatures but the need of cost reduction is still preventing a 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 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.

Electronics, Green communication & data crunching

Electronics applications are based on superconducting thin films usually embedded in multi-layer structures. Passive high-frequency and microwave devices utilize the ultra-low high-frequency losses which superconductivity brings. Filter systems mostly made of 123-HTS offer an improved coverage in rural areas and better usage of limited transmission bandwidths in densely populated areas. Due to these attributes such filter systems have been installed in more than thousand base stations for wireless communication, especially in the US. Active devices utilize Josephson Junctions (JJs) which represent highly non-linear contacts between two weakly coupled superconductors, as sensing and switching elements. Today the advanced Nb junction technology allows fabrication of circuits reaching a hundred of thousands of JJs. Single junction devices are routinely used as microwave frequency-mixers in radioastronomy. JJs or arrays of JJs have also been used for other types of sensors with exceptional performance e.g. X-ray detectors or far-infrared sensors in THz spectroscopy and scanners, in particular in the space applications area to detect very faint signals. Meanwhile there are many different types of superconducting radiation and particle detectors showing better performance than standard systems. For example superconducting single photon nanowire detectors have outperformed semiconductor-based sensors and will be introduced in many applications. On the other side there is an immense progress to use JJ arrays as radiation sources especially in the THz frequency region. SQUIDs, with their otherwise unattainable ultra-high magnetic field sensitivity, have for a long time been in use for materials characterization and evaluation, scientific instrumentation (e.g. scanning SQUID microscopes) and some very special applications such as geophysical exploration and archeology. SQUID multiplexers are used for readout of thousands of pixels in detector arrays. Voltage standards worldwide routinely used in metrological laboratories, are based on arrays of thousands of JJs. Besides the commercial DC standards for 10 Volt pulse driven arrays can synthesize quantum based AC voltages. Superconducting devices give new possibilities for other quantum standards like a current standard or in the field of quantum computing (superconducting Qubits). Examples of the even more challenging integrated circuits for digital signal processing are Analogue-to-Digital-Converters embedded with superconducting microprocessors, especially for radio communication systems or routers for directing large data streams in communication networks. Superconducting digital electronics overcomes the problems of latching logic of the 1970s by the single flux quantum (SFQ) logic but recent developments like energy-efficient rapid SFQ show even better performance in digital processing. The combination of ultra-high switching speed, ultra-low switching losses, quantum accuracy and nearly distortion-free signal transmission make them the perfect choice in applications areas where semiconductors have reached the performance limits.

The future need of intensive data crunching driven by Internet traffic, cloud computing, smartphones usage and connected objects, without taking into consideration the performance limits of current systems, requires an enormous quantity of energy that is not compatible with sustainable development and energy efficiency requirements defined during COP21. In particular, the needs of exascale computing power cannot be met with present technologies, although the minimization of energy consumption of current systems by more sophisticated algorithms and better architectures is required and considered in the Horizon 2020 goals of the EU. The energy challenge for the digital world of 2050 overwhelms by far the capabilities of current technologies. The main reason is that, with current classical technologies, every digital operation is associated to a loss of energy, an increase of entropy and heat, instead of work. In practice, an RC-circuit is charged then discharged for every clock cycle. Improving the architecture by keeping the same hardware can reduce the loss of energy by a reasonable amount that is far from the orders of magnitudes required by the future digital usages.

Going quantum is necessary to change the paradigm of data processing, by transporting and displacing data with a limited amount of energy, rather than destroying and creating new data for each single digital operation, at the cost of heating and wasting energy. Going quantum is natural with superconductors. It does not mean that energy-wasting digital systems will be replaced (superconducting systems have to be cooled, which also has a energy cost), but it means that a hybridization is necessary to place the most suitable technology at the best place.

Superconductors have the ability to integrate on the same circuit quantum accurate sensors with digital processing. Today they represent the only technology that can process data with an energy-efficiency at least 10 times better than any other technology, while requiring nearly 100 times less energy and operating at a temperature that does not bring burden in terms of ease-of-use.

Two kinds of complementary superconducting digital technologies exist:

- Single-Flux-Quantum (SFQ) based systems that are already proven and currently need to enter in a pre-industrial phase to go towards more complex systems, with more functionalities, increased processing power and industrial autonomous coolers, as it is planned in the United States and Japan. These systems can be operated adiabatically, and may be used as in interface to qubits that also adds processing capabilities.

- Quantum computing systems that are still in a research phase and need more time to mature and provide complex multi-purpose products. These systems need to be cooled at a very low temperature (below 100 mK) for which technology is not yet enough energy efficient to plan large scale industrial applications.

Both technologies rely on the same devices and they differ mostly by circuit design and temperature of operation. They are complementary since SFQ systems are cooled at a temperature intermediate between the one for quantum computing systems and room temperature.

The development of the semiconductor technology has changed the world since the nineteen sixties and seventies, giving an advantage to countries that jumped first on them and dealt with the semiconductor paradigm, e.g. Japan and the United States, advantage which has never been caught up with in Europe, in spite of huge investments in the semiconductor industry.

The paradigm of a quantum world based on superconductors may well be reproduced with the same countries lying ahead or behind, if Europe does not seize the opportunity to go ahead with a technology for which knowledge is at the highest level, and industrial players capable of bringing the needed infrastructure. Welfare of European citizen and European sovereignty will depend on how well it masters the emerging technologies of tomorrow. More than a technological decision, it is a political one. The right choice has to be made at the right moment.

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. Magnetocardiography (MCG) and Magnetoencephalography (MEG) systems based on SQUIDs are installed in more than one hundred hospitals all over the world working on clinical research on heart and brain. Developments are ongoing towards applying HTS in this medical field with significantly simpler cooling technology. New medical applications include Positron Emission Tomography and cancer treatment using proton therapy where the beams can be controlled non-destructively by SQUID based monitors.

Cryogenics

The need for cryogenic cooling has been voiced for decades and has become of increasing importance with time. Indeed in many scientific projects cryogenics is essential for the accomplishment of the scientific objectives, offering unique advantages and unmatched performance. For more than half a century Cryogenic Engineering has been identified as a key technology for fundamental research activities as well as for practical applications in our daily lives (NMR for instance). Particle physics, astrophysics, magnetic and inertial fusion are fields of physics which need complex equipment or infrastructures; one can mention for instance the LHC, Tore Supra, JT-60SA, ITER, Laser Mega Joule (LMJ), and in the future, Hiper, DEMO, the Future Circular Collider (FCC), X-rays and infrared satellites, etc.… all projects for which cryogenics is one of the key issues. In this context, one very promising technology is indeed the use of superconductors, which could have a substantial impact on several technologies as discussed. In this temperature range, down to 4 K, cooling is achievable and commercially viable. The broader implementation of superconductive components requires cryogenic packaging or insulation, reliable supply of liquid cryogens like Helium (LHe, 4.2K), Hydrogen (LH_2, 20K), Neon (LNe, 27K) and Nitrogen (LN_2, 77K) or, alternatively, reliable operation of cryocoolers adequate for these specific applications. Another issue is that superconducting systems not only need optimised cryogenic facilities, but also (non-superconducting) materials and components with the appropriate mechanical, thermal and electrical properties qualified for low-temperature operation. But this is all achievable: Thousands of Magnetic Resonance Imaging (MRI) systems have been operated reliably over tens of years worldwide, demonstrating that cryogenics can be made invisible, efficient & reliable. Time intervals for the refill of LHe tanks used in MRI or Nuclear Magnetic Resonance Spectroscopy (NMR), have been extended and are in the range of several years. Although recent concerns regarding the reliable supply of He have acted as a stimulus for the development and integration of cryocoolers, a number of specific requirements for cryogen-free cooling with maintenance-free operation have already been demonstrated over several years. Development toward reliable low temperature cryogen free system is still ongoing, and the production of reliable long-life cryocoolers in larger quantities in the future will inevitably bring prices down further.

3. BENEFITS FOR EUROPE

3.1. IMPACT ON EUROPEAN ECONOMY AND RELEVANCE FOR THE EUROPEAN INDUSTRY

A coordinated activity on the European level is, therefore, needed to support and accelerate the implementation of novel superconductor technological and engineering approaches as a cornerstone of social and economic development. Traditionally the first significant market for superconductivity were magnets for science, research and technological development 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 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, lower noise, quantum-precision sensitivities or ultra-high speed are motivations for current developments in the following areas: electric power, industrial processing, transportation, (new) medical applications as well as information and communication. 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.

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.

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.

Green computing and data centres based on energy efficient (and adiabatic) superconducting electronics would save Europe vast amounts of energy and will define a new market for the future.

3.2. IMPACT ON SOCIETY

Streams of information, energy, goods and people continue to steadily increase and will probably do so throughout the 21st century. At the same time we begin to face effects of the related global climate change which the ongoing growth of the world population will further enhance and so the need of novel technologies for an "Energy transition" has become unavoidable. Already today, the growth rates of energy consumption in rapidly developing countries like China, India or Brazil are high. Moreover, current cost trends e.g. for copper or rare earth materials demonstrate the worldwide growing demand and our dependency also on the affordable access to limited raw materials. Thus both energy and raw materials are becoming increasingly expensive, and constraints with regard to environmental protection are becoming more stringent. The correlation between the electricity consumption and the prosperity of society on the one side, and the necessity for a sustainable and most efficient use of all resources on the other, will continuously increase the demand for best practice solutions in electrical, communication computing and electronic engineering.

Thousands of MRI systems which have been operated reliably over decades worldwide, with a huge impact on the health policies, demonstrate that cryogenics can be made invisible, efficient & reliable - cooling is makeable! Then the ultimate performance of "super"-conductor technology stands for enabling sustainable solutions and saving rare raw materials. It contributes to overcoming technological barriers, to implementing novel concepts and to meeting many current and future needs which are both economically important and environmentally desirable. System integration of superconductor technology could thus become one of the key competences of the 21st century and it is crucial to develop existing expertise in cryogenics and superconductor technologies and to extend it into fields of future strategic importance.

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, intensified by the activities of the FLUXONICS Network – the European Foundry for Superconducting Electronics (http://bit.do/supercomputer) and 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, such as S-PULSE for electronics, EUROTAPES for conductors, SUPRAPOWER or ECOSWING for wind turbines, BEST PATHS for cables, SUNJET for the electrical plane, NanoSC for vortex physics, IRON SEA for perspectives of iron based superconductors for electronics applications and many ERC projects spanning a wide range of scientific research with huge potential for technological developments .

In the cryogenic fields, Europe has a strong historical heritage – discovery of superconductivity, whole range of cooling solutions – and holds considerable expertise with several laboratories being leading R&D performer in cryotechnologies, as well as topnotch industries (Air Liquide, Linde, Thales, Astrium to name a few). In April 2015 the Cryogenics Society of Europe was founded that brings together all those in Europe active in cryogenic technologies and potential user communities to stimulate and develop applications of these technologies. At the moment of this writing the CSE had 18 corporate members and 50 individual members.

- **Comparison with existing international research initiatives linked to this proposal**

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.

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.

4. WHAT WOULD IT TAKE TO DO IT

- **Added value**

The proposed flagship will extend and integrate the existing and future initiatives between the leading research institutes in academic and non-academic environments and the high-tech industries and companies. Together with the high level of funding, this will give a critical mass to boost the development and the dissemination of the superconducting technology applications in the industry and the society, as well as to continue to cultivate the world-class European scientific excellence in this field. It will give a unique opportunity not only to sustain investment and coordinate public investments and strategies in Superconductivity, but also to attract new researchers into the field and to Europe to push the superconducting technologies from existing "concept validation" phases to "pilot production and demonstration" phase of new products.

- **Scale of the effort and time required**

The Superconductors initiative will coordinate all the main European actors in the Basic and Applied Superconductivity fields, with the goal to establish collaborations among many academic and industrial research groups with a global effort estimated in the range of €900M over the 10 coming years.